Compressed Air Information

edited by

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PREFACE.

This publication has been called for by many inquiries addressed to the Editor of "COMPRESSED AIR" asking for various papers, some of them original and others compiled, which have been published in that little magazine during the first five years of its existence.

The supply of the early issues having been long since exhausted and the demand continuing, an effort has been made to present in a single book of reasonable size all the important practical information contained in the first five volumes.

No attempt has been made to introduce new matter, but the various papers, editorials and notes have been selected and arranged under suitable headings so that any one seeking information on this subject may be afforded facilities for finding it properly classified.

The principal claim to recognition rests on the practical character of the material, as the little magazine from which these papers have been compiled has endeavored to record the every-day experiences of engineers familiar with the handling of compressed air apparatus. These experiences cover a wide field and are not simply the opinions of a few men, but those of many, hence it is believed that the collection of this data in one book will prove of service to the engineer and student.

Full credit is given to the different authors for all abstracted or contributed articles, and the editor wishes to acknowledge his indebtedness to Mr. J. J. Swan for his valuable assistance in compiling.

New York, Jan. 12, 1903. W. L. SAUNDERS.

PRODUCTION.

AIR POWER.

The power of air is shown in the cyclone and whirlwind uprooting the stanchest trees and exhibiting a power that has been estimated to be beyond any that is within the control of man.

The power of air is shown when the sail of the ship is made to drive thousands and tens of thousands of tons weight through the waves of the sea. What power has done greater service to mankind than this? Air power has been the means by which continents have been discovered and populated. It has done more for civilization than most of us realize.

The power of air when applied to the rock drill is shown in the building of great tunnels and in the development of mines. The "Hoosac," "Sutro" and New York Aqueduct Tunnels would have been almost impossible but for compressed air. The great piers of the Brooklyn Bridge required compressed air in the caissons to enable them to reach solid rock foundations. By no other means known to engineers could this bridge have been built; and so with most of the great bridges and tunnels of the world.

The power of air is shown in the Bessemer converter and in the blast furnace producing iron and steel, the most useful metals known to mankind.

Air power is shown in the brakes on the train, when hundreds of tons, moving fifty miles an hour, are brought to a standstill within a few hundred feet. Think of the power required to do this! The little air compressor perched on the side of the great engine brings all this about. Think of the lives that have been saved by the air brake!

The power of air is shown in the gas engine which uses a combination of air and gas as an explosive mixture of great force. The hot air engine produces power with air alone.

Air power is used to move railroad switches and signals more than twenty miles from the source of supply. Air hoists, air jacks and air lifts are valuable auxiliaries. Water is raised from subterranean sources and delivered to the reservoir by compressed air. The power of air drives the shell from the dynamite gun. Granite is cut and carved by the pneumatic tool. Air power is used to raise sunken ships. The fall of water converted into air power is used miles away to produce useful results.

Air power in shops is used to clean castings, for punching, caulking, tapping, drilling, reaming, chipping, riveting and painting.

As an interested reader of your magazine, I find its terse and pithy articles have the effect of sharpening my appetite for more information concerning the subject of Air Power, which to the non-expert, like myself, is like an "undiscovered country." A host of questions arise in my mind, suggested by your magazine. But I venture now to ask one which is purely scientific and fundamental, viz: In compressing air, why is it that heat is generated, or, to put it conversely, why does the heating of air expand it?

Doubtless these questions may seem to you very simple, but I am free to admit, that while I have a theory about this matter, I cannot prove it scientifically.

NEW YORK. INQUIRER.

Our correspondent asks two questions—1. Why is it that heat is generated? and 2. Why does this heating expand the air?

1. In compressing air, heat is produced because the piston does work upon the air which, being confined, does no work in return; hence there is a direct conversion of work into heat. We do not believe that there is any such *thing* as heat, but that what we call heat is the sensible effect of vibration. A moving piston, being the vibration of a mass, may be converted into moving molecules of air. Prof. Tyndall, in his book "Heat a Mode of Motion," illustrates the point by dropping a lead ball from the ceiling to an anvil on the floor, heat being produced and measured in the ball. "The motion of the lead," says Prof. Tyndall, "as a mass has been transferred to the atoms of the mass, producing among them the agitation we call heat." It is following this law of nature that heat is produced when a target is struck by a shot. In the fire box of a locomotive we produce heat which is converted through the boiler to the engine and into the motion of the train. This motion may be converted back again into heat and the train brought to a standstill by friction in the axles, and this result is sometimes brought about by hot boxes on a train.

2. Heat expands air as it affects almost all bodies. It is supposed that this expansion is caused by the increased vibration acting to pull apart the atoms of the substance. It tends to destroy the cohesion in the particles.

EARLY PNEUMATICS.

The application of the old time-honored saying, "There is nothing new under the sun," meets with no more striking illustration than in the harnessing of that mighty element—the air—to do man's bidding.

The seventeenth century demands and very justly merits our warmest admiration for one of its great inventions, the "air pump," and its creator, the famous burgomaster of Magdeburg, Otto von Guericke, was the wonder of his age; yet we are told that Galileo, not long before, made the discovery of the underlying principle of that and all such experiments, namely, that air is ponderable. However, could these and other great scientists have suspected that their knowledge was antedated more than a thousand years by a certain Heron of Alexandria, who lived, invented and died under the mummied Ptolemies, Philadelphus and Euergetes, they would doubtless have been not a little disconcerted. But they had no means of obtaining such information—happily for the peace of mind of their shades—for it has only been in recent years that any knowledge of the Egyptian inventor has come down to us, and this through such rare channels, that in a treatise by a noted French "savant," M. Duteus, on the "Origin of Discoveries Attributed to Modern Inventors," a work in which the author tries to make the best possible case for the Ancients, the name of Heron is not even mentioned.

Of late, however, the investigation of some of Heron's discovered writings, scanty as they are, and the finding of a few scattered notices bearing on his wonderful inventions, have developed a keen interest in their author, and established his claim to be ranked with the leading lights of the world, among men of science and antiquaries in general.

Nothing is known of his life beyond the facts that he flourished between 284 and 221 B.C., and that he was the pupil of Ctesibus. Even his name is shrouded in mystery, so that while some speak of him as Heron, others feel justified in omitting the final "n." A certain popular celebrity has accrued to his name through the common pneumatic experiment called "Hero's Fountain," in which, as every student of Natural Philosophy will remember, a jet of water is sustained by compressed air.

Another claim to recognition is a steam engine of his invention—one spoken of at some length in his writings. This remarkable machine worked precisely on the principle of "Barker's Mill." A boiler with arms having lateral orifices is made to revolve around a verticle axis. The steam issues from the lateral orifices, and the uncompensated pressure upon the parts opposite the orifices turns the boiler in the direction opposite to that of the issue of the steam.

Still another engine described in Heron's Pneumatics has also a double forcing pump used for a fire engine, and various other applications of the elasticity of air and steam have all tended to secure him that position in the scientific world which has been attained by a few of the Ancients and is unanimously sustained by the cheerful readiness of us Moderns to recognize, appreciate and applaud the "divine spark" when discovered not only in our own times, but over the lapse of centuries.

At a time when a work on "the Seven Wonders of the World," was more or less a record of contemporaneous history but with just enough flavor of antiquity to make the era of 250 B. C. seem comparatively young and progressive —in that complacent, tolerant way, with which human nature is wont to view past achievement in the light of present possibility—Philon of Byzantium wrote his "Ancient History," recorded the work of his beloved Master Ctesibius, chronicled some truly marvelous discoveries and inventions of his own and completed the mission of his destiny on the field of battle, 212 B. C.

His descriptions of "The Hanging Gardens of Assyria," "the Pyramids of Egypt," "the Statue of Jupiter Olympus," "the Colossus of Rhodes" and all the other wonderful creations of the early genius of man, which constitute the world-famous "Seven Wonders,' are set forth with a grace and elegance worthy of present imitation, but, in many places, with a too-studied regard to rhetorical effect which robs the writings of that directness of simplicity without which no work can hope to live, in its first freshness forever. Therefore, it is that musty book-shelves and worm-eaten tomes must be consulted to learn of Philon the "litera-teur"—but Philon the mechanician and ancient authority on the besieging and defending of cities, seems quite another personage.

Two of his books on military engineering, are on the general subject of the manufacture of missiles, while a third covers a wide range, including the arming of harbors, the use of levers and such mechanical powers, as also other contrivances connected with the storming and resisting of towns. In the latter, he advocates a strange and barbarous system of warfare, advising that on the approach of the enemy through an open country, all springs and grain be poisoned. For this policy, even in ancient times, he was severely censured.

But modern attention has been directed to him chiefly through his notice of an invention of Ctesibius—that master mind, for the sake of whose teachings Philon left his home and removed to Alexandria to become, like Heron, his instructor's devoted disciple.

This invention was an instrument of war, and consisted of a tube out of which an arrow was shot by means of compressed air. This is one of the oldest applications of that mysterious force, the modern air-gun being an evolution of Ctesibius' ingenious machine.

Over sixteen centuries elapsed between the first invention and the next model, and in 1560 we find that the new gun had a butt end of hollowed metal containing a reservoir in which air was compressed by means of a force pump. The balls were placed in the little receptacle, which was furnished by a stop-cock, and as one shot was sent off, the stop-cock was opened and a fresh projectile inserted. Naturally, the force of projection diminished as the reservoir of compressed air emptied, so that after every few discharges, it became necessary to re-compress the air.

Some years later this model was improved upon, but even in its best form, it has left much to be desired in point of time saving, and furnishes a golden opportunity to some nineteenth century genius to make the air-gun a more deadly weapon than its rival in fire-arms—or better still, to devise a machine of such dimensions that so vast a quantity of air could be compressed within it, that its liberation would annihilate the largest army ever massed together among the nations.

Thus might the possibility of war be averted by the appalling consequences of facing an unchained element made obedient to the operation of a single individual.

That genius of human progress who presides over the rapid supplying of man's needs, passing over electricity, water and steam, selects air as the force best adapted to serve his ends.

This benign spirit appeared in the person of a certain Dr. Denys Papin, who lived nearly two centuries ago in the quiet town of Blois, and under the rule of "le grand monarque," in beautiful France.

To this distinguished Frenchman we are indebted for the first suggestion of conveying compressed air through pipes as a means of transmitting power; and toward the end of the century, his fertile brain conceived the idea of projecting parcels through a tube by means of compressed air. Never before, in the history of inventions, did the application of this principle to such an end take form in the minds of the world's great scientists. Dr. Papin, therefore, stands today as the pioneer in that field.

After the death of the doctor, we are told, the invention took a sleep of a hundred years—which might be a long sleep for anything else, but is, for an invention, only a reasonable nap.

We do not hear again, therefore, of any atmospheric system of propulsion until 1810, when George Medhurst, a mechanical engineer, took out a patent in England "for a means of conveying goods, letters, parcels and passengers by means of a tube and a blast of compressed air."

In the same year he published a pamphlet on "A New Method of Conveying Letters and Goods with Great Certainty and Rapidity," in which appear the first *practical* suggestions for the introduction of what is now known as the "Pneumatic System." This work foreshadows almost everything since discovered in connection with the subject of air propulsion.

A little later in the year appeared another pamphlet by Medhurst, entitled, "A System of Inland Conveyance for Goods and Passengers." In the latter, unfortunately, the zeal of the inventor carried him beyond his limitations, and as a result, he made a failure of the car system—as, indeed, did Vallence, his English rival, and Pinkus, a clever American.,

However, the system for conveying light goods, such as letters, parcels, etc., proved a complete success, and now in its perfected form it operates by connecting the tubes containing the carriers, one with a vacuum chamber and the other with a compressed air chamber, air being condensed behind the carrier in one and exhausted before it in the other at the same time by a double-barreled air pump, operated by an engine of one horse-power and attaining a speed of about forty miles an hour.

The first line of this system was controlled by "The Pneumatic Dispatch Tube Company" of London, in 1859, between Euston Square Station and the Post Office in Eversholt street, later extending its charter to Holborn. The entire distance covered is 3,080 yards, laid with easy gradiants.

The telegraph offices of London were the next to eagerly adopt the new system for communicating with the central office. At each way station of the line is a receiving apparatus consisting of two short barrels, parallel with the main tube, either of which may be put in or out of connection with the line by means of a lever; one of these is open at both ends so as to allow a carrier to pass through unimpeded, but the other is almost entirely closed at one of its ends, so that when it is switched into line with the main tube it intercepts the carrier. Of course, the time when a carrier is expected to arrive is telegraphed to the receiving station.

To-day every great city in the world has its commerce facilitated by this ingenious device; and it would require only a little time and thought on the part of the inventors of this age to perfect the passenger tube to such an extent as to make a luxurious pneumatic railway solve the burning question of transportation.

At first electricity dazzled the scientist and inventor by the fascination of her indefinite and mysterious possibilities, but the silent depth and power of her equally fair sister, compressed air, is now taking so firm a hold upon the imagination and judgment of the thinkers of to-day, that she bids fair to outstrip her rival in the race for dominion.

One of the first applications of the force of compressed air in this century was the pneumatic dispatch tube, and its inventor, George Medhurst, was regarded by his English compatriots as occupying an unenviably conspicuous position on the wrong side of that partition which, according to the poet, divides great wits from madness.

The success of his tubes for the conveyance of letters and light parcels, however, completely vindicated him from all taint of mental unbalance, and even though he failed in establishing an effective pneumatic railway in Great Britain, the Britons ended by admiring the man and standing in respectful attitude before the unlimited possibilities of the force. Indeed, such a hold did this power gain on the English mind that a proposition was considered by the Government of connecting Ireland and England by the "Pneumatic Dispatch Tube System," laid beneath the waters of the Irish Channel in order to facilitate and expedite mail carrying. But the times were not ripe for its perfection, so the operations of the plan were suspended.

However, a line between the London and Glasgow telegraph stations was established, and an amusing anecdote is told of how an American at the Scottish town, who afterwards wrote his experience to the "Boston Transcript," first made acquaintance with the system.

Thinking that an error had been made in the transmission of his message to London, the gentleman in question desired to see the original blank. The operator, with an amused smile, told him that his message was then at the London main office. He replied, "Yes, yes, I know; but I want my own copy that I wrote out here about a half an hour ago." The clerk answered, "I understand what you mean, sir; but your copy has been in London for the past half hour, and if you will step here and apply your ear to this opening, I think I can convince you, in a few seconds, of the truth of my statement and show you your message." The operator then sent a dispatch, and presently the astonished listener remarked a peculiar whirring sound, and—he writes—"seventeen seconds later I heard the tinkling of a little bell announcing the arrival of the carrier, close at my ears, and in a moment more I had my original message in my hands."

He straightway became an ardent disciple of the new system, and led, doubtless, by the enthusiasm which characterizes most zealots, the American gentleman made several small misstatements, among them that of the time said to be consumed between the London and Glasgow stations. In point of fact, the carrier would have been required to attain a speed of four miles a second in order to cover the distance in question, and would have, moreover, been rendered red hot before the expiration of the first second. But allowance must be made for all converts, and as he was correct in his essential statements, let the mantle of charity, by all means be extended.

Since the success of Medhurst's invention, America, that liberal patron of the best in every branch of advancement has lent her encouragement to all new applications of the magnificent force of compressed air, and as a result, we have our coal and gold mined by this power, canals dug, rocks drilled, sunken vessels raised, sheep sheared, carpets dusted, cars cleaned, clocks and sewing machines run, ships steered, locomotives propelled, stone carved, and street railways operated. One is therefore constrained to ask, "Could electricity do more?"

FRANCIS MALOY.

VIEWS OF A NON-EXPERT.

These remarks are presented as the views of a non-expert, who has, nevertheless, been impressed for years with the possibilities of compressed air as a motive power in conjunction with an adequate mechanical medium.

The present advanced development of the power was foreshadowed from the beginning of the century; but the knowledge of the latent force of air in this condition far antedates even that period. As with nearly all the great powers of modern science and mechanics, progress has gone by slow and painful steps, through many failures, many apparently insurmountable difficulties, into the region of practical, universally acknowledged success.

The best known compressed air engine in the early years of the century was that invented by Dr. Sterling and his brother, James Sterling, C. E., of Edinburgh, Scotland, in the year 1816. The air was compressed for this machine to the pressure of from eight to ten atmospheres but, as in the case of the early steam engines, the machine was not a commercial success. It had the effect, however, of stimulating interest and invention.

Captain Ericsson, who had not yet come to the United States to begin his work of revolutionizing modern war vessels, took up the idea and at length produced a working machine. It differed from Sterling's in being of much lower pressure. Its bulkiness, in proportion to power, and the intense heat evolved, were serious defects and rendered it only another link in the chain of experimentation.

In 1867 Sir George Cayley and Philander Shaw showed a machine at the Paris Exhibition of simple construction and greatly increased power. In this machine the compressed air was delivered into the furnaces, where, combined with the fuel, it formed the gases of combustion. The greater heat thereby produced was used to act upon the pistons and was then discharged. This machine avoided the defect of Ericsson's, in which the intense heat evolved acted as a destructive agent upon the machine itself. The heat "economizer" was also introduced. Through its medium the heat which is rejected by the fluid when it falls in temperature is saved and made to do work in conjunction with the direct power of the compressed air. A great difficulty has been the formation of ice in the pipes by the freezing of the water in the air; but this has been practically overcome.

In work in mines, tunnels and confined situations, compressed air has demonstrated its great superiority over steam or any other power. Thus in the boring of the great Mt. Cenis tunnel, air was compressed by water power and carried in pipes to the heart of the mountain to work the boring machines. In that situation steam would have been intolerable, owing to its discharge in the confined space. The compressed air also possessed another immense advantage, namely, the ventilation and cooling of the tunnel. As the compressed air was discharged it expanded to the status of the surrounding air, and as it expanded it fell in temperature, thus cooling the surrounding air and causing ventilation.

These earlier uses of compressed air were, however, only preparatory to the development of the power to-day.

Who can deny that this power has a great future before it? Its forces are drawn from the inexhaustible storehouse of the atmosphere; its economy is expressed, in part, by the old phrase, "as cheap as air."

Power and economy—the economy of power—is the great desideratum of industry and mechanics, the real philosopher's stone that will transmute all things to gold, and the chained energy of the air—chained to the perfected machine of this day of mechanical triumphs—is surely an ideal solution of the age-long problem.

JOHN J. ROONEY.

COMPRESSED AIR PRODUCTION.

Compressed air is air under pressure. It is usual to define compressed air as air increased in density by pressure, but we may produce compressed air by heat alone, as illustrated by the discharge of a cork from an empty bottle when heated. Though one of the oldest of the sciences, compressed air is, in its development and use, one of the youngest. Hero, of Alexandria, a century before Christ, experimented and wrote upon "Pneumatics," calling special attention to the influence of heat in expanding and contracting air. It is said that Hero put into practical use an invention by which the opening and closing of temple doors was effected by the alternate rarefaction and condensation of air which was brought in contact with heated and cooled surfaces of altar tops. Yet the science of pneumatics played no important part in industrial progress until scarcely more than a century ago it came into general use for diving bells, and was later on applied by Brunel to caisson work.

In 1830 the French Academy of Sciences gave a medal to Thilorier for his method of compressing gases by stages. In 1849 the Baron von Rathen suggested the use of compressed air at 750 pounds pressure per square inch in locomotives. It is a singular fact that the Baron, in describing the method by which he proposed to attain this high pressure, advised compound compressors with intercoolers. The special advantages of cooling the air between the different stages of compression were set forth. This stage compression and inter-cooling is one of the most important recent improvements made in air-compressing machinery.

Until recent years the use of compressed air in America has been confined almost exclusively to mining, tunneling, bridge-building, or to work in a confined space for which no other power was available. Electricity has recently become a competitor of compressed air in that it, too, may be used in confined spaces, and may be transmitted long distances and distributed. Until such competition arose the question of producing compressed air economically was but little agitated. The attention of engineers was mainly devoted to the development of an apparatus for using compressed air, it being taken for granted that air was an expensive power at best. The manufacturer sought to perfect his compressor on lines of low first cost, light weight, economy of space and general availability. Dry, pure air, delivered at a sufficient pressure by a machine which could be depended upon, has been the controlling consideration.

Compressed air and air-compressing machinery have been considered, and the science developed by two classes of men—the practical men and the engineers. The practical men confined their work to the machine. The confusing diagrams and figures of the engineers were not considered, because they were not understood. The engineers took occasional plunges into compressed air theories, producing figures controverting certain well-established and so-called practical facts, and almost invariably basing the conditions of compressed air economy upon questions of thermodynamics. The problems produced by the engineers were too mathematical for the practical compressed air men. These men knew too little of the theory of compressed air, hence progress in the science has been slow.

During recent years an impetus has been given to compressed air development by the strides made by electricity, and by the increased use of compressed air in the arts. Electricity, although apparently a competitor, has really played the part of a friend in pointing out the possibilities of transmission and use of air in directions before unknown; thus a market has been created.

The perfection of the air compressor on lines of economy naturally followed the wide use of compressed air in competition with steam and electricity. The best steam engine practice has been applied to the compressor. Compound condensing Corliss engines are now used in connection with air cylinders of new design.

The whole subject of compressed air may be divided into three heads:

Production.

Transmission.

Use.

No better evidence is needed of the obscurity of the science, even among engineers, than the fact that it is the usual thing to look upon compressed air as an expensive power, because of the great loss which is suffered during transmission. The great losses and the serious difficulties encountered in reality do not belong to transmission. Compressed air power may be transmitted and distributed with no greater difficulty than the distribution and transmission of illuminating gas. It is a question of the size of pipe, volume and the pressure. There is not a properly designed compressed air installation in operation to-day that loses over five per cent. by the transmission alone. The question is altogether one of the size of pipe, and if the pipe is large enough the friction loss is a small item. It is undoubtedly true that there are places where a conduit has been laid for a certain volume of air, and where the supply has been increased without increasing the size of the conduit, the result of this being that more air is forced through the pipe than its sectional diameter will admit economically; hence the velocity of flow is increased, and as the friction is in direct proportion to the velocity the loss of power is also increased. The largest compressed air long-distance power plant in America is that at the Chapin Mines in Michigan, where the power is generated at Quinnesec Falls, and transmitted three miles. This is not an economical plant, but the loss of pressure, as shown by the gauge, is only two pounds, and this is the loss which may be laid strictly to transmission. During the construction of the Jeddo Tunnel, near Hazelton, Pa., compressed air at 60 pounds pressure was conveyed 10,860 feet from the central station. The writer was called upon to explain a mysterious condition which existed on both ends of the line. The pressure gauge recorded the same figures and the gauges were sent to the shops for repairs, because everybody was convinced that "something was wrong." The result was not changed when the gauges had been "repaired," it being evident that this apparently perfect economy of transmission was due to the fact that a large pipe (nearly six inches in diameter) was used at that time to convey so small a volume of air that the velocity in the pipe produced so small a friction loss that it could not be recorded on the gauge.

Having defined compressed air we must next define heat, for in dealing with compressed air we are brought face to face with the complex laws of Thermodynamics. When we produce compressed air we produce heat, and when we use compressed air as a power we produce cold. Based on the material theory of heat, it was said that when we take a certain volume of free air and compress it into a smaller space we get an increase of temperature, because we have the heat of the original volume occupying less space; but no one at this date accepts the material theory of heat. The science of Thermodynamics teaches that heat and mechanical energy are only different phases of the same thing, the one being the motion of molecules and the other that of masses. This is the accepted theory of heat. In other words, we do not believe that there is any such *thing* as heat, but that what we call heat is only the sensible effect of motion. In the cylinder of an air compressor the energy of the piston is converted in molecular motion in the air, and the result or the equivalent is heat. A higher temperature means an increased speed of vibration, and the lower temperature means that this speed of vibration is reduced. If we hold an open cylinder in one hand and a piston in the other, and place the piston within the cylinder, we here have a confined volume of air at normal temperature and pressure. These particles of air are in motion and produce heat and pressure in proportion to that motion. Now, if we press the piston to a point in the center of the cylinder, that is, to one-half the stroke, we here decrease the distance between the cylinder head and the piston just one-half; hence each molecule of air strikes twice as many blows upon the piston and head in traveling the same distance, and the pressure is doubled. We have also produced heat (about 116 degrees), because we have expended a certain amount of work upon the air; the air has done no work in return, but we have increased the energy of molecular vibration in the air, and the result is heat.

But what of this heat? What harm does it do? If we instantly release the piston which we have forced to one-half stroke, it will return to its original position less only a fractional part, due to friction. We have, therefore, recovered all or nearly all the power spent in compressing the air. We have simply pressed and released a spring, and this illustration shows what a perfect spring compressed air is. We see also the possibility of expending one horse-power of energy upon air and getting almost one horse-power in return. Such would be the case in practical work if we could use the compressed air power *immediately and at the point where the compression took place.* This is scarcely possible, as the heat in the air is soon lost by radiation, and we have lost power.

Thirteen cubic feet of free air at normal temperature and barometric pressure weigh about 1 pound. In the illustration referred to about 116 degrees of heat are liberated at half stroke of a compressor. The gauge pressure at this point reaches 24 pounds. According to Mariotte's law, "the temperature remaining constant, the volume varies inversely as the pressure," we should have 15 pounds gauge pressure at half stroke. The difference, 9 pounds, represents the effect of the heat of compression in increasing the relative volume of the air.

The specific heat of air under constant pressure being 0.238, we have $0.238 \times 116 = 27.6$ heat units produced by compressing one pound, or 13 cubic feet, of free air into one-half its volume; 27.6×772 (Joule's equivalent) $= 21{,}307$ foot pounds. We know that 33,000 foot pounds is one horse-power, and we see how easily about two-thirds of a horse-power in heat units may be produced and lost in compressing one pound of air. Exactly this same loss is suffered when compressed air does work in an engine without reheating, and is expanded down to its original pressure. In other words, *the heat of compression and the cold of expansion are in degree equal.*

Figure 1 is a sketch designed to indicate graphically the effect of heat and cold in compression and expansion of air.

The sketch illustrates an open cylinder, which may serve both as an air compressor and an air engine. The piston at the point shown is supposed to confine a volume of free air in the cylinder and at a temperature of 60 degrees; let it be pressed down until it reaches the point indicated by 45 pounds, and the pressure will follow the dotted lines marked "Adiabatic." This is, of course, assuming that the heat, which is invariably produced by compression, is suffered to remain in the air and to influence the pressure. We here have a confined volume of compressed air at a pressure of 45 pounds and a temperature of 320 degrees. Let there be no absorption of heat and the piston if released will return to the starting point, the pressure following exactly the line indicated during compression and the temperature returning to 60 degrees. In such a case we assume, of course, that the piston is frictionless. This points to the fact that com-

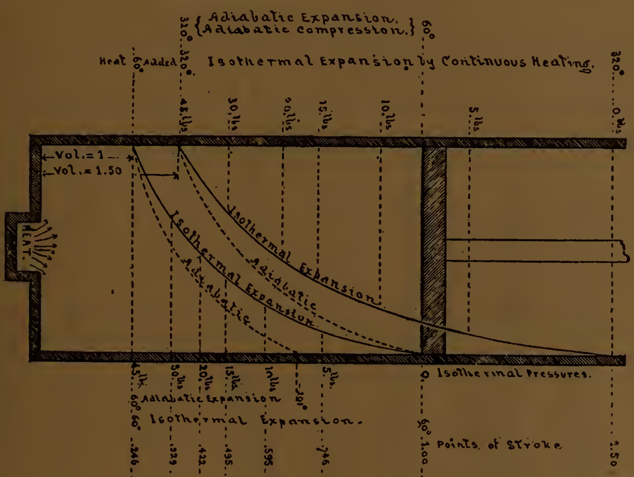

FIG. I.

pressed air is a perfect spring, and that the heat of compression when utilized can be made to return its full value of energy.

An Air Compressor provided with no cooling device would show a pressure line following closely that marked "Adiabatic" on Fig. 1. The hot compressed air confined in the cylinder at the 45-pound point, if transferred through pipes to an air engine and maintained hot until used, would be available for work in the same proportion (less a little friction) as we have shown in the theoretical case where the piston, used as a compressor, is driven back to the starting point. Practically, it is impossible to convey hot compressed air any distance from the compressor, for air, though very slow in taking up heat, has so low a specific heat that it parts with its temperature rapidly. Steam having a higher specific heat may be conveyed as a power even through naked pipes, and this fact has led to mistakes in regard to the possibilities with compressed air.

Returning to Fig. 1, let us imagine that the piston has been stopped at the 45-pound point, and that the compressed air, which, as we have seen, has a temperature of 320 degrees, is transferred into a receiver and used at a point say half a mile distant. The temperature will now be reduced to that of the surrounding medium, or to the initial temperature, which the sketch shows to be 60 degrees; and if the system is well designed, that is, if the pipes are large enough and there are no leaks or other irregularities, we will have nearly 45 pounds pressure on the other end of the line, as there is a direct elastic medium between the two points. But the volume will be reduced in size, because of the reduced temperature, and will correspond with the space underneath the lowest dotted line in the figure marked "Volume I." If it is now used without reheating to do work in an engine, the line of reduction in pressure will follow the lower dotted line marked "Adiabatic" until it reaches the point marked 201 degrees, which repre-

TABLE I.—OF THE VOLUME AND WEIGHT OF DRY AIR AT DIFFERENT TEMPERATURES UNDER A CONSTANT ATMOSPHERIC PRESSURE OF 29.92 INCHES OF MERCURY IN THE BAROMETER (ONE ATMOSPHERE), THE VOLUME AT 32° FAHRENHEIT BEING I.

Temperature in degrees.	Volume in cubic feet.	Weight of a cubic foot in lb.	Temperature in degrees.	Volume in cubic feet.	Weight of a cubic foot in lb.	Temperature in degrees.	Volume in cubic feet.	Weight of a cubic foot in lb.
32	1·000	0·0807	275	1·495	0·0540	1,300	3·585	0·0225
42	1·020	0·0791	300	1·546	0·0522	1,400	3·789	0·0213
52	1·041	0·0776	325	1·597	0·0506	1,500	3·993	0·0202
62	1·061	0·0761	350	1·648	0·0490	1,600	4·197	0·0192
72	1·082	0·0747	375	1·689	0·0477	1,700	4·401	0·0183
82	1·102	0·0733	400	1·750	0·0461	1.800	4·605	0·0175
92	1·122	0·0720	450	1·852	0·0436	1,900	4·809	0·0168
102	1·143	0·0707	500	1·954	0.0413	2,000	5·012	0·0161
112	1·163	0·0694	550	2·056	0·0384	2,100	5·216	0·0155
122	1·184	0·0682	600	2·158	0·0376	2,200	5·420	0·0149
132	1·204	0·0671	650	2·260	0·0357	2,300	5·624	0·0142
142	1·224	0·0660	700	2·362	0·0338	2,400	5·828	0·0138
152	1·245	0·0649	750	2·464	0·0328	2,500	6·032	0·0133
162	1·265	0·0638	800	2·566	0·0315	2,600	6·236	0·0130
172	1·285	0·0628	850	2·668	0·0303	2,700	6·440	0·0125
182	1·306	0·0618	900	2·770	0·0292	2.800	6·644	0·0121
192	1·326	0·0609	950	2·872	0·0281	2,900	6·847	0·0118
202	1·347	0·0600	1,000	2·974	0·0268	3,000	7·051	0·0114
212	1·367	0·0591	1.100	3·177	0·0254	3,100	7·255	0·0111
230	1·404	0·0575	1,200	3·381	0·0239	3,200	7·459	0·0108
250	1·444	0·0559						

sents the theoretical temperature of the air when exhausted at atmospheric pressure. We now see that the piston, instead of returning to the starting point, has only had power enough behind it to return it to a point about half way.

The illustration points to the importance in compressed air economy of reducing to the lowest point practicable the temperature of the air before and during compression and conversely increasing to the highest point the temperature before and during use or expansion.

If, in the case referred to, heat had been applied during expansion, the pressure would follow the line marked "Isothermal Expansion," and the piston might be returned to the starting point.

Another case is shown by the sketch in which the air is compressed adiabatically to 45 pounds pressure and heat enough is applied during expansion to maintain the temperature at 320 degrees until the air is exhausted at atmospheric pressure. This case is purely theoretical and illustrates the possibility of obtaining more power out of a given volume of air after compression than was expended at the compressor.

Experiments made by M. Regnault and others on the influence of heat on pressures and volumes of gases have enabled us to fix the absolute zero of temperature as about -461 degrees Fahrenheit. This point,—461 degrees below zero, has been taken to be the theoretical point at which a volume of air is reduced to nothing. The exact figures representing absolute zero vary with different authors, but for all practical purposes -461 degrees F. is near enough. The volume of air at different temperatures is in proportion to the absolute temperature, and on this basis Box has produced Table 1.

The effect of the heat of compression in increasing the volume, and the heat produced at different stages of compression, are shown by Table 2 (Box):

A cubic foot of free air at a pressure of one atmosphere (equal to 14.7

TABLE 2.—HEAT PRODUCED BY COMPRESSION OF AIR.

Atmospheres.	Pressure. Pounds per Sq. Inch above a Vacuum.	Pressure. Pounds per Sq. Inch above the Atm'sph're (Gauge Pressure).	Volume in Cubic Feet.	Temperature of the Air throughout the Process. Degrees.	Total Increase of Temperature. Degrees.
1·00	14·70	0·00	1·0000	60·0	00·0
1·10	16·17	1·47	0·9346	74·6	14·6
1·25	18·37	3·67	0 8536	94·8	34·8
1·50	22·05	7·35	0·7501	124·9	64·9
1·75	25·81	11·11	0·6724	151·6	91·6
2·00	29 40	14·70	0·6117	175·8	115·8
2·50	36·70	22·00	0·5221	218·3	158·3
3·00	44·10	29·40	0·4588	255·1	195·1
3·50	51·40	36·70	0·4113	287·8	227·8
4·00	58·80	44·10	0·3741	317·4	257·4
5·00	73·50	58·80	0 3194	369·4	309·4
6·00	88·20	73·50	0·2806	414·5	354·5
7·00	102 90	88·20	0·2516	454·5	394·5
8·00	117·60	102·90	0·2288	490·6	430·6
9·00	132·30	117·60	0.2105	523·7	463·4
10·00	147·00	132·30	0·1953	554·0	494·0
15·00	220·50	205·80	0·1465	681 0	621·0
20·00	294·00	279·30	0·1195	781·0	721·0
25·00	367·50	352·80	0·1020	864·0	804·0

pounds above a vacuum) at a temperature of 60 degrees, when compressed to twenty-five atmospheres, will register 367.5 pounds above a vacuum (352.8 pounds gauge pressure) will occupy a volume of 0.1020 cubic foot, will have a temperature of 864 degrees, and the total increase of temperature is 804 degrees.

These tables apply to dry air only. The effect of moisture will vary the figures of temperature, and to some extent will affect the pressures, but many useful deductions may be drawn from the tables. It is seen for instance by studying table 1 that a volume of dry air will be doubled if its temperature is increased about 500 degrees, and conversely, of course, if the volume remains constant an increase of about 500 degrees in temperature will double the pressure. The addition of moisture serves to increase these figures, because moisture increases both the specific heat and the heat conducting capacity of the air.

The thermal results of air compression and expansion are shown by the accompanying diagram (Fig. 2). Both the temperature of the air and its volume are shown at different stages of compression. The simplest application of this diagram is that which gives the gauge pressure represented at different points of the stroke. This is shown in the vertical lines. But in compressing air we produce heat, and it is important to know the temperature at any given pressure, also the relative volume. All of these are shown in the diagram. The initial volume of air equal to 1 is taken and divided into ten equal parts. Each division between two horizontal lines, shown by the figures at the right, representing one-tenth of the original volume.

The vertical and horizontal lines are the measures of volumes, pressures and temperatures. The figures at the top indicate pressures in atmospheres above a vacuum; the corresponding figures at the bottom denote pressures by the gauge. At the right are volumes from one-tenth to one. At the left are degrees of temperatures from zero to 1,000 degrees Fahrenheit. The two curves which begin at the upper left hand corner and extend to the lower right are the lines of compression.

The upper one being the "Adiabatic" curve, or that which represents the pressure at any point on the stroke with the heat developed by compression remaining in the air; the lower is the "Isothermal," or the pressure curve uninfluenced by heat. The three curves which begin at the lower left hand corner and rise to the right, are heat curves and represent the increase of temperature corresponding with different pressures and volumes, assuming in one case that the temperature of the air before admission to the compressor is zero, in another sixty degrees, and in another one hundred degrees.

Beginning with the adiabatic curve, we find that for one volume of air, when compressed without cooling, the curve intersects the first vertical line at a point between 0.6 and 0.7 volume, the gauge pressure being 14.7 pounds. If we assume that this air was admitted to the compressor at a temperature of zero, it will reach about 100 degrees when the gauge pressure is 14.7 pounds. We find this by following down the first line intersected by the adiabatic curve to the point where the zero heat curve intersects the same line, the reading being given in figures to the left immediately opposite. If the air had been admitted to the compressor at 60 degrees, it would register about 176 degrees at 14.7 pounds gauge pressure. If the air were 100 degrees before compression, it would go up to about 230 degrees at this pressure. Following this adiabatic curve until it intersects line No. 5, representing a pressure of five atmospheres above a vacuum (58.8 lb. gauge pressure) we see that the total increase of temperature on the zero heat curve is about 270 degrees; for the 60 degree curve it is about 370 degrees, and for the 100 degree curve it is about 435 degrees. The diagram shows that when a volume of air is compressed adiabatically to 21 atmospheres (294 lb. gauge pressure) it will occupy a volume a little more than one-tenth; the total increase of temperature with an initial temperature of zero is about 650 degrees; with 60 degrees initial temperature it is 800 degrees, and with 100 degrees initial it is 900 degrees. It will be observed that the zero heat curve is flatter than the others, indicating that when free air is admitted to a compressor cold, the relative increase of temperature is less than when the air is hot. This points to the importance of low initial temperature. It is plain that a high initial temperature means a higher temperature throughout the stroke of a compressor. The diagram gives the loss of temperature during compression from initial temperatures of 0 deg., 60 deg., 100 deg. If we compare the compression line from zero with the compression line from 100 deg., we observe that in compressing the air from, say 1 atmosphere to 10 atmospheres, the original difference, which

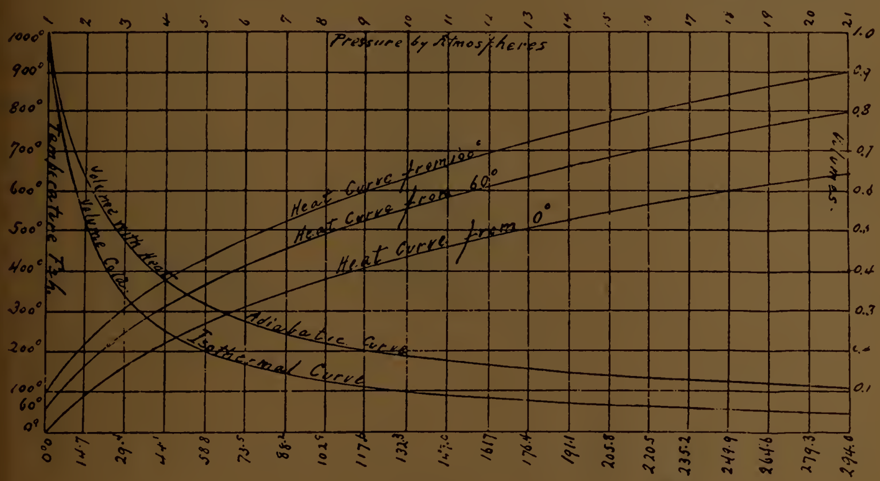

FIG. 2.

at the start was only 100 deg., has now been about doubled; that is, it has reached 200 deg., and in carrying the compression to 20 atmospheres the difference now becomes about 250 deg. Each horizontal division represented by the figures at the left is equal to 100 deg., and the space between any two adjacent horizontal lines may be subdivided into 100 equal parts representing 1 deg. each.

Where there is a system of cooling the air during compression, the lines on the indicator cards can be traced between the adiabatic and isothermal curves on the diagram., In practice the best compressors show a line about midway between these two curves. Compressors using a spray of water for cooling show a pressure line a little nearer the isothermal, but for reasons which will be referred to later on, spray compressors are now but little used.

For all practical purposes in using this diagram it is best to follow the adiabatic curve in all determinations, except where the exact pressure line is known. This diagram will be found convenient to those who are called upon to figure the pressure at different points in the stroke of an air compressor, and it points out the common error of neglecting to take into consideration in one's figures the fact that, at the beginning of the stroke, one atmosphere in volume already exists. Beginning at the upper left hand corner, the adiabatic pressure curve intersects the first vertical line at that point in the stroke when the pressure on the gauge will register 14.7 pounds.

The next vertical line shows where the gauge reaches 29.4 pounds, and it is evident here that the piston of an air compressor travels much farther in reaching 14.7 pounds than in doubling that pressure or in reaching 29.4 pounds; thus an air compressor is an engine of unevenly distributed resistance. During the early stages of the stroke it has a slowly accumulating loal to carry, while later on this

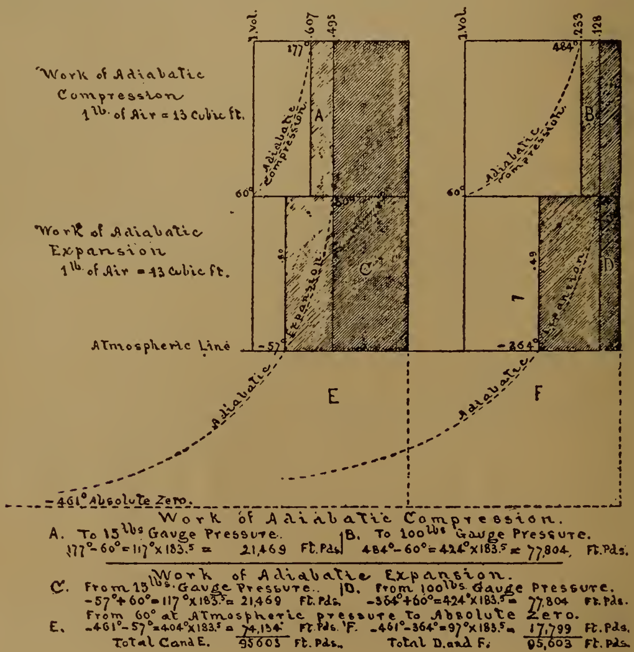

FIG. 3.

load is multiplied very rapidly. This is one of the reasons for heavy fly wheels in air compressors.

Figure 3 is a graphic diagram drawn for the purpose of illustrating the fact that the power which is contained in any volume of air at a given pressure is dependent upon its distance in temperature above the absolute zero, and that there is as much power in a pound of air at fifteen pounds gauge pressure and 60 degrees temperature as there is in one pound of air at 100 pounds gauge pressure and 60 degrees temperature. One pound, or thirteen cubic feet of air at fifteen pounds pressure and 60 degrees temperature, is represented by the space C. The *available* power in this air is 21,469 foot pounds. By available power is meant the amount of power which can be utilized when this air is expanded adiabatically to atmospheric pressure. The diagram shows that when such pressure is reached the temperature will be—57 degrees Fahr. There still remains in this air a certain amount of *intrinsic energy,* and the diagram and figures show that this energy is equal to 74,134 foot pounds. This added to the available energy gives us 95,603 foot pounds, as the whole energy contained in one pound of air at fifteen pounds pressure and 60 degrees temperature.

D represents one pound of air at 100 pounds pressure and 60 degrees temperature. Its available energy is 77,804 foot-pounds, and its intrinsic energy is 17,799 foot-pounds, or the total energy is 95,603 foot-pounds, which is exactly equal to the case just cited.

These figures show the correctness of that thermodynamic law, which states that the power of any elastic gas is in direct proportion to its height of fall. So long as the temperature is above the absolute zero, there is as much power in the same body of air when expanded adiabatically from a moderate temperature to an extremely low one, as when expanded from a high temperature to a moderate one, and this offers to some extent a limitation to that system of reheating which increases the volume without at the same time increasing the pressure.

The development of heat when air is compressed is, perhaps, the best illustration of the acknowledged thermodynamic principle that work and heat are interchangeable unit for unit. When air is compressed all the work done in compression is converted into heat. This heat is capable of being converted back again into power. But the question is frequently asked, if it be true that the power applied in the steam cylinder of an air compressor is all converted into heat in the air cylinder, how is it that power still remains in the compressed air after the heat has been lost through transmission?

In order to get a clear understanding of this, we must know that air is a power in itself before compression; that it contains a certain capacity for work due to its elasticity. It is not, however, in a condition *available* for work until compressed. This energy is made available by giving it a height of fall which is represented by a difference in pressure between the compressed air on one side and the free air on the other.

If we box up free air at any given temperature and under normal atmospheric conditions, we have within the enclosure a well defined amount of energy. We cannot use it to perform work unless the pressure outside is less than that inside the enclosure. This may be accomplished by placing the closed vessel in the rarified atmosphere, such as exists at altitudes, but in any case, there is a well defined quantity of intrinsic energy within the air itself, the limit being measured by the height of fall between the free air in the vessel and absolute zero.

Compression as now practiced only serves the purpose of placing the natural power which we have in the air, into a condition which makes it possible for us to utilize it. This points to an undeveloped science in the use of compressed air. Inasmuch as we lose all the power expended in compression and yet have a capacity for useful work equal to from 30 to 50 per cent. of that power, it is plain that there are possibilities in the science which are now misunderstood and not realized.

It is theoretically possible to realize out of compressed air more power than was expended at the compressor. This has been shown in Fig. 1, but that this statement might not be confused with perpetual motion theories, the sketch shown in Fig. 4 has been prepared.

Sulphuric acid in its concentrated form will, when exposed in an open dish absorb moisture from the atmosphere to the extent of about double its weight. A hypothetical assumption is made of a pump arranged to discharge sulphuric acid in the direction shown by the arrow to an open dish, elevated (say) 100 feet.

The amount of power necessary to discharge a certain quantity of sulphuric acid into this dish is exactly equal to the power which the sulphuric acid is capable of giving out when falling back again, less the friction of the pump, leakage, etc. Now, let us assume that the sulphuric acid in the open dish remained there long enough to absorb moisture from the atmosphere until its weight has been doubled; it will thus obviously have twice the amount of power

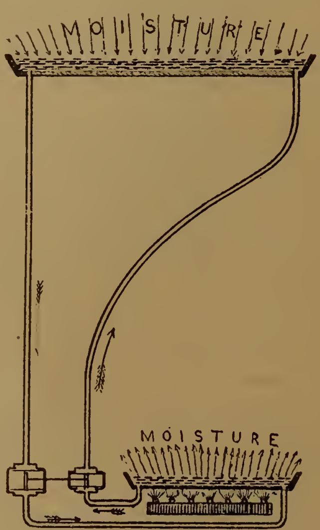

Fig. 4.

in falling back again, and if the friction and leakage losses were not too great, it will be capable of driving the pump and of returning an equivalent volume of the concentrated acid to the dish. If the same acid is used over again, the moisture must be driven out, and lamps are shown in the sketch provided for this purpose. The analogy between this hypothetical case of sulphuric acid and one of compressed air is, that, as with acid we may draw power from moisture which is contained in the air, so with compressed air may we draw upon the intrinsic heat energy of the atmosphere.

If it were practicable to compress air isothermally—that is, without heat—we might illustrate the point referred to in the foregoing by placing an air compressor in a cold room, or what would amount to the same thing, taking in cold air to the cylinder of the compressor, this air being taken, for instance, from a cold storage room, and on being compressed the temperature being maintained at the initial point. This cold compressed air might then be led in pipes, placed on the surface of the ground and exposed, say, to the hot sun, so that when used its temperature might be largely increased above that at the compressor.

We would here have a case of reheating by natural conditions, and the possibility of obtaining more power at the motor than was expended at the compressor is made apparent.

All this appears to be but theory, yet the value of the argument lies in the fact that it points to what may be accomplished in the future and to the importance at present of low initial temperature at the compressor and high temperature at the motor. It is a common thing to see air compressors at work in engine rooms drawing the air into the cylinder at the temperature of the engine room, which, in many instances, especially in winter, is 50 degrees higher in temperature than that of the air on the outside. Even where air compressors are used with concentrated inlets made for the express purpose of being connected with the atmosphere from the outside, this question of economy by low initial temperature is frequently neglected. For every 5 degrees by which the initial temperature of the intake air is lowered, there is a gain of one per cent. in volume.

It is not a difficult matter to construct an air compressor plant where the intake air is made to pass over refrigeration pipes. In cities where ice-making plants are in operation, the best point to place the air compressor is alongside the ice-making machines, the combination of the two industries being advisable.

On the other end of the line reheating is of great importance. A perfect reheater has not yet been found, though at this time reheaters are in use which give practical results. It has already been demonstrated that compressed air may be increased in temperature and thus proportionately increased in volume and efficiency by the application of heat in a very economical manner, the quantity of coal consumed in proportion to the gain in economy being very small.

Mr. Robert Hardie, in his experiments with a pneumatic motor using a hot water reheater, has figured the cost of reheating at one-eighth the coal required at the compressor. Professor Haupt, referring to this heater, makes the following statement:

"The power required to compress 1,000 cubic feet of free air to 2,000 pounds per minute would be 400 horse-power, consuming 1,200 pounds of coal per hour at a cost of $1.80 (at $3 per ton), and the cost of reheating would not exceed 22 cents to double the work performed. That these statements are not simply theoretical deductions have been proved by actual tests. The Rome air motor when using a reheater ran fourteen miles on a consumption of 308 cubic feet of free air per mile. When the air was not reheated, the consumption of air per mile was 661 cubic feet."

The first loss in air compression, that due to the fact that the heat produced cannot be maintained, is an unavoidable loss. The second loss may be called the influence of the heat of compression, and is due to the fact that this heat increases the relative volume of the air and resists compression. This heat of compression has long been the *bete noire* of air compressor builders. At first it seriously affected the valves and packing, and this served as an argument in favor of injecting water into the cylinder, the claim of manufacturers being that by keeping down the heat of compression repairs would be less and accidents due to the destruction of parts by heat would be avoided.

The injection of water into the air cylinder is usually known as the Colladon idea. Compressors built on this system have shown the highest isothermal results. It is plain that the injection of cold water in the shape of a finely divided spray directly into the air during compression will lower the temperature to a greater degree than to simply surround the cylinder and parts by water jackets.

Two systems are in use by which it is attempted to absorb the heat during compression. These systems divide air compressors into two classes—

(1) Wet compressors.

(2) Dry compressors.

A wet compressor is one which introduces water directly into the cylinder during compression.

A dry compressor is one which admits no water to the air during compression.

Wet compressors may be subdivided into two classes—

(1) Those which inject water in the form of a spray into the cylinder during compression.

(2) Those which use a water piston for forcing the air into confinement.

The advantages of water injection during compression are as follows:

(1) Low temperature of air during compression, hence a reduced mean resistance and a saving of power.

(2) Increased volume of air per stroke, due to filling of clearance spaces with water, and to a cold air cylinder.

(3) Low temperature of air immediately after compression, thus condensing moisture at the air receiver.

(4) Low temperature of cylinder and valves, thus maintaining packing, etc.

(5) Economical results due to compression of moist air. (See Table No. 4.)

The first advantage is by far the most important one, and is really the only excuse for water injection in air compression.

The percentage of work of compression (dry air) which is converted into heat and lost when no cooling system is used is as follows:

Compressing to	2	atmospheres, loss	9.2	per	cent.
"	" 3	"	" 15.0	"	"
"	" 4	"	" 19.6	"	"
"	" 5	"	" 21.3	"	"
"	" 6	"	" 24.0	"	"
"	" 7	"	" 26.0	"	"
"	" 8	"	" 27.4	"	"

We see that in compressing air to five atmospheres, which is the usual practice, the heat loss is 21.3 per cent., so that if we keep down the temperature of the air during compression to the isothermal line, we save this loss. The best practice in America has brought this heat loss down to 3.6 per cent. (old Ingersoll Injection Air Compressors), while in Europe the heat loss has been reduced to 1.6 per cent. Steam-driven air compressors are usually run at a piston speed of about 350 feet per minute, or from 60 to 80 revolutions per minute of compressors of average sizes, say 18 inches diameter of cylinder. Sixty revolutions per minute is equal to 120 strokes, or two strokes per second. An air cylinder 18 inches in diameter filled with free air once every half second, and at each stroke compressing the air to 60 pounds, and thereby producing 309 degrees of heat, is thus by means of water injection cooled to an extent hardly possible with mere surface contact. The specific heat of water being about four times that of air, it readily takes up the heat of compression.

A properly designed spray system must not be confused with the numerous devices applied to air cylinders by means of which water is introduced. In some cases the water is merely drawn in through the inlet valves. In others it passes through the centre of the piston and rod, coming in contact with the interior walls of the air cylinder between the packing rings. Introducing water into the air cylinder *in any other way, except in the form of a spray, has but little effect in cooling the air during compression.* On the contrary, it is a most fallacious system, because it introduces all the disadvantages of water injection without its isothermal influence. Water, by mere surface contact with air, takes up but little heat, while the air having a chance to increase its temperature, absorbs water through the affinity of air for moisture, and thus carries over a volume of saturated hot air into the receiver and pipes, which on cooling (as it always does in transit to the mine), deposits its moisture and gives trouble through water and freezing. It is therefore of much importance to bear in mind that unless water can be introduced *during compression to such an extent as to keep down the temperature of the air in the cylinder,* it had better not be introduced at all.

If too little water is introduced into an air cylinder during compression, the result is warm, moist air, and if too much water is used it results in a surplus of power required to move a body of water which renders no useful service.

The following Table 3 deduced from Zahner's formula gives the quantity of water which should be injected per cubic foot of air compressed in order to keep the temperature down to 104° F.:

TABLE 3.

Compression by atmosphere above a vacuum.	Weight of water to be injected at 68° Fah. to keep the temperature at 104° Fah. in lbs. of water and per lbs. of free air.	Weight of water to be injected at 68° Fah. to keep the temperature at 104° Fah. in lbs. of water for 1 cu. ft. of free air.
2	0·734	0·056
3	1·664	0·089
4	1·469	0·113
5	1·701	0·131
6	1·891	0·145
7	2·063	0·158
8	2·204	0·167
9	2·329	0·179
10	2·440	0·188
11	2·542	0·195
12	2·634	0·202
13	2·719	0·209
14	2·798	0·215
15	2.871	0·223

Experiments were made under the personal supervision of Prof. Denton at the Stevens Institute of Technology, to determine the relative effects in air compressors of water injection and water jackets. An extended controversy had been carried on in the "Engineering and Mining Journal" between the writer and others upon the question whether or not the injection of water reduced the temperature and increased the efficiency. It was claimed by some that the efficient indicator cards taken from certain injection compressors were not reliable because of leakage. It was only on such grounds that the proximity of

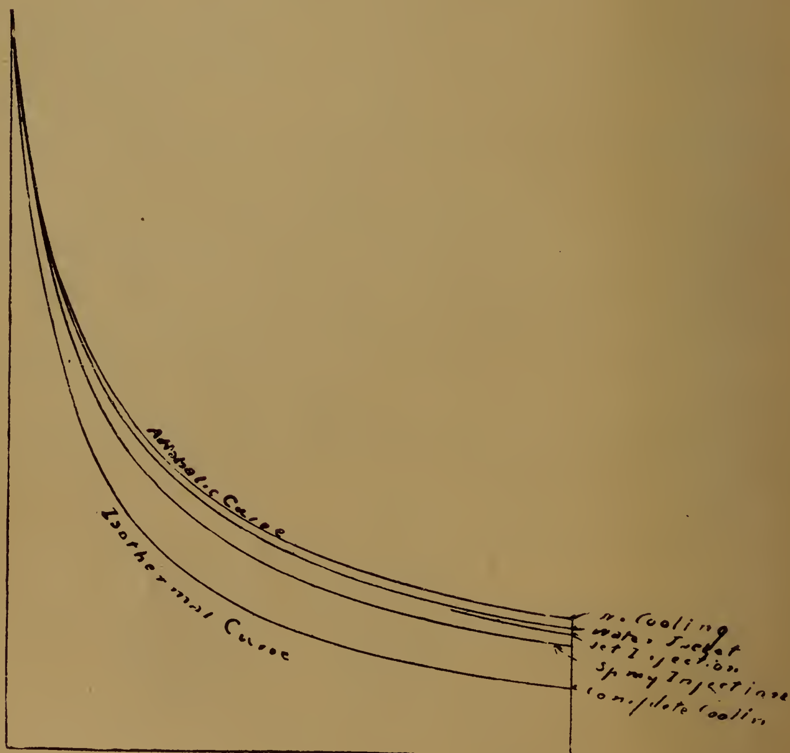

FIG. 5.

the pressure line to the isothermal could be explained away. In the Stevens Institute tests the greatest care was exercised to secure air-tight pistons and valves, and as these experiments were unbiased and in the hands of experts, the results may be accepted as conclusive so far as indicating isothermal economy by an efficient system of injection. Fig. 5 herewith represents graphically the results obtained at the Stevens Institute.* No clearance is shown, because the purpose of the illustration is to show the comparative effect of the various methods of cooling. The air was compressed to 150 pounds gauge pressure, the

*From a paper by Mr. R. A. Parke.

TABLE 4.—SHOWING THE RELATIVE QUANTITY OF WORK REQUIRED TO COMPRESS A GIVEN VOLUME AND WEIGHT OF AIR, BOTH DRY AND MOIST—ALSO RELATIVE VOLUMES WITH AND WITHOUT INCREASE OF TEMPERATURE FROM COMPRESSION.

Tension in Atmospheres.	Compression at a Constant Temperature. Mariotte's Law.			Compression with Increase of Temperature.						Loss of Work in Compressing one Cubic Meter in Kilogram-meters.	Percentage of Work of Compression Converted into Heat and Lost.	Final Temperature if Water is used in Compression.	Percentage of Water to Air Required.	Foot Pounds to Compress One Pound Air.	
	Volume	Work of Compression.		Volume	Work of Compression. (Dry.)		Temperatures. (Dry.)		Ratio of Greater to Less Temperature.	By increase of Temperature alone.				Dry.	With sufficient Moisture.
		Cubic Meters, in Kilogram-meters.	Cubic Feet in Foot Pounds		Cubic Meters in Kilogrammeters.	Cubic Feet in Foot Pounds.	Cent.	Fah.	Absolute.						
			Deduced from 3.			Deduced from 6.						Fah.			
1	0·1						20	68	1·0			68			
2	0·5	7199	1468	0·612	7932	1618	85·5	186	1·222	733	0·092	111	3·0	23500	22500
3	0·333	11356	2316	0·459	13360	2725	130·4	267	1·375	2004	0·150	135·5	4·0	37000	35000
4	0·25	14260	2909	0·374	17737	3618	165·6	330	1·495	3477	0·196	153·5	4·8	48500	45000
5	0·200	16580	3383	0·320	21209	4326	195·3	384	1·595	4029	0·218	167	5·4	58500	52500
6	0·167	18475	3768	0·281	24310	4959	220·5	429	1·681	5835	0·240	179	6·0	67000	60000
7	0·143	20038	4087	0·252	27048	5517	243·2	470	1·758	7040	0·260	190	6·4	75000	66000
8	0·125	21422	4370	0·229	29518	6021	263·6	506·5	1·828	8096	0·274	...	....	....	....
9	0·111	....	....	0·210	....	....	282	539·6	1·891	....	....	....	....	....	....
10	0·100	....	....	0·195	...	....	299	570·2	1·950	....	....	...	....	....	....
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

work done in each case being represented by the area between the pressure curve and the rectangular lines.

The pressure curve is determined in each case by the formula—

$$\frac{P}{P_1} = \left(\frac{V_1}{V}\right)^N.$$

In the case of isothermal compression (assuming no heat produced), the exponent N=1. In adiabatic compression (the full effect of the heat of compression being available), N=1.408. It is obvious that the value of the exponent N will vary between the two points 1, and 1.408. From a large number of indicator cards taken at the Stevens Institute the following values were shown:

Water jacket	N=1.35
Water jet injection.........................	N=1.33
Water spray injection.......................	N=1.25

It has been demonstrated by experiments made in France that the power required to compress dry air has been prepared from the data of M. Mallard, and shows that for five atmospheres the work expended in compressing one pound of dry air is 58,500 foot pounds, while that for moist air is 52,500 foot pounds. In expansion also moisture in the air adds to the economy, but in both cases the saving of power is not great enough to compensate for the many disadvantages due to the presence of water. Mr. Norman Selfe, of the Engineering Association of N. S. W., has compiled a table which shows some important theoretical conditions involved in producing compressed air.

There are many serious objections, however, to the use of water within the air cylinder. These objections are so serious that it has been found to be the best practice to suffer the heat loss during compression, and thus simplify the apparatus. Some of the objections may be stated as follows:

1. The mechanical difficulties involved in introducing the water into the cylinder so intimately mixed with the air during compression as to reduce the temperature of compression immediately when produced.

2. Impurities in the water, which, through both mechanical and chemical action, destroy exposed metallic surfaces.

3. Wear of cylinder, piston and other parts, due directly to the fact that water is a bad lubricant; and as the density of water is greater than that of oil, the latter floats on the water and has no chance to lubricate the moving parts.

4. Wet air arising from insufficient quantity of water and from inefficient means of ejection.

5. Mechanical complications connected with the water pump, and the difficulties in the way of proportioning the volume of water and its temperature to the volume, temperature and pressure of the air.

6. Loss of power required to overcome the inertia of the water.

7. Limitations to the speed of the compressor, because of the liability to break the cylinder head joint by water confined in the clearance spaces.

8. Absorption of air by water.

Before the introduction of condensing air receivers, wet air resulting in freezing was considered the most serious obstacle to water injection; but this difficulty no longer exists, as experience has demonstrated that a large part of the moisture in compressed air may be abstracted in the air receiver. Even in the so-called dry compressors a great deal of moisture is carried over with the compressed air, because the atmosphere is never free from moisture. This subject will be referred to more fully when treating of the transmission of compressed air.

A serious obstacle to water injection, and that which condemns the wet compressor, is the influence of the injected water upon the air cylinder and parts. Even when pure water is used, the cylinders wear to such an extent as to produce leakage and to require reboring. The limitation to the speed of a compressor is also an important objection. The claim made by some that the injected water does not fill the clearance spaces, but is aerated, does not hold good, except with an inefficient injection system.

Whether it be water or spray which occupies the clearance space, it is impossible for air and spray to occupy the same place at the same time.

The writer has increased the speed of an air compressor (cylinders 12 in. and 12 in. by 18 in., injection) ten revolutions per minute by placing his fingers over the orifice of the suction pipe of the water pump. The boiler pressure remained the same, the cut-off was not changed and the air pressure was uniform, hence this increase of speed arose from the fact that the water was restricted and the clearance spaces were filled with compressed air, which served as a cushion or spring. While the volume of compressed air furnished by this compressor would be somewhat reduced by the restriction of the water, yet the increase in speed which was obtained without any increase of power, fully compensated for the clearance loss.

Unless the water of injection can be used efficiently as a cooling agent, its value for clearance does not compensate for the disadvantages attending its use. In some of the early types of air compressors water was introduced through the inlet valves during the suction stroke; but this is an objectionable plan, because it has little effect on the heat produced until the discharge of the air, and furthermore, there is the danger of introducing too much water, and thus reducing the volume of air and endangering the cylinder heads.

The presence of moisture in the air reduces the heat loss, hence, as shown by Table No. 4, less power is required to compress moist than dry air. It is not necessary to inject water during compression in order to gain this advantage, as the atmosphere is usually moist. The presence of moisture in the air has an important bearing upon the compression, transmission and use of air. Before compressed air became generally used, its value was thought to be prohibitive, mainly because it was said that the air would freeze. This freezing was, of course, nothing more than the formation of ice due to the presence of moisture in the air, this moisture having been first deposited in the shape of water by expansion and cooling, and afterwards, the temperature going down below the freezing point, it became ice. This has some time since ceased to be a serious matter, and on the whole the presence of the moisture has been found to be more beneficial than otherwise, because by increasing the specific heat of the body with which it is in contact, it reduces the temperature during compression and tends to increase it during expansion. In transmission it is simply necessary to keep the temperature from falling below the dew point, or to put in suitable receivers for draining the pipes. Where reheaters are used, the presence of moisture is decidedly advantageous.

The amount of moisture in the atmosphere varies with the climate. Air is never perfectly dry; never, except in rare instances, does it contain less than 25 per cent. of the moisture necessary to saturate it. It is not an uncommon thing to read in the meteorological reports in the newspapers during the summer that the moisture during an oppressively hot day reached 98 per cent., and even 99 per cent. In winter it is usually 80 or 85 per cent. At 65 per cent. we consider it moderately dry; 50 per cent. being commonly called dry air.

Otto Van Guericke invented the air-pump in 1650. In 1753 Holl used an air engine for raising water. At Ramsgate Harbor, Kent, in the year 1788, Smeaton invented a "pump" for use in a diving apparatus. In 1851, William Cubitt, at Rochester Bridge, and a little later an engineer, Brunel, at Saltash,

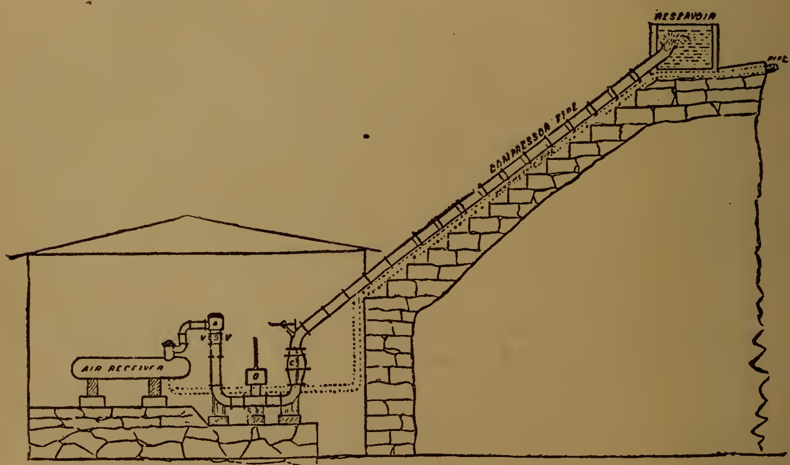

FIG. 6.—SOMMEILLER AIR COMPRESSOR USED AT THE MT. CENIS TUNNEL.

used compressed air for bridge work. In 1852, Colladon patented the application of compressed air for driving machine drills in tunnels. The first notable use of compressed air is due to Prof. Colladon, of Geneva, whose plans were adopted at the Mont Cenis tunnel. M. Sommeiller developed the Colladon idea and constructed the compressed air plant illustrated in Fig. 6.

The Sommeiller compressor was operated as a ram, utilizing a natural head of water to force air at 80 pounds pressure into a receiver. The column of water contained in the long pipe on the side of the hill was started and stopped automatically, by valves controlled by engines. The weight and momentum of the water forced a volume of air with such shock against a discharge valve that it was opened and the air was discharged into the tank; the valve was then closed, the water checked; a portion of it was allowed to discharge and the space was filled with air, which was in turn forced into the tank. The efficiency of this compressor was about 50 per cent.

At the St. Gothard tunnel, begun in 1872, Prof. Colladon first introduced the injection of water in the form of spray into the compressor cylinder to absorb the heat of compression.

Fig. 7 illustrates the air cylinder of the Dubois-Francois type of compressor, which was the best in use about the year 1876. This compressor was exhibited at the Centennial Exposition and was adopted by Mr. Sutro in the construction of the Sutro tunnel. A characteristic feature seems to be to get as much water into the cylinder as possible. The water which flooded the bottom of the cylinder arose from the voluminous injection; this water was pushed into the

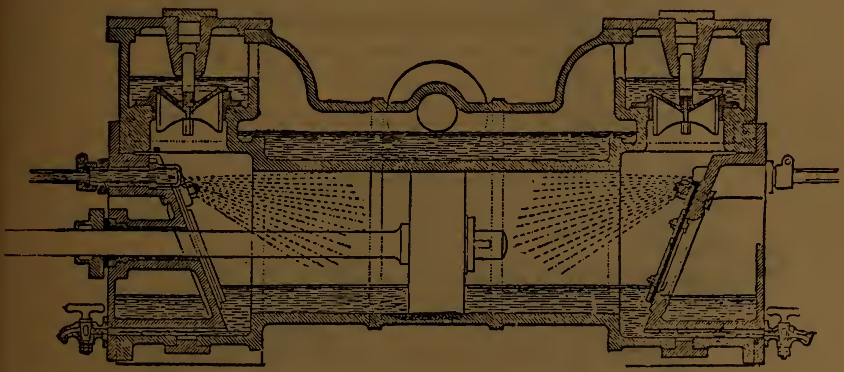

Fig. 7.—Dubois & Francois, 1876.

end of the cylinder and some of it escaped with the air through the discharge valve.

An improved pattern of this compressor is shown in Fig. 8.

The first air compressor used on a large scale for practical work in America is shown in Fig. 9.

This machine was used at the Hoosac Tunnel, being built a little prior to 1866. The design was made under the direction of the Massachusetts State Commission, of which Mr. John W. Brooks was chairman and Mr. Thomas Doane, chief engineer for tunnel construction. It is believed that Mr. Doane deserves the largest share of credit for the invention and development of this compressor, and it is to the credit of these early designers to note that after the completion of the Hoosac Tunnel the compressor was transferred to the Marble Quarries, at Sutherland Falls, Vt. (now called Proctor), and that it has been used continuously up to the present time, compressing air to about 40 pounds to the square inch. Rock drills and channeling machines of modern construction are now using this air for quarrying the beautiful marble of Vermont.

The first channeling machine was tried in this quarry perhaps with compressed air furnished by the Hoosac Tunnel compressor.

The compressor is so simple that it may be readily understood by looking at the plan. It consists of 4 horizontal air cylinders, the pistons of which are propelled by a turbine wheel. The cylinders are single acting, the air being admitted through poppet valves placed in the piston. Each cylinder is 13 in. in diameter by 20 in. in stroke. It was originally intended for a speed of 120 revolutions per minute, but it has been run over 70 revolutions. The cooling arrangement applied to this compressor was simply an injection of water through the inlet valves into the cylinders, though since its use at Hoosac Tunnel, injection

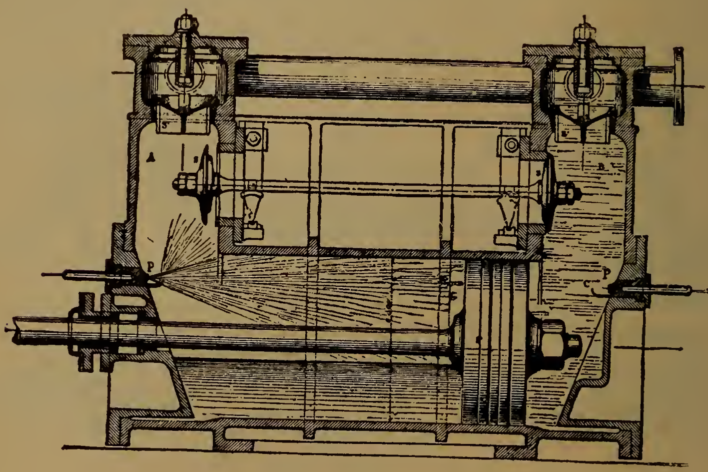

FIG. 8.—DUBOIS & FRANCOIS, 1884.

has been abandoned, and a simple stream of water from a jet is allowed to play upon the cylinders.

These illustrations are interesting from an historical point of view, as indicating the line of thought which early designers of air compressing machinery followed. As the necessity for compressed air power grew, inventors turned their attention to the construction of air-compressing engines that would combine *efficiency* with *light weight* and *economy of space and cost.* The trade demanded compressors at inaccessible localities, and in many cases it was preferred to sacrifice isothermal results to simplicity of construction and low cost.

It is evident that an air compressor which has the steam cylinder and the air cylinder on a single straight rod will apply the power in the most direct manner, and will involve the simplest mechanics in the construction of its parts. It is evident, however, that this straight line, or direct construction, results in an engine which has the greatest power at a time when there is no work to perform. At the beginning of the stroke, steam at the boiler pressure is admitted behind the piston, and as the air piston at that time is also at the initial point in the stroke, it has only free air against it. The two pistons move simultaneously as the resistance in the air cylinder rapidly increases as the air is compressed. To get economical results it is, of course, necessary to cut off in the steam cylinder so that at the end of the stroke, when the steam pressure is low, as indicated by the dotted line (Fig. 10), the air pressure is high, as similarly indicated in the other cylinder. The early direct-acting compressor used steam at full pressure throughout the stroke. The Westinghouse pump applied to locomotives, is built on this principle, and those who have observed it work have perhaps noticed that its speed of stroke is not uniform, but that it moves rapidly at the beginning,

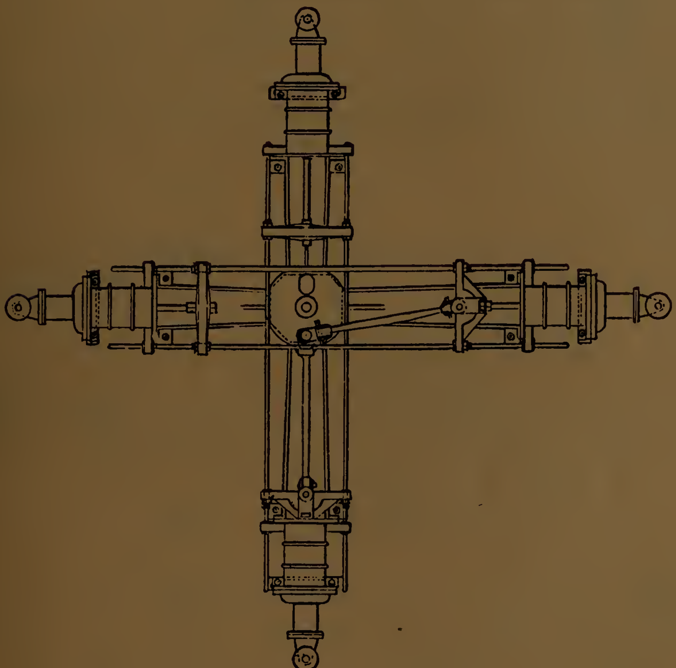

FIG. 9.

gradually reducing its speed, and then seems to labor until the direction of stroke is reversed. This construction is admitted to be wasteful, but in some cases, notably that of the Westinghouse pump, economy in steam consumption is sacrificed to lightness and economy of space.

Many efforts were made to equalize the power and resistance by constructing the air compressor on the crank shaft principle, putting the cranks at various angles, and by angular positions of steam and air cylinders. Several types are shown in Fig. 11.

Angular positions of the cylinder involve expensive construction and unsteadiness. Experience has proved that there is nothing in the apparent difficulty in equalizing the strains in a direct-acting engine. It is simply necessary to add enough weight to the moving parts, that is, to the piston, piston rod, fly wheel, etc., to cut off early in the stroke and secure rotative speed with the most economical results and with the cheapest construction. It is obvious that the

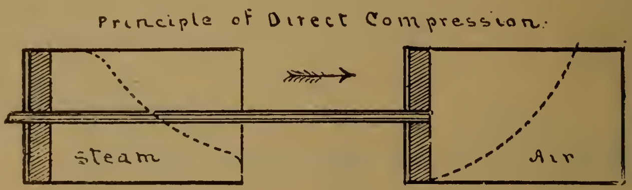

FIG. 10.—DIRECT COMPRESSION ILLUSTRATED IN THE STRAIGHT LINE AIR COMPRESSOR, IN WHICH THE MOMENTUM OF THE FLY WHEEL EQUALIZES THE PRESSURE.

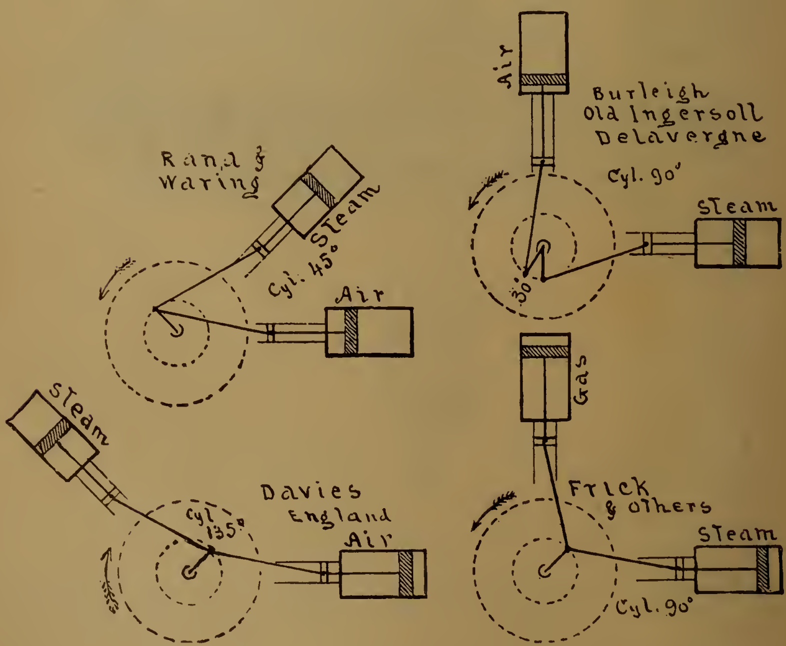

FIG. 11.

theoretically perfect air compressor is a direct-acting one with a conical air cylinder, the base of the cone being nearest the steam cylinder. This, from a practical point of view, is impossible. Mr. E. Hill in referring to the fallacious tendencies of pneumatic engineers to equalize power and resistance in air compressors, says:

"The ingenuity of mechanics has been taxed and a great variety of devices have been employed. It is usual to build on the pattern of presses which do their work in a few inches of the end of the stroke and employ heavy fly wheels, extra strong connections, and prodigious bed plates. Counterpoise weights are also attached to such machines; the steam is allowed to follow full stroke, steam cylinders are placed at awkward angles to the air-compressing cylinders and the motion conveyed through yokes, toggles, levers; and many joints and other devices are used, many of which are entire failures, while some are used with questionable engineering skill and very poor results."

Fig. 12 illustrates the theory of Duplex Air Compressors. The hydraulic piston or plunger compressor is largely used in Germany and elsewhere on the Continent of Europe, but the duplex may be said to be the standard type of European compressor at the present time. It is also largely used in America. Fig. 12 shows the four cylinders of a duplex compressor in two positions of the stroke. It will be observed that each steam cylinder has an air cylinder connected directly to the tail rod of its piston, so that it is a direct-acting machine,

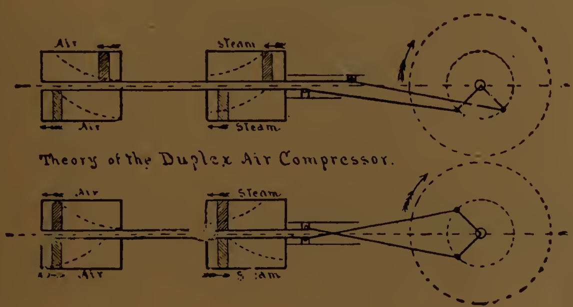

FIG. 12.

except in that the strains are transmitted through a single fly wheel, which is attached to a crank shaft connecting the engines. In other words, a duplex air compressor would be identical with a duplex steam engine, except in, that the air cylinders are connected to the steam piston rods. The result is, as shown in Fig. 12, that at that point of the stroke indicated in the top section, the upper right hand steam cylinder, having steam at full pressure behind its piston, is doing work through the angle of the crank shaft upon the air in the lower left hand cylinder. At this point of the stroke the opposite steam cylinder has a reduced steam pressure and is doing little or no work, because the opposite air cylinder is beginning its stroke. Referring now to the lower section, it will be seen that the conditions are reversed. One crank has turned the center, and that piston which in the upper section was doing the greatest work is now doing little or nothing, while the labor of the engine has been transferred to those cylinders which a moment before had been doing no work.

This is the theory of the Duplex Compressor, but it can hardly be said to be true when applied in practice, because of the heavy fly wheel which is placed on the main shaft. This wheel takes up and equalizes the power imparted by the steam pistons, and in fact it is the fly wheel which really does the work of compression at or near the end of each stroke. Heavy fly wheels are therefore essential in order to produce the best results with duplex compressors.

In the duplex pattern, the crank shafts being set quartering, as is the usual construction, the engine may be run at low speed without getting on the center. Each half being complete in itself, it is possible to detach the one when only half the capacity is required.

Commercially the Duplex Compressor appeals to the trade in that one side, or a half duplex, is furnished with a fly wheel and outboard bearings designed for a complete duplex machine, so that at first, at a little more than half the expense, one side is erected and when more air is needed the capacity of the plant is doubled by adding the other half. Where large capacities are required, the duplex will admit of larger air production with economical engines, and at less expense when the cost of the plant is considered in proportion to the volume of air furnished.

Mr. John Darlington, of England, gives the following particulars of a modern air compressor of European type:

"Engine, two vertical cylinders, steam jacketed, with Myer's expansion gear. Cylinders, 16.9 inches diameter, stroke 39.4 inches; compressor, two cylinders, diameter of piston 23·0 inches; stroke 39·4 inches; revolutions per minute, 30 to 40; piston speed, 39 to 52 inches per second; capacity of cylinder per revolution, 20 cubic feet; diameter of valves, viz., four inlet and four outlet, 5½ inches; weight of each inlet valve, 8 lbs.; outlet, 10 lbs.; pressure of air, 4 to 5 atmospheres. The diagrams taken of the engine and compressor show that the work expended in compressing one cubic meter of air to 4·21 effective atmospheres was 38,128 lbs. According to Boyle and Mariotte's law it would be 37,534 lbs., the difference being 594 lbs., or a loss of 1·6 per cent. Or if compressed without abstraction of heat, the work expended would in that case have been 48,158. The volume of air compressed per revolution was 0·5654 cubic meters. For obtaining this measure of compressed air, the work expended was 21,557 pounds.

"The work done in the steam cylinders, from indicator diagrams, is shown to have been 25,205 pounds, the useful effect being 85½ per cent. of the power expended. The temperature of air on entering the cylinder was 50 deg. Fah.; on leaving, 62 deg. Fah., or an increase of 12 deg. Fah. Without the water jacket and water injection for cooling the temperature it would have been 302 deg. Fah. The water injected into the cylinders per revolution was 0.81 gallons."

We have in the foregoing a remarkable isothermal result. The heat of compression is so thoroughly absorbed that the thermal loss is only 1·6 per cent.; but the loss *by friction of the engine* is 14·5 per cent., and the net economy of the whole system is no greater than that of the best American dry compressor, which loses about one-half the theoretical loss due to heat of compression, but which makes up the difference by a low friction loss.

The wet compressor of the second class is the water piston compressor, Fig. 13.

The illustration shows the general type of this compressor, though it has been subject to much modification in different places. In America a plunger is used instead of a piston, and as it always moves in water, the result is more satisfactory. The piston, or plunger, moves horizontally in the lower part of a U-shaped cylinder. Water at all times surrounds the piston and fills alternately the upper chambers. The free air is admitted through a valve on the side of each column and is discharged through the top. The movement of the piston causes the water to rise on one side and fall on the other. As the water falls the space is occupied by free air, which is compressed when the motion of the piston is reversed, and the water column raised. The discharge valve is so proportioned that some of the water is carried out after the air has been discharged. Hence there are no clearance losses.

The chief claim for this water piston compressor is that its piston is also its cooling device, and that the heat of compression is absorbed by the water.

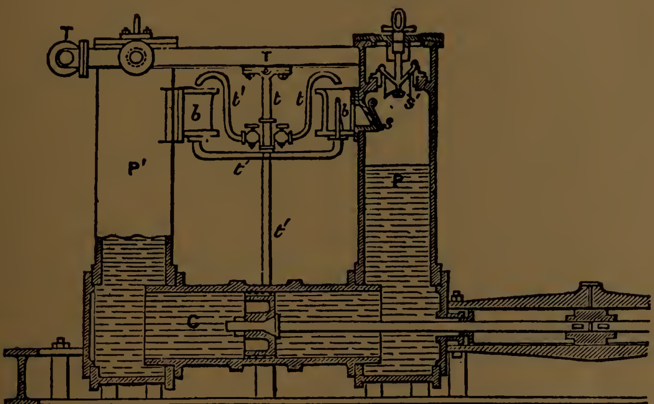

Fig. 13.—Hydraulic or Wet Air Compressor.

So much confidence seems to be placed in the isothermal features of this machine that usually no water jacket or spray pump is applied. Mr. Darlington, who is one of the stanch defenders of this class of compressors, has found it necessary to introduce "spray jets of water immediately under the outlet valves," the object of which is to absorb a larger amount of heat than would otherwise be effected by the simple contact of the air with the water-compressing column. Without such spray connections, it is safe to say that this compressor has scarcely any cooling advantages at all, so far as air cooling is concerned. Water is not a good conductor of heat. In this case only one side of a large body of air is exposed to a water surface, and as water is a bad conductor, the result is that a thin film of water gets hot in the early stage of the stroke, and little or no cooling takes place thereafter. The compressed air is doubtless cooled before it gets even as far as the receiver, because so much water is tumbled over into the pipes with it; but to produce economical results, the cooling should take place *during compression.*

Water and cast iron have about the same relative capacity for heat at equal volumes. In this water piston compressor we have only one cooling surface, which soon gets hot, while with a dry compressor, with water jacketed cylinders and heads, there are several cold metallic surfaces exposed on one side to the heat of compression, and on the other to a moving body of cold water.

But the water piston advocate brings forward the question of speed. It is said that, admitting that the cooling surfaces are equal, we have in one case *more time* to absorb the heat than in the other. This is true, and here we come to an important class division in air compressing machinery *high speed and short stroke* as against *slow speed and long stroke.* Hydraulic piston compressors are subject to the laws that govern piston pumps, and are, therefore, limited to a piston speed of about 100 feet per minute. It is quite out of the question to run them at much higher speed than this without shock to the engine and fluctuations of air pressure due to agitation of the water piston. The quantity of heat produced—that is, the degree of temperature reached—depends entirely upon the conditions in the air itself, as to density, temperature and moisture, and is entirely independent of speed. We have seen that it is possible to lose 21·3 per cent. of work when compressing air to five atmospheres without any cooling arrangements. With the best compressors of the dry system one-half of this loss is saved by water jacket absorption, so that we are left with about 11 per cent., which the slow moving compressor seeks to erase. We are quite safe in saying that the element of *time alone* in the stroke of an air compressor could not possibly effect a saving of more than half of this, or 5½ per cent. Now, in order to get this 5½ per cent. saving, we reduce the speed of an air-compressing engine from 350 feet per minute to 100 feet per minute. We must, therefore, in one case have a piston area *three and one-half* times that of the other in order to get the *same capacity of air,* and in doing this we build an engine of enormous proportions, with heavy moving parts. We load it down with a large mass of water, which it must move back and forth during its work, and thus we produce a percentage of friction loss alone equal to twice or even three times the 5½ per cent. heat loss which is responsible for all this expense in first cost and in maintenance, but which really is not saved, after all, unless water injection in the form of spray also forms a part of the system.

It is obvious that cost of construction and maintenance have much to do with the commercial value of an air compressor. The hydraulic piston machine not only costs a great deal more in proportion to the power it produces, but it costs more to maintain it, and it costs more to run it. It is not an uncommon thing to hear engineers speak of the hydraulic piston compressor as the "most economical" machine for the purpose, but that it is so "expensive" and takes up so much room, and requires such expensive foundations that, unless persons are "willing to spend so much money," they had better take the next best thing, a high speed machine.

The hydraulic piston compressor has one solitary advantage, and that is, it has no dead spaces. It was conceived at a time when dead spaces were very serious conditions. Valves and other mechanism connected with the cylinder of an air compressor were once of such crude construction that it was impossible to reduce the clearance spaces to a reasonable point, and furthermore, the valves were heavy and so complicated that anything like a high speed would either break them or wear them out rapidly, or derange them so that leakages would occur. But we have now reduced inlet and discharge valves and all other moving parts connected with an air cylinder to a point of extreme simplicity. Clearance space is in some cases destroyed altogether by what is, as it were, an elastic air head which is brought into direct contact with the piston. All this reduces clearance to so small a point that it has no influence of any consequence. The moving parts are made extremely simple.

Mr. Sturgeon, of England, has applied a most ingenious and successful inlet valve, which is opened and closed by the friction of the air piston rod through the gland. Mr. Sergeant in America has introduced the piston inlet valve, which is opened and closed by its own inertia. We have, therefore, reached a point at which high speed is made possible.

In the single or straight line compressor it is difficult to equalize power and resistance with long strokes. The speed will be jerky, and when slow the fly wheel rather retards than assists in the work of compression. This action tends to derange the parts and makes large bearings a necessity. The piston in a long stroke compressor travels through considerable space before the pressure reaches a point where the discharge valve opens, and after reaching that point it has to go on still further against a prolonged uniform resistance. This makes rotative speed difficult in single direct acting machines. During the early part of the stroke, the energy of the steam piston must be stored up in the moving parts, to be given out when the steam pressure has been reduced through an early cut-off. With a short stroke and a large diameter of steam cylinder we are able to get steam economy or early cut-off and expansion without compounding.

In compressors of the single or direct acting type with steam and air cylinders of equal diameter it is possible to obtain a pressure of air twice as great as the boiler pressure. This apparent enigma is made plain when it is understood that at the beginning of the stroke there is no resistance in the air cylinder. The steam end at this point has its greatest power, and the supply may be cut-off and the steam expanded in proportion to the pressure required in the air end, and the speed of the machine. The indicator card shows a large volume and low pressure in the steam end, and a smaller volume and higher pressure in the air end, so that what is made up in the air card by high pressure is represented in the steam card by greater volume, and the area of one is nearly equal to that of the other. This can be seen by referring to Fig. 10.

If we omit the cut-off on the steam end the pressure, instead of following the dotted lines, will be maintained at its maximum throughout the stroke, while the air pressure, or resistance, does not reach the steam pressure until the piston has passed the center of the cylinder; hence if there is sufficient inertia in the moving parts, there will be no difficulty in getting an air pressure higher than that of the steam.

CLEARANCE.

The early designers of air compressors, as shown in the Dubois & Francois illustrations (Figs. 7 and 8), mention clearance loss in air compressors as a very serious matter. Even at the present time some air compressor manufacturers admit water through the inlet valves into the air cylinder, not so much for the purpose of cooling as to fill up the clearance spaces. A long stroke involving expensive construction is sometimes justified by the claim that a saving is effected by reduced clearance losses.

Clearance in a properly designed compressor is a loss of volume only, not a loss of power. Let us assume, for the sake of illustration, that we are compressing air with a machine which is provided with so efficient a cooling device that all of the heat of compression will be absorbed as soon as produced. In other words, that we can compress air isothermally. In such a machine as this there will be a slight loss of power due to clearance space, because we would have a certain volume of air in the cylinder at each stroke, and upon which work had been done and heat produced, that heat having been absorbed and the air being retained in the cylinder. In other words, we would have a production and abstraction of heat, which would represent power lost. Isothermal compression is practically impossible; hence we do not abstract the heat from the compressed air in the clearance space, but a large portion of this heat remains, and acts expansively upon the air, imparting its power to the piston at the moment of reversal of stroke. A reasonable clearance space behind the air piston serves a useful purpose in overcoming the inertia of the piston and moving parts acting like a spring at the end of each stroke.

The clearance space in modern air compressors of the best design (including the counter-bore and discharge valve clearance) varies from .002 to .0094 of the volume of free air furnished by the cylinder. The variation is somewhat dependent upon the length of stroke of the machine. At 75 lbs. pressure, and making due allowance for increased volume of air due to heat, the clearance loss of volume varies from .01 to .047, or from one to five per cent. of the air when compressed. The actual space between the piston and the head at the end of the stroke being 1-16".

It must not be inferred that the designers of an air compressor may neglect the question of clearance; on the contrary, it is a very important consideration. If we have a large clearance space in the end of an air compressor which is used to compress air to high pressures, we may readily understand a condition of things that would result in no discharge of compressed air at all, because of too large a clearance space. The entire volume of the cylinder might be compressed and retained in the clearance space, and the compressor will take in no free air on the return stroke, because the clearance space air when expanded is sufficient to fill the cylinder at normal or atmospheric pressure.

Loss in capacity of air compressors by clearance is in direct proportion to the pressure.

Owing to the loss of capacity by clearance in high pressure compressors, it is important that the cylinders be compounded. By compounding the air in the cylinders the clearance loss is reduced because of the reduced density in the air in the clearance space.

Builders of air compressors employ three methods to reduce the clearance loss: (1), By long strokes of piston, so that the percentage of cylinder volume to that of clearance space is reduced to a minimum. (2), By filling the space with water. (3), By not allowing the full reservoir pressure to accumulate in the clearance space above the inlet valve.

The long stroke plan is the best for reducing clearance, except in machines of the single type, where economical compression and rotative speed cannot be accomplished with a long stroke. The use of water to fill clearance spaces has been referred to previously when treating of water injection.

The clearance in the initial cylinder is filled with air at a pressure less than the receiver pressure; and as the diameter of the high pressure cylinder is small, the loss in capacity by clearance is reduced. Mr. E. Hill states that a single type of compressor should have a stroke of 68 in., in order that its clearance loss shall not exceed that of a compound compressor of 24 in. stroke when both compressors are forcing air against 60 pounds pressure.

Fig. 14 illustrates the effect of clearance in loss of volume in an air compressor. The diagram illustrates a typical case in compressors of cheap design and manufacture, the loss in volume amounting to about 20 per cent.

Unnecessary complications have been applied to air compressors to overcome clearance loss. Mr. Sturgeon has designed an air cylinder with lifting

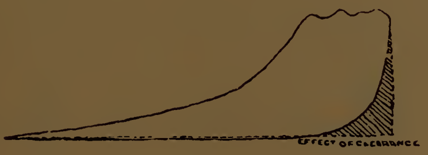

Fig. 14.—Showing Effect of Clearance.

heads, so that the piston slightly raised the head at each stroke, thus reducing clearance to an exceedingly small figure.

A simple method of reducing the clearance loss is by a passage or bypass grooves in the end of the cylinder arranged in such a way that when the piston reaches the end of the stroke it passes over the grooves and thus allows the high pressure air, which is confined in the clearance space, to pass to the other side of the piston. The air in such cases is usually allowed to pass through the grooves at a velocity not exceeding 100 ft. per second. This plan is, however, subject to objections, and it is doubtful that there is anything gained by it. The load on the air piston is suddenly removed when the grooves are uncovered, and thus the cushion behind the piston is destroyed, and unless the cushion in the steam end is effective the compressor will pound badly at the end of each stroke.

The commonest form of inlet valve applied to air compressors is the poppet. It is plain that as soon as the piston starts from the extreme point of stroke nearest the cylinder head, it is followed by the air confined in the clearance space until that point is reached when the pressure in the cylinder is equal to the pressure outside. From this point the action of the piston is now to produce a partial vacuum within the cylinder, resulting in opening the poppet inlet valves against the tension of the spring which holds them to their seats. The result of all this is that the poppet valve construction does not admit of a full air cylinder, as no air from the outside is admitted during a portion of the stroke. Even after the inlet valves are opened there is more or less friction through the passages which reduces the atmospheric pressure. There is seldom less than one pound per square inch difference in pressure between the air within and without the cylinder. This, though apparently small, results in a very serious reduction of efficiency.

A common defect in air compressor construction is insufficient space for proper delivery after compression. The discharge valves and discharge passages are so contracted as to offer considerable resistance to the passage of the air which should be discharged at the same velocity as that at which the piston moves. As the area in the cylinder head is usually small, the volume of valve area is restricted to the minimum. Heavy springs are used in order to prevent the valves from hammering, and the result of this is a loss of power. It is not a difficult matter to admit the air through a valve which is moved by direct mechanical connection, and without springs, but many difficulties are in the way of positive movement in discharge valves. The exact point when it is desired to admit the air is fixed for all pressures and temperatures, but not so with the point of discharge. This varies in proportion to the pressure, and this is effected more or less by the conditions of temperature, dryness and density of inlet air, and the cooling effect during compression. It would not do to hold the discharge valves closed after the pressure in the cylinder has reached the point of pressure in the receiver. Equally serious in loss of efficiency would it be to open a discharge valve before the air in the cylinder has reached the receiver pressure; hence the poppet form of discharge valve is generally used.

Designers of air compressors seldom consider the velocity at which the compressed air is discharged from the cylinder. When the discharge valves are first opened the piston is moving with considerable velocity, which discharges the air in some cases at a velocity of 200 ft. per second. This is, of course, gradually reduced as the piston nears the end of the stroke.

Poppet valves when used either for inlet or discharge should be small in diameter and light in weight. Various designs involving poppet valves of large diameter have been applied to compressors, but they have invariably failed because the increased inertia of a large valve will pound the seats and break the springs. Where poppet valves are used, a large number of small, light valves is the best construction. The movement of a poppet valve should be as short as possible, in order to minimize the wear which results from constantly striking the seat.

It is important in designing an air compressor to provide ample inlet space, so that the cylinder will be filled with air and thus maintain the full volumetric capacity of the machine. The usual area of inlet is 1-10, the area of the piston, though in slow speed compressors this might be reduced considerably. Compressors provided with a concentrated inlet through which the air is drawn alternately at one end and the other of the piston, do not require as large an area of inlet as the intermittent type, because the air when once started through the inlet is maintained constantly moving in one direction and toward the cylinder; thus a draft of air is produced which materially aids in piling up the pressure at the point of reversal of stroke. It must be borne in mind that while the piston is drawing the air into the cylinder its speed is variable. At the beginning, when turning the centre it is slow, increasing rapidly until it reaches its maximum speed at the centre of the stroke and then decreasing until it reaches the point when the inlet valve closes. At that point the piston is at a standstill, and inasmuch as its speed has been gradually reduced, it is natural to expect that the velocity of the air when started at a high rate is to a certain degree maintained, resulting in a completely filled air cylinder.

Table No. 5 gives the proportions of air cylinders, valves and clearance spaces in air compressors of the best modern design. In this case the inlet is concentrated; that is, the air is drawn into the cylinder through a piston inlet

TABLE No. 5.—PROPORTIONS OF AIR CYLINDERS.

Sizes of Air Cylinders.	Per Ct. of Clearance. Free Air.	Per Ct. of Clearance Air Compressed to 75 lbs.	Area of Cylinder. Sq. in.	Air Inlet.			Air Discharge		
				Size of Pipe.	Area of Pipe.	Per Ct. of Area.	No of Valves	Area of Valves.	Per Ct. of Area.
10¼ in. x 12 in.	.0094	.047	78	2 in.	3.14	.04	2	5.4 sq. in.	.07
12¼ in. x 14 in.	.0086	.043	113	2½ in.	4.9	.043	2	8 8	.078
14¼ in. x 18 in.	.0066	.033	154	3 in.	7.	.045	3	13 2	.085
16¼ in. x 18 in.	.0066	.0330	201	3½ in.	9.6	.047	3	13 2	.065
18¼ in. x 24 in.	.0049	.0225	255	4 in.	13.	.051	8	35.2 sq. in.	.14
20¼ in. x 24 in.	.0049	.0225	314	4½ in.	16.	.051	8	35.2	.11
22¼ in. x 24 in.	.0049	.0225	380	5 in.	20.	.053	10	44.	.116
30¼ in. x 60 in.	.002	.01	707	6 in.	28.	.04	18	79.2	.112
36¼ in. x 48 in.	.002	.01	1018	7 in.	38.5	.038	20	88.	.086

The clearance on the ends of cylinders is 1-16 inch on each end, and is the same on all cylinders, for pressure up to 100 lbs. On high pressure cylinders the end clearance is reduced to 0. The percentage of clearance at 75 lbs. is taken as 5 times free air, thus allowing heating.

tube, hence five per cent. of the area of the cylinder is sufficient for the inlet. These dimensions have been practically tested, and in no case, even at the maximum speed of the machine, has there been any evidence of contraction.

The discharge valve area depends upon the speed of the compressor, and for the best results should be about ten per cent. of the cylinder area for a piston speed of 300 feet per minute, or fifteen per cent. for a speed of 450 or 500 feet.

In the usual air-compressor plant the free air is taken in from the engine-room. This is a mistake which is so apparent that it is difficult to account for its existence. It is not only desirable to compress clean, dry air (which is not usually found in the engine-room), but the economy and capacity of an air-compressing plant are largely dependent upon the temperature of the intake air. A low temperature increases the capacity, and adds to the efficiency of the machine.

A concentrated inlet connecting the valves with a point outside the engine-room is the best construction. A chimney made of wood will serve the purpose very well, though cooler air can be obtained by drawing it from a well. The presence of water in the well is no disadvantage, provided the water is cold. The intake air might advantageously be passed through cold water, or subjected to a spray of water for the purpose of reducing its temperature and destroying the impurities.

For every five degrees that the temperature of the intake air is lowered below that of the engine-room, there is a gain of one per cent. in volume. In summer only a few degrees difference can be obtained, but in winter the difference between the air inside and outside is often fifty degrees.

Mr. E. Hill has compiled the following table, showing the discharge of a compressor having an intake capacity of 1,000 cubic feet of free air per minute; the temperature of the intake air varying from zero to 110°, and in each case being discharged at a uniform temperature of 62° F., and at atmospheric pressure:

Temperature of Intake Air.	Volume taken into Compressor.	Volume discharged, if measured at 62 degrees and atmospheric pressure.
0	1,000 cubic ft.	1,135 cubic ft.
32	1,000 "	1,060 "
62	1,000 "	1,000 "
75	1,000 "	975 "
80	1,000 "	966 "
90	1,000 "	949 "
100	1,000 "	932 "
110	1,000 "	916 "

Mr. R. A. Parke, in a paper read before the New York Railroad Club, illustrated the great importance of supplying the compressor with cold air, as follows:

"With an ordinary single-stage compressor, furnished with no cooling appliance, the delivery temperature of the air at the compressor is about 437 degrees. It may be assumed that, in every ordinary case of transmission, the temperature of the air falls to that of the locality where it is used, with an accompanying shrinkage of volume, so that, in the present example, the temperature of the air used would be 60 deg., and each cubic foot of air delivered at the compressor shrinks to .58 cubic feet before being used. If the temperature of the atmospheric air received in the compressor were 40 deg. instead of 80 deg., the delivery temperature would be but 371 deg., and, when cooled to 60 deg., the shrinkage of each cubic foot delivered would be only to .626 cubic feet. Thus eight per cent. greater volume of atmospheric air, at a temperature of 80 deg., must be compressed than would be necessary if the temperature of the air were 40 deg."

Low temperature of intake air is so important that the plants established for the purpose of compressing air for power distribution should be located with this question prominently in mind. An ice-making plant, or a cold-storage room, is the best place for an air-compressor. In such a place as this, with the temperature of the intake air at or near zero, the compressor, provided with compound cylinders jacketed by a circulation of cold brine, and thoroughly cooled between the stages, we might produce compressed air at a low temperature and a high efficiency. This cold, dry air, distributed over or under ground (thus increasing its temperature in transit), and heated before use, might develop an efficiency beyond that which is possible in the use of electricity, hydraulics, or any other form of secondary power.

AIR COMPRESSING MACHINES.

In describing air pumps or compressors we will endeavor to confine ourselves strictly to such machines as are at the present time in practical operation. The large field of patented designs, antiquated types and such like, will be omitted.

The simplest form of air pump is the little apparatus with which every one is familiar, namely, the pump for inflating the bicycle tire, Fig. 15.

FIG. 15.—A BICYCLE AIR PUMP.

This little pump is made both single and double acting, the single acting device being the simplest form of air compressor. The piston rod is the discharge passage, the piston packing being a simple leather washer which is aided by the air pressure in forming a perfectly tight joint, the piston is fixed, the cylinder being grasped in the hand and forced forward. This little device is interesting in that its use reminds us of an important fact in air compressing—the development of heat. After a few strokes the heat produced is quite perceptible. This heat is not due to friction, but it represents the conversion of the work done by the hand into heat. When there is little resistance or little air in the tire the heating is not noticed because but little work is done. As soon, however, as the tire becomes inflated the action of the pump is more difficult to perform and the heat increases. It is not an uncommon experience for this pump to fail to act, due to the sticking of the little check valve which connects the cylinder through the piston rod with the interior of the tire. When this valve is stuck it will be noticed that on pressing the pump cylinder forward and letting it go, it is quickly pushed back to its original position, heat has been produced and there is evidently a pressure within the cylinder tending to hold its front end firmly against the piston. Where does this pressure come from? We had only free air and no pressure before giving the stroke to the cylinder, and now it has returned to its original position and tends to go further. There has been no leakage from the tire because the check valve is tight and immovable. We have simply compressed a volume of confined air as we would compress a spring, yet unlike a spring it apparently has power to go further than its original position. This is because we have done work upon the air, it has failed to get away, heat has been produced because the air has done no work in return. This heat expands the air, thus giving it additional power to recover, and as the cylinder is a light thing it is pushed back to its original position with but little expenditure of energy. If the pump and its confined air are now allowed to cool down to the temperature of the surrounding atmosphere the tension in the cylinder will be relieved and the original conditions will be recovered. Even a bicycle pump may teach us important lessons in thermodynamics.

Hand pumps of larger sizes are made for medical service and other uses, the principle being simply that of a piston forced backward and forward in a cylinder. Where larger volumes of air are required hand pumps provided with

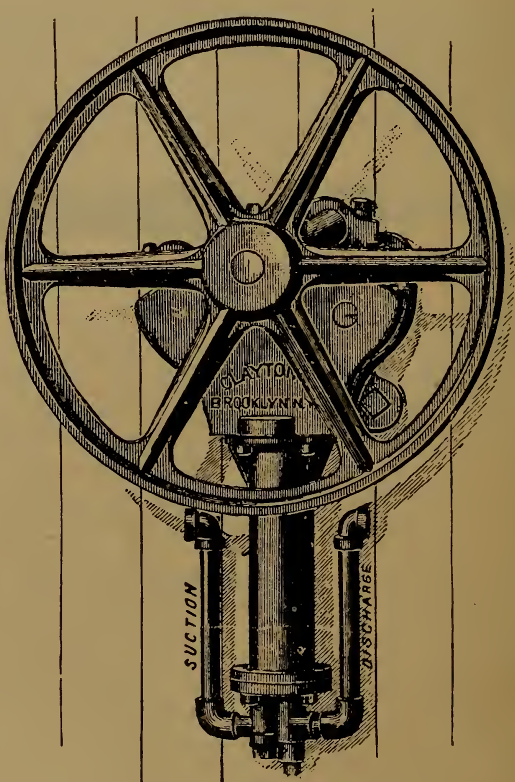

Fig. 16.

fly-wheels and operated by one or more men have been introduced and are largely used. The commonest pattern is the Vertical Belt or Hand Air Pump (Fig. 16), which may be run by hand or by power as desired.

The High-Pressure, Vertical, Belt Air Pumps are built in response to many applications for a reliable and small belt or hand power air pump to compress air to 300 pounds pressure. There have been several more or less important improvements made on the original design, and on the larger sizes the suction and discharge pipes are cast solid to the cylinder.

They can be bolted against any pillar, wall or strong board, and driven by a heavy pulley wheel of such diameter and width of face as required to attain the pressure wanted; when required to be worked by hand power they are provided with a handle in fly-wheel, which can be run by one or two men to a proportionate pressure.

The air brake pump is the simplest form of power air compressor with which we are familiar. Furthermore it is a machine so largely used that it deserves more than a passing notice. There are more air compressors used for the purpose of operating brakes than for all other purposes combined. It has been estimated that 30,000 of these pumps are in service. Fig. 17 illustrates the improved 9½-inch Westinghouse pump.

TABLE 6.—VERTICAL, BELT OR HAND AIR PUMPS. PRICE LIST.

Number.	Diameter of Air Cylinder in inches.	Length of Stroke in inches.	Number of Revolutions per minute.	Cu. Ft. Measurement of Free Air Compressed per minute.	Attainable Air Pressure in lbs. per square inch.	Price.
1	2	6	150	1	300	$50
2	2¼	6	150	2	300	50
3	3	6	150	3	250	60
4	4	6	140	6	200	70
5	5	6	140	10	150	80
6	6	6	130	13	100	90
7	7	6	130	17	50	110
8	8	6	120	20	30	130

THE NINE AND ONE-HALF INCH IMPROVED AIR PUMP.

DESCRIPTION OF THE AIR BRAKE PUMP.

60. Top Head, complete (Includes parts Nos. 72, 73, 74, 75, 76, 83, 84, 85, 108, 109 and 8 of 110.)
61. Steam-cylinder, complete. (Includes parts Nos. 90, 91, 92, 93 and 94.)
62. Center Piece, complete. (Includes parts Nos. 2 each of 95, 96 and 97.)
63. Air-cylinder, complete. (Includes parts Nos. 4 of 86, 2 each of 87, 88 and 89, and 1 each of 90, 91, 92 and 106.)
64. Lower Head.
65. Steam Piston and Rod. (Includes 2 each of 67 and 68, 69 and 2 of 70.)
66. Air Piston, Complete. (Includes 2 of 67.)
67. Piston Packing Ring.
68. Piston Rod Nut.
69. Reversing-Valve Plate.
70. Reversing-Valve Plate Bolt.
71. Reversing-Valve Rod.
72. Reversing-Valve.
73. Reversing-Valve Chamber Bush.

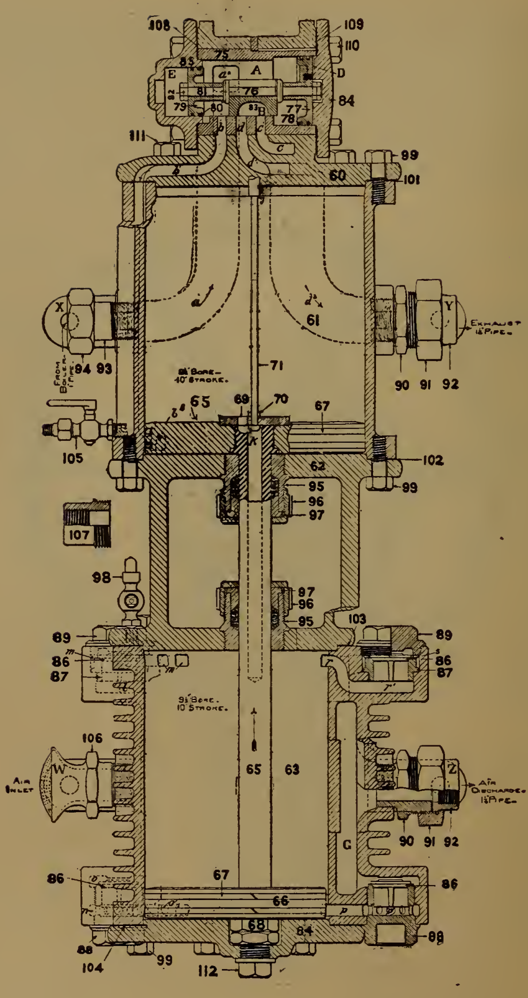

FIG. 17—THE NINE AND ONE-HALF INCH IMPROVED AIR PUMP.

74. Reversing-Valve Chamber Cap.
75. Main Valve Bush.
76. Main Piston Valve, complete. (Includes Nos. 77, 2 of 78, 79, 2 of 80, 81 and 4 of 82.)
77. Large Main Valve Piston Head. (Includes 2 of No. 78.)
78. Large Main Valve Piston Packing Ring.
79. Small Main Valve Piston Head. (Includes 2 of No. 80.)
80. Small Main Valve Piston Packing Ring.

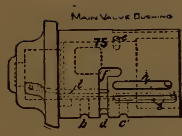

FIG. 2.

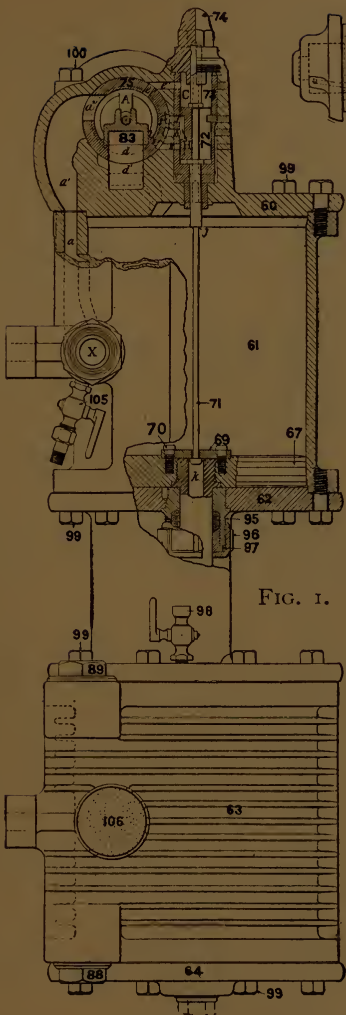

FIG. 1.

FIG. 17—THE NINE AND ONE-HALF INCH IMPROVED AIR PUMP.

81. Main Valve Stem.
82. Main Valve Stem Nut.
83. Main Slide Valve.
84. Right Main Valve Cylinder Head.
85. Left Main Valve Cylinder Head.
86. Air Valve.
87. Air Valve Seat.
88. Air Valve Cage.

89. Valve Chamber Cap.
90. One and One-fourth Inch Union Stud.
91. One and One-fourth Inch Union Nut.
92. One and One-fourth Inch Union Swivel.
93. One Inch Steam Pipe Stud.
94. Governor Union Nut.
95. Stuffing Box.
96. Stuffing Box Nut.
97. Stuffing Box Gland.
98. Air-cylinder Oil Cup.
99. Short Cap Screw.
100. Long Cap Screw.
101. Upper Steam Cylinder Gasket.
102. Lower Steam Cylinder Gasket.
103. Upper Air-cylinder Gasket.
104. Lower Air-cylinder Gasket.
105. Drain Cock.
106. Air Strainer.
107. One Inch Steam Pipe Sleeve.
108. Left Main Valve Head Gasket.
109. Right Main Valve Head Gasket.
110. Main Valve Head Bolt.

The air pump was designed without any thought of economy in the use of steam, the main consideration being economy of space, light weight and absolute reliability of action. Economy in the use of steam to compress the air is quite secondary to other and more important considerations. The use of a crank and fly-wheel is incompatible with economy of space, and a compressor with directly operated steam valves is a necessity. Because of this, the clearance space in the air cylinder must be about double that required in a fly-wheel machine in order to avoid pounding. The steam ports, and especially the exhaust ports, must be contracted to prevent too high piston speed and consequent pounding when the pump is working against low air pressures. For the same reason the air discharge valves must also be small. The steam must be used non-expansively as the resistance of the air pressure is greatest toward the end of the stroke, requiring the highest steam pressure at that time, and having no inertia of moving parts to help it around the center.

Several years ago experiments were made by the Westinghouse Company extending over a period of two years, the purpose being to determine the question of steam economy. The eight-inch pump had been designed at a time when the average locomotive boiler pressure was about 120 lbs., and in order to secure an abundant supply of air the area of the steam piston was made about 15 per cent. greater than that of the air piston. Between that time and the time when the tests were begun, the steam pressure of locomotive boilers had become considerably increased, so that the greater area of the steam piston of the air-pump was no longer necessary. Experiments were conducted both with a simple pump of suitable proportions to meet the changed conditions of service, and with a compound pump, designed to attain the highest steam economy subject to the peculiar limitations of the service.

The following descriptions of these tests are given by Mr. Parke in his paper before the New York Railroad Club.

"The design of compound pump which seemed to best meet the requirements has two steam cylinders, respectively 6 inches and 10 inches in diameter, and each of 10 inches stroke. Live steam is admitted to the smaller or high-pressure steam cylinder throughout the entire stroke, and, upon the return stroke, it expands into the larger or low-pressure steam cylinder, no live steam being admitted to the latter. All the ports of both steam cylinders are controlled by a single steam valve. There are two air cylinders, the diameters of which are respectively 6½ inches and 9½ inches, and the stroke of each is 10 inches. Atmospheric air is drawn into the larger or low-pressure air cylinder, and compressed therefrom into the smaller or high-pressure air cylinder. In the latter, the air is further compressed and delivered thence to the main reservoir. The piston of the high-pressure steam cylinder operates that of the low-pressure air cylinder, and the piston of the low-pressure steam cylinder operates that of the high-pressure air cylinder. The reversing valve is actuated by the high-pressure steam piston. By this arrangement, the complete stroke of both the high-pressure steam piston and the low-pressure air piston is always assured, so that the pump cannot become dead, and a cylinder full of free air is always secured. The pump is operative at any steam pressure, the pressure at which the air can be delivered, depending, of course, upon the available steam pressure.

TABLE 7—STEAM CONSUMPTION. DIFFERENT TYPES OF COMPRESSORS.

PUMP.	Volume of Free Air Compressed to 90 lbs. and Discharged.	
	Per Min.	Per Pound of Steam at 140 lbs. Pressure.
8 inch	26.3 cu. ft.	1.85 cu. ft.
9½ inch	44.9 "	2.49 "
Compound	43.3 "	4.89 "
5-inch Duplex	29 4 "	2.06 "
7 " "	38.7 "	2.43 "
Simple compressor, operated by simple engine	....	8.80 "
Two-stage compressor, operated by compound, non-condensing engine.	....	13.70 "

"The design of simple pump resulting from these experiments was what is now known as the 9½-inch pump, which has one steam and one air cylinder, each 9½ inches in diameter, with a 10-inch stroke.

"In the tests of the various pumps, as to efficiency and capacity, the steam was condensed in a surface condenser, at atmospheric pressure and weighed, and the volume of air actually delivered was carefully measured. The conditions under which the tests were made were those of about the average service to be expected on the road; that is, the steam pressure used was 140 pounds and the pumps were required to deliver against an air pressure of 90 pounds.

"Table 7 indicates the capacities and efficiencies of the various types of air-brake pumps under these conditions. For comparison, this table also indicates the volume of free air compressed to 90 pounds and delivered per pound of steam by a single-stage commercial-compressor, operated by an efficient simple engine, and by a two-stage compressor, with intercooler, operated by a compound non-condensing engine.

"The most striking feature of this table is the low efficiency of an air-brake pump, in comparison with a suitable compressor for a commercial supply of compressed air. Steam generation in stationery boilers for ordinary power purposes, is comparatively uniform, and the amount of fuel burned is practically proportional to the quantity of steam used. Under such conditions, unless the volume of compressed air required is very small or is required at irregular intervals and in uncertain quantities, it is not economy to use an air-brake pump in the place of a suitable compressor.

"At the conclusion of these pump tests, it was decided to place the 9½ inch pump upon the market, and, although the design of compound pump selected proves entirely satisfactory as to capacity, and requires only one-half the steam used by any air-brake pump in the market, it was decided to abandon any thought of offering it for sale. The reasons for the latter decision were chiefly the following:

"While the only working parts added to those of the simple pump are the additional pair of pistons and two additional air valves, a long experience has led to the conviction that simplification and not complication of air pump construction is what the best interests of the railroads require. The increased number of parts necessarily implies greater cost of maintenance and renewals, additional glands to be kept packed, a considerably increased number of sources of leakage, and the additional pair of cylinders materially increases the bulk and the weight of the pump. This was regarded as the most serious objection to the introduction of a double pump.

"Another serious objection is heating of the air end of the pump. It has been fully explained that compounding, or compressing in stages, is the method most to be preferred, when the air is cooled between the stages. It might also have been stated that for practical reasons, compounding the air, without cooling between the stages, is the worst method. By this method the air is theoretically delivered by the high-pressure air-cylinder at about the same temperature as it is from the air cylinder of a simple compressor; but the temperature of the air taken into the cylinder of a simple compressor is that of the atmosphere, while that of the air taken into the high-pressure air cylinder of the compound method (without cooling), is from 200 to 300 degrees above that of the atmosphere. It is evident, therefore, that the mean temperature of the air in the high-pressure air cylinder of the compound method, is very much higher than that of the air in a simple compressor. Indeed, it several times occurred, during the experiments referred to, that when a pump of the two air-cylinder type was allowed to run freely for twenty-five or thirty minutes, under the conditions stated, the maple plank upon the brick wall of the testing room to which the air cylinders were bolted, took fire. Such high temperatures of the high-pressure air cylinder are productive of serious evils. The two air cylinders are necessarily cast in one piece, of an irregular shape, and expansion by heat is inevitably accompanied by distortion. This distortion at the air cylinders is aggravated by the still further increased temperature resulting from binding of the pistons. Unless the air pistons are originally fitted so loosely as to permit them to leak badly, they bind and cut, causing great wear and materially increasing the cost of maintenance. The distortion of the air cylinders always causes a large amount of leakage past the pistons, and the actual efficiency of such pumps is far below that calculated for them. As it is wholly impracticable to introduce a cooling chamber upon a locomotive, in connection with the compound air cylinders, this type of pump seems to be very undesirable.

"The one other important reason for abandoning the compound pump is that steam economy in an air-brake pump is not of importance or value. Such a

Fig. 18—Direct-acting Steam Air Compressor.

conclusion may at first cause some surprise, but a little study of the conditions will fully support it. The steam requirements of a locomotive are very difficult ones to meet, as the demand for steam to operate the engine fluctuates very greatly. The steam required by an air-break pump is not only an exceedingly small proportion of the quantity generated, but it also fluctuates between limits widely apart. The air-brake pump does its heaviest duty while standing at stations and in descending grades.

"At such times the engines of the locomotive use no steam, and such steam as is then used by the air-brake pump would otherwise probably escape through the pop valve. It is well known that, with the most careful firing, it is practically impossible to prevent a waste of steam through the safety valve at such times."

In connection with a series of tests of a Baldwin compound locomotive upon the Baltimore & Ohio R. R., in 1890, the consumption of steam in various incidental ways was ascertained. The weights of steam which passed through the whistle, the blower and the pop valve, were computed. Instead of allowing the pop valve to blow off, a vent pipe from the steam dome was carried into the tender, and the weight of steam which would pass through it per second, when a valve in the pipe was opened, was ascertained. During the runs, when the steam reached such a pressure that the pop valve was on the point of blowing off, the valve in the vent pipe was opened, and, by noting the length of time that it remained open, the quantity of steam which so escaped was easily computed. The number and lengths of blasts of the whistle were also noted, together with the time that the blower was used. The amount of steam used by the 8-inch air-brake pump was also computed. It was found that, after the train brake apparatus had become fully charged, the pump continued to run with an average speed of about 62 strokes per minute. This would seem to indicate a considerable amount of leakage in the train pipe and connections. The writer has observed the operation of the 8-inch pump upon a considerable number of different trains, the air-brake apparatus of which was in such condition as he happened to find it. It was found that, after the brakes had been charged throughout the train, the number of strokes per minute made by the pump were from 24, for a four-car train, to 47 for a seven-car train, the average of all the cases observed being 36.

During the trials of the Baldwin compound, three separate runs were made from Baltimore to Philadelphia, with the same train, making the same time, and with the same number of scheduled stops. In the report of Mr. George H. Barrus, the steam used in different ways during these runs was computed as follows:

	Whistle.	Blower.	Safety Valve.
	415 lbs.	153 lbs.	220 lbs.
	503 lbs.	198 lbs.	99 lbs.
	425 lbs.	72 lbs.	302 lbs.
Average,	448 lbs.	141 lbs.	207 lbs.

The average computed steam consumption of the air pump, under the conditions of its actual operation, was 690 lbs. Under the ordinary conditions of the brake apparatus in service, with the air pump making about 36 strokes per minute to keep up the pressure after the apparatus is once charged, the steam consumption, computed upon the same basis as that used in the report of these locomotive trials, would have been 400 lbs. It will be seen from these figures, therefore, that about the same quantity of steam was used by the whistle as is used by the air pump, and that, even in these locomotive trials, where unusual care was undoubtedly exercised in firing, the loss of steam by the safety valve was about half that which should be used by the air pump.

Under the ordinary conditions of service, although the steam used by the air pump is largely that which would otherwise be lost at the safety valve, it is most probable that the amount of steam lost at the safety valve is greater than that used by the air pump.

It will thus be understood that, with the fluctuating conditions of locomotive service, the steam consumption of the air-brake pump is an insignificant factor in the economy of steam production. It has never been demonstrated, so far as the writer is aware, that a locomotive hauling an air-braked train, with the brake apparatus in ordinarily good condition, consumes, in the long run, a

Fig. 19.

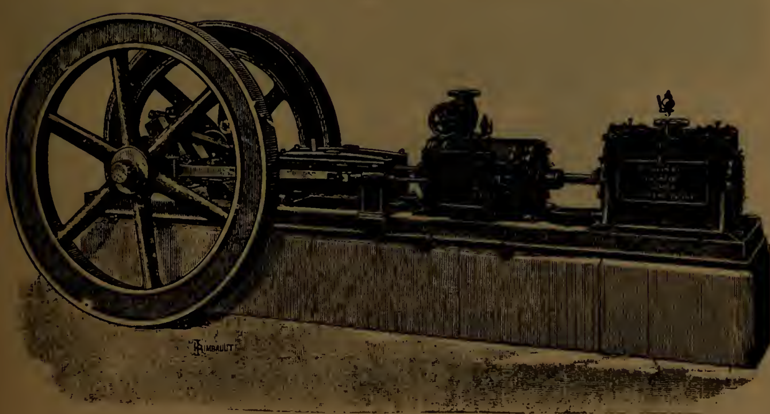

Fig. 20.

pound more coal than the same locomotive, without an air pump, would use in hauling the same train when braked by hand, and there is no good reason to believe that it would.

Fig. 18 illustrates the simplest type of small air compressor built on the Straight Line or Direct Acting plan. The machine is designed for light transportation and for use in places where a compact, self-contained and very simple compressor is wanted. The steam and air cylinders are connected to a crosshead which moves in guides arranged between the cylinders. The fly wheels, which are joined by connecting rods to this crosshead, are mounted in bearings close to the steam cylinder. Slide valves are used operated by eccentrics, though in some of the larger sizes the adjustable cut-off serves to aid this type of machine in fuel economy. The air cylinder is provided with poppet inlet and discharge valves, and is water jacketed. Simplicity of design is followed in machines of this type, no claims being made to high fuel economy.

Fig. 19 shows another type of simple, low cost, single or direct acting compressor. No crosshead is used. A single fly wheel with crank, shaft and connecting rod are placed between the cylinders.

Fig. 20 is shown for the purpose of illustrating the English type of single or straight line compressor. The machine shown is known as "Schram's patent."

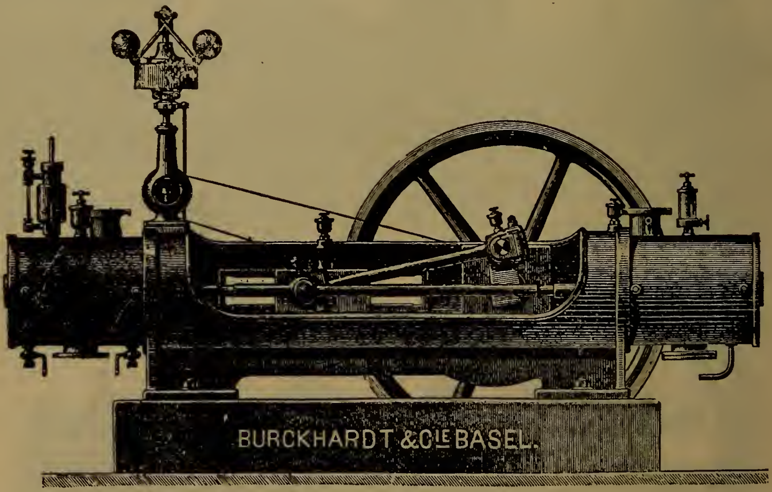

FIG. 21.

A single cast iron bed plate is used, thus making the machine self-contained, and the fly wheel's crosshead and connecting rod are placed on the bed, the steam cylinder being located between these parts and the air cylinder. This construction brings the steam and air cylinders close together, but the machine is not as compact or as simple as the direct acting compressor of the American type.

Another form of European compressor on the straight line plan is shown in Fig. 21. This machine is made by Messrs. Burckhardt & Co., Basel, Switzerland. The steam and air cylinders are widely separated and are connected by a single piston reel joined at or near its centre by a crosshead, to which the connecting rod is attached.

Fig. 22 illustrates a type of straight line compressor of the larger sizes. The following are the specifications on which these machines are built:

CYLINDERS.—Steam Cylinder, 14 inches in diameter, by 18 inch stroke. Air Cylinder, 14¼ inches in diameter, by 18 inch stroke. Cylinders made of the best cast iron suitable for this purpose, and of proper strength and thickness for carrying 100 pounds pressure, after being re-bored once.

WATER JACKET.—Air Cylinder and heads provided with Water Jackets.

BED PLATE.—Bed Plate of the Box Girder type, made in a single casting. The bed plate to extend throughout the compressor connecting both cylinders and all parts, and strong enough to withstand the severest strain of air compressing work.

BEARINGS.—Bearings to form an integral part of the bed plate, provided with removable bronze boxes, adjustable, accurately bored, and scraped to a true bearing surface.

SHAFT.—Main Shaft of hammered steel, 6 inches diameter in the bearings, turned, finished and key-seated, and free from flaws or other imperfections.

FLY WHEELS.—Two square rim Fly Wheels, 6 ft. 0 in. in diameter, with face and edges nicely turned and hubs bored and key-seated to fit shaft. The wheels to weigh when finished not less than 3,125 pounds.

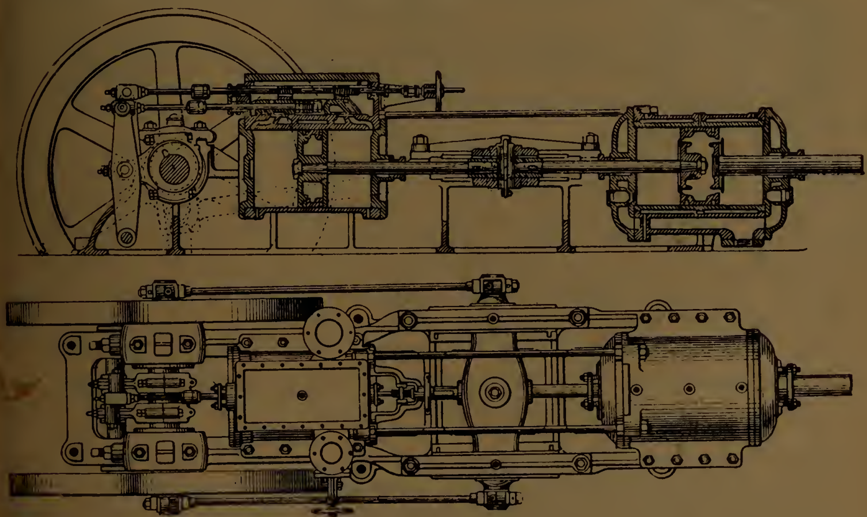

FIG. 22.

CRANK.—Crank pins of best hammered steel and securely fastened in fly wheels, and fly wheels counterbalanced.

VALVE GEAR.—Valve Gear of the slide valve type, with Meyer adjustable cut off gear.

PISTON ROD.—Piston Rods to extend through back head of steam cylinder and front head of air cylinder, and securely fastened in cross-head.

CROSS-HEAD.—Cross-head of cast steel and amply strong, provided with bronze shoes, and with adjustment for piston rods.

MATERIAL USED.—Piston Rods, Valve Rods, Connecting Rods and Crank Pins, of the best forged steel. Boxes for crank and cross-head pins of composition metal.

Throttle Valve.—Steam Cylinder provided with a Globe Throttle Valve, with flanges and hand wheel turned and polished. Valve provided with drain connection.

Governor.—The Compressor is provided with an Automatic Pressure Regulator and unloading device.

Indicator Connection.—Provision made on both steam and air cylinders for Indicator connections.

Oiling Devices.—Oil Cups for all wearing parts; one sight feed Lubricator for steam cylinder, one Ingersoll-Sergeant Lubricator for air cylinder. All oiling devices extra large.

Weight.—Total weight of Compressor ready for shipment, 10,800 pounds.

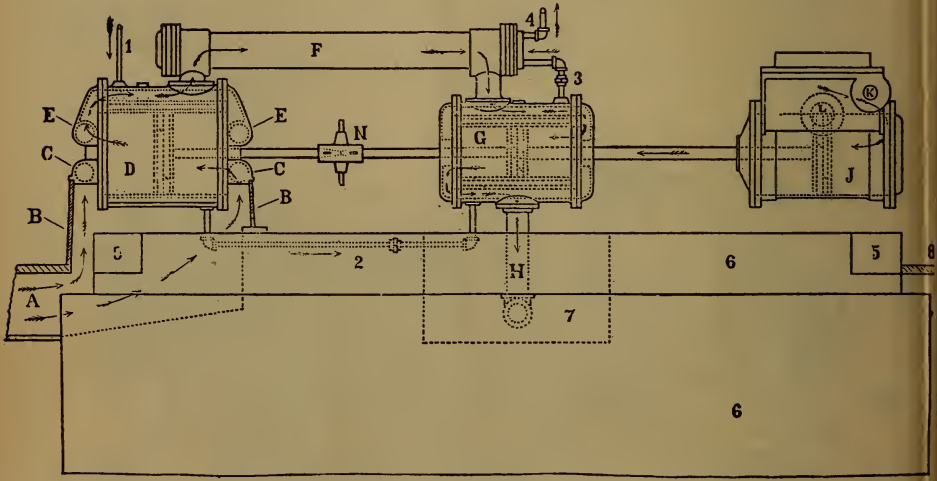

Fig. 23.—Compound Air Compressor.

Arrows on the water pipes show the direction of water circulation. When pistons move as indicated by the arrow on the piston rod, steam and air circulate in direction shown by arrows in the cylinders.

A—Inlet Conduit for Cold Air.
B—Removable Hoods of Wood.
C.—Inlet Valve.
D—Intake Cylinder.
E—Discharge Valve.
F—Intercooler.
G—Compressing Cylinder.
H—Discharge Air Pipe.
J—Steam Cylinder.
K—Steam Pipe.
L—Exhaust Steam Pipe.
N—Swivel Connection for Cross-head.

O—Air Relief Valve, to effect easy starting after stopping with all pressure on the pipes.

1—Cold Water Pipe to Cooling Jacket.

2 and 3—Water Pipe.

4—Water Overflow or Discharge.

5—Stone on end of Foundation.

6—Foundation.

7—Space to get at underside of Cylinder.

8—Floor line.

Where larger volumes of air are required the direct acting type gives place to the compound and duplex. It is not considered good practice to build single compressors with air cylinders larger than 26 inches in diameter except where the air is compounded.

Fig. 23 illustrates a popular type of Direct Acting Compound Compressor. The merits of this compressor are referred to by the manufacturers as follows:

"The large air cylinder on the left determines the capacity of the Compressor, and for the illustration we have taken its piston at 100 square inches area. The small air cylinder in the center can have an area of 33 1-3 square inches. The small piston only encounters the heaviest pressure, and at 100 lbs. pressure the resistance to its advance is 3,333 lbs. The resistance against the large piston is its area multiplied by the pressure which is caused by forcing the air from the large cylinder into the smaller cylinder, which is in this case 30 lbs. per square inch. But as this 30 lbs. pressure acts on the back of the small piston and hence assists the machine, the net resistance of forcing the air from the large into the small cylinder is equal to the difference of the area of the two pistons multiplied by the 30 lbs. pressure. This is 66 2-3 by 30, and equals 1,999 lbs. Hence, 1,999 lbs., the resistance to forcing the air from the large into the smaller cylinder plus 3,333 lbs., the resistance in the smaller cylinder to compressing it to 100 lbs., is the sum of all the resistances in the compound cylinders at the time of greatest effort. This is 5,333 lbs. The time of greatest effort is at the end of the stroke, or when the engine is passing the center. In the single machine this resistance is 10,000 lbs., hence we see that in the compound machine the maximum strains are less by over 46 per cent., or nearly one-half. By thus reducing the work to be done at the end of the stroke, more work is done in the first part of the stroke, and the resistance is made nearly uniform for the whole stroke.

"The next step is to render the application of power also uniform for the whole stroke. This is accomplished in a very simple and effective manner. The steam and air pistons and crosshead are mounted on the same piston rod. These parts are purposely given weight enough so that it requires most of the power of the steam over and above the air resistance at the beginning of the stroke to start them forward at the required speed. At the end of the stroke, when the steam has become weak by expansion, the power stored up in the momentum of these reciprocating parts is given out in useful work, and the parts are brought to a state of rest by expending their force upon the air in the compressing cylinders. As the energy which can thus be stored and given out by the reciprocating parts depends upon their weight, and the *square* of the number of revolutions, it is evident that rotative speed is the most important factor. Hence very long strokes are not desirable, because at the same piston speed the machines make fewer revolutions than machines of shorter strokes. Therefore, the power is not applied to the work so uniformly, and greater strains are brought on shafts, connecting rods and other parts, and larger fly-wheels, and frequently double engines, are necessary for successful operation, especially when steam

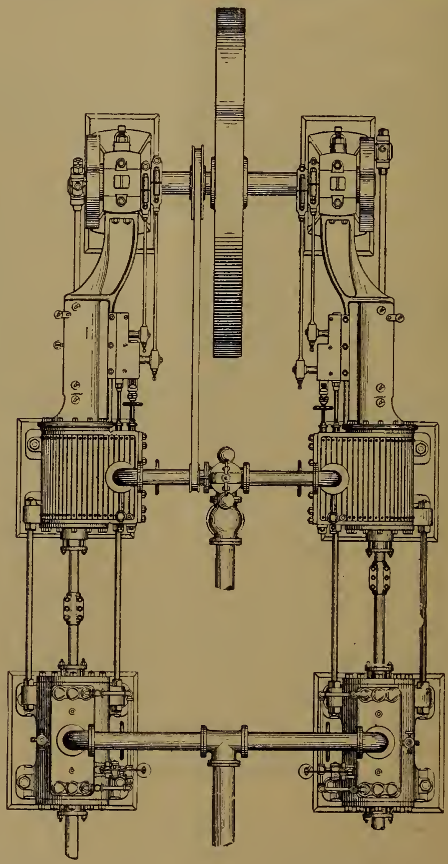

FIG. 24.

is to be used expansively. The value of rotative speed for economical steam consumption is too well known to need reviewing here. It is of interest, however, to note that the quick rotation that is valuable for applying the power uniformly also contributes to steam economy.

"Uniform resistance and uniform power both applied, as in this compressor, as direct end thrust and pull upon a straight steel piston rod, do not leave much work for fly-wheels to perform. Their presence, however, is necessary to regulate the steam valve motions, to control the length of stroke, to even up and balance trifling inequalities of power and resistance and to secure a uniform speed to the machine."

Figure 24 illustrates a common type of Duplex Compressor where the steam end is of simple construction, provided with the Meyer valve gear, the cut-off being adjusted by a hand wheel while the machine is in motion. The point of cut-off is indicated by a pointer which moves over a graduated scale. The machine is run with a wide open throttle, being controlled entirely by the cut-off, which is proportioned in accordance with the steam and air pressures. An ordinary ball governor is used to regulate the speed of the engine and to prevent it from running away in case of breakage of air pipes or sudden loss of pressure. Attached to the ball governor manufacturers usually add a pressure governor or regulator which is used to reduce the speed when the air pressure reaches the maximum. Various types of frames are used, some of them of the Corliss pattern; but for the purpose of insuring stability, freedom from breakage, and to resist the sudden strains which are brought to bear during compression, the frames, bearings and fly wheel are usually heavy. The steam and air pistons are in some patterns tied together by a heavy cast iron sole plate and tie rod. The bearings are usually of phosphor bronze, are unusually broad, and are provided with means for taking up wear. The cranks are usually made of wrought iron, and the crank pins, crosshead pin, piston rods, shafts, valve rods, links and pins, and all wearing parts, are of steel, and when possible this is hardened and ground. The heavy fly wheel gives a smooth, uniform motion, and aids in steam economy, by admitting of early cut-off. When running one side of the compressor at a time, the fly wheel prevents irregularity of motion. In this type of compressor the air cylinders are usually fitted with poppet valves, although manufacturers have succeeded in so far perfecting the positive moved valve and the piston inlet that they are applied with economy to the Meyer Duplex machines. The air cylinder is sometimes made of hard brass, owing to the better conductivity of this material, and is as thin as can be made with safety. The cylinders of some machines are provided with jackets for water circulation, and the piston and piston rods are hollow. A telescopic water tube is introduced at the back end of the cylinder, and cold water is supplied to aid in keeping down the temperature during compression. The introduction of cold water in this way undoubtedly reduces the heat of compression, but it is subject to the many disadvantages found in water injection. The water, unless free from foreign matter, is liable to destroy the cylinder, and even when pure it is difficult to lubricate the parts, the water itself being a bad lubricant. This applies to that type where the water passes through the piston and in contact with the walls of the cylinder between the rings and completely around the piston. It is obvious that this leaves a thin coating of moisture in contact with compressed air which is at a temperature much higher than that of the water; and as the volume of air is so much greater in proportion than that of the water, the result is an absorption of the water, which goes off into the air receiver in the form of moisture, to be afterwards deposited in the pipes when the temperature of the compressed air is reduced in transmission. It is claimed by the makers that one of their Duplex Meyer Cut-off Compressors was used and tested at Shaft No. 13

on the New York Aqueduct by Prof. James E. Denton, of Stevens Institute of Technology, and that it produced a horse power with a consumption of 25 pounds of steam per horse power per hour.

A duplex compressor can be regulated so as to run at high or low speeds. It may even stop and start automatically. Where the air is used intermittently—that is, where the use is irregular—a governor is furnished which will adjust the machine to a slow speed when little air is being used, stop when no air is required, and start again when necessary, thus using the steam only in proportion as the work is done.

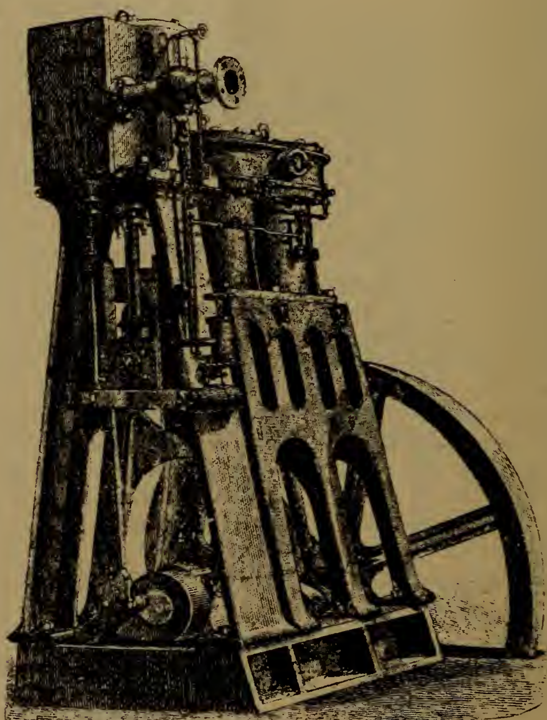

Fig. 25.

The following are specifications of a type of Duplex Meyer Cut-off Valve Compressor:

Cylinders.—2 Steam Cylinders, 14 inches diameter, by 18 in. stroke.

Two Air cylinders, 14¼ inches diameter, by 18 in. stroke.

Cylinders made of the best cast iron suitable for this purpose, and of sufficient thickness to safely carry 100 pounds pressure after re-boring once.

Piston Inlet.—Air cylinders of the Piston Inlet type.

Water Jacket.—Air cylinders and heads provided with water jackets, FRAME.—Frames of the Corliss Girder type, and strong enough to withstand the severest strain of air compressing work.

BEARINGS.—Main pillow blocks provided with removable shell boxes of best composition metal, accurately bored and scraped to a true bearing surface.

SHAFT.—Main shaft of hammered steel, 6 inches in diameter in the bearings, and 7 inches in the center, of proper length, turned finished and key-seated, and free from flaws or other imperfections.

CRANKS.—Cranks of the disc pattern, of selected charcoal iron, and of ample strength and proportion for the work required.

FLY WHEEL.—One square rim fly wheel, 8 feet in diameter, with hub bored and key-seated to fit shaft. The wheel when finished to weigh not less than 4,500 pounds.

VALVE GEAR.—Valve gear of the slide valve type, with Meyer adjustable cut-off.

PISTON RODS.—Piston rods extended through back head of steam cylinders, and attached by means of couplings to piston rods of air cylinders.

TIE RODS.—Air cylinders securely fastened to steam cylinders with tie rods.

GOVERNOR.—A fly ball governor of approved pattern placed in main steam pipe, and driven with belt from main shaft.

LAGGING.—Steam cylinders covered with polished black walnut. Space between lagging and cylinder to be filled with mineral wool.

MATERIAL USED.—Piston Rods, Eccentric Rods, Connecting Rods, Crank Pins, Cross-head Pins and Valve Rods of the best forged steel. Boxes for main crank pins of best composition metal.

THROTTLE VALVE.—Both steam cylinders provided with a throttle valve, with flanges and hand wheel turned and polished.

INDICATOR CONNECTION.—Provision made on both steam and air cylinders for indicator connections.

OILING DEVICES.—Graduating sight feed oil cups for all wearing parts; one sight feed lubricator for each steam cylinder; one Ingersoll-Sergeant lubricator for each air cylinder.

WEIGHT.—Total weight of compressor ready for shipment, 22,500 pounds.

Figure 25 represents a type of Vertical Compressor which consists of a steam engine connected by means of a crank shaft with two single-acting air pumps, all placed in an upright position. It is compactly built, and is as economical as this type of machine will admit. The cranks are so placed in relation to each other that the greatest power of the engine is applied at the time of greatest resistance in the air cylinders. Water injection is usually applied to these machines, and it is a matter of note that it is in this compressor that water injection has had its longest service, and has given its best results. One reason for this may be found in the fact that the cylinders being placed vertically, are not subject to the wear and destruction which accompanies water injection machines of the horizontal type. This compressor has been largely used in the western part of the United States for mining service, though of recent years, notably at the Anaconda Copper Mines, it has been replaced by machines of a more improved and more economical type on the pattern of the Duplex Corliss Compound.

A type of vertical air compressor used in Europe, known as the "Champion," has both the inlet and the outlet valves with their seats arranged in the cylinder covers; the form of the frame is such that the valves can be readily moved without disturbing the cylinder cover joints. The inlet and outlet valves are provided with very long guides to insure their continued working without damage, and being placed vertically, the wear is more evenly distributed. The air cylinder and outlet valve boxes are surrounded by cold water jackets.

The experience of American manufacturers, which has been more extensive than that of others, has proved the value of direct compression as distinguished from indirect, as shown clearly in this type of machine. By direct compression is meant the application of power to resistance through a single straight rod. The steam and air cylinders are placed tandem. Such machines naturally show a low friction loss, because of the direct application of the power to the resistance. This friction loss has been recorded as low as 5 per cent., while the best practice is about 10 per cent. with the type which conveys the power through the angle of a crank shaft to a cylinder connected to the shaft through an additional rod. W. L. SAUNDERS.

Editor Compressed Air:

Dear Sir:

Having been greatly interested in your series of articles on the development of the air compressor, I beg leave to call your attention to a few points in the article in the November number of your paper.

In the abstract of Mr. Darlington's test, the figures show an efficiency of compressions of 98.4% ($\frac{37534}{38128}$) which is scarcely credible, as the resistance of the outlet valves alone will generallly cause a greater loss than this.

It is a well known fact that indicator springs are temporarily weakened by heat and they are therefore adjusted under steam. As an instance of this fact, I recently tested a spring under steam pressure and found the scale to be 32.6. On allowing the indicator and testing drum to cool and then admitting compressed air, the scale was found to be 34. These figures were verified by three separate trials, the scale of the spring varying slightly at different pressures as is always found, but the comparative results remaining the same.

If Mr. Darlington did not calibrate his air compressor indicator springs with air, and his engine indicator springs with steam, his results are liable to an error of fully five per cent., and this error is in all probability the cause of the high efficiency of compression and the low efficiency of mechanism.

Further on the article reads as follows: "Hydraulic piston compressors are subject to the laws that govern piston pumps and are therefore limited to a piston speed of about 100 feet per minute. It is quite out of the question to run them at much higher speed than this without shock to the engine and fluctuations of air pressure." * * *

In the first place, modern practice for "piston pumps" of a size to be compared with air compressors is 250 feet per minute (see "Kent," page 605). I have lately seen a pump running at a piston speed of 300 feet a minute against a water pressure of 325 pounds, and have taken indicator cards from this pump showing entire absence of injurious shock.

Also any one can see in this country at a mine, the name of which I am not at liberty to mention, fully a thousand horse-power of hydraulic plunger compressors running at a piston speed of between 230 and 250 feet per minute, and running day and night, year in and year out, and the indicator cards are exceptionally good. Yours truly, CHARLES P. PAULDING.

EDITOR COMPRESSED AIR:

1.—If I compress air to 150 lbs. per inch in reservoir No. 1, and then cool it down with water to 35° f. h., and then recompress it to 200 lbs., and then expand it in my refrigerator, will it produce a greater degree of cold in the refrigerator than it would if I had compressed it to 200 lbs. in the first place and cooled it to 35°?

2.—What pressure do the street cars carry in your town?

3.—Is there any trouble with freezing of the valves in small compressed air engines?

4.—If compressed air is left a long while in a tight reservoir does it lose any of its expansion force?

5.—Will the compressing cylinder get red hot if it has no water jacket?

6.—What per cent. of loss is there from the steam engine to the air motor, or how much less energy is there at the motor than at the engine that supplies the air?

7.—How many volumes of air have to be compressed into one to get 50 lbs. to the square inch?

8.—How high can water be raised with economy with air?

9.—Is it cheaper than pumps for a long lift?

10.—Does the higher pressure produce the most cold when expanded?

11.—Will an engine give as much power with air as steam at the same boiler pressure?

Please answer and oblige, J. S. SHERMAN.

1.—No; the temperature at end of expansion depends upon the initial temperature and the number of expansions. In both cases you have the same initial pressure in your motor, and therefore can produce the same degree of expansion.

2.—Storage pressure of 2,000 lbs. per square inch, and a working pressure ranging from 130 to 150 lbs.

3.—All trouble can be avoided by enlarging the exhaust opening. If the air is reheated before admission to motor, a low temperature at exhaust will be avoided and the efficiency will be increased (see COMPRESSED AIR, p. 71, No. 5).

4.—No.

5.—No; the theoretical temperature at end of compression without cooling for 60 lbs. gauge pressure, is 382° F.

6.—See articles in Compressed Air, page 89, No. 6, and page 13, No. 4, for full discussion on this point.

7.—4.4 volumes, for equal temperature compression.

8.—The highest practical lift made at present is 200 feet. Cases of still greater lift are on record.

9.—The Pohlé air lift compares very favorably in economy with the direct acting pump.

10.—The higher the pressure the greater the expansion, and therefore the lower the temperature.

11.—If you mean that the initial pressure in the motor is to be the same in each case, and the air is to be used without reheating, then the steam will be more efficient as a fluid.

GROWING INTEREST IN COMPRESSED AIR.

An evidence of the growing interest taken in compressed air was noticed at the recent monthly meeting of the New York Railroad Club, held in the rooms of the American Society of Mechanical Engineers in New York City. A paper was presented at that meeting by Mr. Shields, in which compressed air and its application to railroad shops was discussed. The attendance at the meeting was exceptionally large; perhaps the largest held since the organization of the Club. The discussion of the subject was so general that it was found necessary to close the meeting on account of the lateness of the hour, before the subject had been exhausted. It is likely that there will be a continuation of the discussion at a subsequent meeting.

Railroads have been quite active of late in developing compressed air apparatus. There is no particular reason why railroad shops should use compressed air to any better advantage than machine shops and foundries in general. If compressed air is a good thing in railroad shops, the same reasons that make it so apply to other shops. That it is a good thing, and that its use is growing, no one doubts. Its advantages and the saving that is effected by its use are now established facts. Some of the figures representing this saving were given at the meeting. In looking for the reasons why railroads have been pioneers in this line, we turn to the air pump used on locomotives. This pump, or compressor, had done such good work for years, and has become so familiar to the master mechanic that it turned attention to compressed air power. The simplicity of the apparatus, the ease with which it was cared for and understood by mechanics, and the apparent applicability of the air to so many different purposes, led to developments in this line.

An old locomotive sent to the shop for repairs was immediately robbed of its air pump, which was bolted against the wall of the shop and put into use, serving a useful purpose in helping to repair the engine. Shops in this way became equipped with a number of air pumps, until it was apparent that an air compressor properly designed for economic production of compressed air should have a permanent place in the establishment.

All this bears out the view which we have always taken of this subject; that is, that the use of compressed air has not grown as rapidly as it should, because it is not understood. It is looked upon as too much of a mystery, and the idea has existed in the minds of men that at best it is an expensive power to produce. A little experience with it convinces the most incredulous that it is not an expensive power either to produce or use, nor is its use dangerous as some suppose; on the contrary, there is no power so humane. There is certainly nothing explosive about air itself. When confined in a weak vessel it may create a disturbance, but there is no occasion for the use of weak vessels in either steam or compressed air. It is evident that an explosion in a steam vessel is more likely to produce hurtful results than if the same vessel were filled with air. Not only is the scalding effect from steam objectionable, but there is usually a confined body of superheated water held down by the steam and always ready to expand into hot steam globules as soon as there is a release of pressure. This means a large reserve force which under usual conditions surrounding explosions will result in a damage more serious than any likely to occur or hardly possible with compressed air.

COMPRESSED AIR: ITS PRODUCTION, TRANSMISSION AND USE.*

Air being such a common subject, requires no introduction. Compressed air is simply air under pressure, or air increased in density by pressure or by heat. It is one of the oldest of the sciences, although in its general application one of the youngest, for it is only within the last thirty or forty years that compressed air has been used for mining and tunneling, for which no other power was available, and in fact in all the early uses of compressed air, it was only used where it was considered a necessity regardless of expense, it having always been termed an expensive power. It is true that it takes work to compress air, although the writer has heard of instances where contractors, when the compressor first became known, wanted to run drills on open rock work with compressed air, thinking they would thereby abandon their boiler plant and save buying coal, their idea of a compressor being a machine which would furnish air without using power, or, in other words, a modified form of perpetual motion. It is also true that there are losses in the compression and use of air to which no attention was paid in the earlier machines, and which exist in many plants to-day, where, however, the great convenience of the air and its saving in many other ways more than make up for the loss due to the compressor.

The one great loss in the compression of air is due to the heat caused by compression and the consequent increase in the volume of the air. The minor losses are clearance in the air cylinder, the heating of the intake air in passing through the valves, and the friction of the compressor. The first two of these amount to very little, and are hardly noticeable in a good machine. The last

*An Address delivered at Lafayette College, Easton, Pa., by Mr. William Prellwitz.

loss mentioned, friction, amounts to from 7 to 15 per cent., depending to a great extent on the amount of care that is taken with the machine. To clearly illustrate the work that is done in an air cylinder, we have recourse to the indicator, and the following diagram, Fig. 26, shows an indicator card taken from a water jacketed air cylinder (the card having the isothermal and adiabatic lines plotted on same), an examination of which gives us the actual results obtained.

Referring to Fig. 26, we have the adiabatic or heat line A-B, which represents the work done if there were no cooling effect in the cylinder, the line A-C representing the actual work done in the cylinder, and the isothermal or constant temperature line A-D, which is the line the indicator would make if all the heat generated could be carried off during the work of compression.

This latter condition does not exist in our high speed machines of to-day, but one can imagine it to exist in a machine where the piston travels slow enough that all the heat would be carried off by the water jacket or by radiation.

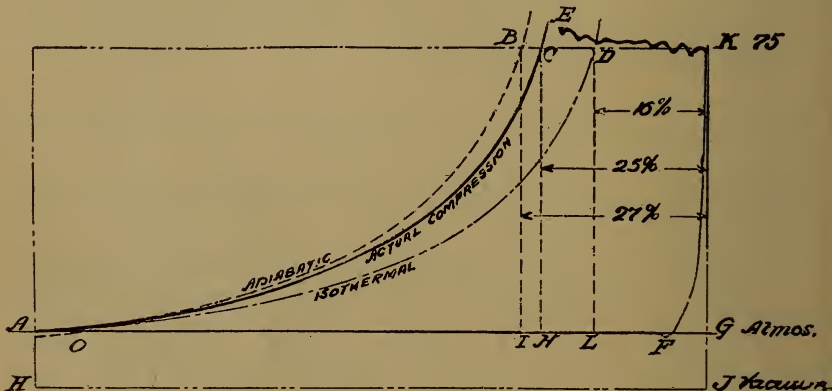

FIG. 26.

In following the movement of the piston in the cylinder, suppose it starts at A, the cylinder then being full of free air, and moves to the right, the pressure in the cylinder at any point is represented on line A-C. When the piston reaches C, it has compressed the air to the receiver pressure and it must then push the compressed air out through the discharge valves into the receiver. Owing to the weight of the discharge valves and the tension of the springs holding them to their seats, the pressure in the cylinder reaches a few pounds above the receiver pressure before the valves open, as shown at E, and there gradually drops to the receiver pressure at the end of stroke, the irregularities in the line being due to the fluttering of the discharge valves and the vibration of the indicator arm.

The piston having reached the end of stroke, comes to a standstill while the crank is passing the dead center, and as the current of air that held the discharge valves open in passing out of the cylinder has ceased, the discharge valves close by the tension of the springs back of them. The piston now starts to recede—the air under pressure that was left in the cylinder due to the clearance space expanding until it becomes atmospheric pressure at F, when the inlet valves open and the cylinder is filled with free air. If the indicator line follows along the atmospheric line, we know that the inlet area is not restricted and we are getting a volume of free air at atmospheric pressure represented by the travel of piston from F to A, this representing the actual free air capacity of the machine. The volume between G and F representing the air contained in the clearance space, expanded, is lost as far as the capacity of the machine is considered; and although this air required work in compressing it to 75 lbs. pressure, it has given out its work in expanding, helping to compress the air on the other side of the piston.

The only loss in work due to the clearance space is that resulting from the small amount of cooling that the confined air has been subjected to, its volume when hot having been a trifle more and having required more work to compress it, but this is rarely taken into account. We thus see that the clearance space in the cylinder is not a loss of power, but a loss of capacity, which is allowed for by deducting anywhere from 3 to 10 per cent. of the cylinder volume, according to the design of the air cylinder and the length of stroke of same—it being evident that the longer the stroke for the same size cylinder the less will be the percentage of clearance. On some indicator cards it is noticed that the intake air pressure falls below the atmospheric line, showing that the air inlet is restricted, or, as is common on air cylinders having poppet inlet valves closed by a spring, the tension of the spring when the piston is moving slow at the end of the stroke, will close the valves before the piston has completed its stroke, so that when the end of stroke is reached a partial vacuum is formed in the cylinder. Where these defects exist, the piston must travel a distance as A-O before the atmospheric line is reached, and the volume of the cylinder would be O-F, instead of A-F, making the 10 per cent. allowance for clearance necessary, while 3 to 4 per cent. should be sufficient on a well designed machine.

The temperature of the air at 75 lbs. gauge pressure without any cooling is 419 degrees, although this is somewhat lower in the cylinder, due to the jacket cooling; and from actual readings on thermometers placed in the discharge pipe close to the cylinder, the temperature is from 300 to 360 degrees, according to the size and speed of the machine.

Referring again to Fig. 26, we have the volume C-K-N-G, representing about 25 per cent. of the free air volume at, say, 340 degrees temperature, to put into the receiver at each stroke of the machine. As the receiver is anywhere from 10 to 20 ft. from the compressor, and as it has a large surface exposed for radiation, its temperature will be considerably less than that of the air leaving the cylinder, which will consequently be cooled and reduced in volume, and as the air is generally used a considerable distance from the compressor, it will have reached atmospheric temperature by the time it is used and our original volume C-K-N-G, when leaving the cylinder, will have shrunk to D-K-L-G by the time it was used, being then only 16-25 of what we would have had had the air been used hot directly as it left the compressor.

This shows us clearly the two most important factors where a large saving can be effected in the production and the use of air—the first being to cool the air as much as possible during compression, and the second to heat the air as much as possible before using; and although the above diagram represents the actual conditions of many of the small compressor plants in existence in which the air is used as explained, these losses can be and are successfully overcome in most of our large compressor plants of to-day where air is being produced and used, with a less expenditure of coal than if steam were used direct, leaving all the saving by the use of the air as a clear gain for the operators.

Turning our attention now to the main factor for the economical compression of air, which is to cool it as much as possible during compression, we having the following styles of compressors for the accomplishment of same, namely: the wet compressors or those in which water is used in the cylinders; the dry or water-jacketed compressors, and the compound or stage compressor, where the work of compression is done in two or more cylinders, the air being cooled in passing from one to the other.

Of the first named style there are two forms, one being that in which the water is let into the cylinder with the incoming air, and the other in which the

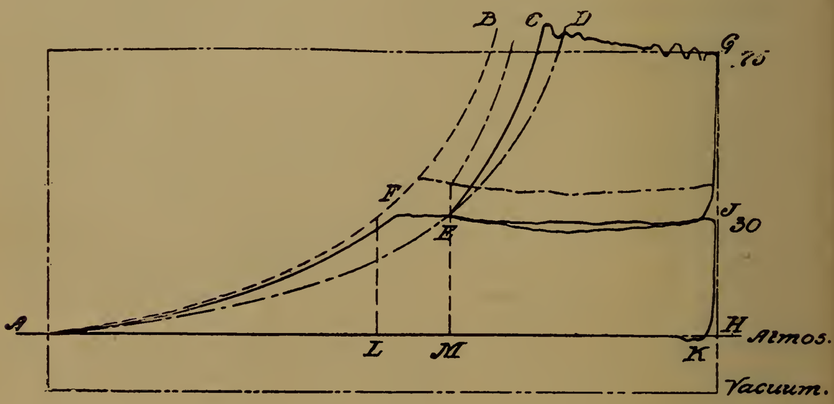

FIG. 27.

water is injected into the cylinder in the form of a spray while the air is being compressed. In the first form there is a great deal of water in the cylinder, which then very much resembles a pump, but as the air and water do not become mixed, the air is but very little cooled, while the water, on the other hand, reduces the efficiency of the machine by the increased friction in the cylinder and the slower speed that the compressor must be run at. The water injection machine, on the other hand, is the best known way of cooling the air in a single cylinder, but as it still retains all the disadvantages of having water in the cylinder, causing often the rapid wearing of the parts, all of the American compressors of today are made with water jacketed cylinders, the loss in economy being more than counterbalanced by having a machine which will not require the constant renewal of parts.

In designing an air cylinder, the object is to get as much of the body of the cylinder and heads jacketed as possible, the heads in particular being the most effective, as they are exposed to the air during the entire length of stroke, while the body surface diminishes as the piston travels toward the head. The smaller the air cylinder the more effective is the jacket, for in cylinders of different diameters the volume of air they contain is proportional to the square of their diameter, while the cooling surface is in the direct ratio of the diameter; that is, if one cylinder were twice the diameter of the other, it would hold four times the volume of air and only have about twice the cooling surface, being thus only one-half as efficient as the small cylinder. Compressors have been built where the air cylinder proper was made up of a great number of small cylinders all enclosed in water, and they have given very economical results, but they are expensive to build and very liable to get out of order owing to the large number of small valves required for the many cylinders.

The most economical way of compressing air is by doing it in stages; that is, using two or more cylinders, compressing it to a low pressure in the first, then passing it through a cooler cooling it to atmospheric temperature and then further compressing it to a higher pressure, cooling it and compressing it again, and so on, depending on the pressure required, the two-stage or compound compressor being used for pressures between 60 and 300 lbs., the three-stage or triple compression between 300 and 1,000 lbs., and the four-stage or six-stage between 1,000 and 3,000 lbs., or higher.

We have in Fig. 27 a combined indicator card of a compound compressor, in which A-B is the adiabatic, A-D the isothermal, and A-F-E-C the line showing the actual work done in the cylinder. The low pressure card is represented by A-F-J-K, the pressure reached in same being governed by the size of the high pressure cylinder and the efficiency of the intercooler. The distance, H-M, represents the volume of the high pressure cylinder in proportion to the low pressure cylinder represented by H-A, the diagram showing that the compression line in the high pressure cylinder starts at the isothermal line, showing that the air was cooled to atmospheric temperature before entering the high pressure cylinder.

The compressed air leaving the low pressure cylinder is represented by F-J-H-L, and passing through the cooler it shrunk in volume to E-J-H-M, representing the size of the high pressure cylinder. Had the cooler not been perfect, the air would have retained part of its heat, keeping its volume consequently larger, and a higher pressure would have been necessary in the low pressure cylinder, the card then being as shown by the dash-dotted line representing more work done in the cylinder. This shows the necessity of having a perfect cooler, the important part of which is that the air is broken into thin sheets so that it can be easily cooled. The air and water should also travel in opposite directions, so that the air in leaving the cooler meets the coldest water, and the cooler should also hold a sufficient volume of air so that there will be no drop in the intake air pressure of the high pressure cylinder.

Comparing the compound cylinder card, Fig. 27 with Fig. 26, it is seen that the amount of work represented by F-B-C-E has been saved, amounting to about 14 per cent. of the total work, or where it took 16 H. P. to compress 100 cu. ft. of free air to 75 lbs. in a single cylinder, a compound cylinder would use 13¾. Where air is to be compressed to higher pressures, the saving in compounding becomes more marked—500 lbs. pressure requiring 40 H. P. for compressing 100 cu. ft. of free air in a single cylinder, and 30 H. P. in a compound cylinder, or a saving of 25 per cent., this percentage increasing with higher pressures, and at 2,000 lbs. using four cylinders for doing the work, the work saved over a single cylinder is 45 per cent.

As the object is to cool the air as much as possible during compression, the colder the air is to start with the better; thus a considerable saving can be effected by taking the air supply from as cold a place as possible, carrying the air through a wooden box to the compressor. Approximately for every 5 degrees that the intake air is colder than the air in the engine room, a saving of one per cent. is effected in the running of the machine; and as there are many days in the winter months where there is a difference of 50 degrees between the temperature indoors and outside, a saving of 10 per cent. can be effected by supplying the compressor with the cold air from outdoors, instead of using the hot air of the engine room. Using cold air increases the capacity of the machine, a difference of 50 degrees in the air used amounting to about 10 per cent. increase in the amount of air the compressor will deliver.

We have so far in our figures been dealing with compressed air at sea level where the atmosphere has a pressure of 14 7-10 lbs. At higher altitudes the atmosphere is more rarefied, representing less pressure per square inch, as shown by the following table:

PRESSURE.

At	¼	mile	above	sea level	—14.2	lbs.	per	sq. inch.
"	½	"	"	"	—13.33	"	"	"
"	¾	"	"	"	—12.66	"	"	"
"	1	"	"	"	—12.02	"	"	"
"	1¼	"	"	"	—11.42	"	"	"
"	1½	"	"	"	—10.88	"	"	"
"	2	"	"	"	— 9.88	"	"	"

Or an approximate reduction of ½ lb. per square inch for every 1,000 feet of ascent. Owing to the rarefied condition of the air at high altitudes it is evident that when this air is compressed its volume under pressure will be considerably less than if the same volume of free air at sea level pressure had been compressed to the same pressure.

According to Mariotte's law, the pressure of any gas varies in the inverse ratio of the volume, the temperature remaining constant, or the volume of a given quantity of gas is inversely as the pressure it supports; or representing

P' as being the absolute pressure at any point of the stroke,

P the original absolute pressure,

V the volume corresponding to the required point of the stroke, we have for the pressure at any point of the stroke,

$$P' = \frac{P}{V}$$

or for the volume at any point of stroke—

$$V = \frac{P}{P'}$$

Remembering that in all computations absolute pressures (pressures above vacuum) are to be taken, and not gauge pressures; remembering also that the results obtained will be in absolute pressures from which the atmospheric pressure must be deducted to obtain the gauge pressure. Applying Mariotte's law in determining the difference in volume by compressing at sea level or at an altitude, suppose we compress one cubic foot of free air at the sea level to 75 lbs. gauge pressure, which equals 90 lbs. absolute pressure, we have by Mariotte's law—

$$V = \frac{P}{P'} \text{ or } V = \frac{15}{90}$$

Suppose we were compressing air at an altitude of one mile, where the pressure of the atmosphere, according to our table, is 12 lbs., we have by the same law—

$$V = \frac{P}{P'} \text{ or } V = \frac{12}{87}$$

or only about 4-5 as much air as when at sea level.

As many air compressors are now used at high altitudes, allowance is made for this loss by deducting a certain percentage; in the above case, 20 per cent. from the rated capacity of the machine, amounting to 7 per cent. at ¼ mile altitude, and increasing abouc 4 per cent. for each additional ¼ mile of altitude, at two miles the loss being about 34 per cent.

As the volume of air decreases, the required power of the compressor also decreases, but the capacity decreases in a greater ratio than the power necessary to compress, hence it follows that operations at a high altitude are more expensive than at sea level. At 10,000 feet this extra expense amounts to over 20 per cent.

Having now given a general description of the work done in an air cylinder, I will briefly describe the construction of the air compressors that are in general use to-day. Probably the simplest and the best machine for a small plant is what is known as a straight line self-contained machine, in which the air and steam cylinders both in a direct line are fastened to a common bed-plate.

Fig. 28 shows a steam and air indicator card taken from such a machine, from which it is seen that the greater part of the work in the steam cylinder is done at the beginning of the stroke, while in the air cylinder it is done at the latter part of the stroke. To make this possible where steam is to be used expansively, as shown in the card, it is necessary to use heavy fly-wheels and reciprocating parts on the machine, the energy of the steam cylinder at the beginning of the stroke being stored in the fly-wheels, which in turn give up their energy in compressing the air at the end of the stroke.

The question is often asked, How is it possible with the same size cylinders to get a higher air pressure than the steam pressure used? By referring to Fig. 28, it will be seen that the steam card represents a higher mean effective pressure than the air card, showing that the steam cylinder has done the most work owing to the friction of the machine, although the air card shows the higher pressure. This is due to the energy of the steam cylinder being stored in the fly-wheels, and where the fly-wheels are made sufficiently large and heavy, no trouble is experienced in getting from 50 to 75 per cent. higher air pressure than the steam pressure used; this, however, being very poor steam economy,

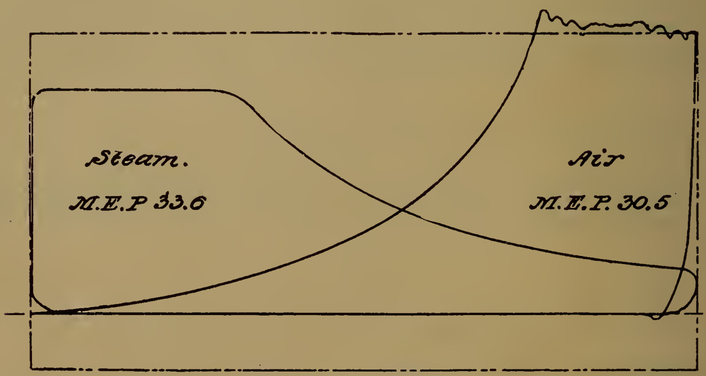

Fig. 28.

as it would be necessary to cut off late in the steam cylinder, utilizing very little of the expansive power of the steam. For good economy, working at about 80 lbs. steam and air pressure, the cylinders should be about the same diameter, thus allowing from ¼ to ⅜ cut-off in the steam cylinder; or if higher air pressures are required, the size of the steam cylinder should be increased accordingly.

It must not be understood that a compressor cannot be built without a fly-wheel, for there are thousands of such in every-day use, by which I refer to the air pump used on every locomotive. It would not be fair to criticize this machine in connection with the duty it performs, for it has too well stood the test of years, its lightness and compactness being more valuable features than economy in the use of steam; but commenting on the same, when used in a shop we have but to understand that for each stroke of the machine a full cylinder of steam is required at the maximum air pressure, comparing which with the fly-wheel compressor where steam is cut off at ¼ stroke, shows that the air pump has used four times as much steam as the air compressor would have used for compressing the same amount of air.

Another form of wheelless machine is that in which the air cylinder at each stroke and after being filled with free air, is filled with air at receiver pressure by opening the discharge valve at the beginning of stroke. The air cylinder now has a uniform maximum load for its entire stroke resembling the water cylinder of a pump, but this also necessitates a whole cylinder of steam at maximum pressure to do the work.

Attempts have been made on wheelless machines to use steam expansivly by making the reciprocating parts, noticeably the crosshead, of sufficient weight that their momentum would compress the air at the end of the stroke after the steam had been cut off, but a machine of this kind can only be designed for a fixed speed and pressure, the weight being too heavy if run faster, and not of sufficient weight to do the work if run slower,—making in all a poor substitute for a machine that is called upon to do a variable amount of work. From these accounts it is seen that the fly-wheel is really a necessary part for an economical compressor.

The straight line compressor is made with many different arrangements of cylinders, the steam cylinders, air cylinders, or both, being compounded, but in all of these the work of the cylinders is in a direct line and the fly-wheel uses its stored up energy twice in each revolution to overcome the maximum load at the end of stroke.

To more uniformly distribute the work during each revolution, the duplex form of compressor has been adopted as the best type for the larger and better machines. This is essentially two straight line machines placed side by side with a common shaft for the two, the cranks of same being set at 90 per cent. to each other. This divides the work through four parts of the revolution, making the machine more uniform in its motion and allowing it to run slower and with better steam economy than a straight line machine, avoiding also all dead centers, so that the machine can be started up at any part of the stroke. The duplex compressor is also made with different arrangements of cylinders, the best types being those having cross compound steam and air cylinders.

These two types of machines are to-day considered the standard; but as an air compressor is but a steam engine with an air cylinder attached, it has probably been built in every form, whether horizontal or vertical, that a steam engine has ever been built.

In determining the style of compressor best suited for the given duty, conditions such as the size of plant, cost of fuel, the length of time the plant will be used, cost of foundations and first cost of machine must be considered, for the higher the efficiency of a compressor the greater will be its first cost; but for a permanent plant no machine can be too good or too economical in its operation.

As air is generally used under the same conditions and with the same machinery that uses steam, the true way of comparing the efficiency of a compressor would be to compare the volume of cold compressed air that the compressor will furnish with the volume of steam the compressor used at the same pressure to furnish the amount of air.

Assuming it thus, the efficiency of a straight line compressor, non-compound, would be about 60 per cent.; a duplex Corliss compressor non-compound, about 65 per cent., and a duplex Corliss compressor with compound condensing steam and compound air cylinders with inter-cooler, about 90 per cent., or in the latter case we would have 90 per cent. as much cold air as steam that was used. If we consider for a moment the properties of compressed air as compared to steam, we find everything in favor of the air, as it remains ever ready to be used, regardless of the exposed condition of the pipes through which it passes, while steam, if carried around in uncovered pipes outdoors, condenses very fast, this condensation often amounting to from 15 to 30 per cent., so that if air was used under these conditions, it would be more economical than steam, without taking into consideration the great convenience of the air and the saving it effects in the increased running of the machinery, less friction, saving of hose and oil, and the ease with which all machinery and pipes can be handled owing to their being always cool. We have thus far only considered the use of air when in a cold condition, but far greater economy can be obtained by heating the air before using, as will be explained later on.

We often read lengthy articles on the efficiency of an air compressor plant where the compressor and all the pumps and hoisting engines or machinery that used the air were carefully indicated and figured out, and they find that the work the air done in horse-power is only about one-third of the indicated horse-power of the compressor; or, in other words, that the compressor plant has only an efficiency of 33 per cent. This certainly looks very unfavorable for the use of compressed air, but it nevertheless is a condition which exists, the reason for the same being due to the very uneconomical machinery with which air is always used, and it is this uneconomical use of air which has done much to keep it from being more generally employed as a power.

The above statement as to the efficiency of a plant is, however, misleading, unless one takes into consideration as to how the power is measured at the compressor and how the air is measured in being used. The indicated horse-power of the compressor is the amount of work done in compressing the air, using, however, in an economical machine the full expansive power of the steam, or at the end of the stroke when the steam cylinder is ready to exhaust, no pressure, and consequently no work, is left in same.

In the pumps, hoisting engines or drills using the air, we have, however, a different condition. Here the cylinders are filled full of air under pressure, and at the end of stroke, when the cylinders open to exhaust, the whole cylinder-full of air under pressure is allowed to escape into the atmosphere, utilizing none of the expansive power contained in same; in other words, the power is supplied or measured at the compressor when used in the most economical way, while the air is used in the most wasteful way, hence accounting for the poor showing; but it must be remembered that the machine which used the air would use steam under the same wasteful conditions, and would show a correspondingly poor efficiency if compared with the same volume of steam used expansively in an economical engine. The amount of steam used to compress the air, if used direct in the pumps and hoists, would be but little more than enough to run the same, and the efficiency of the compressor plant would be from 60 to 90 per cent., according to the compressor, when compared with the volume of steam used, as against 33 per cent. when horse-powers are figured. Hence, as previously stated, the only intelligent way of making comparisons of the efficiency of the air system would be to compare volumes, and not horse-powers.

TRANSMISSION OF AIR.

Of the transmission of air, very little need be said, for it is simply carried around in pipes, the same as steam or water, but being more easily handled than either, for no matter what the length of pipe, there will be no condensation as with steam, and no shock as with water. As to the distance that air can be carried, that depends entirely on the volume of air and the size of pipe, the only loss being a reduced pressure at the end of pipe line, caused by friction if the pipe is not of sufficient size, but at this reduced pressure the air has a larger volume, so that the loss is not as much as the fall in pressure would make it appear.

Air pipe lines have in different places been laid for distances of 15 miles or more, but the average pipe lines in tunnels and around quarries run from 1,000 to 10,000 feet, for which conditions the pipes can generally be made large enough at a small expense, so that the friction will only amount to a few pounds loss of pressure.

As a practical example of what would be required, if 1,000 cu. ft. of free air compressed per minute to 80 lbs. pressure, was to be carried a distance of 5,000 feet, a 5-inch pipe line would show a loss of pressure of about 6 lbs., and a 6-inch pipe about 2½ lbs., all elbows in the pipe line increasing the friction, so as few as possible should be used. The friction loss may be considered for ordinary purposes as being proportional to the length of pipe and as the square of the velocity of the air, twice the volume passing through the same size pipe, giving about four times the friction.

A receiver should always be placed close to the compressor, to better equalize the work on same, answering also at the same time as a separator, taking much of the water and oil out of the air, these dropping to the bottom of the receiver, where they are blown out at frequent intervals. A second receiver should be placed where the air is to be used, as the air being still further cooled will drop most of its moisture, which can be again blown out at the second receiver, leaving dry air to be used in the machine. All pockets in pipe lines should be avoided, as they have a tendency to hold water and thus retard the free passage of the air; and wherever a machine is used at the end of a long air pipe draining in the direction of same, provision should be made for blowing out the water before using the air. Should it become necessary to pass air through a pipe line, which must of necessity have many pockets in same, so much water may be held in the pockets that very little air pressure would be gotten at the end of the line. Where these conditions exist, much trouble can be avoided by thoroughly cooling the air, thereby taking out all its moisture to a temperature lower than that of the pipe through which it will pass, so that the air will have a tendency to take up moisture in the pipe instead of dropping its water in same. By doing this the air pipe will always remain free, so that the full air pressure will be gotten at the end of the line. For carrying the air to cranes and hoists rubber hose has admirably fulfilled the requirements, for with the use of quick-acting couplings or a line of hose wound on a drum, every convenience has been obtained.

USE OF AIR.

In the use of air, about the only objection that has been offered to the same is the freezing up of the exhaust. Whenever air is used expansively, it must draw its heat from the surrounding objects, and if any moisture remains in the air it will have a tendency to freeze the same. The freezing of the exhaust can be avoided by having the air perfectly dry before using, hence the object of the receivers and drains; or if this is not possible, a small stream of water about the size of a needle in the exhaust will have the desired effect. As these preventives to frost, however, do not add any to the economy of the system, the only true way of overcoming all the tendency of the air to freeze is to reheat the same before using, getting back all of the work or the volume of the air that was lost in cooling while passing from the compressor to where it was to be used. This heating of the air is to-day successfully and economically accomplished, the heating of same increasing its volume from 35 to 50 per cent., this increase costing only about one-sixth the amount of coal in the heater that the compressor used for compressing an equal volume of air.

Heaters in use to-day are made similar to a stove where the air in thin sheets passes over the heated sides of a jacket, or other forms are made where the air passes through hot water, both of these having been very successful in their application.

When a compound condensing compressor, with compound air cylinders producing about 90 per cent. as much cold air as steam that was used, has the air reheated before it is used, we can easily see how the compressed air plant can claim to have an efficiency of about 20 per cent. more than if steam were used direct, regardless of the many other advantages and conveniences that are due to the air.

COMPRESSED AIR IN ENGLAND.

This is a subject which has, during the past few years, been creating more genuine interest than some of the later discovered motive forces.

It used to be said that we know but little of the possibilities of electricity, and one hears the same now being said concerning compressed air, but we are expecting something from it—something startling, on the lines of liquid air. What a triumph for air—compressed or liquid— if it could solve the perpetual motion problem, with surplus power to spare. We are looking to you in America for these new developments. It would be doubly startling if they came from any other country, as it is a common saying here, that all things new and wonderful must come from America, so consequently your reputation is more or less at stake in this matter.

We, throughout Europe, are no doubt a long way behind you in the economical compression of air and the application of the same, due to a variety of causes, the chief of which is the air compressing manufacturer; who, instead of trying to construct his compressor on more economical lines and reduce to a minimum the loss of power between the steam and the air cylinders, seems to have accepted a certain low standard of efficiency, and no serious attempt has been made to improve upon it; it having been taken, that a great loss is inevitable, and that compressed air is only used when it is absolutely necessary, such as in mining operations, tunnel driving and other dark corners, where other motive forces are not practical; but happily this idea is fast dying out, owing largely to the publicity compressed air has attained during the last year or so, and the fact is being largely accepted that compressed air is not only useful in dark confined spaces, but in the open daylight as well, competing alongside of steam and electricity, and in many cases where steam is practicable, air is found more economical in its application. It speaks volumes for it, that in every case where it has been installed, for open quarry work, etc., for operating rock drills, cranes and other motors, the users are strong in its praise, and would not again go back to steam. Unfortunately, compressed air in the past has been judged only by the loss of power between the steam and air cylinders, and the great convenience and saving in application has been overlooked. However, the time is rapidly approaching when compressed air will be recognized at its full value, and given its proper place. By that time it will be found that there are two kinds of air compressors—the good and the bad; the latter, dear at any price. If the public in the past had only purchased from well-known and tried manufacturers of this class of machinery the results would have been quite different.

One reason for our engineers being so long in adopting pneumatic appliances has been the difficulty of getting a satisfactory air compressor; and in many cases pneumatic tools have been tried and condemned, when it was entirely the fault of the compressor in not giving sufficient pressure, and being otherwise unsatisfactory.

There is no class of engine made in this country on so many different designs in attempting to accomplish the same purpose as the air compressor, and in the majority of cases, the fatal mistake is made of not properly proportioning the fly-wheel. It is the apparent simplicity of the air compressor which has tempted many old established engineering firms to take up its manufacture as a kind of side issue, which needed but little attention; but many soon discovered to their cost, that they had made a mistake, and that to design and manufacture a successful air compressor was no simple matter, but one which required years of study. As an instance, to show the difference between a good air compressor and a bad one, I might give a few details of two I saw a short time ago. One was constructed by a well-known and noted air compressor company and the other by a well-known firm of engineers, who had never before built an air compressor. The dimensions of the latter compressor are as follows: Steam cylinder 12-in. diam., air cylinder 12-in. x 15-in. stroke. This engine running at its maximum speed could not supply air above 20 lbs. pressure per square inch, for keeping one 3-in. cylinder by 5½-in. stroke rock drill at work, through a large pipe, distant only a few hundred yards. The other compressor, with dimensions as follows:—12-in. steam cylinder and 12-in. air cylinder by 14-in. stroke, and running at about two-thirds of its speed, was able to maintain 60 lbs. pressure per square inch, with two 3-in. cylinder drills constantly at work, through similar size pipe and under the same conditions. Of course, this is an extreme case, the first compressor being a badly designed one and the necessity for reducing clearance spaces in the air cylinder having been ignored by the builder.

I might cite one more instance of some of the bad designs on the market: this time a belt compressor, constructed by quite a different firm, but proving equally unsatisfactory. The main driving pulleys for operating this compressor are about 4 feet in diameter; the fly-wheel pulleys on compressor are about 2 feet 6 inches in diameter (and very light in construction); the air cylinder is 16-in. diameter by 18-in. stroke, and running at a speed of about 75 revolutions per minute. With this compressor it is found quite impossible to raise more than 20 lbs. pressure per square inch; in fact, this result can only be accomplished with difficulty, and abnormal wear and tear on the belts, owing to their lashing.

In larger size compressors we find much better design, construction and workmanship than is found in the small sizes. This is owing to the greater demand for big compressors for Colliery work, etc., the makers having gained more experience; but that experience has only led them to proportion their compressor a little better, and make it more of a mechanical job. (There is, however, much yet to be desired in this line). The inlet valves, which are the weak point in all our compressors, seem to have undergone but little improvement during the past twenty years. Better material is now being used, and consequently the danger of the engine being wrecked by valves breaking and falling into the cylinder is much lessened. However, even now, it is not found safe to run at more than about 300 feet piston speed per minute, as anything faster would hammer up the valves, which would then become leaky and dangerous. This is a serious drawback, as otherwise the engine would be capable of running double the piston speed, which would naturally increase the capacity of the air compressor. These remarks, of course, apply to compressors with 5 to 6 feet stroke and above 18-in. diam. cylinder, which are practically the only type made in this country.

It also not infrequently happens that the compressor manufacturer is not sufficiently informed on the subject to know what size air pipes to advise or what kind of oil to use in the air cylinder. Consequently, in the first case, too small air mains are often put down over long distance, with the natural result of causing too much friction, and in the latter case, the air valves become clogged up and after a short existence, the air compressor is a complete wreck.,

Compressed air as applied to steet cars seems to be having but little attention and development on this side; and it seems that the conditions are most favorable, as there is considerable opposition on the part of the public to having the streets disfigured with electric wires. However, all the chief cities have, or are about starting the overhead trolley system, but any enterprising firm who could put some favorable facts and reliable data before some of the corporations contemplating the adoption of mechanical power for street car service would no doubt have unprejudiced consideration, and a successful installation in any important city would be followed by the universal adoption of compressed air. With the exception of London, the compressor power station could be so placed as to be within 3 to 5 miles of the terminus of the tram lines.

Take Glasgow (a very large city), and the power stations need not be more than 3 miles from the terminus.

COMPRESSED AIR.*

Our earliest authentic records of the application of air in a physical or mechanical sense are found in a book by Hero of Alexandria, who lived, so we are informed by historians, from 284 to 221 B. C. Hero is said to have been a student of Ctasibus, who is credited with producing the first pneumatic air gun. Later produced a book of Pneumatics, "Hero's Pneumatics." This was a review of the art up to his time, a remarkable work in which is recorded a variety of pneumatic devices used mostly by the tricky, yet shrewd, priests to intimidate the ignorant, child-like men of those days into an awed and superstitious obedience. Among these pneumatic appliances, the most of which the author makes no claims to have invented, is one, the Hero Fountain, a simple device quite as familiar to the world as the steam engine. Other early records tell of the primitive efforts of Philo of Byzantium and the fathers of the early Chaldean Church. But it was only after centuries had rolled by that, so far as we know, any advance was made. To Boyle, a physicist, may be credited the next mile stone in this field of science. Boyle's law, named after its discoverer, and proposed about 1662, sometimes credited to Mariotte, states that at a given temperature the volume of a body of gas varies inversely as the pressure, density and elastic force, and it is this law, verified time and again since then, which forms the foundation of thermodynamics. Dr. Papin is credited with suggesting, in 1700, the use of air for forcing carriers through tubes. Eighteen hundred is the year in which the blast furnace is claimed to have been introduced into Wales. Other physicists have added here and there the laws and theories which constitute the science of thermodynamics, and enable us to calculate and predict the probable action of our thermal machines.

Among the many entitled to the most credit the names of Avagardo, Gay Lussac, Torricelli and Regnault stand out most prominently. Another period equally as important but more recent includes the names of Rankine, Carnot, Thurston, De Volson Wood and others who have formulated and collated the scattered facts and developed the laws of thermodynamics into an exact science. So much has been written by those mentioned and dozens of others about the general subject of gases, among which we may include air, that it is hardly possible to impart much that is new except from the practical standpoint; that is, from the point of application of the principles to the actual machines.

To begin with, let us consider air as a material, as it is. In other words, it is a substance, and, it so happens, a composite substance. Its constituents, speaking now of ordinary air, are oxygen, argon, nitrogen, carbonic acid, and a certain amount of water vapor; generally speaking, it is regarded as made up of 23 parts by weight of oxygen and 77 parts by weight of nitrogen, or by volume 21 parts of oxygen and 79 parts of nitrogen. This air surrounds the earth like a shell to a depth of about 20 miles. It varies in density from practically nothing where it shades off into space to that produced by a pressure of 14.7 lbs., which we call "atmospheric pressure."

At 0° C. (32° F.) and atmospheric pressure (14.7 lbs.) one pound of dry air occupies a space of 12.386 cu. ft., and conversely a cu. ft. of air weighs 0.0807

* J. J. Swann, in *The Sibley Journal.*

lbs. These figures for an average temperature, say 60°, are 13.089 cu. ft. and 0.0764 pounds per cubic foot. In other words, an increase in temperature with a constant pressure increases the volume of this air. Being a substance it has properties like other substances. It is elastic and can expand or be compressed. This compression may be done in three ways: isothermally, with temperature kept constantly by some refrigerating device; adiabatically, in which the temperature is allowed to increase as it will, the containing vessel being protected to keep in the accumulated heat; and a combination of isothermic and adiabatic compression, or the system of compression approached in the best machines of to-day.

Before discussing compressed air in the modern meaning of the term, it is desirable to divide our subject, and this is easily done because it naturally falls into three sub-divisions:

1. Production.
2. Transmission.
3. Use.

Or the compression, the transmission and the expansion. Air is not a perfect gas, but it is enough so for our purposes; hence, the laws and formulas used in considering a perfect gas may be applied to it as well.

A perfect gas is one which, when under a constant pressure, will have a rate of expansion exactly equal to the rate at which it absorbs heat; or, a perfect gas is one with which, for each given increment of pressure, there will be an equal increment of heat. Stated as an equation we have

$$(p)_{v\ \text{constant}} \propto t \qquad (v)_{p\ \text{constant}} \propto t$$

$$pv \propto t$$

$$\text{or } \frac{pv}{t} = \frac{p_1 v_1}{t_1} = C = (\text{constant}) \ldots\ldots\ldots\ldots (1)$$

in which the prime letters represent a different set of values from p, v and t, which are the initial values for pressure, volume and temperature. Reducing this to 0° Centigrade and considering one cubic foot of dry air at the sea level, we have

$$\frac{p_0 v_0}{t_0} = \frac{14.7 \times 144 \times 12.38}{460.66 + 32} = 53.21$$

$$\text{then } \frac{pv}{t} = C, \quad pv = 53.21 \times t,$$

or in the metric system,

$$pv = 29.20 \times t.$$

This is simply another way of stating Boyle's, or Mariotte's, law of perfect gases, and, while not absolutely true for all gases, it may, for engineering purposes, be employed for the so-called permanent gases, including air.

As already stated, the relations of pressure, volume and temperature may be considered in two ways, isothermally and adiabatically.

Consider for a minute Fig. 29, which represents a cylinder with an area of 1 sq. ft. and a length of about 14 ft. filled with air under atmospheric conditions, say 14.7 lbs. pressure and 60° F. temperature. We will then consider the cylinder surrounded by a refrigerating medium or device capable of absorbing any heat which may be generated above that which is resident in the surrounding air under the atmospheric conditions. If the piston is now advanced, the air is condensed, the molecules have less and less space in which to travel, molecular impacts increase in frequency and the temperature of the whole gas increases, thus giving evidence of the generation of heat. However, if we may use the expression, this surplus of heat is absorbed by the refrigerator as fast as produced, and we have the relation of pressure and volume called for in the equation $p\ v = C$ (constant), which, graphically, is an equilateral hyperbola asymtotic to the X and Y co-ordinate axes.

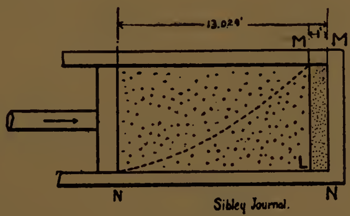

FIG. 29.

Adiabatic compression under the same conditions would be accomplished by substitution for the refrigerator, lagging or packing which would prevent the removal or addition of heat from or to the cylinder.

The advance of the piston, as in the former cases, decreases the space in which the molecules move, hence their movements become more rapid, their minute impacts occur with increased frequency and force, and, as a result, there is an increase in the amount of heat present in the cylinder. This heat causes a positive expansion of the enclosed air, necessitating an application of increased power to move the piston. In other words, other things being equal, adiabatic compression requires the expenditure of more power than isothermal compression. The equation representing this adiabatic compression must then be different from isothermal compression, and it can be shown mathematically that

$$p\ v^{\gamma} = p_1\ v_1^{\gamma} = \text{Constant.} \quad \text{Thus: } DH = O.$$

$$C_v\, dt = -p\, dv$$

$$C_p\, dt = v\, dp$$

where C_v =specific heat at constant volume

C =specific heat at constant pressure

$$\text{dividing } \frac{dp}{p} = -\frac{C_p\, dv}{C_v\ v} = -\gamma\frac{dv}{v}$$

$$\text{Integrating, } \log\frac{p}{p_1} = \log\left(\frac{v_1}{v}\right)$$

When p_1 and v_1 are the initial limits, the other limits being general.

$$\text{hence, } p\, v^{\gamma} = p_1\, v_1^{\gamma} = \text{constant}$$

$$\text{eliminating } p \text{ by using } p\, v = \text{Constant} \times t$$

$$\frac{t}{t_1} = \left(\frac{v_1}{v}\right)^{\gamma - 1} \text{ and } = \left(\frac{p}{p_1}\right)^{\frac{\gamma - 1}{\gamma}}$$

These are the equations of adiabatics for a perfect gas in which v, p, t, are initial limits, and v_1, p_1, t_1 other values taken anywhere, or terminal. The term γ is a constant and is the ratio of the specific heats, which are constant for perfect gases. That is,

$$\frac{C_p}{C_v} = \gamma$$

$$\text{for air, } \gamma = \frac{0.2375}{0.1689} = 1.406.$$

It is thus seen that the apparatus which, in compressing from one condition to another, effects the greatest cooling will be the most efficient.

COMPRESSION.

To all intents and purposes the compression which we obtain even in the best forms of air compressors is nearly adiabatic, and even if it is not, the con-

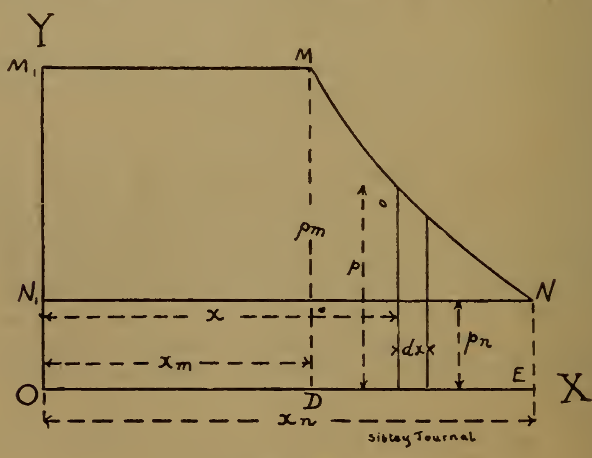

FIG. 29a.

sidering of it as such is an error on the right side. Such being the case, let us consider the work necessary to compress a cylinder full of air. To start with, we have our cylinder either single or double acting, connected with a receiver or reservoir, the passage to which is closed by a discharge valve. The pressure in this reservoir is something above atmospheric, say P_m: our cylinder is filled with free air under atmospheric conditions. As the piston is advanced towards the closed end the pressure of the enclosed air increases along the curve *M N* to *M,* which is the pressure P_m of the receiver. The discharge valve then lifts and the further advance of the piston performs the work of forcing the now compressed air into the receiver against approximately a constant pressure.

We thus have the work done in a complete stroke divided into two portions. That of compression and that of delivery. The piston is, of course, shoved ahead by the piston rod, in turn connected with some form of enginc. There is, however, an additional pressure of 15 lbs. per sq. inch assisting, due to the free air entering the inlet valve on the other end of the cylinder. This pressure is balanced, however, by a like pressure at the exit of the receiver.

If, Fig. 29a, we let the increasing pressure of the air be p, which at N would be 14.7 lbs., atmospheric pressure, and p_m the receiver pressure, F the piston area, and x the distance from O the piston is at any moment. Then the work done in compression will be represented by the area $M\ N\ L$ and that of delivery by the area $M^1 M\ L\ N^1$.

$$\left\{\begin{matrix}\text{area} \\ \text{M M L} \\ \text{work of} \\ \text{comp.}\end{matrix}\right\} = w_1 = -\int_E^D F(p - p_n)\,dx \quad \ldots\ldots\ldots\ldots (a)$$

in which p and x are variable

$$\left\{\begin{matrix}\text{area } M_1 \\ \text{M L } N_1 \\ \text{work of} \\ \text{delivery}\end{matrix}\right\} = w_2 = -\int_D^O F(p_m - p_n)\,dx \quad \ldots\ldots\ldots\ldots (b)$$

in which $p = p_m$ and is constant

adding (a) and (b) and simplifying, we have, work per stroke

$$= W = w_1 + w_2 = 3 v_m p_m \left\{ 1 - \left(\frac{p_n}{p_m}\right)^{1/3} \right\} \dagger \quad \ldots\ldots\ldots\ldots (2)$$

For convenience in approximate calculations, the following table will prove of value:

TABLE 8.—HORSE POWER DEVELOPED TO COMPRESS 100 CUBIC FEET OF FREE AIR, FROM ATMOSPHERE TO VARIOUS PRESSURES.

Gauge Pressure Pounds.	One-Stage Compression D. H. P.	Gauge Pressure Pounds.	Two-Stage Compression D. H. P.	Four-Stage Compression D. H. P.
10	3.60	60	11.70	10.80
15	5.03	80	13.70	12.50
20	6.28	100	15.40	14.20
25	7.42	200	21.20	18.75
30	8.47	300	24.50	21.80
35	9.42	400	27.70	24.00
40	10.30	500	29.75	25.90
45	11.14	600	31.70	27.50
50	11.90	700	33.50	28.90
55	12.07	800	34.90	30.00
60	13.41	900	36.30	31.00
70	14.72	1000	37.80	31.80
80	15.94	1200	39.70	33.30
90	17.06	1600	43.00	35.65
100	18.15	2000	45.50	37.80
		2500		39.06
		3000		40.15

† Church's Mechanics of Engineering, page 637.

Two-, three-, and poly-stage compression employs exactly the same formulas, introducing, however, the condition of inter-cooling. At the end of the compression in the first cylinder the discharge valve opens and the air passes out into the inter-cooler, which is being emptied at the same instant by the air passing into the high pressure cylinder. The cubic dimensions of the cylinder should be such that the compressed charge can pass in and just fill the cylinder, thus preventing any loss of pressure due to expansion.

The work involved in compressing a given weight of air, say one pound, is obtained by assuming pressures and temperature, or by measuring them in the case of an operating engine, and employing the formulas already given. Assume p_1 as our original pressure with an absolute temperature T_1. Let p_c = pressure at end of the first compression. We have the equation already given (in which $n = \gamma$).

$$u_1 = \frac{n}{n-1} R\, T_1 \left[\left(\frac{p_c}{p_1} \right)^{\frac{n-1}{n}} - 1 \right]$$

R is a constant = C. The second stage starts at p_c and runs to p_2 with a final temperature T_2

$$u_2 = \frac{n}{n-1} R\, T_1 \left[\left(\frac{p_2}{p_c} \right)^{\frac{n-1}{n}} - 1 \right]$$

Adding, we have,

$$u = (u_1 + u_2) = \frac{n}{n-1} R\, T_1$$

$$\left[\left(\frac{p_c}{p_1} \right)^{\frac{n-1}{n}} + \left(\frac{p_2}{p_c} \right)^{\frac{n-1}{n}} - 2 \right]$$

To determine the value of p_c which will make the work a minimum, we make the first differential equal zero, which gives,

$$p_c = \sqrt{p_1 p_2}$$

and using this value in the above combined equations, we get the expression

$$U = \frac{2n}{n-1} R\, T_1 \left[\left(\frac{p_2}{p_1}^{\frac{n-1}{2n}} - 1 \right) \right]$$

The same process can be employed for three, four or others stages. Stated differently this formula means that

$$\text{Total work} = \frac{(\text{No. of stages})\, n}{n-1}$$

$$(\text{constant}) \left(\begin{matrix} \text{absolute initial} \\ \text{temperature} \end{matrix} \right)$$

$$\left[\left(\frac{\text{final pressure}}{\text{initial pressure}} \right)^{\frac{n-1}{(\text{No. of stages})\, n}} - 1 \right]$$

It is sometimes desirable to know the mean effective pressure resulting from a given compression. This may be obtained from the formulas

$$\text{Mean effective pressure} \begin{cases} \text{Adiabatic} = \dfrac{n}{u-1}\, p_1\left[\left(\dfrac{p_2}{p_1}\right)^{\frac{n-1}{n}} - 1\right] \\[2ex] \text{Isothermal} = p_1 \log_e \dfrac{p_2}{p_1} \end{cases}$$

These are derived by dividing the equations representing the total work of adiabatic compression and delivery of one pound of air by v_1

$$U = \frac{n}{n-1}\, p_1 v_1 \left[\left(\frac{p_2}{p_1}\right)^{\frac{n-1}{n}} - 1\right]$$

and

$$U = p_1 v_1 \log_e \left(\frac{p_2}{p_1}\right)$$

In determining the efficiency of compression it is usual to divide the total isothermal work by the total work of adiabatic compression, the initial pressures and temperatures and the final pressures being the same in both cases. This applies to both cases.

For more than one stage the numerator remains the same, the denominator alone changing to correspond with the proper number of stages.

The temperature (absolute) at the end of the compression is found from the formula

$$\frac{p_m}{p_n} = \left(\frac{T_m}{T_n}\right)^3$$

$$T_m = T_n \left(\frac{p_m}{p_n}\right)^{1/3}$$

The air at the temperature, T_m, passes to the reservoir or into the transmission mains, where it loses heat by conduction and radiation until it reaches a final temperature, T_n. During this cooling the volume has decreased, but the pressure has been maintained by air constantly being forced into main by the compressor, which keeps the density, γ, constant. The mechanical equivalent of the heat lost in this cooling is lost work and naturally reduces the efficiency of the machine.

To-day the range through which compressed air is used calls for pressures from as low as 10 pounds, as in the case of pneumatic tubular dispatch, to as high as 3,000 pounds, which is the maximum pressure used for street railway work. However, by far the greatest field is found between 50 to 1,000 pounds.

For convenience we may sub-divide the production of compressed air into three pressures.

1 Low	from	5 to	50 pounds.
2 Medium	from	50 to	500 pounds.
3 High	from	500 to	5000 pounds.

The first of these finds its most extensive use in blast furnace operation, for which purpose the engines are nearly all of the vertical slow speed Corliss type, with large air cylinders.

This first class is almost universally of the single compression type; that is, all the compression is done in one cylinder. The second or medium class includes by all odds the greater portion of air machinery used at the present time. In it are all the compressors operating coal cutters, rock drills and machine tools of every sort, such as hammers, chippers, riveters, etc. In this class single and double or compound compression is customary.

With pressures above about 100 pounds compounding is necessary, both as a matter of economy and for safety. The term compounding is here mentioned for the first time and calls for an explanation.

When we compress air only as high as 100 pounds in a single cylinder without cooling, that is, adiabatically, temperatures ranging from 475° to 550° F. are reached. In other words, the cylinder walls and working parts are hot

TABLE 9.—HEAT PRODUCED BY THE COMPRESSION OF AIR.

Atmospheres.	Pounds per sq. in. above a vacuum.	Pounds per sq. in. above atmosphere gage pressure.	Volume in cu. ft.	Temperature of air throughout the process, degrees F.	Total increase of temperature degrees F.
	Pressure.	*Pressure.*			
1.00	14.7	0.00	1,000	60.0	00.0
1.10	16.17	1.47	.9346	74.6	14.6
1.25	18.37	3.67	.8536	94.8	34.8
1.50	22.05	7.35	.7501	124.9	64.9
1.75	25.81	11.11	.6724	151.6	91.6
2.00	29.40	14.70	.6117	175.6	115.8
2.50	36.70	22.00	.5221	218.3	158.3
3.00	44.10	29.40	.4588	255.1	195.1
3.50	51.40	36.70	.4113	287.8	227.8
4.00	58.80	44.10	.3741	317.4	257.4
5.00	73.50	58.80	.3194	369.4	309.4
6.00	88.20	73.50	.2806	414.5	354.5
7.00	102.90	88.20	.2516	454.5	394.5
8.00	117.60	102.90	.2288	490.6	430.6
9.00	132.30	117.60	.2105	523.7	463.4
10.00	147.00	132.30	.1953	554.0	494.0
15.00	220.50	205.80	.1465	681.0	621.0
20.00	294.00	279.30	.1195	781.0	721.0
25.00	367.50	352.80	.1020	864.0	804.0

enough to melt ordinary solder, or as hot as steam between 950 pounds and 1,000 pounds pressure. With this temperature the greatest difficulty is experienced in lubricating the cylinders and valves, owing to the valves and passages becoming clogged with a thick gummy substance, or a coke-like material. This is really burnt oil, easily explained when we remember that the flash point of the most staple cylinder oils is not over 450° F., and is on an average nearer 425°. In addition to the inconvenience and loss of efficiency due to clogged discharge ports and pipes, and the heat and annoyance and increased wear due to the hot parts, there is a real and considerable danger from explosions, which result from the formation of an explosive mixture of vaporized oil and compressed air. In the early days of compressed air several unfortunate accidents resulted from disregard of this heat of compression.

In a compound compressor, that is, one in which the air is partially compressed in one cylinder, then transferred to a second cylinder and the compression continued to the maximum, the opportunity for cooling the air and preventing this increase of temperature is doubled because the cylinder surface is twice as great as in the first case, and also an opportunity is afforded to pass the air through what is called an inter-cooler, which is a form of reservoir designed to bring the air which passes through it into intimate contact with cooling surfaces, which are continually cooled by running water.

Assuming, again, a compression of 100 pounds. If we draw air into the first cylinder at atmospheric pressure and temperature and compress it to about

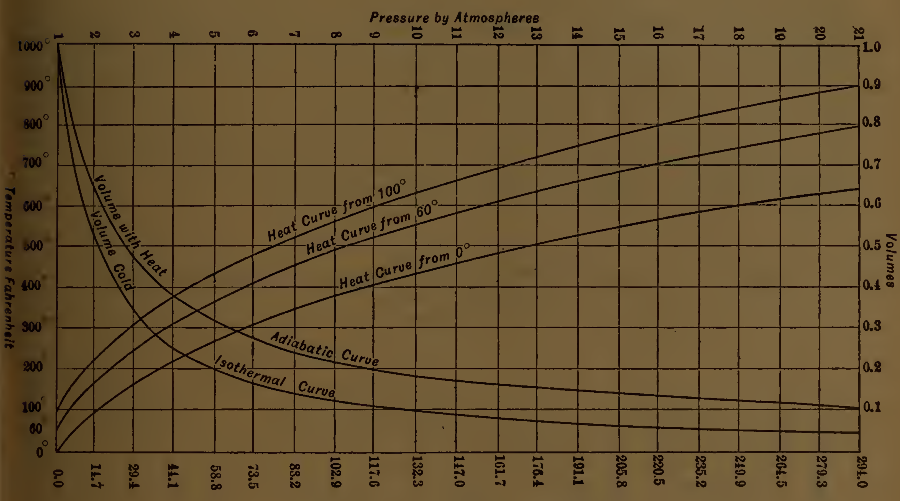

FIG. 30.—SAUNDERS' CURVES.*

30 pounds, the resulting temperature is from 200° to 260°, according to the effectiveness of the cooling jackets of the cylinder. If the air then is passed through an intercooler of sufficient capacity, the temperature is reduced to practically that of the intake, and possibly something lower, say 70 degrees; it then passes on to the second cylinder, quite cool, and at a pressure of 30 pounds. In this cylinder it is raised to 100 pounds, and here again the temperature increase will be only from 200° to 250°, which is too low to cause any inconvenience.

Compounding, however, does not result in any material economy, unless the air is thoroughly cooled between the stages. Hot air in the cylinder of an air compressor means a reduction in the efficiency of the machine, because there is not sufficient time during the stroke to cool thoroughly by any available means.

* W. L. Saunders. "Compressed Air Production."

Water jacketing, the generally accepted practice, does not by any means effect thorough cooling. The air in the cylinder is so large in volume that but a fraction of it is brought in contact with the jacketed parts. Air is a bad conductor of heat and takes time to change its temperature. The piston, while pushing the air toward the head, rapidly drives it away from the jacketed surfaces, so that little or no cooling takes place. This is especially true of large cylinders, where the economy effected by water jackets is considerably less than in small cylinders. Leaks through the valves or past the piston will explain many isothermal cards, and until something better than a water jacket is devised it is well to seek economy in air compression through compounding.

In the case of high pressures such as those indicated in the third class, that is, from 500 to 5,000 pounds, it is essential to employ three or four stages; the same general process is employed as in the compounding, there being first, second and third compressions, and first, second and third intermediate intercoolers. This arrangement makes it possible to deliver air under these high pressures at a temperature even less than that of the atmosphere. Of course, there is quite a range between summer and winter conditions, and these have their effect; but the advantages of stage compression are facts. It has been found that a difference of 5° at the inlet valve causes a variation of about 1 per cent. in the efficiency, and the curves shown afford an idea of the increased work brought about by a slight increase in initial temperature.

TABLE 10.—INCREASED EFFICIENCY RESULTING FROM STAGE COMPRESSION.

"COMPRESSED AIR."

Gauge Pressures.	One Stage.		Two Stage.		Four Stage.	
	% of work lost in terms of Isothermal Compression.	% of work lost in terms of Adiabatic Compression.	% of work lost in terms of Isothermal Compression.	% of work lost in terms of Adiabatic Compression.	% of work lost in terms of Isothermal Compression.	% of work lost in terms of Adiabatic Compression.
60	30. %	23. %	13.38%	11.8 %	4.65%	4.45%
80	34.	25.26	15.12	13.12	5.04	4.80
100	38.	27.58	17.10	14.62	8.00	7.41
200	52.35	34.40	23.20	18.88	9.01	8.27
400	68.60	40.75	29.70	22.90	12.40	11.04
600	83.75	44.60	32.65	24.60	15.06	13.10
800	90.	47.40	35.80	26.33	16.74	14.32
1000	96.80	49.20	39.00	28.10	16.90	14.45
1200	106.15	51.60	40.00	28.60	17.45	14.85
1400	108.	52.	41.60	29.4	17.70	15.00
1600	110.	53.3	42.90	30.0	18.40	15.54
1800	116.80	54.	44.40	30.6	19.12	16.05
2000	121.70	54.8	44.60	30.8	20.09	6.65

The four stage compressors are used for charging mine locomotives, for power transmission and for such special apparatus as charging of pneumatic street cars, etc.

The preceding table will serve to illustrate the large saving that it is possible to effect by compounding. From it the percentage of work lost by the heat of compression, taking isothermal compression, or compression without heat, as a base, can be obtained for pressures from 60 to 2,000 pounds.

In the above figures no account is taken of jacket cooling, as it is well known among pneumatic engineers that water jackets, especially cylinder jackets, though useful, and perhaps indispensable, are, as just explained, inefficient, especially so in large compressors. The two and four stage figures in this table (columns 3 and 4) are based on reduction to atmospheric temperature, 60° Fahrenheit, between stages. This is an important condition, and in order to effect it much depends on the inter-cooler, and a rule which might be observed to advantage among engineers is to specify that the manufacturers should supply a compressor with coolers provided with one square foot of tube cooling surface for every 10 cu. ft. of free air furnished by the compressor when running at its normal speed.

The table shows that when air is compressed to 100 lbs. pressure per sq. in. in a single stage compressor, without cooling, the heat loss may be 38 per cent. This condition, of course, does not exist in practice, except, perhaps, at exceedingly high speeds, as there will be some absorption of heat by the exposed parts of the machine. It is safe, however, to say that in large compressors that compress in a single stage up to 100 lbs. gauge pressure, the heat loss is 30 per cent. This, as shown in the table, may be cut down more than one-half by compounding or compressing in two-stages, and with three-stages this loss is brought down to 8 per cent., theoretically, and perhaps to 3 per cent. or 5 per cent. in practice.

A great deal of time and attention have been devoted to coolers and *inter-coolers* by the larger manufacturers of air compressors, and the most successful form now employed resembles a surface steam condenser. In this, speaking now of the "Sergeant" type (Fig. 31), the heated air, direct from compressors, passes into an upper opening, and down between a large number of small tinned copper tubes, held vertically in a sort of chimney. The air finally emerges into the shell portion of the inter-cooler and is free to travel through the top to the outlet tube. The smaller tubes mentioned terminate at either end in plates, into which they are expanded. The cooling water enters through the lower pipe and is forced upwards through the cooler tubes, and finally emerges at the water outlet at the top. The water tubes are set so close together that they divide the incoming stream of air into thin sheets and bring it into very intimate contact with the cooling surface. As stated, the air is caused to enter at the top and pass downward, while the cooling water enters at the bottom and passes upward. This is the accumulating principle upon which all successful liquid air apparatus have been constructed.

A properly designed inter-cooler should reduce the temperature of the compressed air to its original point; that is, to the temperature of the intake air. In can do even more than this, especially in winter, when the water used in the inter-cooler is of low temperature. A simple coil of pipe submerged in water is not an effective inter-cooler, because the air passes through the coil too rapidly to be cooled in the core, and such inter-coolers do not sufficiently split up the air to enable it to be cooled rapidly. This splitting up of air is an important point. A nest of tubes carrying water and arranged as described, so that the air is forced between and around the tubes, is an important point in an efficient form of inter-cooler. If the tubes are close enough together and are kept cold, the air *must* split up into thin sheets while passing through. Such devices are

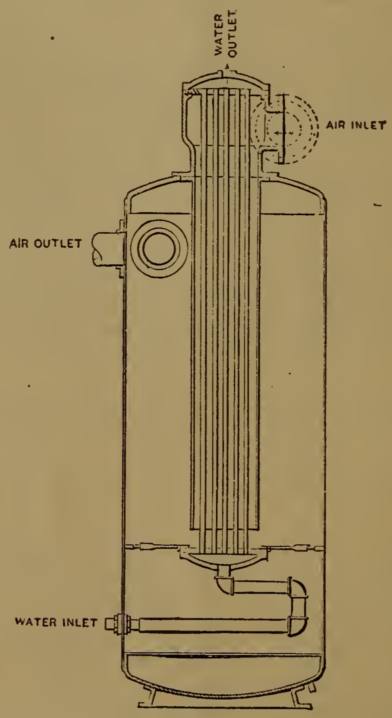

FIG. 31.—THE SERGEANT INTERCOOLER.

naturally expensive; but first cost is a small item when compared with the efficiency of the compressor, measured in the coal and water consumed.

Receiver-intercoolers are more efficient than those of the common type, because the air is given more time to pass through the cooling stages, and because of the freedom from wire drawing which may take place in intercoolers of small volumetric capacity.

Aftercoolers are in some installations as important as intercoolers. An aftercooler serves to reduce the temperature of the air after the final compression. In doing this it serves as a dryer, reducing the temperature of air to the dew point, thus abstracting moisture before the air is started on its journey. In cold weather, with air pipes laid over the ground, an aftercooler may prevent accumulation of frost in the interior walls of the pipes, for where the hot compressed air is allowed to cool gradually, the walls of the pipe in cold weather act like a surface condenser, and moisture may be deposited on the inside for the same reason that we have frost on the inner side of a window pane. In using these aftercoolers, and also intercoolers, it is good practice to allow from 8 to 10 cu. ft. of free air per minute for each square foot of cooling surface. Further, an allowance of 1 lb. of water for each 2 cu. ft. of free air should be made.

Makeshift aftercoolers are frequently employed, such as abandoned boilers, sections of large pipe, which are placed outdoors and provided with a drain and relief valve. These serve in special cases, but for ordinary practice it pays to use a standard aftercooler. The use of an aftercooler cannot be too strongly recommended, as it will be the means of avoiding many of the ills usually laid at the door of the compressing apparatus.

The heat given out or wasted in this cooling down to receiver temperature may be represented by the equation

$$Q = C_p(T_1 - T_2)$$

or, by substitution,

$$T_2 = \left(\frac{p_2}{p_1}\right)^{\frac{n-1}{n}} T_1$$

$$Q = C_p\left[\left(\frac{p_2}{p_1}\right)^{\frac{n-1}{n}} - 1\right] T_1$$

which, when translated into ordinary language, means that the quantity of heat, (Q) equals the specific heat at a constant pressure, times the absolute initial temperature, multiplied by an expression made up of the quotient of final pressure divided by the initial pressure raised to the $\frac{n-1}{n}$ power, from which 1 is subtracted, n being an exponential occurring in the equation of compression $p v^n = C$ (constant), and will depend upon the degree of perfectness of cooling during compression, ranging from 1 for isothermal compression to 1.414 in the case of adiabatic.

In selecting an air compressor, the conditions under which it is to operate must be carefully considered, as it is impossible to design a single compressor which will fit all conditions. The most important factors are: pressure desired, the character of apparatus to be operated, the cost of fuel, allowable space and quantity of air required. Generally speaking, economy has not been the most important consideration until recently. Where a large volume of air is required, and the character of the work is fairly constant, so that the demands upon the compressor are not varying to too great an extent, and where the cost of fuel makes it desirable to produce the air at a small cost, it has been found by experience that at a fairly low speed, compound Corliss engine gives the best results. In such plants as may be termed permanent, a compressor using a compound Corliss engine, running condensing, with compound air cylinders (the air being intercooled and also aftercooled), will be found to transfer the mechanical power to available air power most economically. For coal mining and places where the service is intermittent, fuel is cheap and the service of a skilled engineer is not desirable, it has been found that a "straight-line" single acting compressor best meets the conditions.

In compressed air practice, as in engine or boiler practice, it is well to install a larger machine than is needed at the time, because it invariably happens that the demand increases, and compressors, in common with other apparatus, work best under designed conditions.

All forms of compressor engines in which energy is used to compress air, can be sub-divided into rotary compressors, such as blowers and fans used for large volume low pressure work, and reciprocating compressors following in form the conventional steam engine design. That is, a horizontal or vertical cylinder, piston, cross head, connecting rod, crank and fly wheel. These may again be sub-divided into those driven by steam, or driven by water power, belts of one sort or another, or motor driven, either direct or geared. It is this general class of air, or, for that matter gas, compressors which has slowly but surely made for itself a name, and has developed into one of the large American industries.

The three classes into which reciprocating apparatus for the production of compressed air naturally fall, and considerations of convenience, first cost and economy of operation, have resulted in the development of certain distinct types of compressors, which may be classed under the general heading of self-contained, steam actuated compressors, and those operated by some external means.

Both classes may be simple, duplex or poly-compression machines. Experience, however, has sifted out the best forms, which are as follows:

STEAM ACTUATED.

(1). Straight Line; that is, steam and air cylinders in one line, mounted on a continuous girder frame. A self-contained, reliable type; a great user of steam, but a most satisfactory type where fuel is inexpensive and where a large amount of air is not needed. Usually single stage compressors, but often built in two or three stages.

(2). Duplex. Usually built with two parallel engines, connected by 90° cranks to a single flywheel shaft, with air cylinders behind each steam cylinder. Both steam and air cylinders are the same diameter. This type makes no great pretense at economy, but finds an extensive field in locations where fuel is not high and where simplicity and small first cost are important, and where considerable air or high pressures are desired.

(3). Compound. Of the same general character as the duplex, except that either or both air and steam cylinders are compounded. In some cases the engine may be run condensing. This is, however, hardly necessary, except for very large sizes, where it is far more desirable to use the last class, or Corliss type.

(4). Corliss Type. As implied in the name, this class includes compressors in which the engine portion employs the well-known Corliss valve motion. Such compressors, with few exceptions, are of the horizontal type, the air cylinder or cylinders, as the case may be, being placed tandem to the steam cylinders. They are employed where the volume of air desired and the fuel conditions demand the most economical form of engine. They are usually compounded, both for steam and air, and usually run condensing.

PORTABLE AIR COMPRESSING OUTFIT.

The long felt want for a compact and serviceable Mounted Air Compressor has been lately supplied in a neat design, by Fairbanks, Morse & Company, of Chicago, as shown in the cut herewith.

The machine consists of one of their Combined Gasoline Air Compressors, mounted complete on a truck, making a portable outfit which can be easily drawn about. It is supplied with two square water tanks; one for cooling the engine cylinder and the other for cooling the air cylinder. The air receiver tank is located under truck and connected to compressor with unloading valve interposed, thus maintaining a steady and uniform pressure. The gasoline tank is suspended at back of truck and under cylinder. The engine is fitted with a silencer for ex-

FIG. 32.—PORTABLE AIR COMPRESSOR.

haust, is equipped with both electric and torch ignitors, and is all connected up ready to run.

The compressor illustrated herewith was built for the Cleveland Ship Building Company, to be used in connection with pneumatic riveting tools in the construction and repairing of vessels.

It will be noticed that the machine is self-contained on one iron frame, and the pistons of the power cylinder and the air cylinder are connected by distance rods. In this way one crank and connecting rod serves for the operating of both power and air pistons.

The machine has a capacity of 70 cubic feet at 80 pounds pressure. Gasoline is used for fuel and as the engine is of about 12 horse power, the machine if kept to its full load would consume approximately twelve gallons of gasoline for a run of ten hours.

The engine is equipped with an automatic governor which feeds fuel in proportion to the amount of work supplied, which in this case would be the quantity of air delivered.

The air end is fitted with an automatic unloading valve. This valve controls the pressure, keeping it to a given point. When the amount of air used is less than that delivered, the unloading valve comes into action, and the air cylinder is cut out, thus relieving the load upon the engine, and by this fuel is saved.

COMPRESSED AIR VS. ELECTRICITY.

BY FREDK. S. WATKINS, M. E.

Closely allied to the generation of power, the transmission of power is a problem continually increasing in importance. Whatever the method used to convert the natural forces into useful work, the next problem is what system to employ to transmit this power to a distance, to be used as the circumstances of any particular case may require.

Although many different contrivances are in use for transmitting power within comparatively short distances, when we consider distances of say 1,000 feet or over, but two methods have yet attained any special prominence—electricity and compressed air. The rapidly awakening interest in the latter is but an indication of the future before it, when its general adaptability becomes better known.

In any problem of this class, in order to properly select from several different systems, we have the following points to consider:

1. First cost of complete plant.
2. Efficiency of system.
3. Cost of operation, including repairs.
4. Reliability, or freedom from break-downs.
5. Difficulties met with in operation.

With the first cost we must also consider the efficiency or percentage of useful work realized, for as we are figuring upon a certain amount of power to be delivered at the end of the line, it is necessary to have a plant of sufficient size to deliver this amount of power, after allowing for all losses.

Any method requiring a number of separate stages, each with its own apparatus more or less complicated, must necessarily have large losses, requiring the expenditure of more work to obtain the final result, and this is one important point in which compressed air has an advantage.

Starting the same as an electric plant, with the prime mover, generally a steam engine, we find at once in the usual type of direct connected air compressor a machine so comparatively simple in construction, that good practice will show an efficiency in the compressor of 90 per cent. of the energy of the steam. The compressed air has then only to be conducted through a properly constructed pipe line to the point of application, in which practical tests have shown the loss to be less than 10 per cent. in distances of one mile.

In transmitting electricity to any distance the losses are heavy, requiring constant attention to the proper insulation and protection of the line, a slight accident to which would cause an enormous loss. Where compressed air can safely be relied upon for a loss of less than 10 per cent., electricity would ordinarily suffer a loss of not less than 30 per cent., frequently a much higher one. This shows that considerably less boiler and engine capacity is required by the compressed air plant, reducing first cost by no small amount. For transmitting the power, the pipe line required by an air plant may usually be taken at about the same as the cost of an electric line for the same power. Strange as it may at first seem to compare a pipe line to a copper wire in cost, when it is taken into account that the pipe requires no provisions beyond being tight, requiring no special protection against the elements, where the wire must be carefully insulated and strung on poles or placed in expensive underground conduits, all involving expensive outlays for labor and material, we at once see the cost more or less equalized.

Arrived at the point of application at the end of the line, the same simplicity always attends the compressed air operations, for we need but a properly designed engine built to perform its special duty, and ordinarily giving out in useful work 90 per cent. of the power received from the compressed air. We have in this instance about 72 per cent. of the power of our prime mover transformed again into useful work one mile away. Even if the electric motor had the same 90 per cent. efficiency, it would give out at the end of the line but 57 per cent. of the power of the prime mover, at least 10 per cent. having been lost in the generator, and 30 per cent. of this afterwards lost in the line. We have then 57 per cent. realized, as compared to 72 per cent. realized by the compressed air system, or in other words, the latter system would require that proportion less in boiler and engine capacity. This explains, in connection with the relatively lower cost of the machinery, why it is that a compressed air plant is so much lower in first cost than an electric plant delivering the same amount of power.

As for the cost of operation, since the compressed air plant requires less power to start with, it requires less fuel to supply the necessary power; the amount invested being less, it represents less interest on the capital, and a smaller amount to be annually marked off for depreciation; the construction throughout being more simple and less liable to accidents, the item of repairs is very materially reduced.

Regarding the reliability, when we consider that compressed air is but little affected by atmospheric changes, and that all mechanism is readily accessible for repairs, we see that there is but little to get out of order, and only to be quickly and easily repaired. One greatly overrated cause of trouble has been the "freezing" or more properly "frosting" of the moisture contained in the air upon the expansion of the compressed air in the cylinder of the machine. This has been overcome in modern appliances, and when we hear of a compressed air machine freezing, we know it to be a case of carelessness or poor design, things that no process can always be free from.

The difficulties encountered in electrical operations are numerous, and in many cases impossible to overcome. Everything must be guarded with the closest scrutiny, demanding the highest skilled and educated labor; lightning, moisture, etc., are constant causes of trouble; extreme care is required by the operators to avoid receiving the dangerous and often fatal current; the machinery runs at high speed, requiring buildings and foundations of the most substantial construction.

Compressed air has none of these difficulties to contend with. The compressor is but little more than a steam engine with one or more extra cylinders and their valves, all of simple design; it runs at safe speeds, is clean, comparatively noiseless, and safe in every way, and the same may be said of the compressed air machine at the other end of the line, considered in itself.

In addition to other advantages, the expanding air exhausted into the atmosphere is a medium under control for ventilating and cooling, a feature often of importance in engine rooms, and particularly so in mining.

Advance in any line always has a certain amount of prejudice to overcome, and compressed air has this to encounter in its progress. Its advocates in no way attempt to underrate the importance electricity holds in fields peculiarly adapted to itself, in these it still reigns supreme. Give compressed air a stand on its own merits, with appliances to suit the conditions, and we have a medium of transmission convenient and economical, and susceptible of a wonderful variety of applications.—*Industrial Reporter.*

THE VOLUMETRIC EFFICIENCY OF AIR COMPRESSORS AT HIGH ALTITUDES.

It is well known that an air compressor will not deliver the same amount of compressed air at any given high altitude that it does at sea level. The percentage of delivery, or the volumetric efficiency of the compressor, is sometimes assumed to be the same for air compressed to any pressure. This is not, however, the case, and the supposition that it is may in some cases lead to serious consequences, especially if the compression of the air is considerable. Thus, the percentage of compressed air delivered at an elevation of 10,000 feet, at a gauge pressure of 30 lbs., is only 76 per cent. of what it would be at sea level; whilst if the air is compressed to 80 lbs. gauge pressure, the efficiency is only 71½ per cent. Therefore, assuming that an air compressor will deliver at sea level 100 cubic feet of air compressed to 30 lbs. gauge pressure, it will, with the same piston speed and number of strokes, deliver only 76 cubic feet of air, compressed to 30 lbs., at an elevation of 10,000 feet above the sea. The equivalent volume of free air is, however, the same in both cases.

Hence, we see that the efficiency diminishes as the pressure to which the air is compressed increases, these differences of efficiency being, however, greater in proportion for the lower pressures than for the higher ones. The formula for calculating this efficiency is a very simple one, namely:

$$\text{Efficiency} = \frac{A}{G+A} \times \frac{G+14.72}{14.72}$$

where

A=Atmospheric pressure at any elevation,

G=Gauge pressure,

G+A=Absolute pressure at any elevation,

G+14.72=Absolute pressure at sea level.

The atmospheric pressure at any elevation is easily found by means of the following original but simple formula, which, it need not be said, is an empiric one:

$$\text{Atmospheric pressure at any elevation} = A = 14.72 - \frac{57{,}000\,N - N^2}{100{,}000{,}000}$$

where

N=Elevation in feet at which the pressure A is sought.

This formula gives results in some cases varying about one-sixth of one per cent. from certain published tables, but it has the advantage that when plotted it gives a *perfect* curve, which no table that I have seen will do.

To find the volume of air compressed to any pressure, which is equivalent to a given volume of free air, at any elevation, we have the formula—

$$\text{Volume compressed air} = \text{Volume free air} \left(\frac{A}{G+A}\right)$$

A being, as before, the atmospheric pressure at the given elevation.

WILLIAM COX.

USEFUL COMPRESSED AIR FORMULAS.

In the application of compressed air errors sometimes occur because there are no available rules and formulas which apply to the subject. I have, therefore, prepared the following simple formulas, which I have used in my experience:

Rule to Describe the Isothermal Curve or to find the Pressure at Any Point in the Stroke of an Air Compressor During Isothermal Compression or Constant Temperature.

Mariotte's law: The pressure of any gas varies in the inverse ratio of the volume, the temperature remaining constant, or

$$(a) \qquad P' = \frac{P}{V}$$

P' being the absolute pressure at any point of the stroke;
P the original absolute pressure;
V the volume corresponding to the required point of the stroke.
Required the pressure at one-half the stroke, compressing isothermally.

$$P' = \frac{15}{1/2} = 30 \text{ lbs. absolute} - 15 = 15 \text{ lbs. gauge pressure.}$$

Required the pressure at seven-eights of the stroke.

$$P' = \frac{15}{1/8} = 120 \text{ lbs. absolute} - 15 = 105 \text{ lbs. gauge pressure.}$$

Required the pressure at one-quarter of the stroke.

$$P' = \frac{15}{3/4} = 20 \text{ lbs. absolute} - 15 = 5 \text{ lbs. pressure}$$

Mariotte's law also applies in determining change of pressure in volumes of compressed air due to change of volume.

Given a volume of air, say 1 cu. ft., at a pressure of 30 lbs. on the gauge, what will be the pressure indicated if this air is forced into one-half the space?

$$(b) \qquad P' = \frac{1 \times (30 + 15)}{1/2} = 90 \text{ lbs. absolute} - 15 = 75 \text{ lbs. gauge pressure.}$$

Reversing the problem: Given a volume of air, say 1 cu. ft., at a pressure of 75 lbs. on the gauge, what will be the pressure indicated if this air is expanded to 2 cu. ft.?

$$P' = \frac{1 \times (75 + 15)}{2} = 45 \text{ lbs. absolute} - 15 = 30 \text{ lbs. gauge pressure.}$$

Example: A receiver 3 ft. in diameter and 6 ft. long is filled with compressed air which indicates 60 lbs. on the gauge. What will be the pressure if this volume of air is enclosed in a receiver 4 ft. in diameter and 12 ft. long?
Volume of first receiver $= 3^2 \times .7854 \times 6 = 42.4$ cu. ft.

Volume of second receiver $= 4^2 \times .7854 \times 12 = 150.8$ cu. ft.

$$P' = \frac{42.4 \times (60 + 15)}{150.8} = 21.1 \text{ lbs. absolute} - 15 = 6.1 \text{ lbs. gauge pressure.}$$

The same rule applies in calculating volumes. In dealing practically with compressed air, we speak of pressure above the atmosphere, but in making calculations for volumes serious errors frequently occur because the atmospheric pressure (15 lbs.) is lost sight of.

For instance, a cubic foot of air represents about 15 lbs. absolute pressure, and if we wish to know what volume this cubic foot will occupy when it is subjected to a pressure (isothermally) of 60 lbs. per square inch above the atmosphere, we must figure thus:

$$(c) \qquad V' = \frac{1 \times 15}{60 + 15} = 0.20 \text{ cu. ft.}$$

Given 1 cu. ft. of compressed air at 45 lbs. gauge pressure, what volume will this air occupy when subjected to a gauge pressure of 60 lbs.?

$$(d) \qquad V' = \frac{1 \times (45 + 15)}{60 + 15} = 0.8 \text{ cu. ft.}$$

Free Air.—By free air is meant air at atmospheric pressure, which is about 15 lbs. per square inch at sea level.

Given a volume, say 500 cu. ft., of free air, what volume will this air occupy when compressed (isothermally) to 60 lbs. gauge pressure?

$$V' = \frac{500 \times 15}{60 + 15} = 100 \text{ cu. ft.}$$

Reversing the problem, how much free air is represented by 100 cu. ft. of compressed air at 60 lbs. gauge pressure?

$$V' = \frac{100 \times (60 + 15)}{15} = 500 \text{ cu. ft.}$$

VOLUMES OF FREE AND COMPRESSED AIR FURNISHED BY AIR COMPRESSORS.

Example. The air cylinder of a compressor is 12 ins. in diam., stroke 18 ins. What volume of free air will it furnish (theoretical) when running at 120 revolutions per minute? 120 revolutions represents 360 ft. piston speed per minute.

$12^2 \times .7854 = 113.1$ area in square inches. $\dfrac{113.1 \times 360}{144} = 282.7$ cu. ft. free air.

And by (*c*) $\dfrac{282.7 \times 15}{60 + 15} = 56.5$ cu. ft. of compressed air at 60 lbs. on gauge.

A rule by which volumes of compressed air may be approximately determined from volumes of free air, is to divide by the number of atmospheres.

For instance, 60 lbs. represents 5 atmospheres (absolute); 500 cu. ft. of free air, divided by 5, equals 100 cu. ft. of compressed air at 60 lbs. gauge pressure.

As pressures are not always given in even multiples of atmospheres, this rule serves only to determine approximate results.

REDUCED EFFIENCY OF AIR COMPRESSORS AT DIFFERENT ALTITUDES.

The previous figures are based on the pressure of air at sea level, or 15 lbs., (about) per square inch. As air compressors are frequently used at altitudes, it is desirable to know the extent to which an increased altitude affects the capacity of the compressor. Following are the barometric pressures at different altitudes:

	Lbs. per sq. in.
Pressure at 1/4 mile above sea level	14.02
" " 1/2 " " "	13.33
" " 3/4 " " "	12.66
" " 1 " " "	12.02
" " 1 1/4 " " "	11.42
" " 1 1/2 " " "	10.88
" " 2 " " "	9.88

Free air as applied to the volume of a compressor, or the space traversed by the piston, is not affected by change of altitude, but free air when applied to pressures either absolute or indicated, and to volumes of compressed air, is modified according to the density of the air at corresponding points.

Example: Required the volume in cu. ft. of compressed air furnished by an air compressor when at work one mile above sea level. Also, the volume in cu. ft. of free air representing the reduced efficiency of the compressor when at work at this altitude.

Given an air compressor of the following dimensions: Diameter, 12 ins.; stroke, 18 ins.; revolutions per minute, 120.

We have seen by a previous example that this compressor furnishes 282.7 cu. ft. of free air (theoretical) at sea level, and that this volume represents 56.5 cu. ft. of compressed air at 60 pounds on the gauge. If this compressor is used at an altitude of one mile above the sea, what volume of compressed air will it furnish at 60 pounds on the gauge, the speed remaining the same?

Free air furnished by compressor, 282.7 cu. ft.

Barometric pressure at altitudes of one mile, 12.02 lbs., then by (*c*) substituting the reduced barometric pressure we have:

$$V' = \frac{282.7 \times 12.02}{60 + 12.02} = 47.18 \text{ cu. ft. at 60 lbs. on gauge.}$$

And if it is desired to know how many cu. ft. of free air at sea level are represented by 47.18 cu. ft. of compressed air at 60 lbs. we have by

$$(d)\quad V' = \frac{47.18 \times (60 + 15)}{15} = 235.9 \text{ cu. ft. of free air at sea level, and } 282.7 -$$

235.9 = 46.8 cu. ft. of free air, representing the reduced efficiency of the compressor when used at altitude of one mile.

In practice, approximate determinations of the reduced efficiency of air compressors are made by deducting the percentage of difference between the barometric pressures of the respective latitudes.

The volume at sea level being 1, that at

¼ mile above sea level will be	7%	less
½ " " " " " "	11%	"
¾ " " " " " "	16%	"
1 " " " " " "	20%	"
1¼ " " " " " "	24%	"
1½ " " " " " "	28%	"
2 " " " " " "	34%	"

W. L. SAUNDERS.

VOLUMETRIC EFFICIENCY IN AIR COMPRESSOR PRACTICE.

Volumetric efficiency in air compressor practice is a subject which has been neglected by builders of machines and by the public generally. Catalogues of air compressors, with great unanimity, claim about 100 per cent. volumetric efficiency: In other words, the capacity of an air compressor in free air compressed is measured by the piston displacement, the theoretical volume of the cylinder being taken at a certain piston speed. It is plain that no machine however perfect will deliver as much air as this, because clearance, leakage, etc., must be taken into account. So long as makers are not required to give a guarantee, it is well enough to base figures upon the piston displacement as this gives a base line for comparison. Recent improvements in air compressors have been in the line of reduced volumetric losses. The old DuBois-Francois type of compressor which used water in the air cylinder for the purpose of cooling and filling the clearance spaces made slow speed necessary and the abandonment of water injection followed closely the development of improved forms of valves reducing clearance spaces to a minimum. The theoretical volumetric efficiency of an air compressor is also reduced in actual practice because it is not possible to fill the cylinder at atmospheric pressure except perhaps at very slow speeds. Any light indicator spring will show from one to three pounds vacuum in an air cylinder when used at its normal piston speed. The higher the speed, the greater this vacuum will be. A partial vacuum is necessary in any case to get the air in the cylinder, even with a perfectly free mechanically moved inlet valve of large area. In compound compressors the pressure line in the initial cylinder usually shows a partial vacuum greater in proportion as the cylinder is larger and usually more noticeable than in the ordinary indicator card because of the use of the light spring. Actual volumetric efficiencies vary from 85 per cent. in small poppet valve compressors to 97 per cent. with long stroke Corliss machines. In the latter this high efficiency cannot be maintained at a piston speed of over 350 feet per minute. 97% volumetric efficiency is obtained in high class Corliss compressors of the best type. The usual straight line or pony type of compressor which is designed to run at high speed does not give a high volumetric efficiency, because of the inertia of the discharge valves which does not permit them to seat quick enough to prevent some of the compressed air from getting back into the cylinder on the return stroke. This type of machine furnished by makers of first-class air compressors working under the normal conditions will give about 90 per cent. volumetric efficiency. A compressor of this type with an air cylinder say 20" in diameter by 24" stroke, and which has a rated piston speed of 375 feet per minute, if run at only 250 feet per minute, will show a volumetric efficiency of 95 per cent. and this will be reduced in proportion as the speed is increased. These figures are based on perfectly tight valves and piston, a condition which should exist in machines of the first class when in the hands of good engineers.

RELATIVE EFFICIENCIES OF A COMPRESSED AIR PLANT DUE TO DIFFERENCE OF LEVEL ABOVE AND BELOW SEA LEVEL.

The atmosphere surrounding the earth forms a layer extending about 45 miles in height, and being ponderable and very elastic, its density will vary with the height.

At the sea level the weight of a column of atmospheric air one square inch in area will balance a column of mercury 30" high one square inch in area, and corresponds to a pressure of 14.7 pounds per square inch.

Now, if we take the sea level as a basis for comparison as to the density or weight per cubic foot, we will find that the higher up we go the more rarified the air becomes, due to diminished height of the atmosphere above us, and by descending the shaft of a mine the contrary effect takes place. However, in the mine or in any level below the sea this contraction of the air is counteracted by the increasing temperature as we approach the centre of the earth.

From observations taken at different parts of the world this increase has been found to average 1 deg. F. for every 61 ft. depth. The temperature also changes with increasing altitudes. However, since there is no uniform change in temperature throughout the world for points at the same elevation, it will be hard to estimate this effect generally, and in order to show this influence of temperature and pressure, we must assume some specific case.

A motor using compressed air at full stroke and at 80 pounds per square inch, will require at any level either above or below the sea level—

$$\frac{229.5}{\left(1-\frac{p_a}{p_2}\right)p_a} = \text{cu. ft. free air}$$

per minute per I. H. P.

where p_a = atmospheric pressure

p_2 = absolute working pressure.

From a study of this formula it will readily be seen that as the atmospheric pressure diminishes, the cu. ft. free air required per H. P. will increase, and consequently a larger compressor will be required at an elevation than at sea level to enable the motor to do the same amount of work in a given time.

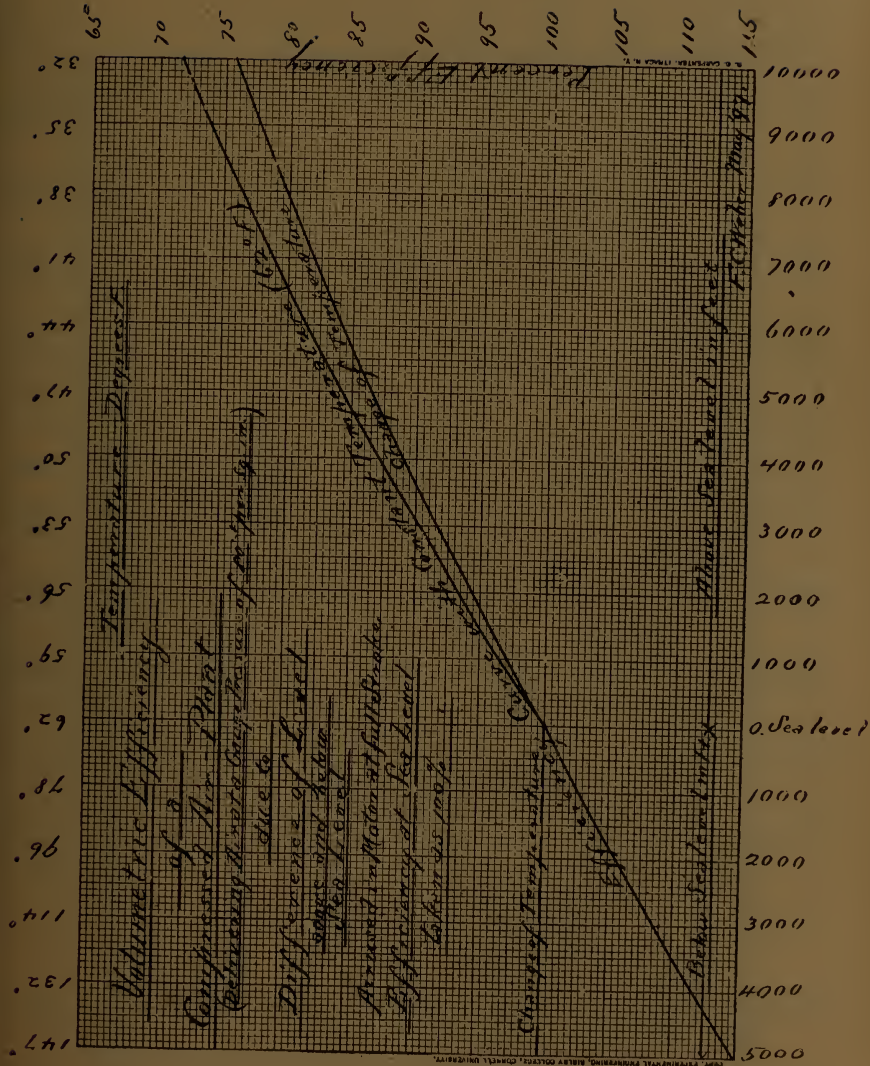

FIG. 32a.

VOLUMETRIC EFFICIENCY OF A COMPRESSED AIR PLANT (DELIVERING AIR AT A GAUGE PRESSURE OF 80 LBS. PER SQ. IN.) DUE TO DIFFERENCE OF LEVEL ABOVE AND BELOW SEA LEVEL. AIR USED IN MOTOR AT FULL STROKE. EFFICIENCY AT SEA LEVEL TAKEN AS 100 PER CENT.

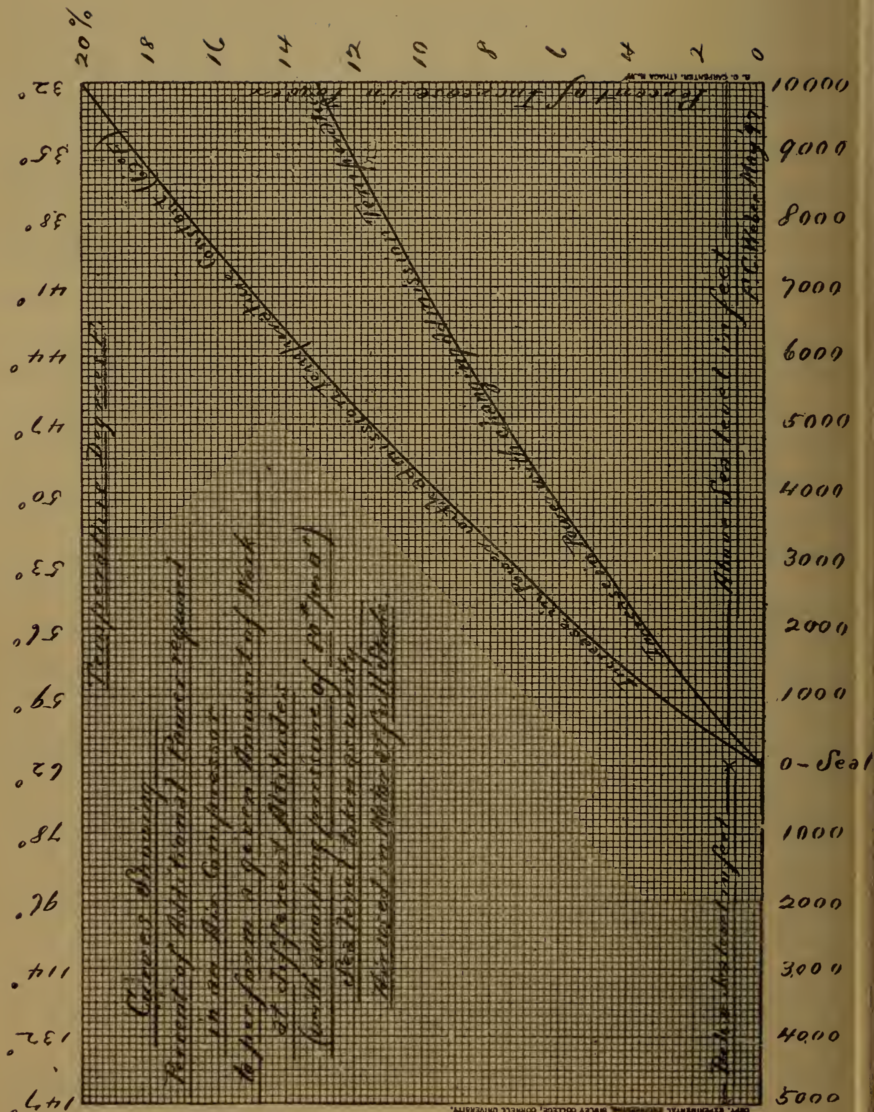

FIG. 32b.

CURVES SHOWING PER CENT. OF ADDITIONAL POWER REQUIRED IN AN AIR COMPRESSOR TO PERFORM A GIVEN AMOUNT OF WORK AT DIFFERENT ALTITUDES (WITH A WORKING PRESSURE OF 80 LBS. PER SQ. IN.). SEA LEVEL TAKEN AS UNITY. AIR USED IN MOTOR AT FULL STROKE.

The relative efficiencies due to change of volume have been plotted in the curves shown on page 104a. Both temperature and difference in levels above and below sea level have been taken account of, so that by reference to this chart it will be an easy matter to select an air compressor of sufficient capacity to supply a motor with an equivalent volume of air, no matter where it may be located provided temperature changes and working pressure are the same as assumed in the curves.

Thus, given an altitude of 6,000 ft. above sea level, and provided the temperature at this level is the same as at the sea level, then by referring to the chart and reading along the 6,000 ft. level line until we intersect the constant temperature curve, we will find by reading across to the right that the efficiency of an air compressor at this altitude is but 81.5 per cent. of its efficiency at sea level; and in order to produce the same efficiency, the free air capacity of compressor will have to be increased 18.5 per cent. When the temperature of the air changes proportionately from 62 deg. F. at sea level to 32 deg. F. at 10,000 ft. altitude, the efficiency in the case we have assumed will be 84.2 per cent. (as will be seen from the curves).

The efficiency at 2,000 ft. below the sea would be 105.5 per cent. provided the temperature was constant (62 deg. F.); however, the rise in temperature of 1 deg. F. for every 61 ft. depth, exactly offsets the gain which might be effected by increased density, and therefore the efficiency is practically constant for all depths below sea level.

The change in volume due to different altitudes also effects the power required to perform a given amount of work. The mean effective pressure per cubic foot is less at an altitude than at sea level, but the number of cubic feet required to produce the same effect at an altitude as at the sea level is more, and the product of the two (M. E. P. x Vol. = power expended), is greater. Curves on page 104b show the relative effect for the different altitudes and different temperatures. Thus at 6,000 ft. and temperature at 62 deg. F. (same as assumed at sea level), the increase in power for a given effect will be 13.30 per cent. If the temperature changes proportionately from 62 deg. F. at sea level to 32 deg. F. at 10,000 ft. altitude, the increase in power will be but 8.8 per cent. The difference between both curves shows the benefit obtained from cold air.

F. C. WEBER.

EXPERIMENTAL MECHANICS.

Method of Calculating and Recording the Results of the Experiments Made During the Supplementary Term.

BY PROF. D. S. JACOBUS, '84.

TABLE XVI.

TEST OF AIR COMPRESSOR.

1. Dimensions in inches and clearance.	Bore of air cylinder	
	Bore of steam cylinder	
	Stroke of both pistons	
	Clearance of air cylinder in per cent	
2. Revolutions per minute		

3. Temperature of air in degrees Fahr ... { Initial entering compressor ... ; Final in delivery pipe two feet from compressor ...
4. Temperature of jacket water in degrees Fahr. ... { Initial ... ; Final ...
5. Temperature of water injected in degrees Fahr ... { Initial ... ; Final when drawn from separator in delivery pipe ...
6. Weight of jacket water per minute in pounds ...
7. Weight of water injected into air cylinder in pounds ...
8. Barometric pressure in inches of mercury ...
9. Indicated horse-power of air cylinder ...
10. Indicated horse-power of steam cylinder ...
11. Per cent. of indicated power of steam cylinder lost in friction ...
12. Value of γ in the equation $pv^{\gamma}=$ constant for the air compression curve ...
13. Weight of air compressed per minute calculated from the indicator card, in pounds ...

METHODS TO BE EMPLOYED IN CALCULATING THE RESULTS.

Items 1 to 8 contain the data observed during the test.

9. Same as item 13 of Engine Test, Table III*, except that there is no factor of 2 in the numerator, because the compressor is single acting.
10. Same as item 13 of Engine Test, Table III*.
11. $\{$(Item 10—item 9) $\div$ item 10$\}\times 100$.
12. An indicator card of the air compressor is shown in Fig. 33.

If the temperature of the air had remained constant during compression then the curve of compression *AB* would be isothermal and the product $p\ v$ of the pressure and the volume would be constant. The air is not,

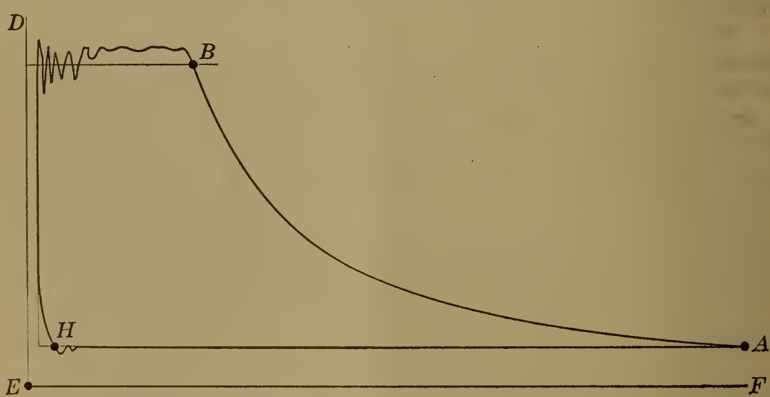

FIG. 33.—INDICATOR CARD OF THE AIR COMPRESSOR.

however, thoroughly cooled during compression and the equation becomes

$$p\,v^{\gamma} = C = \text{a constant.}$$

Lay off the lines of zero pressure and volume *EF* and *ED* in Fig. 1. If the pressure and volume at *A* be designated by the subscript *a* and that at *B* by the subscript *b*, we have

$$p_a v_a^{\gamma} = C, \quad \text{and} \quad p_b v_b^{\gamma} = C.$$

* Refers to set of Tables used at Steven's Institute.

From these equations we have

$p_a v_a^y = p_b v_b^y$, from which log. p_a + y log. v_a = log. p_b + y log. v_b and

$$y = \log. \frac{pb}{pa} \div \log. \frac{va}{vb} \text{ ....(A)}$$

The values of $\frac{pb}{pa}$, or the ratio of pressures, and the ratio of volumes $\frac{va}{vb}$ will be the same no matter what scale is employed in measuring pa, pb, va, vb; hence we may measure the distance on the indicator cards in inches and substitute in equation (A).

13. Determine the net volume swept through by the piston per revolution in cubic feet and multiply by the number of revolutions per minute, in order to determine the volume of air compressed per minute for full displacement; multiply this by the ratio of the distance *HA* to the length of the indicator card to allow for the effect of clearance. The volume of air compressed per minute multiplied by the density at the pressure *AF*, or that corresponding to the pressure of the atmosphere, will give the weight compressed per minute. To find the weight of one cubic foot of air at the pressure shown by the barometer and the temperature of the air on entering the compressor, make use of the table given on page 381 of "Kent's Mechanical Engineers' Pocket Book." The density corresponding to the temperature given in this table is multiplied by the factor,

$$b \div 30,$$

where b is the barometric pressure in inches of mercury (not corrected to 32° Fahr.), or more exactly by the factor,

$$b' \div 29.92,$$

where b' is the barometric pressure corrected to 32° Fahr.

It is assumed in this computation that the temperature of the air in the cylinder, just before compression, is that of the external air. Usually this is not the case as the air is heated during admission, and there is an increase in volume, and consequently a loss of capacity due to this cause. In experiments made by Messrs. Gause and Post, Class of '91, this loss was found to be about 10 to 15 per cent.—*Stevens' Indicator.*

THE USE OF WATER POWERS BY DIRECT AIR COMPRESSION.*

Probably one of the oldest applications of the use of water power to the wants of man was a form of hydraulic air compressor which operated as an entrainment apparatus, and is the well-known water bellows or trompe of the Catalan forges.

This apparatus, briefly described, consisted of a bamboo pole disposed at a slight inclination from the perpendicular, into the upper end of which a stream of water was led, entraining air with it in its downward passage. The lower end of this bamboo pole was introduced into a bag made of the skin of some animal, the air being allowed to escape from the water into the upper part of the bag,

*The movement toward fuller utilization of the yet unrealized water resources of the world is one which is constantly quickening. With greater use comes larger study of adaptation of machinery and methods of water-power development and transmission. The peculiar means described by Mr. Webber has more than a passing interest.—*Editors' Engineering Magazine.*

from whence it was led by pipes or tuyeres to the forge, the water being allowed to escape from the lower edge of the bag. From this original device a great many improvments have been worked out, and besides this, a number of other forms of hydraulic air compressors, or of compressors using other liquids for compressing air or other gases, have been designed.

A very simple form is a displacement apparatus,* consisting of a water reservoir and two air chambers of about three times the capacity of the water chamber. Water is led into the reservoir, compressing the air contained in it into the two chambers and giving a pressure of about 1.6 atmospheres.

Siemens invented an apparatus on the principle of the steam injector, but the use of this was confined principally to the production of a vacuum; it is used

FIG. 34.—THE MAGOG DAM AT HIGH WATER.

to operate the pneumatic dispatch tubes in London. It has also been used for blast purposes in Siemens' furnaces and in sugar works.

Another quite ingenious device, shown in a patent granted to W. L. Howe, consists of two flat plates enclosing an air space from which a pipe leads to the atmosphere. The upper plate is perforated with conical holes, the smaller end being adjacent to the air-space between the two plates. Directly opposite the apertures of the upper plate are corresponding conical apertures in the lower plate, with the smaller end of the aperture next the air space, the lower and larger part of the conical openings being prolonged by tubes; the upper plate is kept under a head of water; the water jet, passing across the thin air-space referred to, draws in the air through the large air pipe and compresses it through the smaller orifices.

Another device using a somewhat similar principle was invented by M. Romilly† and consists of a conical tube attached to an air reservoir by its larger

* Appleton's Cyclopedia of Applied Mechanics, fig. 138, page 37.

† Appleton's Cyclopedia of Applied Mechanics, fig. 139, page 37.

end, and having a check valve interposed in the passage so as to prevent the air from escaping. Water is then injected into the smaller end of this conical tube through an ajutage in the form of a liquid vein at a given pressure, which entrains the air with it and causes it to be compressed in the reservoir. But the apparatus just described did not really employ the same methods as those used in the old trompe. One of the first inventions carrying out this idea was made by Mr. Frizell, of Boston, Mass. His invention made use of an inverted syphon having quite a little horizontal run between the two legs. A stream of water was led into the upper end of the longer leg, and at the top of the horizontal run between the two legs of the syphon was provided an enlarged chamber in which the air would separate from the water, the water being then led off from the lower part of this air chamber and passed off through the shorter leg of the syphon, the pressure of the air accumulated in the air chamber being therefore due to the height of water maintained in the shorter leg of the syphon. This application of carrying upward the water, after the air was separated from it, so as to produce a considerable pressure upon the air, seems to have been original with Mr. Frizell, and in this feature his device differs from the old trompe.

Mr. Frizell made two working models of this type of apparatus. In the first one the legs of the syphon were 3 inches in diameter, the head of water being 25 inches, and an efficiency of 26½ per cent. was obtained. A larger apparatus was then constructed at the Falls of St. Anthony, on the Mississippi River, a few miles above St. Paul; the longer leg of the syphon in this plant was 15 inches by 30 inches and the short leg of the syphon 24 inches by 48 inches in section; the height of water above the air chamber was 29 feet. The head in feet varied from .98 to 5.2, the first head being just sufficient to cause a flow through the pipes. The working head varied from 2.54 feet to 5.02 feet and the efficiency from 40.4 per cent. to 50.7 per cent., the quantity of water in these cases varying from 5.92 to 11.89 cubic feet per second.

Mr. Frizell estimates from the experiments he has made that with a shaft 10 feet in diameter, a depth of 120 feet, and a fall of 15 feet, the efficiency would be 76 per cent., and with a head of 30 feet and a fall of 230 feet, the efficiency would be 81 per cent.

Another device, differing somewhat from that of Mr. Frizell, was invented by A. Balochi and A. Krahnass in 1885, and consisted of a syphon carrying water from an upper reservoir down to another reservoir situated at a lower level, the lower end of the syphon being projected through an inverted vessel placed nearly at the bottom of the second reservoir. Just beyond the bend of the syphon, and in line with the vertical axis of the longer leg thereof, was an air pipe projecting into the descending column of water, thus entraining the air with the descending column, and carrying it down into the inverted chamber, where the air escaped from the top and the water passed out from the bottom of the inverted vessel into the lower chamber. This also produced pressure on the air in the top of the inverted chamber, due to the height of the water column upon it.

Another device, patented by Arthur in 1888, differs from the last in having a stream of water led directly into the top of the vertical pipe. Inserted into the mouth of this pipe was a double cylindrical cone, making an annular air passage surrounding the mouth into which the water was delivered. The water, after passing through the upper cone and there being compressed and its velocity increased, then passed into the inverted cone, where the velocity was somewhat decreased and the water became more diffused. This lower cone was perforated with holes opening into the annular air chamber previously described, causing air to be entrained with the falling water. Inside of this down-flow pipe was a ver-

FIG. 35.—COMPRESSOR HEAD TANK AND WEIR.

The air compressor is blowing off.

tical delivery pipe for the compressed air, having its lower end enlarged and open at the bottom. Projecting upward into this enlarged air-delivery pipe was a water escape pipe through which the water passed after having parted with the air. This escape pipe was in the form of an inverted syphon and maintained a pressure on the air in the delivery pipe, due to the elevation of the water at its discharge point above the air line in the large end of the delivery pipe.

A number of other patents on apparatus of this type were issued to Charles H. Taylor, Nos. 543,410; 543,411; 543,412, July 23, 1895; his invention consisted principally of a down-flow passage having an enlarged chamber at the bottom and an enlarged tank at the top. A series of small air pipes were projected into the mouth of the water inlet from the large chamber at the upper end of the vertically descending passage, so as to cause a number of small jets of air to be entrained by the water, Taylor seemingly having been the first one to introduce the plan of dividing the air inlets into multiplicity of smaller apertures evenly distributed over the area of the water inlet.

Taylor at first seems to have attempted to utilize centrifugal action in causing the separation of the air and water in the large chamber at the bottom of the compressed column, but afterward abandoned this scheme and used, instead, forms of deflected plates in combination with a gradually enlarging section of the lower end of the down-flow column in order to decrease the velocity of the air and water and cause partial separation to take place, and also using

FIG. 36.—VIEW TAKEN BY POINTING THE CAMERA DIRECTLY DOWNWARD OVER THE EDGE OF THE WEIR.

The clouds are made by the finely-divided particles of air carried in suspension. In the limpid Magog water these may be traced 40 or 50 feet below the weir.

the deflector plates to cause the water to change its direction of flow, evidently with the idea that the air would escape more readily.

The latter improvements on this device have been in the method of introducing the air into the mouth of the downwardly flowing water column, so as to insure the largest proportion of air being taken down with the water, and in methods of decreasing the velocity of the combined air and water at the bottom of the descending column, causing the water to part more readily with the air, the water then passing out at the bottom of the enlarged chamber into an ascending shaft, maintaining upon the air a pressure due to the height of water in the uptake, the air being led off from the top of the enlarged chamber by means of a pipe.

The first one of these compressors on the Taylor principle was installed at Magog, Quebec, to furnish power for the print works of the Dominion Cotton Mills Company. The head of water is 22 feet; the down-flow pipe is 44 inches in diameter, and extends downward through a vertical shaft 10 feet in section and 128 feet deep. At the bottom of the shaft the compressor pipe enters a large tank 17 feet in diameter and 10 feet high, which is known as the air chamber and separator.

A series of very careful tests on this plant demonstrated that out of a gross water horse power of 158.1, 111.7 horse power of effective work in compressing air has been accomplished, giving, therefore, an efficiency of 71 per cent. It is found that the air after compression shows a very considerable decrease in moisture from that of the air entering the compressor, although in contact with the water all the time. This is probably due to the moisture in the bubble of air being pressed or squeezed out to its surface and then absorbed by the surrounding water. The air is compressed at the temperature of the surrounding water and the compression is isothermal. Owing to these facts, there is no loss by heat of compression and again by radiation, in using the air, and there is a practical result which is of more importance; the hydraulically-compressed air can be expanded down to a temperature much below the freezing point, while atmospheric air with its usual amount of moisture, mechanically compressed, cannot be used at all, owing to the freezing up of the exhaust passages of the motor in which the attempt to use it is being made.

The accompanying photographs give an idea of the extent of the plant and of the volume of water used. The last one, showing the air carried in suspension, is especially interesting. The air cloud may be traced in the water quite as distinctly as it is shown in the photograph, for 40 or 50 feet below the weir.

William O. Webber,
in *The Engineering Magazine.*

RATIOS OF AREAS OF INLET AND OUTLET VALVES TO THAT OF THE AIR CYLINDER.

In an air compressor what are the correct ratios of areas of inlet and outlet valves to that of the air cylinder?—Ajax, Baltimore, Md.

There is no such thing as correct ratios in cases of this character. We can only say what seems to be the most common and approved practice, or what experience has demonstrated to be, upon the whole, the best. Valve areas on a compressor depend largely upon the style of valve employed, that is, whether the opening is one concentrated area, and also whether the valve is held open to get all this area throughout the stroke. Roughly speaking, about 5,000 feet per minute velocity for the air passing the valve gives good results, a slow running machine, that is, one having low piston speed, hence requiring a smaller valve area than a fast running machine. In compressors using the "piston inlet" valve and having from 300 to 350 feet piston speed, the inlet area is from 5 to 6 per cent., this area, however, being concentrated and positive for the whole length of the stroke. In this case, the velocity of the air is 7,000 feet per minute, but good results are shown. On large compressors, where the steam cylinders are of the Corliss type, and the piston speeds are as high as 500 to 600 feet per minute, the inlet areas, with the same type of valve as before, range from 6½ to 7 per cent., and the discharge areas (poppet valves) from 10 to 12 per cent., giving about the same velocity in the air passages as with the slower machines. On machines having poppet valves all around probably 12 per cent. of area is necessary, as machines with but from 7 to 10 per cent. area have shown considerable vacuum on the inlet, the springs tending to hold the valves partially closed and reducing the practical area. About 10 per cent. area for both the inlet and discharge valves should be sufficient for almost any good style of valves and for piston speeds not exceeding 400 feet per minute. The area of the discharge valves should not be less than that of the inlet valves, as, although the volume of air passing the discharge valves is, of course, much less than that passing the inlet valves, the time allowed for the passage is also proportionately less. While the inlet valves are open, or should be, during the whole of the intake stroke, the discharge valves can be open only for one-fourth or fifth, or other small portion of the stroke, according to the pressure. For most of the above, we are indebted to Mr. William Prellwitz, M. E., chief draftsman of the Ingersoll-Sergeant Drill Company, Easton, Pa., and it is based upon the practice and experience of that company.—*Am. Mach.*

CURVES SHOWING TEMPERATURE OF AIR DURING COMPRESSION.

Two curves are shown in the diagram, the ordinates representing pressures and the abscissae volumes. The curve drawn in full line shows the compression of air without any cooling effect, while the one drawn in dotted line shows the compression of air at a constant temperature. The former is the adiabatic curve whose equation is

$$\frac{p_2}{p_1} = \left(\frac{v_1}{v_2}\right)^{1.408}$$

the latter is the isothermal curve and has the equation

$$p \times v = \text{constant}.$$

In single stage compression the power required for compression may be calculated without taking into consideration the slight cooling effect due to the water jacket; the air will, therefore, be assumed to follow the adiabatic curve.

Starting at the left the first column of figures gives the gauge pressure for each horizontal line. The second column gives the Indicated Mean Effective

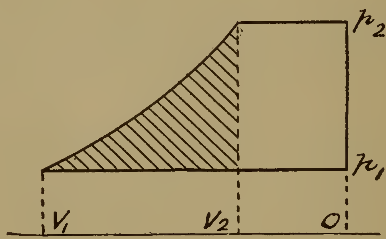

FIG. 37.

Pressures. These were calculated by a formula which was derived in the manner shown in figures 37 and 39.

The area of the shaded portion of the diagram Fig. 37, is

$$= \frac{p_2v_2 - p_1v_1}{1.408 - 1} = 2.45\ (p_2v_2 - p_1v_1)$$

In order to get the area of the shaded portion of the diagram Fig. 39, which represents the work done during the stroke of the air piston, we have to add

$$p_2v_2 - p_1v_1$$

this makes the

$$\text{Area} = 3.45\ (p_2v_2 - p_1v_1)$$

Dividing this by v_1 will give us the

$$\text{I. M. E.} = 3.45\left(p_2\frac{v_2}{v_1} - p_1\right) \text{ formula (1)}$$

The third column gives the Horse Power required to compress one cubic foot of free air, measured by the displacement of the air piston.

When $p =$ I. M. E. pressure in lbs. per sq. in.

$a =$ area of air piston in sq. in.

$P =$ piston speed in feet per min.

$D =$ displacement in cubic feet per min.

then

$$H.P. = \frac{a \times p \times P}{33000}$$

$$D = \frac{a \times P}{144}$$

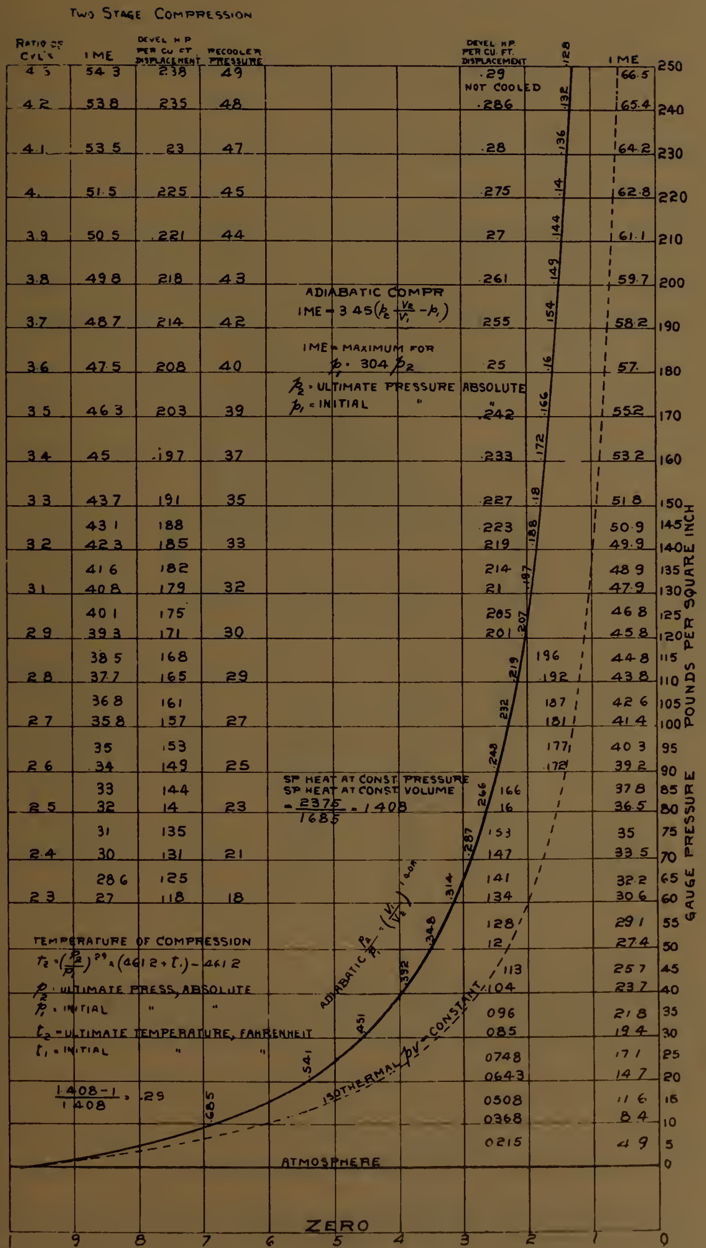

FIG. 38.—AIR DIAGRAM.

and the Horse Power required per cu. ft.

$$\frac{H. P.}{D} = \frac{a \times p \times P}{33000} \times \frac{144}{a \times P}$$

or

$$\text{H. P. per cu. ft.} = .00437\, P \quad \text{formula (2)}$$

The four columns at the left give similar data for two-stage compression. The I. M. E. pressures were calculated for air partly cooled by taking a mean between the pressures obtained by adiabatic and isothermal compressions.

The ratios of cylinders given will distribute the load evenly among the two

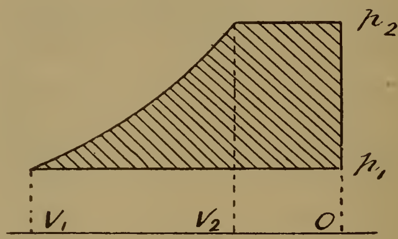

FIG. 39.

cylinders; they may, of course, for practical reasons, be varied considerably without impairing the efficiency of the machine.

Formula (1) for the I. M. E. pressure will, for the two extreme cases

$$p_1 = o \text{ and } p_1 = p_2,$$

give the value I. M. E. $= o$.

It is evident that between these two values there must be a maximum. This will be obtained when

$$p_1 = .304\, p_2 \quad \text{formula (3)}$$

This formula will be found useful in calculating gas compressors where the gas comes in under a head but is expected to drop to atmospheric pressure in the future. The driving mechanism of such a compressor should be calculated for this maximum.

HEAT REQUIRED TO RAISE THE TEMPERATURE OF AIR.

Air, in common with all other gaseous substances, possesses the property of requiring various amounts of heat to raise its temperature through a given range, according to the circumstances under which the heat is applied. This point is of so much importance that an entire article would be needed to elucidate it properly; but for the present it will be sufficient to say that the "specific heat" here given for air (*i. e.,* the number 0.238) assumes that the air that is to be heated is constantly at atmospheric pressure—that is, it assumes that throughout the entire process of heating, the air is never exposed to a pressure that is sensibly higher or lower than that of the atmosphere. This condition is often fulfilled in practice, and the specific heat here given will therefore be found useful. When other conditions prevail, however, some different value must be used for the specific heat—a value that can be determined only when the new conditions are fully given.

In calculating the number of heat units required to warm a given mass of air from one temperature to another one, we proceed precisely as we did in the case of iron; that is, we first calculate the heat that would be absorbed by an equal weight of water, and then we multiply by 0.238, which is the "specific heat"

TABLE II.—WEIGHT OF A CUBIC FOOT OF AIR, AT ATMOSPHERIC PRESSURE (.0 to 600° F.).

Temperature of Air. (Fahr.)	Weight of a Cubic Foot. (Pounds.)	Temperature of Air. (Fahr.)	Weight of a Cubic Foot. (Pounds.)	Temperature of Air. (Fahr.)	Weight of a Cubic Foot. (Pounds.)	Temperature of Air. (Fahr.)	Weight of a Cubic Foot. (Pounds.)
0°	.0864	100°	.0710	200°	.0603	300°	.0523
10	.0846	110	.0698	210	.0594	320	.0510
20	.0828	120	.0686	220	.0585	340	.0497
30	.0811	130	.0674	230	.0576	360	.0485
40	.0795	140	.0663	240	.0568	380	.0474
50	.0780	150	.0652	250	.0560	400	.0463
60	.0765	160	.0641	260	.0552	450	.0437
70	.0750	170	.0631	270	.0545	500	.0414
80	.0736	180	.0621	280	.0538	550	.0394
90	.0723	190	.0612	290	.0531	600	.0376

of air (at constant pressure). Air is usually estimated in cubic feet instead of in pounds, because it is much easier to measure its volume than its weight. If, therefore, we have a certain volume of air given, and we wish to find out how much heat will be required to warm it through a certain range of temperature, we must first find out how much it weighs. To accomplish this without too much labor we may make use of the accompanying table, which gives the weight (in pounds) of a cubic foot of air at various temperatures, but always at atmospheric pressure.

To illustrate the use of this table, and the method of calculating the number of heat units required to heat a given mass of air through a given range of temperature, let us take the following problem: It is proposed to heat a mass of air from 50° Fahr., to 110° Fahr., by passing it, at atmospheric pressure, over a coil of steam pipe. The proposed mass of air, when measured at 50° Fahr., occupies 500,000 cubic feet. How many heat units will be required? To solve this problem we first find out how much the air *weighs*. By referring to the table we see that one cubic foot of air, at 50° Fahr. and atmospheric pressure, weighs 0.078 of a pound. Hence 500,000 cubic feet (measured under these same conditions) will weigh

$$500{,}000 \times 0.078 = 39{,}000 \text{ pounds.}$$

Having found the weight of the air in this manner, we proceed to calculate the amount of heat required by first figuring it as though the substance to be heated were water. Thus the initial temperature is 50° and the final temperature is 110°, and the difference between these is 110° — 50° = 60°, which is the number of degrees through which the temperature of the mass must be raised. There being 39,000 pounds of the air, we should have to communicate

$$39{,}000 \times 60 = 2{,}340{,}000 \text{ heat units}$$

to it, if it were *water*, in order to heat it from 50° to 110°. To take account of the fact that the substance is *air* instead of water, we multiply this result by 0.238 (the "specific heat" of air at constant pressure), just as in the case of iron we multiplied by 0.117. Thus we have

$$2.340{,}000 \times 0.238 = 556{,}920 \text{ heat units,}$$

which is the quantity of heat that would be required to raise 500,000 cubic feet of air from 50° to 110°, the air being measured at 50° Fahr., and its pressure remaining equal to that of the surrounding atmosphere throughout the operation.

DENVER, Nov. 21, 1898.

Editor COMPRESSED AIR:

I have been investigating the question of the development of heat in compressing air at low pressures, and have failed to find any table which gives accurately the heat developed.

I will be very much obliged if you know of any table which will give the following information. If you will send it to me or advise me where I can get it, or if you can give me the figures in this particular item, I will be very much indebted to you.

What I want to know is this: Given 10 cubic ft. of air at 32 degs. F. and atmospheric pressure, how much pressure will be necessary to raise the temperature of this air to 33 degs., and how much reduction in the volume of the 10 ft. will there be at this pressure?

Thanking you in advance for any trouble you may take in this matter, I am,

Yours very truly, MINING ENGINEER.

The diagram shown on page 19 of this book (Fig. 2), and also in COMPRESSED AIR, Vol. I., No. 3, page 7, shows the relative difference in volumes, pressures and temperatures during the compression of air. This diagram does not give the difference as close as 1 deg., but it may serve your purpose; if not, we would refer you to Shones' tables, printed in the *Scientific American Supplement*, No. 279, and prepared by Isaac Shone, C. E. We know of no tables closer than these, which are for differences of one pound pressure. They may be readily interpolated for fractions of a pound equal to 1 deg. rise in temperature. The only formula applicable to the case is that of Dubois and Röntgen, which was used by Shone in computing the tables published in the *Scientific American Supplement*, No. 279, to which we have referred. The formula is for differences of temperature due to compression by compression or volume differences. It would have to be inverted for differences of pressure or volume due to temperature. The inversion is not stated in the books, but can be done with some experimental computation.

The formula is:

$$\frac{p}{P}^{0.29} \times 461.2 + T = t,$$

in which p is atmospheric pressure=14.7; P=pressure of compression, which for your case we assume as 14.8, or one-tenth pound advance in pressure; 461.2= absolute zero F. and T=temperature above zero F., or 32 deg., as you suggest; t=temperature of compression. The 0.29 is the logarithmic exponent, for which the computation must be logarithmic.

$$\text{Then } \frac{14.8}{14.7}^{0.29} \times 461.2^\circ + 32^\circ = t \text{ and}$$

14.8 = log.	1.170262
14.7 = log.	1.167317
Substract	0.002945
Multiply by exponent	0.29
	0.00085405
Add log. 493.2 =	2.693023
	2.69387705
Log. number	494.19
Subtract	493.20
	.99° rise in temperature.

You will notice by an examination of Shone's table that an interpolation can be made that will answer all practical purposes for low pressures, and with care may be made for any pressure within the scope of that table. For low pressures 1-10 of a pound pressure, or volume, very nearly corresponds with 1 deg. F. difference of temperature.

COMPRESSED AIR:

SIRS:—

The table for per cent. of work lost due to heat of compression, in the July number, may be criticised by your readers for stating the per cent. of loss in some cases greater than 100%.

It appears from results that the work lost is stated in terms of *isothermal* compression, but since it is more practical to state the loss in per cent. of *adiabatic* compression, I suggest reference be made to table in Vol. I., No. 4.

I think that I am responsible for both tables given, and consider the table in Vol. I. the more intelligent of the two; and make this suggestion so that the man who thinks he has found a big mistake, i. e., in having a loss greater than the actual work done, can use the other formula. Yours, truly,

F. C. WEBER.

New York, July 22, '98.

The table published in our July number is correct, but that it may not be misunderstood we have asked Mr. Weber to further illustrate this important point in air compression.

TABLE 12.—DELIVERED HORSE POWER PER 100 CU. FT. FREE AIR COMPRESSED FROM ATMOSPHERIC TO GAUGE PRESSURE.

Gauge Pressure lbs. per □″	One Stage Compression Adiabatic.	Isothermal Compression.	Difference between Adiabatic and Isothermal.	% of work lost in terms of Isothermal Compression.	% of work lost in terms of Adiabatic Compression.
60	13.41	10.32	3.09	30. %	23. %
80	15.92	11.90	4.02	34.	25.26
100	18 10	13.15	4.95	38.	27.58
200	26.20	17.20	9.00	52.35	34.40
400	36.	21.35	14.65	68.60	40.75
600	43.20	23.90	19.30	83.75	44.60
800	48.80	25.70	23.10	90.	47.40
1000	53.50	27.20	26.30	96.80	49.20
1200	58.50	28.35	30.15	106.15	51.60
1400	61.20	29.40	31.80	108.	52.
1600	64.30	30.10	34.20	110.	53.3
1800	66.80	30.80	36.00	116.80	54.
2000	69.80	31.50	38.30	121.70	54.8
				A	B

When air is compressed in one stage to a pressure of 2,000 pounds per square inch, more power (theoretically) may be consumed in overcoming resistance due to the heat of compression, than is required to compress the air isothermally hence the importance of stage compression and inter-cooling when dealing with high pressures. This point is clearly brought out by Mr. Weber in the following interesting figures.—Ed.

Interpretation of tables "A" and "B."

Neglect all friction losses.

Consider the case of compressing 100 cu. ft. free air to 2,000 lbs. gauge pressure.

To do this work in a one stage compressor will require 69.8 H. P.

Of this 69.8 H. P. 38.3 H. P. which is due to the heat of compression, will be lost (usually) due to radiation, before the air reaches the motor.

Table "A" expresses this loss in per cent. of the power available at the motor, which in this case is 1,216 times the available power, or it is 121.6% of the isothermal Horse Power of compression.

Table "B" expresses this loss in per cent. of the power actually put into the compressor, and in this case represents 54.8% of that power or the adiabatic Horse Power of compression.

As we are dealing with the "compressor end" in this article, it will be more pertinent to express the loss in terms of adiabatic compression which is done in table "B."

Editor Compressed Air:

I think it would be valued by your readers if you could give a diagram showing the temperature and volume which would result from compressing air, adiabatically, and in a single stage, to very high pressures, say 2,500 to 3,000 lbs. per square inch. Probably only an approximation could be given, but even that would be serviceable. Failing this, could you give a constant to enable same to be determined by calculation?

Is there a point in air compression where the temperature reaches a maximum above which continued compression cannot increase the sensible heat? Suppose this were so and that we had compressed a quantity of air far beyond its (heat) saturation point. Assuming that we use this immediately in a motor, how will cooling take place? Must the pressure fall to the heat saturation point again before the temperature begins to fall, or does temperature fall at once?

If there is a heat saturation point, must there not also be a cold saturation point? Suppose that in using the above quantity of highly compressed air, we had first allowed it to fall to atmospheric temperature, would it continue to fall in temperature so long as expansion took place?

In the compression of air temperature rises most during the early stages. How is it in expansion? Is it vice versa? T. T.
Newcastle-on-Tyne, Eng.

A diagram of adiabatic air compression, to be of any value, should be made on a larger scale than our space will allow, if carried up to 3,000 lbs. per square in. pressure. Compression to the higher figures is not practicable by one stage compression, for at 1,000 lbs. pressure the air rises to a full red heat, 1313 degrees Fahr., and at 2,000 lbs. to 1709 degrees Fahr.

This is the theoretical temperature, but as much of the heat in the air would be absorbed by the compressor, it would soon become too hot for economical operation.

The formula for the temperature of compression is derived from the relative absolute pressures and a ratio of adiabatic compression for gases. $\left(\frac{p}{P}\right)^{0.29} \times (461.2 + t^\circ) = T^\circ$ Fah., in which $p =$ the ultimate absolute pressure, *i.e.*, the gauge pressure plus 14.7 and $P =$ the atmospheric pressure, 14.7. $t =$ the initial temperature from zero Fahrenheit. —461.2 is the temperature from absolute zero to the zero of the Fahrenheit scale.

The ratio exponent, 0.29, is derived from the quotient of the division of the specific heat of air at constant pressure by the specific heat at constant volume. $\frac{.2375}{.1685} = 1.408$ and $\frac{1.408-1}{1.408} = 0.2908$ the ratio; practically the last figure is dropped and 0.29 used. The logarithm of the quotient of $\frac{p}{P}$ must be used, when the operation will then be for, say 100 lbs. gauge pressure from 60° initial temperature.

$$\frac{114.7}{14.7} = 7.803 \text{ log. } 0.89225$$

Multiplied by exponent, 0.29

Index log. - - 0.2587525

The index of which is $1.8145 \times (461^\circ.2 + 60^\circ) = 945^\circ.71$ Fah. absolute temperature; from which must be deducted 461°.2, leaving 484°.5 as the temperature of compression by the Fahrenheit scale.

The limiting point of heat by the compression of air is unknown, but is probably at the pressure of liquefaction, which has not yet been found with pressures up to 15,000 lbs. per square inch.

Cooling from the expansion of compressed air is inversely in the same ratio as for compression; or, the temperature falls by the same scale that it rises.

As we have said above, the heat saturation point is probably at the pressure of liquefaction; so the cold extreme from expansion is probably at the absolutely zero of expansion or perfect vacuum; which is now accepted as the zero of absolute temperature 461°.2 below the zero of the Fahrenheit scale.

The difference of temperature by compression for equal increments of pressure, is much greater in the lower part of the compression scale than in the upper part, as for example the increase of temperature from atmospheric pressure to 1 lb. per square inch is 10 degrees Fah., while for an increase of 1 lb. pressure from 99 to 100 lbs. is but 2 4-10 degrees Fah. The differences of temperature when plotted on a pressure diagram form a parabolic curve from its axis at absolute zero and terminating at infinite pressure and temperature; the conditions within the limits of practice indicate this curve, as also its inverse order in the expansion of compressed air.

AIR COMPRESSION AT HIGH ALTITUDES.

The Reasons Which Cause Air Compressors to Give Less Efficiency at High Altitude.

[Written for *Mines and Minerals,* by Robert Peele.]

Because of the diminished density of the atmosphere at high altitudes, air compressors do not give the same results in mountainous regions as at sea level. Their effective capacity is reduced by reason of the smaller weight of air that is taken into the cylinder at each stroke. It is necessary, therefore, to make a deduction from the normal output of a compressor of given size, working with air at ordinary atmospheric pressure.

This matter is of special importance in connection with mining operations, because so many mines are at considerable elevations above sea level. The rated capacities of compressors, as given in the makers' catalogues, are for work at normal barometric pressure. This reduction in output is usually tabulated also in the catalogues, and must receive due consideration in order to avoid serious errors in ordering compressors. For example, the volume of compressed air delivered at 60 pounds pressure at an elevation of 10,000 feet is only 72.7 per cent. of the volume delivered at the same pressure by the same compressor at sea level. In other words, a compressor which, at sea level, will supply power for ten rock drills, will, at an elevation of 10,000 feet, furnish air for only seven drills. It should be observed that the heat of compression increases with the ratio of the final absolute pressure to initial absolute pressure. Therefore, as this ratio increases with the altitude, more heat will be generated by compression to a given pressure at high altitudes than at sea level, and there is a corresponding increased loss of work due to the subsequent cooling of the air.

Contrary to a common impression, the volume of compressed air delivered by a given compressor is not proportional to the barometric pressure, nor is the power consumed in producing a given volume of air at a given pressure the same at all altitudes. As a matter of fact, the volume of air furnished by compressors of equal capacity, working at different heights above sea level, diminishes at a somewhat slower rate than the barometric pressure, but the power consumed in producing a given volume of compressed air increases with the altitude. Take one compressor working at normal barometric pressure, assumed for convenience to be 15 pounds, and another working under an atmospheric pressure of 10 pounds, corresponding very nearly to an elevation of 10,000 feet. The first, if compressing to 6 atmospheres, will produce a gauge pressure of $(15 \times 6) - 15 = 75$ pounds. To produce the same gauge pressure the second compressor must work to an absolute pressure of $75 + 10 = 85$ pounds. This, divided by the atmospheric pressure of 10 pounds, gives 8.5 atmospheres required from the second compressor. The ratio between the two, $\frac{6}{8.5} = 0.706$, shows the relative volumes of compressed air produced under the assumed conditions. This is to be compared with the ratio between the corresponding barometric pressures, which is $\frac{10}{15} = 0.666$.

The indicated horse power per cubic foot of piston displacement decreases as the altitude increases, but this decrease is not proportional to the altitude. To compensate for the increase of piston displacement per horse power, when compressing to a given gauge pressure at high altitudes, some builders make the air cylinders of compressors for mountain work of larger diameter than those at sea level, for the same size of steam cylinder.

It is sometimes argued that compressors whose inlet valves are under some mechanical control are of special advantage for work at high altitudes. While there is a measure of truth in this the possible saving which may be effected is necessarily small. The matter presents itself as follows: If the valve resistance be reduced by introducing mechanical control, so that, under normal conditions at sea level, the inlet air begins to enter the cylinder a little earlier in the stroke, the volumetric capacity of the compressor is increased. The loss due to resistance of the valve springs, etc., which may be taken as a constant at 0.75 pounds for ordinary poppet valves, becomes proportionally of greater and greater consequence as the altitude increases, because its ratio to the atmospheric pressure is increased. The percentage of saving obtained by eliminating the spring resistance, though small at sea level, therefore bears an increasing ratio to the atmospheric pressure as the altitude increases. In other words, the inlet valve which presents the smallest resistance at normal atmospheric pressure will be the most economical valve as the atmospheric pressure decreases.

According to the statement made above, the greater the altitude above sea level the smaller will be the ratio between the final pressure at delivery and the atmospheric pressure, that is, the ratio of compression. It is evident, therefore, that the percentage loss due to piston clearance increases with the altitude. It may be questioned whether it is worth while to adopt stage compression for the ordinary pressures used in mining and tunneling, but the case is materially altered at high altitudes. For example, if it be desired to produce a gauge pressure of 75 pounds at an altitude of 5,000 feet, 7.15 compressions are necessary. At sea level this ratio of compression would produce a gauge pressure of 105.1 pounds. So far as the losses due to piston clearance are concerned, therefore, it is as reasonable to employ stage compression for a gauge pressure of 75 pounds at 5,000 feet elevation as for 105.1 pounds at sea level. In a compound compressor, too, it must be remembered that there is but one clearance space; that in the low pressure, or intake, cylinder. The value of the intercooler also increases with the altitude.—*Mines and Minerals.*

TABLE 13.

MULTIPLIERS TO BE USED FOR TRANSFORMING VOLUMES OF COMPRESSED AIR AT VARIOUS PRESSURES INTO CORRESPONDING VOLUMES OF FREE AIR AT ATMOSPHERIC PRESSURE OF 14.7 POUNDS.

PRESSURE IN POUNDS	MULTIPLIER	PRESSURE IN POUNDS	MULTIPLIER	PRESSURE IN POUNDS	MULTIPLIER	PRESSURE IN POUNDS	MULTIPLIER	PRESSURE IN POUNDS	MULTIPLIER
1	1.068027	**26**	2.768602	**51**	4.469377	**76**	6.170052	**101**	7.870727
2	1.136054	**27**	2.836729	**52**	4.537404	**77**	6.238079	**102**	7.938754
3	1.204081	**28**	2.904756	**53**	4.605431	**78**	6.306106	**103**	8.006781
4	1.272108	**29**	2.272783	**54**	4.673458	**79**	6.374133	**104**	8.074908
5	1.340135	**30**	3.040810	**55**	4.741485	**80**	6.442160	**105**	8.142835
6	1.408162	**31**	3.108837	**56**	4.809512	**81**	6.510187	**106**	8 210862
7	1.476189	**32**	3.176864	**57**	4.877539	**82**	6.578194	**107**	8.278889
8	1.544216	**33**	3.244891	**58**	4.945566	**83**	6.646241	**108**	8.346916
9	1.612243	**34**	3.312918	**59**	5.013593	**84**	6.714268	**109**	8.414943
10	1.680270	**35**	3.380945	**60**	5.081620	**85**	6.782295	**110**	8.482970
11	1.748297	**36**	3.448972	**61**	5.149647	**86**	6.850322		
12	1.816324	**37**	3.516999	**62**	5.217674	**87**	6.918349		
13	1.884351	**38**	3.585026	**63**	5.285701	**88**	6.986376		
14	1.952378	**39**	3.653053	**64**	5.353728	**89**	7.054403		
15	2.020405	**40**	3.721080	**65**	5.421755	**90**	7.122430		
16	2.088432	**41**	3.789107	**66**	5.489782	**91**	7.190457		
17	2.156459	**42**	3.857134	**67**	5.557809	**92**	7.258484		
18	2.224486	**43**	3.925161	**68**	5.625836	**93**	7.326511		
19	2.292513	**44**	3.993188	**69**	5.693863	**94**	7.394538		
20	2.360540	**45**	4.061215	**70**	5.761890	**95**	7.462565		
21	2.428567	**46**	4.129242	**71**	5.829917	**96**	7.530592		
22	2.496594	**47**	4.197269	**72**	5.897944	**97**	7 599619		
23	2.564621	**48**	4.265296	**73**	5.965971	**98**	7.666646		
24	2.632648	**49**	4.333323	**74**	6.033998	**99**	7.734673		
25	2.700675	**50**	4.401350	**75**	6.102025	**100**	7.802700		

Formula. $\frac{1}{14.7} \times \text{Pressure} + 1 = \text{Multiplier.}$

Atmospheric Pressure 14.7 pounds = 30″ Barometric Pressure Temperature 60° Fahr.

To find the volume of free air at atmospheric pressure corresponding to a volume of air under pressure, multiply the amount of air under pressure by the multiplier corresponding to that pressure.

For each one-tenth of an inch difference in barometric pressure below 30 inches, first reduce the volume of compressed air into volume of free air at atmospheric pressure of 30 inches or 14.7 pounds, according to the table. Then use the following formula:

$$V^1 = \frac{300}{300-X} V$$

in which V^1 represents the volume of free air at reduced atmospheric pressure; V the volume of free air at atmospheric pressure of 14.7 pounds, and X the decrease in one-tenth of an inch barometric pressure below 30 inches.

For each 5 degrees difference in temperature between end of pipe line and compressor, add or subtract, according to increased or decreased temperature, one per cent. to volume of free air.

Examples: Assume that we have 320 cubic feet of air at 90 pounds pressure, the atmospheric pressure being 14.7 pounds and temperature 60 degrees, both at receiver and end of line. In looking over table of multipliers we find that the multiplier for 90 pounds is 7.12243. Thus the amount of free air would be 320 × 7.12243 = 2279 cubic feet of free air at 14.7 pounds.

Suppose now that this would apply to Leadville, Colo., where the barometric pressure is 20.4 inches. The volume of free air at that pressure would then be as per formula above.

$$2279 \times \frac{300}{300-96} = 3351 \text{ cubic feet.}$$

Assume now the temperature in receiver to be 60 degrees and that the air would be re-heated to 155 degrees, the volume of free air at 155 degrees and 20.4 inches barometric pressure corresponding to above volume of compressed air would be

$$3351 \times \left(1 + \frac{19}{100}\right) = 3987$$ cubic feet of free air at 155° and 20.4 in. barometric pressure

in which 19 represents the increase of volume of one per cent. for each 5 degrees increase in temperature.

The reverse can be done in order to determine the volume of compressed air at various pressures, when the volume of free air, barometric pressure, temperature of free air, temperature of compressed air and terminal pressure are known. This is effected by transforming the multipliers into dividers. Examples: What will be the amount of compressed air obtained from 4,000 cubic feet of free air at 60 degrees receiver temperature with initial barometric pressure of 20.4 inches, initial temperature of 40 degrees and terminal pressure 90 pounds gauge? We first reduce the volume to 30 inches barometric pressure, and have

$$V = V^1 \times \frac{300-X}{300} = 4000 \times \frac{300-96}{300} = 2720$$

cubic feet of free air at 14.7 pounds and 40 degrees. At 90 pounds and 40 degrees we divide the amount by the multiplier corresponding for 90 pounds, and have

$$\frac{2720}{7.12243} = 382 \text{ cubic feet.}$$

For an increase of temperature of 20 degrees we will have an increase of volume of one per cent. for each 5 degrees; thus the total amount would be $382 \times 1.04 = 397$ cubic feet of compressed air at 90 pounds gauge pressure and 60° temperature.

F. SCHMERBER.

REDUCING AIR FROM HIGH TO LOW PRESSURE.

The use of compressed air, especially in cases where it is stored under a high pressure, has created a demand for a regulating valve that will reduce this high pressure to the normal working pressure desired in engines or elsewhere.

The chief difficulty experienced in effecting a reduction from 1,000 lbs. or more, per square inch, to a working pressure of from 100 to 200 lbs., has been

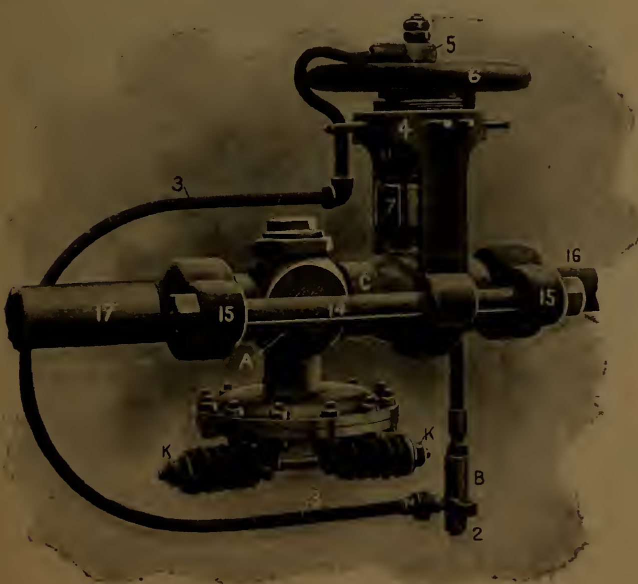

FIG. 40.—MECHANICALLY OPERATED.

found to lie in the fact that, with the maximum initial pressure in the reservoir, the reducing valve was opened to such a slight extent that the excessive wire-dr-wing, and the lodgment of fine particles of scale, cuttings, grit or other foreign substances which are always present under ordinary practical conditions, has resulted in so rapid a wearing of the seats and valves that the leakage quickly became serious, and the tight closing of the valve an impossibility. This difficulty has been entirely obviated by the Foster combination regulator and automatic stop valve.

The valve is made in two forms; one operated mechanically, and the other pneumatically. In the mechanically operated valve (Fig. 40), the high pressure is admitted through the pipe 16, and when the valve in the body C is open, the full pressure of air flows in to the valves of the regulator in the case A. These valves

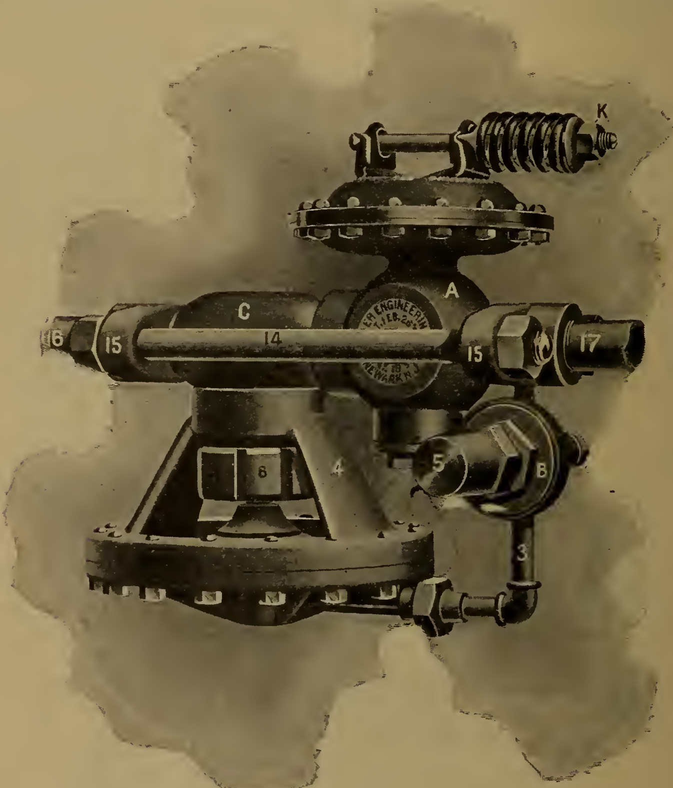

FIG. 41.—PNEUMATICALLY OPERATED.

are controlled by a diaphragm and the springs K, K, as in the standard "Class W" Foster regulator. Here it is reduced or wire-drawn down to the normal working pressure, and flows out through the pipe 17. So long as the throttle remains open, and there is a consumption of air, this state of things continues. When, however, the throttle is closed, the valve in the body C is also closed, and all flow of air from the supply pipe 16 to the regulator valve is cut off—a pipe being tapped in to the body C between the valve and source of supply. This pipe leads to the auxiliary valve B, which may be located in any convenient place in juxta-position to the engine throttle lever, and is always charged with high pressure air from the pipe 16. In B there are two small needle valves, one closing downward and held in that position by the combined pressure of a spring and the high pressure air. Abutting against this valve, and held open by it, is an upward closing valve which projects below the case at 2. When the engine throttle is closed, an adjustable screw in the lever thereof pushes this valve 2 shut and, in doing so, opens the one above it. The opening of this upper valve allows the high-pressure air to pass around through the pipe 3, and thence back to the joint 5, and down the center of the spindle to the top of a piston within the casing 4. This piston rests on the same stem as the valve in the body C, and when air pressure is admitted to the top of the former, the latter is closed, thus shutting off the flow from the pipe 16.

As soon as the throttle is opened, the pressure instantly closes the upper valve in B and, in so doing, opens the valve 2, which allows the air above the piston in 4 to escape to the atmosphere. The valve in C is then opened by the pressure from the pipe 16 beneath it, and air is again admitted to the regulator valve A.

The valve in body C can also be closed by means of the hand-wheel 6, after the manner of an ordinary stop valve.

In the case of the pneumatically actuated valve (see Fig. 2) the high pressure air is admitted at 16 and flows through the valve C to the regulator valve A, where the pressure is reduced as desired and whence it flows out at the delivery 17. Tapped into the delivery pipe 17 is a small pipe leading down to the auxiliary valve B, where it enters beneath a diaphragm which is adjusted by a spring in the casing 5, so that the valve will open when the pressure in pipe 17 has risen a small amount above the normal working pressure. When such a rise has taken place, this valve opens and air passes through the pipe 3 to the back of a diaphragm working against a plate on the stem of the stop valve in C. The admission of this pressure to the back of the diaphragm closes the valve C and cuts off the flow of air. As soon as the working pressure again falls to normal, the needle valves in casing B shuts off admission from pipe 17 and bleed the air from back of diaphragm in stop valve C to the atmosphere and allow this valve to instantly open.

The result of this combination is that the valve in C is always either wide open or closed. There is, therefore, no wire-drawing at this point, and the ample opening of the valve permits any foreign substances that may be entrained by the air, to blow through. When the valve C is closed, that in A opens more than it does when in the normal working position, due to the fall of pressure that take place. Hence, at the instant of the opening of C, a puff of air is sent through A, cleaning the seats and preventing a lodgment of the grit.

The cutting of the valve surfaces due to wire-drawing is obviated by the use of a hardened steel valve, which has been found to be efficient for the purpose.

THE WEIGHT OF AIR.

The properties of air and other gases are so different from the properties of the solid liquids that we can see and measure and handle so readily, that it is not at all to be wondered at that the earlier men of science regarded gases as intrinsically different, in their very essence, from the more familiar and tangible things of our daily experience. The word "gas" was invented by a Belgium chemist named Van Helmont, in the first half of the seventeenth century; and while it is not definitely known where he obtained the suggestion from which the word took form, it is not at all unlikely that it came from the Dutch word "geest," which means "a spirit," and which is related to our common English word "ghost." Whatever the origin of the word, it is certain that the early philosophers considered gases to be essentially different from the other materials of which the world is composed. We do not need to discuss the views that they held about these things, beyond stating that until the year 1644 it does not appear to have occurred to any one that gases (and, in particular, air) possess the property of weight. But in that year the Italian physicist Torricelli invented the barometer, and proved, by conclusive experiments, that air, at least, has weight, just as all the more substantial bodies have; and now, of course, we know that every mass of gas has a perfectly definite weight.

It is not essential to our present purpose to describe, in detail, the experimental methods by which the air has been weighed. It will be sufficient to say that the general process consists in weighing a balloon-shaped flask twice—the first weighing being performed with the flask full of air, while the second is performed after the air has been all pumped out. If air had no weight at all, these two experiments would give identical results; but it is found that, as a matter of fact, the flask is always sensibly heavier when it is full. By taking the differences of the two weighings, we therefore ascertain the weight of the quantity of air that is just sufficient to fill the flask. Knowing this, we next proceed, by means of a separate experiment, to find out the volume of the flask, in cubic inches; and when this has been done, we are in position to calculate the weight of a cubic inch of air, or of a cubic foot of it, or of any other quantity.

Measurements of this sort are exceedingly delicate, and they can be valuable only when performed by experienced men, with the aid of the finest apparatus that can be made. Regnault, whose skill cannot be doubted, and whose apparatus was beyond reproach, found that at the freezing point of water, a cubic centimeter of perfectly pure, dry air weighed 0.0012932 of a gramme, when the barometer stood at 76 centimeters, in his laboratory at Paris. To make this available for practical work in this country we have reduced these figures to their English equivalents; and we find that at ordinary atmospheric pressure, and at the temperature of melting ice (32 degrees Fahr.), a cubic foot of air weighs 0.080681 of a pound.*

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*By "ordinary atmospheric pressure" we mean the pressure that would be exerted by a weight of 14.7 pounds, resting upon a base one inch square, at sea-level in the latitude of Washington; and throughout this article when we use the word "pound" it is to be understood that the data relate always to sea-level, at Washington. We make this explanation in order to guard against possible criticism; but for the purpose of engineering, no attention need be paid to this foot note, and the figures that we give may be used in any latitude, without fear of sensible error. The tables are supposed to be correct for Washington; and if the force of gravity were constant all over the United States, they would be equally exact for all places in the country. As a matter of fact, the earth attracts bodies a little more strongly as we go north, and a little less strongly

It will be observed that we have carefully specified the pressure and temperature of the air, in giving weight. That is because the density of the air varies when these elements vary, unless certain conditions are fulfilled. If a given constant mass of air be compressed, or heated, or modified in any other way, its weight will remain unchanged, just as the weight of any other substance would remain unchanged under similar circumstances. The reason that the weight of a cubic foot of air varies so much under varying conditions of temperature and pressure is, that air is exceedingly expansible and compressible. Suppose, for example, that we had a light steel flask, with a capacity of precisely one cubic foot, and that we filled this box with air at the usual atmospheric pressure, and (say) at 70 degrees temperature. The air so confined would have a certain definite weight. Suppose, next, that we pump more air into the flask, until there is perhaps three times as much air in it as there was before. In pumping in this extra air, we shall materially increase the pressure within the flask; but that does not concern us for the moment. The point that we wish to make is, that the air

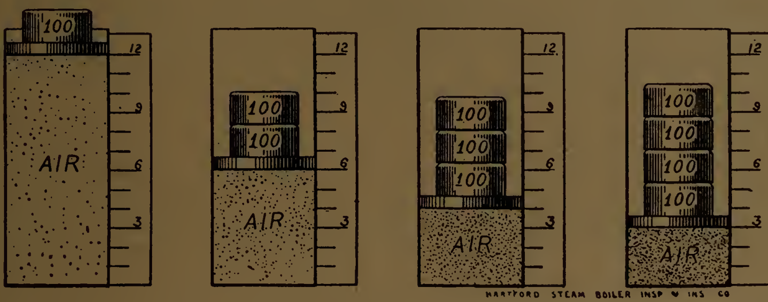

FIG. 42.—ILLUSTRATING "BOYLE'S LAW."

that was originally in the flask weighs just exactly the same as it did before—no more and no less, but the total weight of the air in the flask is now greater than it was before, because we have forced a good deal more air into this one cubic foot of space than there was in it in the first place; and that is the reason (and the only reason) why a cubic foot of air at a higher pressure weighs more than a cubic foot of air at a lower pressure. There is simply more air crowded into this cubic foot, at the higher pressure.

The first experimenter to investigate the behavior of air, under varying pressures, with anything like accuracy, was the English physicist, Robert Boyle, who discovered the fact of nature now known under the name of "Boyle's law." As this law is of constant use in connection with steam engineering and other allied branches, it will be worth our while to give some account of it. The law

as we go south; so that it is not possible to make a table that shall be strictly accurate for all places. The greatest amount by which the tables can be in error from this cause, however, when they are applied to any part of the United States north or south of the latitude of Washington, is only one-ninth of one per cent. this maximum error occurring at Key West.

is very simple and will be readily understood by referring to the illustrations which accompany this article. On the left we have endeavored to represent a metal cylinder, standing on end, in which a definite mass of air confined by means of a weightless piston which fits the cylinder perfectly, and yet without the least friction. We cannot realize, in practice, the condition of an air-tight piston which is at the same time perfectly frictionless; but our limitations in this regard need not prevent us from imagining such a thing, nor from learning something about what the behavior of air would be, if such a state of affairs could be realized. For the sake of further simplicity, we will also suppose that the external air does press down upon the piston at all, but that the only force tending to confine the air is that due to the 100-pound weight which is represented in the engraving. This amounts to assuming that the whole experiment that we are about to describe is performed in a closed chamber, from which the air has been removed by a suitable pump. In practice, such experiments are performed in the open air, and the effects of the external atmospheric pressure are allowed for in the calculations. We could pursue this latter course if we chose to, but as we are not going to actually perform the experiment, but only to think of its being performed, we might as well think of the external atmospheric pressure as being entirely done away with by some such means as we have suggested; for this will save all complication, and enable us to give our undivided attention to one thing that we wish to illustrate.

We have, then, a metal cylinder in which a certain definite amount of air is confined by means of a tight-fitting but frictionless piston; and the only force tending to hold this air confined is that exerted by the 100-pound weight which rests upon the piston. We will suppose that the quantity of air within the cylinder has been regulated so nicely that the weight is held by it at such a height that the bottom of the piston is precisely 12 inches from the bottom of the cylinder. If there is no leakage past the piston, and no change in the temperature of the air, the system will remain balanced in this precise condition forever (so far as we know).

Now, suppose that another 100-pound weight is placed upon the piston. The piston will be immediately forced downward by the additional weight, and the air under it will be compressed, and the pressure that the air exerts against each square inch of the cylinder and the piston will be greater than it was before. There will be various effects produced at the outset, besides the mere reduction of the air to a smaller volume. For example, small currents will be set up in the air, and the air will also become more or less heated. If we wait, however, until all these currents have died out, and the air has cooled again to its original temperature, we shall find that the piston comes finally to rest at a position such that its lower side is almost precisely six inches from the bottom of the cylinder, instead of twelve, as it was originally. That is, by doubling the pressure upon the air we have reduced the volume of the air to one-half of what it was at first—always understanding that the temperature of the air is precisely the same in both cases. If we had loaded the piston with three hundred pounds, we should have found that when the system finally came to rest, the volume of the enclosed air would be one-third of its original volume. If we piled 400 pounds on the piston, we should find that the volume would be reduced to one-fourth of its original value, as shown on the extreme right of the engraving; and so on, for all ordinary pressures. This fact, that the volume of air (or of any other of the so-called "permanent gases") is halved by doubling the pressure, and so on (provided the temperature of the air remains constant), is known as "Boyle's law."

It will be plain, upon examining the engraving, why the weight of a cubic foot (or of a cubic inch) of air varies with the pressure; for under a load (or pressure) of 400 pounds, the same air is forced into a space only one-fourth as great as it occupied under a load of 100 pounds; and therefore its density (or, in other words, its weight per cubic foot, or per cubic inch), is four times as great at the higher pressure.

We have referred, several times, to the necessity of keeping the temperature of the air constant during experiments of this kind, if "Boyle's law" is to be illustrated. We shall now explain briefly what happens when the temperature of the air is not kept constant; and we shall find that the effects of change of temperature are almost equally as simple as the effects of change of pressure. In the interest of simplicity it will be well to state, at the outset, that physicists are in the habit of reckoning temperatures, not from the arbitrary zero of the Fahrenheit scale, but from a point which is approximately 460° Fahrenheit below this zero. The scientific starting point, or zero, so determined, is called the "absolute zero," because it is believed to be the temperature at which all bodies are totally destitute of heat; and temperatures reckoned from this "absolute zero" are called "absolute temperatures." To illustrate: The freezing point of water, on the ordinary Fahrenheit scale, is at 32°; and the "absolute temperature" of this point will therefore be 460° + 32° or 492°. Again, the boiling point of water, under one atmospheric pressure, is 212° on the ordinary Fahrenheit scale; and therefore the "absolute temperature" of this point is 460° + 212° or 672°.

With this much understood, we are now prepared to state what is known as "Gay Lussac's law" (or, "Charles' law"); which is, that if the pressure exerted upon a given mass of air (or any other "permanent gas") be kept constant, the volume of the air (or gas) will vary proportionately to the "absolute temperature" of the gas. For example, consider the second of the engravings accompanying this article, where the air is confined by a total weight of 200 pounds. Let us suppose that this air, at the outset, is at the freezing point, or at 32° on the ordinary Fahrenheit scale; and let us imagine the air to heated, in some way, until its temperature becomes 524° on this same scale, the load of 200 pounds being kept constant all the while. To find out how much the air will expand under these circumstances, we first convert the ordinary temperatures, given above, in "absolute temperature," by adding 460° to each of them. We have 460° plus 32° or 492°, and 460° plus 524° or 984°. Now "Gay Lussac's law" states that so long as we keep the pressure constant, the volume will increase proportionately to the "absolute temperature;" and since 984 is just twice as great as 492, it follows that the air will expand, under the stated conditions, until its volume is precisely double what it was at the beginning. That is, the mass of air shown in the second illustration will push up the load of 200 pounds until the piston comes into the position shown in the first of these illustrations.

By means of the laws of Boyle and Gay Lussac, we can calculate the way in which the volume of a given mass of air will vary under any imaginable circumstances of pressure and temperature, and hence we can calculate how much a cubic foot of air will weigh at any proposed temperature and pressure, when we once know, by experiment, how much such a volume of air will weigh under certain definite standard conditions—say at one atmosphere pressure, and at the temperature of freezing water. Regnault's labors, referred to earlier in this article, showed that a cubic foot of air exposed to a pressure of 14.7 pounds per square inch and a temperature of 32° Fahr., weighs .080681 of a pound (or 1.29 ounces).

The atmosphere that surrounds us buoys up everything that is submerged in it, just as water does, only not to so great an extent. If a cannon ball is submerged in water, the water buoys it up by an amount which is precisely equal to the weight of a mass of water having identically the same size and shape as the cannon ball itself; and when the cannon ball is submerged in air, instead of in water, the surrounding air buoys up the ball by an amount which is precisely equal to the absolute weight of a mass of air having the identical size and shape of the cannon ball; and so on with any other fluid or gas, whether it is water or milk or carbonic acid gas or coal gas or anything else.—*The Locomotive.*

AIR COMPRESSORS.

The widening use of compressed air in the arts has developed a great many types of Air Compressors and has distinctly improved the efficiency of the machine. A few years ago it was an uncommon thing for an Air Compressor builder to supply a machine with compound air cylinders; to-day the best Compressors are of the compound type and an engineer who specifies an Air Compressor for his plant, is wise if he looks carefully into the tender submitted, especially with reference to compounding and intercooling. It is quite as important in large plants that the air cylinders be compounded, as that compound steam cylinders are used, and it is equally as important to supply efficient intercoolers as to use a condenser on the steam end.

There is, naturally, at the present time, but little general familiarity with Air Compressors and compressed air machinery; hence, when those in charge of works decide to install a Compressor, they are at a loss to know how to draw up the specifications or to decide which of the numerous types is preferable. The plan which might be called European, and which applies to machinery and constructive work generally, is to send out specifications and ask for bids. This is a dangerous thing to do unless the person who draws the specificatoins is thoroughly familiar with the eubject. Such familiarity is not likely to exist in places where Air Compressors are required; hence, it is of greater importance to investigate the question as to the experience and standing of the bidder.—How long has a certain concern been building Air Compressors? What shop facilities they have for turning out the work, and what is the general design of their machine. A first-class builder of large experience and a growing business might naturally be expected to supply something of a high class in this line, and yet it may be found, on investigation, that this builder has a specialty that his machines are mainly used for light duty or low pressure, or vice-versa. References and testimonials are easily given and are only of value in connection with a case of this kind in so far as they point to the class of trade which the manufacturer has been supplying, and if the buyer is not in too much of a hurry, he will do well to investigate the references. In connection with this subject, the following specifications have been brought to our notice as having been submitted to builders of Air Compressors, by two of the largest concerns in the country. They may be of interest to our readers as indicating types of specifications which are sent out when calling for bids:

"Dimensions of steam and air cylinders to be determined by maker; to be of sufficient size for compressing 650 cubic feet of free air per minute, to 750 pounds per square inch in three stages, at a maximum piston speed of 400 feet per minute. Initial pressure of steam 80 pounds, taken from a steam line 175 feet in length, from boiler to compressors. The whole machine to be designed to withstand 1250 lbs. pressure in third compressing cylinder.

"Builder to furnish complete plans and detail specifications, templates, foundation bolts, oil cups, sight feed lubricator, exhaust pipe, wrenches, and all fittings to make compressor complete for making trial test; also to furnish, at builder's expense, a competent machinist to superintend the erection of compressor, the buyer to furnish all unskilled labor and prepare the foundations for receiving compressor."

"Capacity.—Capacity of compressor 600 to 650 cubic feet of free air per minute, compressed to 100 pounds per square inch, with 100 pounds per square inch steam pressure.

"Specifications.—Signed specifications to be furnished covering workmanship, guarantee in regard to same, details of various parts, tools with compressor, time of delivery after ordered, etc.

"Plans.—Foundation plans and print showing plan of compressor giving general dimensions, location of pipes, etc. Also photograph or catalogues and page number where compressor is shown to be furnished.

General Information to Be Given.

"Type of compressor.
"Diameter of steam and air cylinders with stroke.
"Free air capacity per minute.
"Piston speed.
"Revolutions.
"Sizes of pipes.
"Floor space.
"Price.
"Point of delivery."

These specifications are conspicuous for their simplicity in that they throw the entire responsibility upon the maker. It is evident that if a maker is called upon to build something not strictly in line with his practice, or which is based upon the design of some other maker, he is not likely to do the subject justice and the buyer will run some risk in placing the order with him, because it will be more or less experimental. Air Compressors can only be built well when based on experience. The best design made by the best men will fail unless tested and developed on lines of practice.

Compressed air, to the average mind, conveys a rather vague meaning, which ranges from the old-fashioned pop-gun to liquefied air. That it is produced by some form of pump is generally understood, but what the pump is, how it works and the principles governing its best action are unthought of points by the layman. The expert, on the other hand, knows the principles involved, and is constantly on the lookout for improvements in details of apparatus. From this standpoint, it is interesting to examine the air compressors exhibited at the Paris Exposition.

In the first place, the number of such compressors is limited, there being, so far as is known to the writer, three compressors in operation on the Champ-de-Mars and three at Vincennes, and several other stationary ones. Of these former, five are American machines. Of course, Paris is an extensive user of compressed air, and its pneumatic street railways, clock and postal systems are unique; but this apparatus does not form part of the Exposition, and it is, therefore, outside of the purpose of this paper to discuss this.

Generally speaking, compressors of all manufactures are horizontal, and the wisdom of having air cylinders behind and in direct line with the steam cylinders seems to have made this form standard practice, as it has certainly been adopted by the important manufacturers on both sides of the water.

The engine may be termed girder framed, either cross, duplex or compound, depending upon initial steam pressure, which, in the United States, averages close upon 100, while on the Continent, it is nearer 75 pounds. Slow speed engines, with a fairly long stroke, are used, the American builders favoring a much longer stroke than the Continental, at least, in the larger sizes.

Cranks are set at 90 degrees, thus balancing better and distributing the load over the entire stroke. With one or two exceptions, heavy flywheels are universal, the necessity of carrying the cranks past dead points being very important and fully understood. One maker, however, has an extremely light wheel, the wisdom of which may be seriously questioned.

Regarding steam valve mechanism, Continental manufacturers lean towards slide valves of the Meyer's type, even in the larger sizes of engines, although poppet and modified Corliss valves are also used in the larger sizes. Manufacturers in the United States prefer the Corliss valve, excepting smaller sizes or those forms intended for places such as coal mines, where steam economy is a minor item.

In a general way, the engines may be termed average, conforming to usual Continental engine practice, certainly no better, and, perhaps, not so good as American practice for the same class of work.

Coming to the air-compressing portion, such as the cylinder valves, etc., some interesting departures, or, perhaps, we may say, antiquities, are noticeable. The larger sizes follow the usual practice of placing the air cylinder on a separate portion of the foundation and holding it at its proper distance by means of bolts or distance pieces. In the case of the smaller sizes, some manufacturers mount all working parts on one base, but the self-contained type, familiar in the United States, is not generally to be observed, and when used, it is a clumsy, awkward appearing affair.

It is when the valves and cooling methods are examined that the chief difference is found. With few exceptions, Continental practice leans towards slide valves, the "Weiss" system. This is nothing more or less than a balanced plate slide valve. No particular effort seems to be made to reduce clearance in this type.

In low pressure work for blowers, poppet valves in the heads are, however, used to some extent. But it is safe to say that on the Continent air compressors for pressures of from 3 to 7 kilos, or even higher, slide valves are the rule. In the United States, with few exceptions, slide valves for air cylinders have been abandoned entirely by progressive manufacturers.

It is interesting to note that Continental steam engine practice employs balanced poppet valves, and for their compressors slide valves. In the States, on the contrary, engines are equipped with slide and Corliss valves, and compressors with poppet valves.

Attention must be called to one type of compressor which is somewhat common. This form resembles a duplex or cross compound engine, the engine portion forming one side and the compressor the other. This type requires heavy cranks, shaft and flywheel, and cannot be as satisfactory as other types, although it is a common type.

Methods of cooling differ. The old injection system of spraying water into the cylinder with the inlet air still finds favor and is employed to some extent. Cylinders are in other cases jacketed fairly well, but the valve of the slide valve types cannot of necessity be cooled, and, in addition, the entering air is in very close contact with the outgoing compressed and hot air.

Compound compression is rather rare, at least for average pressures, and consequently no attempt is made at inter-cooling, which, in the United States, is considered an important feature. After cooling, or a consistent effort to remove moisture after compression, is not considered necessary, largely because low pressures are used and transmission to any considerable distance is seldom attempted.

Contrasted from the standpoint of general appearance, that is, neatness of design, it must be admitted that the American machines have a solid, compact and business-like look which is most pleasing to the practical eye. When it comes to "finish," using the term to mean paint, varnish and nickel plating, it must be admitted that generally the Continental apparatus makes the best showing. Inspection, however, shows splendid work and materials on the essential parts of the American machines, with an accuracy which leaves little to be desired.—J. J. S., in London *Engineering Times.*

INTER-COOLERS.

Builders of air compressors and those who use compressed air will agree that the problem of heating or cooling air is a difficult one. Hot air in the cylinder of an air compressor means a reduction in the efficiency of the machine.

The trouble is, that there is not sufficient time during the stroke to cool thoroughly by any available means. Water jacketing is the generally accepted practice, but it does not by any means effect thorough cooling. The air in the cylinder is so large in volume that but a fraction of its surface is brought in contact with the jacketed parts. Air is a bad conductor of heat and takes time to change its temperature. The piston while pushing the air towards the heat rapidly drives it away from the jacketed surfaces; so that little or no cooling takes place. This is especially true of large cylinders where the economy effected by water jackets is considerably less than for small cylinders. Engineers who are shown indicator cards from large air compressors with pressure lines running away from the adiabatic, naturally regard them with suspicion and look for leaks past the piston or through the valves. Such leaks will explain many isothermal cards, and until something better than a water jacket is devised, it is well to seek economy in air compression through compounding. The great advantage of compounding is in the fact that more time is taken to compress a certain volume of air and that this air while being compressed is brought in contact with a larger percentage of jacketed surfaces. The inter-cooler which should always be used with compound machines effects a larger saving by cooling and thereby causing the air to shrink in volume between the stages. The trouble with inter-coolers is that manufacturers are too prone to build them of cheap construction, economizing in machinery and in space and losing in thermic efficiency. A properly designed inter-cooler should reduce the temperature of the air back to the original point, that is to the temperature of the intake air. It can even do more than this, especially in winter when the water used in the inter-cooler is of low temperature. A simple coil of pipe submerged in water is not an effective inter-cooler, because the air passes through the coil too rapidly to be cooled to the core, and such inter-coolers do not sufficiently split up the air to enable it to be cooled rapidly. This splitting up of the air is an important point. It will not do to depend upon baffle plates, coils and other water jacketed features unless the air is split up while being brought in contact with them. A theoretically perfect inter-cooler is one in which the entire volume of air after partial compression is made to pass through wire cloth of close mesh, each wire being a tube through which water is passed, no such device is in use, as the mechanical difficulties probably stand in the way, but it is well for engineers in drawing up specifications for air compressors to pay close attention to the inter-cooler and in fact to all jacketed surfaces. A nest of tubes carrying water and arranged so that the air is forced between and around the tubes is an efficient form of inter-cooler. If the tubes are close enough together and are kept cold, the air must split up into thin sheets while passing through. Such devices are naturally expensive, but the first cost is a small expense when compared with the efficiency of the compressor, measured in the coal and water consumed.

Receiver inter-coolers are more efficient than those of the common type because the air is given more time to pass through the cooling stages and because of the freedom from wire drawing which may take place in inter-coolers of small volumetric capacity. This wire drawing is similar in effect to insufficient area of inlet and may be noticed by putting a pressure gauge on the inter-cooler.

After-coolers are in some installations as important as inter-coolers. An after-cooler serves to reduce the temperature of the air after the final compression. In doing this it serves as a drier, reducing the temperature of the air to the dew point, thus abstracting moisture before the air is started on its journey. In cold weather with air pipes laid over the ground an after-cooler may prevent accumulation of frost in the interior walls of the pipes, for where the hot compressed air is allowed to cool gradually the walls of the pipe in cold weather act like a surface condenser and moisture may be deposited on the inside for the same reason that we have frost on the inner side of a window pane. Another advantage of the after-cooler is that it keeps the temperature of the line pipe uniform, otherwise this pipe will be hottest near the compressor, gradually cooling down and being thus subject to irregularities of expansion and contraction.

Editor Compressed Air:

In a certain experience with Air Compressors the question arose as to the quantity of water used by the water jackets on simple machines, and in the intercooler on compound machines, for example, take a simple machine 14" by 18", and a compound machine 10" by 12".

Take the temperature of water to be used at 60°, can you say how much water will be used by the water jacket on the simple machine, and how much will be used in the water jackets and intercooler combined on the compound machine? In the case mentioned the cost of water is, say, 8 cents per 1,000 gallons, and used only to operate the compressors.

All water in excess of that used in the boiler was thrown away.

Figuring coal at $2.00 per ton and a boiler that will evaporate about 6 pounds of water to each pound of coal, I would like to have your estimate as to the cost of operating each machine. Yours,

Chicago. Engineer.

The question presented here is best solved by the use of a mathematical formula. However, as the average reader of this column might get a better understanding without the use of symbols, we will try to present the matter as clearly as we know how without them.

The amount of heat taken up by a pound of water has been determined experimentally a number of times, and is a matter of common knowledge to the engineer.

The increase in temperature in compressing air is also known, for every terminal pressure or it can be easily taken with a thermometer.

Having given both the temperatures of air, before and after compression, also the temperature of entering and exit jacket water, we can obtain the pounds of water required for every pound of air (say 13 cu. ft. free air) by dividing the rise in air temperature by the rise in water temperature and multiplying this quotient by 0.2375.

There is considerable radiation going on, however, from unjacketed cylinder heads, and the above product can safely be divided by 2 or 3 to give the weight of water necessary for assumed conditions of temperature.

It is common practice to use the jacket water as feed water for the boilers.

The following is from a recent test observation:

Temp. of air at inlet	78°
Temp. of air at discharge	356°
Rise in Temp. of air	278°
Temp. of entering jacket water	46°
Temp. of leaving jacket water	94°
Rise in Temp.	48°

$$\frac{278}{48} = 5.8 \quad 5.8 \text{x} .2375 = 1.37$$

$$\frac{1.37}{2} = .68 \text{ per pound of air.}$$

Actual as found by test, .31 per pound of air. This is due to *very large* radiating surface in the plant tested and indicates that 3 or 4 would be a better divisor in that case.

If much water is used its temperature will be but little increased in passing through the jacket, and if little water is used the temperature may rise 30° or 40° in the water, but as this would still be much colder than the air, it would still play an important part in cooling the air. We give below a few actual conditions:

An 18″ x 24″ compressor (air pressure 80 pounds) used one pound of water per minute for every 14 cu. ft. of free air, and increased the temperature of water from 53° to 73°, so here it would have been better to use more water, say about a pound for 8 or 10 cu. ft. free air.

On a compound machine the quantity used was one pound of water per minute for 8 cu. ft. of free air, and increased temperature of water from 56° to 83°, or where more water was used, that is, one pound per minute to 2½ cu. ft. of free air, the temperature would be increased from 56° to 66°.—Ed.]

THE SPEED OF AIR COMPRESSORS.

BY FRANK RICHARDS.

The following letter has been handed to me:

"I have never seen in the *American Machinist* any discussion as to the proper speed of an air compressor. What speeds are and what are not practicable? It is obvious to those who have looked into the matter that the speeds of air compressors are commonly low, but whether this is imperative, or whether it is only that present practice has not yet reached the permissible speeds, is the question, and if much higher speeds may yet be employed, what are the present hindrances and what the most promising means for overcoming them? These things seem to me to offer a very good field for useful statement and discussion, and I should be much interested, and I believe many others would be, if the subject were taken up in your columns. A SUBSCRIBER."

The ultimate speed of an air compressor, like that of a steam engine, is the result of a compromise. It is of course desirable that any machine shall accomplish as much as possible, and the inevitable impulse is to speed it up. There is, however, always reached a limit beyond which the speeding up ceases to be profitable. None can be more interested in developing the highest efficiency in any class of machinery than the builders of such machinery, for those who can show the highest efficiency have the best of the argument with the customer. In their search for the higher efficiencies the builders also, if in healthy communication with the users of their machinery, have the best opportunities for learning the conditions, including in this case that of piston speed, which limit and determine the capacity. When the builders publish tables of data concerning their air compressors of different sizes and styles, including piston speeds and volumes of air compressed, we may assume that they speak from the most reliable knowledge, and that they are at the same time disposed to make as good a showing as possible. I have before me the catalogue of one of the largest and most successful builders of air compressors, in which are given the piston speeds of a large number of their machines. These speeds range from 150 feet to 620 feet per minute, the former being for little machines of only 6-inch stroke, and the latter for the largest Corliss engine compressors of 5-foot stroke.

Now, it is rather a matter of taste as to what we shall call fast and what we shall call slow. Our correspondent above would call these speeds slow, while I would not. Steam-driven air compressors usually have no governors or speed regulators, so that they may be speeded up by simply turning the throttle wheel, but not with all-around satisfaction. A large increase of speed will usually give but a small increase of delivery, and the valves and working parts of the machines suffer rapid wear or frequent breakage. Air compressors are often installed for a single job, as for operating rock-drills where a long tunnel is to be driven or a deep shaft sunk, and here little care is given to the compressor if it will but stand by the job to completion, and damage to it is little thought of if large volumes of air can be delivered, and in such service the speed limits of air compressors have been thoroughly, if not closely ascertained.

The objections to high speed for an air compressor begin, right at the beginning, with the operation of getting the air into the cylinder. During the intake stroke, as the piston recedes the air is, of course, driven into the cylinder by the pressure of the external atmosphere. To cause the air to flow in there must always be a difference of pressure between the inside and outside of the cylinder, and the pressure outside can be nothing more than the normal atmospheric pressure, so that the pressure within the cylinder on the intake stroke must always be something less than this. To increase the velocity at which the air must flow in, and especially to start the flowing of the column of air more frequently, as must be done when the speed is increased, demands a greater difference between the internal and the external pressures, or a reduced pressure within the cylinder, and this must mean that a less weight of air will constitute a cylinderful, and less air will be compressed and delivered per stroke.

An additional loss is entailed by an increase of speed in the case of the two-stage compressor, as it must necessarily affect, and always disadvantageously, the efficiency of the intercooler. The intercooler is the only justification of the two-stage compressor, and a two-stage air compressor without an efficient intercooler is a mechanical absurdity. Power is saved by cooling the air after it is partially compressed and so reducing the volume to be operated upon in the second cylinder. The best intercooler at its best is not too efficient, and as when the speed of the compressor is increased the heated air must pass through it more frequently and more rapidly, it cannot be as completely cooled.

An increase in the speed of the air compressor means also increased difficulty in properly lubricating the cylinder. With an inital temperature of 60 degrees Fahrenheit, the final temperature of the air in the cylinder of a single-stage air compressor when delivering air at, say, six atmospheres is above 400 degrees, while in the first cylinder of a two-stage compressor it is nearly 300 degrees, so that the difficulty of maintaining proper lubrication may easily be appreciated. The water jacket may not count for much in its effect upon the air within the cylinder during the compression stroke, but it is of great service in keeping the inner surface of the cylinder at least cool enough to prevent the actual burning of the oil. This service is quite seriously impaired if the piston speeds are much increased. The failure of the lubricant, and the burning and cutting of the cylinder and valve surfaces are familiar and costly experiences accompanying the reckless speeding up of compressors.

There is positive danger in running a compressor at such a speed that the air cooling devices employed do not have sufficient time to do their work completely. Serious explosions have been caused by the ignition of mixtures of oil vapor and air in the cylinders or other parts. One such accident occurred within my knowledge quite recently, in which the intercooler between the cylinders of a compound compressor was blown to pieces, and an important service was interrupted for a long time in consequence. In some cases men have been killed by similar accidents.

And then there is the trouble with the pounding of the valves. The maintenance of the valves of the compressor is usually the largest item of repairs. They are usually poppet valves, and the elasticity of the air causes them to move in both directions at a lively gait and to strike hard, and of course this is much worse at high speeds. There may yet be devised valves with sliding movements that will avoid some of the most objectionable features of the poppet valves, and, so far as they are concerned, make somewhat higher speeds permissible, but they will be more than likely to bring other troubles in their train as great as those which they attempt to cure, and especially in the difficulty of proper lubrication.

Thus there are several particulars to be suggested which tend to limit the profitable speed of the air compressor. They are none of them of a character to be handled with figures and formulas, but experience speaks with sufficient clearness and sharpness in the matter. It is not probable that much higher speeds will be established for air compressors than those now prevailing. The limit will, of course, be where it does not pay, all things considered to run any faster.—*American Machinist.*

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215 Heath St.,
Roxbury, Mass., May 29, 1899.

Editor COMPRESSED AIR:

Being a reader of your paper, and being interested in Carbonic Acid Gas Compressors, I would like to ask you if you know of any lubricant for use on such Carbonic Acid Gas Cylinders that no trouble will occur from the gas being impregnated with foreign odors. What would you advise as a lubricant for same? This is for a compressor for 1,200 lbs. pressure. Also what would be the best arrangement for stuffing boxes to prevent leakage? Yours very truly,

J. J. FINLAY.

Glycerine is used where perfect freedom from odor is required. Cottonseed oil has been used, and if applied sparingly in the stuffing boxes and cylinders is almost odorless. For packing the piston rod of a double-acting carbonic acid gas pump, any of the mixed fibre and rubber packings; the "Garlock" or "Selden" are good. For a plunger pump, cupped leather rings should be used.

COMPOUNDING AIR COMPRESSOR CYLINDER.

The air end of a compressor appears at present to be going through the stages followed by the steam engine during the early history of its development. Low pressures and plain slide valves in the steam engine have given place to higher pressures, compounding and Corliss and other forms of cut off valves. But a few years ago there was but one manufacturer of air compressors in America who built compound machines and who applied positive or mechanically moved valves to the air cylinders. This condition, of course, was largely due to the fact that compressed air was looked upon as a luxury which could only be produced at a sacrifice, and which could only be used in work like caisson sinking, tunnel driving and mining. It is true that there were a few other limited applications of compressed air, but the quantities of air used was so small, that little interest was taken in the item of cost of production. The pace set by electricity, even in mining, and the growing use of compressed air in shops, about railroads and other industrial enterprises brought the question of cost of production to the attention of builders in such a way that it became an important condition in competition to produce air power at low cost, and it has been found that there has been more gained through compounding than through anything else.

The following table will serve to illustrate the large saving that it is possible to effect by compounding. This table gives the percentage of work lost by the heat of compression, taking isothermal compression or compression without heat as a base:

TABLE 14.

Gauge Pressures.	One Stage.	Two Stage.	Four Stage.
	N=1.408		
60	30.00 %	13.38 %	4.65 %
80	34.00 "	15.12 "	5.04 "
100	38.00 "	17.10 "	8.00 "
200	52.35 "	23.20 "	9.01 "
400	68.60 "	29.70 "	12.40 "
600	83.75 "	32.65 "	15.06 "
800	90.00 "	35.80 "	16.74 "
1000	96.80 "	39.00 "	16.90 "
1200	106.15 "	40.00 "	17.45 "
1400	108.00 "	41.60 "	17.70 "
1600	110.00 "	42.90 "	18.40 "
1800	116.80 "	44.40 "	19.12 "
2000	121.70 "	44.60 "	20.00 "

In columns 2, 3 and 4 no account is taken of jacket cooling, it being a well known fact among pneumatic engineers that water jackets, especially cylinder jackets, though useful and perhaps indispensable are not efficient in cooling especially so in large compressors. The volume of air is so great in proportion to the surface exposed and the time of compression so short, that little or no cooling takes place. Jacketed heads are useful auxiliaries in cooling, but it has become an accepted theory among engineers that compounding or stage compression is more fertile as a means of economy than any other system that has yet been devised. The two and four stage figures in this table (columns 3 and 4), are based on reduction to atmospheric temperature 60° Fahrenheit between stages. This is an important condition and in order to effect it much depends on the intercooler. In this device we have a case of jacket cooling which in practice has been found to be efficient where engineers specify intercoolers of proper design. While cooling between stages we may split the air up into thin layers and thus cool it efficiently in a short time, a condition not possible during compression. This splitting up process should be done thoroughly, and while it adds to the cost of the plant to provide efficient coolers, it pays in the end. A rule which might be observed to advantage among engineers is to specify that the manufacturer should supply a compressor with coolers provided with one square foot of tube cooling surface for every ten cubic feet of free air furnished by the compressor when running at its normal speed.

Referring again to the table, we learn that when air is compressed to 100 lbs. pressure per square inch in a single stage compressor without cooling, the heat loss may be thirty-eight per cent. (38%). This condition of course, does not exist in practice, except perhaps, at exceedingly high speeds, as there will be some absorption of heat by the exposed parts of the machine. It is safe however to say that in large air compressors that compress in a single stage up to 100 lbs. guage pressure, the heat loss is thirty per cent. (30%). This as shown in the table may be cut down more than one-half by compounding or compressing in two stages, and with three stages this loss is brought down to eight per cent. (8%) theoretically, and perhaps to three or five per cent. (3% or 5%) in practice. As higher pressures are used, the gain by compounding is greater.

FIRING.

Ignition in compressed air pipes, commonly known as firing, was referred before in these columns. We are not satisfied that the question has been thoroughly ventilated, hence further discussion of the subject seems advisable. Compressed air claims to be and is a safe power. Occasionally we hear of a case of firing, which to some may appear to be a serious objection to the use of air; but if the causes are known and understood, and due care observed, firing becomes merely a matter of carelessness. A building made of wood is not considered unsafe because it will burn when ignited. Compressed air is not inflammable, but during compression by mechanical means, it is found advisable to use oil, and this oil, or the gases from it, are the sources of combustion. In most cases firing may be traced to the use of poor oil, but in others too much oil sometimes causes ignition. It is a common mistake of engineers in charge of compressors to feed oil too rapidly to the air cylinder. It is simply necessary to supply oil enough to keep the interior of the cylinder and the moving parts moistened. Where steam is used there is a tendency to cut away the oil, hence engineers grow accustomed to feeding a larger supply than is required in an air cylinder. There is nothing to cut or absorb the oil in the air end; in fact, it is only after a considerable lapse of time that oil can get away when fed into the cylinder. There is no washing tendency as with steam, and a drop now and then is all that is required to keep the parts lubricated. Where too much oil is used, there is a gradual accumulation of carbon, which interferes with the free movement of the valves and which chokes the passages, so that a high temperature may for a moment be formed and ignition follow. It is well to get the best oil, and to use but little of it.

There are cases where firing has arisen from the introduction of kerosene or naphtha into the air cylinder for the purpose of cleaning the valves and cutting away the carbon deposits. Every engineer knows how easily he may clean his hands by washing them in kerosene; and as this oil is usually available, we have seen men introduce it into the air cylinder through a squirt-can at the inlet valve. This is a very effective way of cleaning valves and pipes, but it is a source of danger, and should be absolutely forbidden. High grade lubricating oils are carefully freed of all traces of benzine, naphtha, kerosene and other light and volatile distillates. The inflammability of such oils is so acute that it is a dangerous experiment to introduce anything of this kind into an air cylinder; and if any of our readers have had an explosion in a case where the engineer uses kerosene, it may be traced to this source. Closed inlet passages leading to the air cylinder through which the free air is drawn from outside the building have many advantages, but one seldom thought of is that they interfere with the tendency of the engineer to squirt kerosene into the cylinder.

Soft soap and water is the best cleanser for the air cylinder, and it is recommended even in cases where the best oil is used. Long service will result in more or less accumulation of carbon; hence it is advised that engineers, once or twice a week, or oftener if necessary, fill the oil cup with soft soap and water and feed it into the cylinder as the oil is fed.

FIRING.

Our attention has been attracted to a case where a receiver took fire on the inside repeatedly. On examination it was found that the drain had only let the water off, leaving a sediment of oil. This was immediately cleansed and the drain enlarged, but it did not, however, remedy the cause of complaint, although it improved matters somewhat.

On asking for advice, they were told that there was something abnormal about the condition of the plant, and were advised to resort to means of cleaning out the compressor and receiver at least once a month, investigating the air compressor to see if the valves were not clogged up, thus causing an excessive temperature in the air cylinder. They were then recommended not to use oil for one day, but instead to use soap suds in the air cylinder, admitting them by the regular lubricator. This would clean out the cylinder. Next a good grade of air cylinder oil should be secured, and only a proper amount of it used—say one drop per five minutes.

These instructions remedied the trouble almost immediately, and we quote the fact thinking the matter might prove of some interest to our readers in general.

The Clifton Colliery Co., Ltd.,
Nottingham, Eng., June 29, 1897.

Editor Compressed Air:

Dear Sir:—I notice in Compressed Air that you invite correspondence from engineers and others interested in compressed air. We have a pair of air compressing engines, cylinders 30 inches diameter by 4 ft. stroke, working at a pressure of 60 lbs. per square inch. The point I particularly wish to bring to your notice is that we have had two explosions in the air cylinders, which is believed to have been caused by the oil used for lubricating the pistons in the cylinders vaporizing and then getting ignited by the high temperature produced by the compression of the air. The oil used was guaranteed to have a flash point of 554° F., and ignition point of 606° F. There have been four other similar explosions with air compressing engines at various collieries in this country. Have you had any other explosions of this kind brought to your notice, and if so, has the cause been made out? If the cause of these explosions could be cleared up it would be very interesting and useful information to users of air compressing engines. If the cause be really due to the oil vaporizing and then becoming ignited, it will be necessary, to prevent explosions from this cause, to use some other material in lieu of oil for lubricating the pistons, or to adopt some other and more effective means of cooling the air during compression, to prevent such high temperatures being produced as will vaporize oil. If you are able to throw any light on this matter, you will greatly oblige,

Yours faithfully, HENRY FISHER.

Ignition in compressed air discharge pipes and passages is not uncommon in America. At times this ignition is in the nature of an explosion. Two Air Receivers were blown up during the construction of the New York Aqueduct, in one case the engine room was destroyed by fire resulting from this explosion. We have also records of two other cases where spontaneous explosions in the Air Receiver have resulted in the destruction of the engine room by fire. Other instances occur where ignition takes place near the Air Compressor, the pipes becoming red hot at the joints. This ignition has been known to extend into the Air Receiver, and in one instance, the flames were carried down into the mine by the compressed air.

In all such cases large volumes of compressed air were used. It is plain that the cause of the explosion or ignition is an increase of temperature above the flash point of the oil which is used to lubricate the Compressor. A thick or cheap grade of cylinder oil should never be used in an Air Compressor. Thin oil which has a high flash point and which is as free from carbon as conditions of lubrication will admit, is the best oil. Our correspondent calls attention to explosions where the flash point of the oil is 554 degrees F., and ignition point 606 degrees F. We know of an instance where ignition took place with oil which had a flash point of 575 degrees F., ignition point 625 degrees F. Conditions were similar to those mentioned by our correspondent, that is the air was compressed to about 60 lbs. per sq. in. gauge pressure. If the temperature of the air before admission to the Compressor is 60 degrees F., and it is compressed to 58.8 lbs. gauge pressure, the final temperature, where no cooling is used during compression, will be 369.4 degrees F., or a total increase of 309.4 degrees. If air is admitted at 60 degrees F., is compressed without cooling to 73.5 lbs. gauge pressure, the final temperature will be 414.5 degrees F., and the total increase of temperature 354.5 degrees. Under such circumstances the question naturally arises how is it possible when using oil with an ignition point of over 600 degrees to get an ignition, especially as water jackets and other methods of cooling are used which should reduce the final temperature? The figures are also based on dry air which increases in temperature during compression to a greater degree than moist air, and it is known that air that is used in compressors is never very dry. The theoretical figures show that in order to get ignition with the oil mentioned, the gauge pressure should be about 200 lbs. per sq. in., where no cooling takes place.

It is plain that there must be an increase of temperature or ignition would not take place. This increase of temperature may result either from an increase of pressure which is not recorded on the gauge, or there may be an increase of temperature without a corresponding increase of pressure. Take the first instance. and it is not difficult to understand that an air compressor might deposit carbon from the oil in the discharge passages or discharge pipes which in the course of time will accumulate and constrict the passages so that they do not freely pass the volume of air delivered by the compressor, hence a momentary increase of pressure might exist in the cylinder heads or in the discharge pipe which leads from the air cylinder to the receiver; this momentary increase of pressure would surely carry with it an increase of temperature which might exceed the ignition point of the oil. A badly designed compressor with inefficient discharge passages might produce this trouble. Too small a discharge pipe or too many angles in discharge pipes might also tend to produce explosions. But we have known instances where ignition has occurred in a well designed system, hence we must look for other causes. In our judgment the majority of cases may be traced to an increase of temperature without an increase of pressure; this increase of temperature can only be excessive where the temperature of the incoming air is excessive. A hot engine room from which air is drawn into the cylinder is a bad condition. We have known cases where the incoming air was drawn from the neighborhood of the boiler, the temperature being close to 150 degrees F. This means, of course, that if the total increase of temperature when air is compressed to 73.5 lbs. gauge pressure is 354.5 degrees, the temperature of the initial air should be added to this figure and that the final temperature might be 504.5 degrees.

But we have known ignition to take place when the temperature of the incoming air was normal, when the discharge passages and pipes were free and of ample area, hence we must look for some other cause. The only possible explanation is that the temperature of the incoming air is made excessive by the sticking of one or more of the discharge valves, thus letting some of the hot compressed air back into the cylinder to influence the temperature before compression. When a piston of an air compressor has forced a cylinder volume of air through the discharge valve, and when this piston has its direction of movement reversed there will immediately be a tendency of the air just compressed and discharged to return to the cylinder. In this it is checked by the discharge valve, but through long and constant use these discharge valves become encrusted with carbon and are not free to move, hence there may be a moment when one of these valves sticks, or it may not seat properly; in either case there will be some hot compressed air in the cylinder when the piston starts on its return stroke of compression, the air may have lost its pressure, but not its temperature, and it is not difficult to understand a leaky discharge valve letting enough air back into the cylinder to increase the initial temperature to two or three hundred degrees. If so, and we are compressing air to 73.5 lbs. gauge pressure we have say 300 degrees temperature in the free air before compression, and as the increase is 354.5 degrees, the resulting temperature might be 654.5 degrees.

As a remedy we would suggest more care in selecting the best air compressor and in frequent cleaning of the discharge valves and passages. The best air compressors are built so that the discharge valves may be readily removed; these valves should be cleaned regularly once a week by the engineer, who should make sure that they fit properly. It is impossible to get good lubricating oil that is free from carbon, hence there will always be more or less carbon deposited on the discharge valves, but this must not be allowed to accumulate.

Inter-coolers between air cylinders and after-coolers between final cylinder and receiver are also recommended. The best inter-coolers are made of nests of brass tubes, the air passing around the tubes and the water through them, hence there is a thorough splitting up of the air and efficient cooling. One of these coolers located in the discharge pipe will absolutely prevent the passage of flame and will insure the protection of the mine against fire even though there be ignition at or near the air cylinder.

AN EXPLOSION IN THE RECEIVER OF AN AIR COMPRESSOR.

The past occurrences of explosions in air compressors receive additional interest from the fact that an explosion has lately taken place in the receiver of an air compressor in Saxony, while one also occurred in the air compressing engines at the Clifton colliery, near Nottingham. The *Gluckauf* report gives the following as the probable cause of the explosion: In the valve-chest of the air cylinder, on the slide valves and on the inner surface of the compressed air pipes, a soot-like residue was found, the origin of which must evidently be referred to the employment of the lubricant; and this residue showed traces of coke formation, thus leading to the conclusion that ignition and combustion must have occurred. This view of the question is strengthened by the circumstances that the residue entered into partial combustion after the explosion, and that previous ignitions of the lubricant, owing to heating of the engine slide-valves, had been observed. The lubricant possesses in common with other organic substances, the property of decomposing at high temperatures, forming gaseous products consisting of hydrocarbons with resinous residue. The incrustation on the valve-chest of the air cylinder and the compressed air pipes proves that such chemical changes took place owing to high temperatures. The gaseous constituents thus formed must have passed, with the compressed air, into the receiver, and have formed there, as well as in the pipes and valve-chests, a highly explosive gaseous mixture which, on being ignited, was capable of causing a very violent explosion. The action of such an explosion must have been so much the more intense as the gaseous mixture was subject to a pressure of nearly 4¾ atmospheres (70 lbs. per square inch) over that of the atmosphere; and this high pressure affords an explanation of the unusually violent mechanical action manifested.

As is evident from the above explanation, the explosion must have originated in the lubricant, and, owing to the great importance of the question, it appeared necessary to determine the composition and also the flashing point of the lubricant employed—which was done at the Royal Testing Station, Berlin. The tests showed the lubricant in question to be a good one and suitable for the purpose for which it was employed. The specific gravity was found to be 0.89 at a temperature of 15° C. (59° F.), while it was proved to be free from animal and vegetable fat and to consist of hydro-carbons which have taken up only a small quantity of oxygen. The ignition point, on the lubricant being heated in open crucibles, is near upon 291° C., the boiling point being 375° C. "This lubricant, is, therefore," states the report, "entirely free from hydrocarbons of low boiling point, and consists of hydrocarbons differing so little from one another that great care must have been exercised in its production." If such an oil be allowed to drop into red-hot retorts it will become decomposed, like all other organic substances, and form gaseous products as well as more or less coke; and, by the evaporation of 20 grammes (2-3 oz.) of such an oil, about 1 cubic metre (35 cubic feet) of air may be rendered explosible. If now, notwithstanding this property of the lubricant, so considerable a fatty residue as that described was found in the valve-chests, this circumstance proves that, in consequence of the insufficient cooling down, and consequently great elevation of temperature, considerable quantities of the oil were gradually decomposed in the valve-chest; and this decomposition, with simultaneous formation of an explosive gas, was favored by the large surface of the valve-chest and the comparatively large quantity of oxygen drawn in. Consequently, the accident must be attributed primarily to insufficient cooling down of the valve-chests.—*Colliery Guardian.*

EXPLOSIONS AND IGNITIONS IN AIR COMPRESSORS AND RECEIVERS.*

BY ALFRED GEORGE WHITE.

The attention of engineers in this and other countries has from time to time been drawn to the results of explosions which have occurred in air compressors and receivers. In some cases the cause has been ascertained; but so far as the author is aware, no systematic investigation of the subject has been made with a view to obviate the disastrous results of explosions and ignitions, which the author believes to be more frequent than is generally known. The following account of a recent occurrence of this nature which came under the author's notice, with a description of the compressor, may help to throw light on the subject.

The air compressor was employed for the purpose of supplying air to rock drills and hoisting engines in a copper mine in Norway. The usual working pressure being between 50 and 60 lbs., the safety valve of the receiver was loaded to blow off at the latter pressure. It had been continuously at work for seventeen years, and was of English make, with two horizontal air cylinders 24 in. in diameter and 36 in. stroke. The motive power was supplied by a high-speed turbine on a horizontal shaft, upon which a pinion was keyed, gearing with a spur wheel on the compressor driving shaft. On this shaft also there were keyed a heavy fly-wheel and two crank discs, which worked the air-cylinder pistons by means of connecting rods in the usual way The inlet valves were plain circular valves with stems, four being placed in each cover of the air cylinders. Bell-crank levers fitted with counterweights were attached to the valve stems for closing the valves at the end of each stroke before compression commenced, the atmospheric pressure opening them simultaneously during the inward or inspiration stroke. The outlet valves were of the ball type, of solid brass, fitted in brass seats, two on each delivery port on the top of the cylinders, their action being regulated by the pressure of air in the cylinders and receiver.

The cooling arrangements consisted of an open water jacket round each cylinder, the water supply being admitted near the surface on one side and discharged through an overflow pipe of ¾ in. bore on the other side at the same level. The water surrounded the cylinders and air delivery ports, and stood about 1 in. deep over the latter. The water supply and discharge being placed

* Excerpt transactions Inst. C. E.

at the same level near the top, the water simply flowed over the surface and did not circulate round the cylinder. It will thus be seen how imperfect the cooling action was in this instance.

The oil used in lubricating the air cylinders was composed of crude fish oil and tallow mixed together, and was put into the cylinders through the inlet valves by a common oil can. The lubrication therefore depended entirely on the attention and skill of the attendant, and no doubt at times a greater or less quantity of oil was poured into the cylinders than was required, and any surplus was driven out through the delivery valves into the air pipes and receiver.

The air receiver, placed inside the compressor-house, consisted of a wrought-iron cylinder about 20 ft. long by 4 ft. 6 in. in diameter, and was connected to the air cylinders by an 8 in. cast-iron pipe. This pipe had an ordinary spigot and socket joint on the horizontal portion between the receiver and compressor. The joint was made of lead, run in and caulked, but owing to the contraction and expansion of the pipe it leaked, and had to be renewed from time to time. On the day of the ignition, and shortly before its occurrence, this joint had been renewed by running molten lead against a hempen gasket, and very soon after the compressor was started, flames blew out in great volume from the safety valve on the air receiver. The attendant succeeded in stopping the compressor within a few moments, but the flames continued for some time and set fire to the compressor-house, which was built of timber, and in the course of half an hour, it was burnt to the ground.

The author considers the cause which led to the fire breaking out in the receiver to have been the ignition of the oil accumulated there and the use of molten lead in making the spigot joint of the pipe referred to, by which the oil must have been first ignited in the pipe. On starting the compressor, the draught of air created would cause the ignited oil in the pipe to set fire to the oil in the receiver, or the fire may have already spread to the receiver. The products of the decomposition of the large quantity of oil in the receiver would, in conjunction with the air, form an explosive mixture, which, failing relief through the safety valve, might have resulted in an explosion. The cause of all explosions and ignitions of this nature can be traced to these phenomena. The case which occurred at the Westphalia Colliery in 1896 resulted in destruction of the air receiver by bursting. In the present instance the rise of pressure does not appear to have been sudden enough to burst the receiver, and the relief afforded by the safety valve averted this catastrophe. When the receiver was opened it was found to contain a quantity of charred oil in the form of a sticky paste about 2 in. deep in the bottom. The air pipes were coated inside with a similar substance. The damage done to the compressor and receiver was, however, considerable, the riveted joints of the latter being started and the lead joints of the contiguous pipes and connections melted out. One cylinder of the compressor and one crank disc was cracked, as also were two arms of the turbine, which was placed inside the house burnt down. The latter effects were chiefly due to the subsequent fire and the water which was thrown upon the heated metal.

The primary cause of this fire was the accidental ignition of the oil by the admission of molten lead into the pipe referred to, but the same effect may be produced by an increase of air pressure, and consequently of temperature, to a point at which the decomposition of the oil and ignition of the air and gas mixture take place, or by the admission of coal dust or inflammable matter into the valves or cylinders of the compressor. The use of oils possessing low-flashing temperatures and the increase of temperature from friction of metallic surfaces improperly lubricated are also elements of danger, besides defective water-jacketing and cooling arrangements.

The temperature of air compressed adiabatically to 58.8 lbs. per square inch gauge pressure from 60° F. initial temperature is 270° F. The air admitted to a compressor is, however, sometimes at a much higher temperature than 60° F., and may in some instances be as high as 100° F.; the temperature of this air when compressed to 58.8 lbs. per square inch gauge pressure will rise to about 430° F., and when compressed to 75 lbs. per square inch, the final temperature is nearly 500° F. This shows the importance of (1) a low initial air temperature; (2) adequate cooling of the air before or during compression; and (3) the use of lubricating oils of high-flashing and ignition points.

A similar ignition to the one mentioned by the author occurred in 1897 in the Clifton Colliery air receiver, and tests were made of the oil then in use, giving the following results:†—

	Flashing Point. Close Test.	Ignition Point.
Sample No. 1	454° F.	594° F.
Sample No. 2	460° F.	588° F.

Lubricating oils of high-class manufacture, distilled from petroleum and used for high-pressure steam engines, give flashing points of from 530 to 560° F. (open test), and ignition points of from 600 to 630° F. It is, however, sometimes the case that oils having a high flashing point are mixed with others having a much lower one, and therefore a guarantee should be demanded, or a test of the oil should be made. The flashing point of the oil used in the compressor described by the author, taking that of Arctic sperm, would be only 446° F.

It is evident that, given reliable oil of high-flashing point and normal conditions of working for a well-designed air compressor, the danger of ignition is practically eliminated, as shown by the following table:—

TABLE 15.

Working Pressure of Air.	Initial Temperature of Air.	Final Temperature of Air Compressed Adiabatically.	High Temperature Oil.	
			Flashing Point.	Ignition Point.
Lb. per Square Inch.	°F.	°F.	°F.	°F.
58.8	60	370	530	600
58.8	100	435	560	630
75.0	100	500	560	630

The final temperature of the air will, of course, be diminished when the air is cooled during compression, in proportion to the efficiency of the cooling

† Transactions of the Federated Institution of Mining Engineers, vol. xiv., part 4.

apparatus; and in hot countries, where the initial temperature of the air is high, the addition of an apparatus for cooling the air prior to admission to the compressor, in addition to other cooling arrangements, would be attended with economical and advantageous results.

With reference to the design of air compressors, the author is of opinion that the following points require special attention:—(1.) The arrangement of the air admission to the compressor in such a manner that the lowest possible initial temperature is obtained, and the air protected from all dust or inflammable matter and sparks. (2.) Efficient water-jacketing of the air cylinders by closed jackets, with water supply under pressure, and, in case of double-stage compressors, an intermediate cooler of adequate capacity. (3.) The more general adoption of compound or double-stage compressors with intermediate coolers, whereby a more effective cooling of the air and greater economy of power are attained. (4.) The employment of automatic lubricators on the air cylinders. (5.) The use of pyrometers, whereby the temperature of the air in each cylinder and in the receiver can be seen by the attendant. (6.) The reduction of clearance at the ends of the cylinders and of the valves ports to a minimum. (6a.) The design of valves having definite action without friction in working, of ample area and readily removable for inspection or cleaning. (7.) The use of tested oils having high flashing points. (8.) Proper arrangements for draining and blowing off accumulated oil in both air receiver and pipes.

About two years previous to the ignition described by the author, an explosion occurred in one of the cylinders of the same compressor, resulting in destruction of the cylinder. The cause of this was not ascertained at the time, but it was probably due either to excessive friction in the cylinder or defective action of the valves, causing an increase of temperature and consequent decomposition of the oil, or to an increase in the air pressure sufficient to burst the cylinder.

The production of fire by means of the sudden compression of air is known to the aborigines of the Philippine Islands, who employ a small tube fitted with a plunger, which, on being sharply struck, ignites combustible matter placed at the bottom of the tube.

EXPLOSIONS IN AIR.

A serious accident occurred recently in the Tintic District at the Mammoth Mine, Mammoth, Utah. An explosion occurred in the air cylinder of a Duplex Corliss Compressor. The accident was very severe, resulting in the death of the Assistant Engineer, Mr. Charles Meranda, and injury to the Chief Engineer, Mr. William Nesbit. The cause of the explosion has been attributed to the oil in the cylinders. The explosion was terrific; the back head was shattered, while the back flange of the cylinder was torn off at several points, particularly at the top, where a portion of the cylinder was blown away.

At the time of the explosion the Chief Engineer, Mr. William Nesbit, was kneeling in front of the cylinder manipulating the inlet valve pin, while his assistant, Mr. Charles Meranda, was standing close by. Meranda was hurled under a work-bench about 10 ft. distant, badly mangled, while Nesbit struck the wall in an unconscious condition. These two men were alone in the engine room at the time, and we understand that when Nesbit regained consciousness he realized that the compressor was running away and staggered to the throttle, falling down three or four times in attempting to shut off the steam, which he finally did, thus preventing the destruction of the compressor, as the governor was rendered useless by the explosion. Parts of the cylinder head tore out a window and shot 50 or 60 feet beyond the building, and we hear that a piece of Meranda's thigh flesh, the size of your two fists, was found on an ore dump 150 feet away. At the time of the accident they were compressing air to 80 pounds at about 60 R. P. M.

Such explosions fortunately are rare in air compressor service, and they serve to emphasize the importance of using only the best grade of air cylinder oil. Cheap oil has no place in air passages and even with the best oil, explosions may occur if too much oil is fed into the cylinder and if sufficient care is not taken to keep the valves and ports clean and free from oil deposit. A form of kerosene engine is made to act on the principle which is illustrated by explosions in the cylinders of air compressors. This oil engine has a chamber which is at first warmed by the heat of a lamp applied externally. After there is sufficient heat to cause the explosion of the kerosene, the lamp is removed and the temperature of the chamber is sufficient to continue these explosions at each return stroke of the piston, which forces hot compressed air in contact with this oil vapor. Here is an engine acting on the explosive principle similar to that in use in all oil engines, yet there is no spark or other direct means of ignition. In the cylinder of an air compressor as the piston approaches the head it compresses the air to a point which in both pressure and temperature is sufficient to cause an explosion provided there is oil vapor present, the flashing point of which is about the same as the temperature in the cylinder. This flashing point of oil is something of a mystery when the oil is used in compressed air. Ordinarily, the flashing point of oil can be easily determined, but when used in compressed air, either the oil is dis-associated and separated into component parts or its flashing point is lowered by contact with the heavily oxygened air chamber. Sufficient importance is not given to the water jackets as a means of preventing explosions. In the case of the oil engine referred to the heat of the cast iron effects the explosion and in an air cylinder we have a similar condition in the shape of a hot cast iron cylinder or head. It is not sufficient to water jacket the cylinder only, but if the heads are not jacketed they are likely to become hot and to materially aid in causing explosions. This is especially true where the air is used at high pressures, and where the compressor is run at high speed. It is merely necessary to put one's hand upon the head of an air cylinder in the engine rooms where compressors are used, to note that this piece of metal is very hot.

EXPLOSIONS.

Continuing the important subject of explosions in compressed air passages, which was alluded to in our last issue, we are convinced that in some cases the cause of the explosion may be attributed to the fact that one or more of the discharge valves fails to close at the end of the stroke of the air compressor, and thus a portion of the hot compressed air from the receiver is let back into the cylinder. The result of this is that when the piston returns for another stroke of compression it acts against a cylinder full of hot compressed air, both temperature and pressure being higher than normal. It is quite possible that the discharge valve which has admitted this hot air may close before the return stroke of the piston. Hence, we have bottled up in the cylinder an unnatural condition of things, which will result in a temperature higher than normal as soon as this air has been compressed to receiver pressure. If we admit air into the cylinder of the compressor at a temperature of 60 degrees F., and at normal atmospheric pressure, this temperature will reach about 415 degrees F. when the gauge registers 75 lbs., thus showing an increase of temperature of 355 degrees. Now, it is a well known fact that all good air compressors have cooling devices, such as water jackets, for the purpose of keeping down this temperature during compression, but it is also quite as well known among those who had had experience in this matter that in large cylinders these water jackets have very little cooling effect. Hence, in air compressor cylinders, as usually made, we may expect approximately the large increase of temperature hereinbefore mentioned. To illustrate this still further, when a volume of air is compressed without cooling to 21 atmospheres (294 lbs. gauge pressure) it will occupy a volume a little more than one-tenth. The total increase of temperature, assuming that we start at an initial temperature of zero, is about 650 degrees; but if we start with an initial temperature of 60 degrees, the total increase is about 800 degrees, and if we start with 100 degrees initial temperature the increase is 900 degrees. When free air is admitted to a compressor cold, the relative increase of temperature during compression is less than when the air is admitted hot. This being the case, we see how important it is to admit air to the cylinders of an air compressor at low temperature, for a high initial temperature means a greater increase of temperature throughout the stroke; and only a slight defect in a discharge valve might result in the destruction of the machine, because of the admission of a small quantity of hot compressed air, thus raising the temperature in the cylinder beyond the flashing point of the oil. We are inclined to think that a leaky discharge valve is responsible for many serious accidents in air compressor service, and this points to the importance of the discharge valve as a feature of the air compressor. It should be designed in such a way as to at least minimize the liability of sticking or leaking. Even with the best form of discharge valve trouble may arise because of the use of bad oil or of too much good oil. Engineers are apt to suppose that an air cylinder of a compressor requires oil just as a steam cylinder does. This is a mistake. Too much oil results in obstruction of the parts and passages, and through the heat a carbon deposit is formed, which causes sticking. This carbon deposit is nothing more than what will result if oil is placed on a hot shovel and allowed to evaporate, except that in the cylinder of an air compressor this evaporation process is going on all the while, and in the course of time a hard, black deposit is formed which interferes with the proper working of the parts. Some engineers find out that this deposit is easily cut away by kerosene oil, and in their anxiety to take the quickest way to remedy the difficulty they throw kerosene oil into the inlet valve—a course which sometimes proves to be the surest way out of all earthly difficulties. Kerosene oil has a flashing point of 120 degrees F., and it is not difficult to understand what the cause of the explosion is under such circumstances.

Air compressors should be provided with discharge valves that are easily accessible and engineers in charge of the plants should clean out all discharge valves and passages at least once a week. Care should also be taken to use a good grade of non-carbonizing oil of a high flashing point, and to use very little of it; one drop every five minutes is enough. Care should also be taken to see that the pipes and passages leading from the discharge valves to the receiver are large and accessible. The receiver itself should be provided with a man-hole and be cleaned out at regular intervals. If, as we have found in some cases, the trouble continues to exist, except that it is now transferred to the pipe line, our next remedy should be to place an after cooler at the receiver, and in this way reduce the temperature of the air to normal condition before it is started on its journey. This is invariably done in pneumatic service, such as switching and signaling work, where it is important to maintain uniform conditions in the air pipe and where dry air is essential. This after cooler is nothing but a surface condenser, which reduces the temperature of the compressed air, causing it to deposit its moisture. There can be no trouble from explosions in a pipe line equipped in this way, and where these lines are long, and where the pipe is laid under ground, the after cooler serves also to prevent much trouble from expansion and contraction. Air pipes laid on the surface in an irregular way over the ground will usually adjust themselves to changes of temperature, but if boxed up or buried the joints are apt to give trouble, unless allowance is made for expansion and contraction, and this is minimized where the compressed air, after leaving the receiver, is brought down to normal conditions.

AIR COMPRESSOR EXPLOSIONS.*

By Alfred George White.

EXPLOSION IN A COPPER MINE.

The air compressor was employed for the purpose of supplying air to rock drills and hoisting engines in a copper mine in Norway. The usual working pressure being between 50 and 60 pounds, the safety valve of the receiver was loaded to blow off at the latter pressure. It had been continuously at work for seventeen years, and was of English make, with two horizontal air cylinders, 24 inches in diameter and 36 inches stroke. The motive power was supplied by a high-speed turbine on a horizontal shaft, upon which a pinion was keyed, gearing with a spur wheel on the compressor driving shaft. On this shaft also there were keyed a heavy flywheel and two crank disks, which worked the air-cylinder pistons by means of connecting rods in the usual way. The inlet valves were plain circular valves with stems, four being placed in each cover of the air cylinders. Bell-crank levers fitted with counter-weights were attached to the valve stems for closing the valves at the end of each stroke before compression commenced, the atmospheric

*Abstract from British Institute Civil Engineers.

pressure opening them simultaneously during the inward or inspiration stroke. The outlet valves were of the ball type, of solid brass, fitted in brass seats, two on each delivery port on the top of the cylinders, their action being regulated by the pressure of air in the cylinders and receiver.

The cooling arrangements consisted of an open water jacket round each cylinder, the water supply being admitted near the surface on one side, and discharged through an overflow pipe of ¾-inch bore on the other side at the same level. The water surrounded the cylinders and air-delivery ports, and stood about 1 inch deep over the latter. The water supply and discharge being placed at the same level near the top, the water supply flowed over the surface and did not circulate round the cylinder. It will thus be seen how imperfect the cooling action was in this instance.

The oil used in lubricating the air cylinders was composed of crude fish oil and tallow mixed together, and was put into the cylinders through the inlet valves by a common oil can. The lubrication, therefore, depended entirely on the attention and skill of the attendant, and no doubt at times a greater or less quantity of oil was poured into the cylinders than was required, and any surplus was driven out through the delivery valves into the air pipes and receiver.

The air receiver, placed inside the compressor-house, consisted of a wrought-iron cylinder about 20 feet long by 4 feet 6 inches in diameter, and was connected to the air cylinders by an 8-inch cast-iron pipe. This pipe had an ordinary spigot and socket joint on the horizontal portion between the receiver and compressor. The joint was made of lead, run in and caulked, but owing to the contraction and expansion of the pipe it leaked, and had to be renewed from time to time. On the day of the ignition, and shortly before its occurrence, this joint had been renewed by running in molten lead against a hempen gasket, and very soon after the compressor was started, flames blew out in great volume from the safety valve on the air receiver. The attendant succeeded in stopping the compressor within a few seconds, but the flames continued for some time and set fire to the compressor-house, which was built of timber, and in the course of half an hour it was burned to the ground.

WHAT CAUSED THE EXPLOSION.

The author considers the cause which led to the fire breaking out in the receiver to have been the ignition of the oil accumulated there and the use of molten lead in making the spigot joint of the pipe referred to, by which the oil must have been ignited in the pipe. On starting the compressor, the draught of the air created would cause the ignited oil in the pipe to set fire to the oil in the receiver, or the fire may have already spread to the receiver. The products of the decomposition of the large quantity of oil in the receiver would, in conjunction with the air, form an explosive mixture, which, failing relief through the safety valve, might have resulted in an explosion. The cause of all explosions and ignitions of this nature can be traced to these phenomena. The case which occurred at the Westphalia Colliery in 1896, resulted in the destruction of the air receiver by bursting. In the present instance the rise of pressure does not seem to have been sudden enough to burst the receiver, and the relief afforded by the safety valve averted this catastrophe. When the receiver was opened it was found to contain a quantity of charred oil in the form of a sticky paste about 2 inches deep in the bottom. The air pipes were coated inside with a similar substance. The damage done to the compressor and receiver was, however, considerable, the riveted joints of the latter being started and the lead joints of the contiguous pipes and connections melted out. One cylinder of the compressor and one crank disk were cracked, as also were two arms of the turbine, which was placed inside the house burned down. The latter effects were chiefly due to the subsequent fire and the water which was thrown upon the heated metal.

The primary cause of the fire was the accidental ignition of the oil by the admission of molten lead into the pipe referred to, but the same effect may be produced by an increase of air pressure, and consequently of temperature, to a point at which the decomposition of the oil and ignition of the air and gas mixtures takes place, or by the admission of coal dust or inflammable matter into the valves or cylinders of the compressor. The use of oils possessing low-flashing temperature from friction of metallic surfaces improperly lubricated is also an element of danger, besides defective water-jacketing and cooling arrangements.

A similar ignition to the one mentioned by the author occurred in 1897 in the Clifton Colliery air receiver, and tests were made of the oil then in use, giving the following results:

	Flashing Point Close Test.	Ignition Point.
Sample No. 1....................	454° Fahr.	594° Fahr.
Sample No. 2....................	460° Fahr.	583° Fahr.

Lubricating oils of high-class manufacture, distilled from petroleum and used for high-pressure steam engines, give flashing points of from 530 to 560 degrees Fahr. (open test), and ignition points of from 600 to 630 degrees Fahr. It is, however, sometimes the case that oils having a high flashing point are mixed with others having a much lower one, and therefore a guarantee should be demanded, or a test of the oil should be made. The flashing point of the oil used in the compressor described by the author, taking that of Arctic sperm, would be only 446 degrees Fahr. It is evident that, given reliable oil of high-flashing point and normal conditions of working for a well-designed air compressor, the danger of ignition is practically eliminated.

About two years previous to the ignition described by the author, an explosion occurred in one of the cylinders of the same compressor, resulting in the destruction of the cylinder. The cause of this was not ascertained at the time, but it was probably due either to excessive friction in the cylinder or defective action of the valves, causing an increase of temperature and consequent decomposition of the oil, or to an increase in the air pressure sufficient to burst the cylinder.

New York, Aug. 19, 1897.

Editor Compressed Air:

Dear Sir: We have before us your issue of July, 1897, and in it we note remarks in reference to ignition in air cylinders of air compressors. This to us is a very interesting subject, and, as you know, we have devoted a great deal of time and money to it, and we are glad to place before you some few facts which may interest your correspondents.

That the occasional occurrence of fire in air compressors is due to the oil present, there can be no doubt, as the oil is the only substance present which can burn; and in this connection we beg to say that the cause of this difficulty cannot be laid to the oil alone, although it is a well-known fact that an inferior oil which contains a large amount of carbon and other foreign substances can readily cause explosions.

That certain structural features of a given machine may facilitate or retard combustion of the oil, will, we think, appear from what follows:

The fact of an air compressor drawing the air from whatever location the compressor may be in, naturally necessitates the presence in the air cylinder of whatever foreign substance there may be in the atmosphere. For instance, in acid or alkali works, coal mines, copper mines, or other places of a similar character where there is an unusual amount of dust or foreign substance in the atmosphere, which being drawn into the air passages of the machine, combines with the excessive amount of residuum or carbon left behind through oxydation, forming a substance for fire to feed on, the fire resulting from causes herein set forth.

Our experience is, that the greatest amount of oxydation takes place at the point where the air passes from the cylinder into the discharge pipe. The result is that continued oxydation naturally decreases the size of the aperture at the mouth of the discharge pipe, and more air is compressed in the cylinder than can pass through the discharge pipe—the result being the re-compressing of the air, and an increased amount of friction, also an abnormal degree of heat in the air cylinder. The result from such cause is very apparent.

As to the oil, it should have the least liability to oxydize that it is possible to secure. The flash point should be as high as good lubricating qualities will permit. What is the flash point? It is that degree of heat at which some constituent part of the oil passes off as vapor, which vapor being inflammable, will ignite if brought in contact with fire.

The mere raising of the temperature of an oil to its flash point will not produce ignition. Another cause must be presented to produce ignition of the vapors. Indeed, such a cause may operate before the flash point is reached, as in the case of sawdust saturated with linseed oil. The cause referred to is, according to the writer's experiments, oxydation of the oil.

Combustion, so far as we have to consider it, is in this case the rapid union of a substance with oxygen with the presence of a flame. There can be, of course, repeated oxydation without flame, but if the action be sufficiently repeated, heat enough will be generated to set the substance on fire. Then if a considerable quantity of inflammable vapor be present, an explosion is likely to follow.

To furnish an oil which shall resist the relatively large quantity of highly heated oxygen (at a pressure of 45 lbs., three times as great on a given surface as at the pressure of the air), is a matter which requires special study and facilities.

We have made a special study of the requirements of an oil which shall reduce the chances of the possibility of spontaneous combustion to a minimum, and where such facts have been present, by the use of our material, a great deal of this serious difficulty has been avoided.

Should any of your subscribers wish to correspond with us further regarding this matter, we would be very glad to do so.

To sum up: Use an oil as little likely to spontaneous combustion as it is possible to secure it. Have as few places where the oil can lodge in the machine as possible; in other words, have as few joints and as few turns in your pipes as it is possible to have, as it is a well known fact that where air strikes a surface in turning past a joint or elbow, friction is the result.

It is also very necessary to avoid the free use of oil. Use just as little as possible. There is a strong tendency on the part of engineers to use too much oil, simply because they want to be sure of having enough—on the principle that it is better to have too much than too little.

In Compressed Air we find another article bearing on this same subject, and the writer begs leave to say, that "to our minds, it is a very unsafe thing to attempt to cleanse a cylinder with soft soap and water, unless an abundance of water is used after the operation to cleanse the cylinder very thoroughly."

Kerosene is still more dangerous; so the only safe method to pursue (to our minds) is to use oil as little liable to carbonize as possible, and to remove and clean the valves at short intervals.

We feel that our experience in the manufacture of a suitable lubricant will at least justify the consumer in making a few experiments. Very truly yours,

FISKE BROTHERS REFINING CO.

Editor Compressed Air:

Dear Sir—I am very much interested in the discussion now going on in your very instructive little magazine, Compressed Air, on the subjuct of explosions and fires in air compressing engines and air receivers. As I have had considerable experience in the handling of compressors, I give you my idea as to the cause of some of the explosions that occur in this type of machinery.

Some ten years ago, during the construction of the New York Croton Aqueduct, I had charge of the machinery at Shaft No. 16, Section 8. We had a duplex air compressor at work with air cylinder 18" diameter x 30" stroke, and maintained a working air pressure of from 80 to 90 lbs. per square inch. The compressor was of the ordinary poppet valve type, and we had the usual trouble with this type of valve—that is, one or more of the valves would stick, due to the carbon deposited on them. The oil used was the best obtainable for this purpose, and was recommended by the manufacturers of the compressors. The air receiver (horizontal) was situated outside of the engine house and was exposed to the hot rays of the sun. On one occasion, in passing the receiver, I noticed that the rubber gasket between the flanges of the air discharge pipe and receiver was on fire, and the pipe itself was red hot. I stopped the compressor soon as possible and took the manhole plate off receiver and found the inside on fire. We got out the fire hose and soon had the fire under control. After the receiver cooled off we made an examination to find out, if possible, what was the cause of the fire, and found the entire interior of the receiver encrusted with carbon at least ⅛" thick. In the meantime, while we were fighting the fire, several miners who had been running rock drills in the tunnel were knocked out by the fumes of the burning carbon and brought to the surface in an insensible condition. This being our first experience of this kind, we were at first at a loss to account for the fire. We started to investigate, and were not long in discovering the cause. As stated in the foregoing, the air cylinders were provided with the ordinary poppet valves, and frequently several of them would stick, and when the engineer would notice that they did not work, would take a squirt-can filled with kerosene oil and squirt a quantity of the oil at the valves to cut the sticky substance; the oil was immediately drawn into the cylinder, and being of a very low flash test, would quickly vaporize, and when the conditions were just right, would ignite and cause an explosion or fire. I have since noticed that this habit of using kerosene oil as above stated is quite a common practice with engineers who run poppet valve compressors. I have no doubt that this is the cause of many of the fires and explosions that take place in compressed air engines. Yours truly,

PHILIP WEISS.

COMPRESSED AIR:

We have had some very peculiar experiences with our compressor during the past few days. The grease in the receiver just outside of the compressor caught fire, heating the receiver so hot that it melted the tar off the outside, and it heated the pipes going to the mine so hot that it melted the tar off for several feet from the receiver, and made the air so hot that the men had to quit cutting and leave the mine; the men who saw it say the receiver was red hot. I have been told that compressors have been known to blow up, and I am going to put a spray of water on the compressor to keep it cool.

We made a connection on to an air pipe from our electric plant, in our No. 3 section with the return current; making the connection at the pit mouth of No. 3 section, and took it off a few feet away from where the pipe goes into the receiver. That is to say, we tapped the discharge pipe that goes to No. 3 section, about four or five feet from the receiver, and put on a ground connection from our electric plant. Have you any idea that this had anything to do with setting the grease on fire? If you are not fully satisfied in your own mind, I wish you would take it up with some electricians, and ask if it is possible for such a thing to happen. Yours truly, ENGINEER.

The best way to prevent the accumulation of grease in the pipes and receiver is to use an oil suitable for the work. This you very evidently have not been doing, but since you would not use that kind of oil, you ought to remove the manhead and give the receiver a thorough cleaning on the inside occasionally. That is what the manhead is for.

Our diagnosis of the case is that you have been using an oil of such character that it has deposited around the discharge valves, the discharge valve ports, and possibly in the pipe between the compressor and receiver a coke like substance which has reduced the area of the passages. Running your compressor, say 120 revolutions per minute, you have filled and emptied that cylinder 240 times per minute or four times per second. One-fourth of a second is a pretty short time for air to get out of the cylinder—just try to imagine how short a space of time that is—and especially when the ports have become obstructed and reduced in area from the deposits is consequent upon the use of an improper oil.

Compressing air to 90 pounds pressure, the natural temperature, without cooling effect would be 430 to 450 degrees, but if your discharge ports were obstructed, the pressure in the air cylinder might easily be a great deal more than 90 pounds. This excess pressure, combined with the friction of the air through the restricted ports might produce a high enough pressure to volatilize or vaporize the oil to an explosive gas. This might set fire to the gum or grease in the discharge pipe or receiver, and result in exactly the condition of affairs which you describe. Under normal conditions we have never known this to occur, but when the air compressor is drawing its air in from the hot engine room is running too fast and under the conditions which your machine has been running under, it could happen. The thing for you to do is to put in another air compressor alongside of the one you have, running the two together at a moderate speed, use an oil better suited to the work, and if the ports are in any way obstructed, have them thoroughly cleaned out. The pipe leading from the receiver to the compressor should be disconnected and examined carefully. Some compressor engineers keep their discharge valves and passages clean and avoid firing by feeding soap suds through the oil cup into the air cylinder. Use common soft soap and say every week run for two or three hours or half a day on soap suds instead of oil, letting the suds feed into the cylinder just as though you were feeding the oil, only let in a little more of it. The difficulty with most engineers is that they feed too much oil into the air cylinder. Oiling an air cylinder is not like oiling a steam cylinder: in the latter case the steam cuts away the oil, while with air a little good oil goes a great ways.

A spray of water in the cylinder of an air compressor certainly keeps the temperature down and adds to the economy of compression, but the objections to water in an air cylinder are so great that we cannot advise you to use it. This used to be common practice years ago, but it has been abandoned except for special cases. You cannot lubricate a wet cylinder and you would have trouble with the parts cutting each other and getting leaky. If you use water enough to do any good, you will have to reduce the speed of the machine materially.

We note that you have got a portion of the pipe line rigged up as a part of the electrical circuit. A six-inch pipe line gives a good deal of metal and under normal conditions the return of such a current through the pipe line ought not to do any harm. We should, however, expect electrolysis effect in time, possibly resulting in the complete destruction of the pipe line. Under certain conditions of grounded or short circuit currents, you might heat the pipe line up to a point where any greasy coating would be ignited and it is possible that in this case your electric current was the last straw that set the thing off. An explosion is not likely to occur right in the cylinder, but if it occurs in the receiver it is dangerous enough.—Ed.

AN AIR COMPRESSOR OF EXCEEDINGLY NOVEL DESIGN.

An air compressor of exceedingly novel and original design has been practically finished by the Chaquette Power Company of Bridgeport, Conn., in accordance with the plans of E. Chaquette, the inventor of the machine.

The machine is calculated to develop 2,500 horse power in the shape of air under a pressure of 100 pounds to the square inch, which it is the intention of the company to distribute through mains for power purposes. The compressor is, essentially, an immense horizontal wheel composed of ten spokes or arms, each formed of two latticed girders connected by suitable bracing. The girders forming each spoke diverge from the centre or hub toward the periphery, and they are united at their outer ends by an encircling system of latticed girders. The general

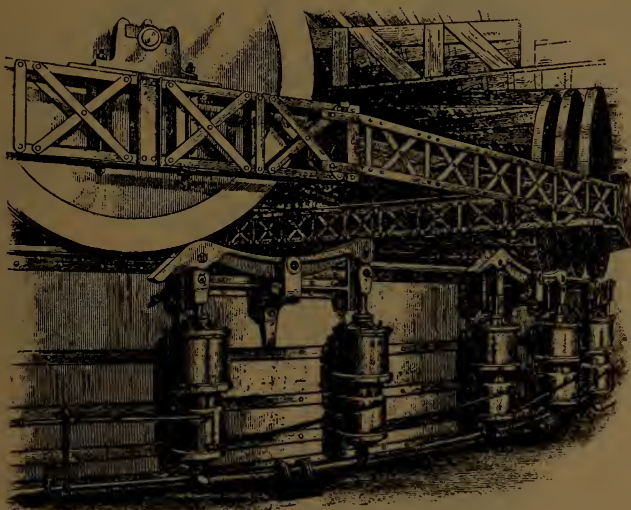


FIG. 43.

arrangement of the wheel thus formed will be understood from the approximately correct plan view, Fig. 43.

Journaled in the outer end of each spoke is a set of three solid wheels which are 9 feet in diameter and each of which weighs about 4½ tons. The centre wheel of each set of three travels upon a circular track, as indicated in Figs. 43 and 44. The track is beveled after the manner of the ordinary bridge turn table track. The other two wheels, the inner and outer, of each set are the actual working wheels of the system, as they operate the air compressors placed around the circular track, which is 82 feet in diameter.

The centre of the wheel is supported upon a rivet provided with a ball bearing placed on a masonry foundation. The hub A, Fig. 44, is formed with a platform in which are placed two compound steam engines, each of 70 horse power. Each engine shaft carries a pinion which engages with an internal gear on the shaft B, Fig. 44. These two shafts, B B, are diametrically opposite each other, and on the outer end of each is rigidly mounted the centre wheel of the sets D D. The great wheel is therefore driven by the engines, which are independent of each other through the shafts B B and centre wheels of the sets D D.

Placed vertically in pairs around the outside of the track are 50 compound air compressors, as shown in Fig. 43. Arranged in the same way around the inside of the track are 50 similar air compressors. Each of the 100 compressors has cylinders 12 and 16 inches in diameter and a common stroke of 12 inches. Pivoted centrally above each pair of compressors, in a bracket secured

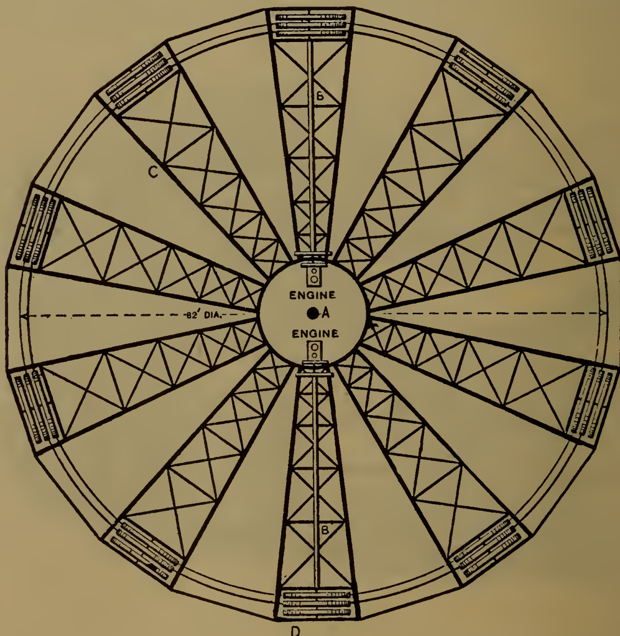


FIG. 44.

to the wall of the track is a rocker, lever shaped, as shown in Fig. 43. Each end of each lever is connected by a link with the piston rod of a compressor. Each lever upon the outside of the track is so located as to be in the line of travel of all the outside wheels of all the sets of three. Each lever upon the inside of the track is placed in the path of the inside wheels. The rocker levers are so formed and arranged as to be struck by the wheels in their passage, and through the connecting links to operate the pistons of the air compressors.

The air tank is in the centre. There is also a 20-inch collectings main, which extends around the inside of the track, and with which suitable pipe connections are made with each compressor. This main conveys the air to the tank, which is expected to carry a working pressure of 100 pounds to the square inch, this pressure having been decided upon as it is the most available one for power distribution.

The operation of the machine will be readily understood. If the wheel should make ten revolutions per minute, there will be 100 impulses or strokes of the air compressors at each revolution, and 10,000 for the ten revolutions it is expected to make in each minute. Knowing the capacity of each compressor, it therefore becomes a mere matter of calculation to ascertain the power developed and made available, as air under pressure, if the wheel could be run at ten turns per minute. Taking into consideration the actual power applied at the centre to turning the wheel, the multiplication expected is something tremendous. As stated by Mr. Chaquette to our representative, it is calculated that of the total power developed, only about 4½ per cent. will be required for the actual turning or operation of the wheel, and that the remaining amount, or about 95½ per cent., will be available for commercial purposes. The momentum of the wheels carried at the ends of the arms or spokes, their great weight compared with the work they are expected to perform, and the constantly increasing leverage of their action upon the several rocker levers, are depended upon for the successful operation of the machine. It may be added in conclusion, that the machine has been protected very completely by letters patent issued to Mr. Chaquette.—*The Iron Age.*

A DIMINUTIVE AIR COMPRESSOR.

An air compressor 12 inches high, 15 inches wide and 28 inches long, and actuated by electricity, is a real thing, and not a mere plaything or curiosity. It is in practical use and doing service on electric cars to control the brakes. It is

FIG. 45.—A DIMINUTIVE AIR COMPRESSOR.

installed under the ordinary car seat, and if it is run for thirty seconds it will compress enough air to stop the car half a dozen times.

The Standard Air Brake Co. build these compressors in connection with their air brakes, and they are as complete as the full-grown compressor used for heavier work.

While the compressor is now used in connection with air brakes exclusively, its field of usefulness could be enlarged to a very great extent.

There are many places where compressed air would be used, were it available, and this little compressor and others of its kind might be profitably employed; such as in pneumatic dispatch tubes, in pottery work for spraying colors, operating small pumps and dental tools, and innumerable other purposes.

THE TAYLOR HYDRAULIC AIR COMPRESSOR.

The compressor shown herein was installed for the Dominion Cotton Mills Co., Limited, to furnish power for their print works at Magog, Quebec.

The installation of the machine was attended with much prejudice. The success attained by this plant has, however, convinced all those who doubted

FIG. 46.—THE TAYLOR HYDRAULIC AIR COMPRESSOR.

the feasibility of the invention. According to tests made on the 7th and 13th of August, 1896, by Prof. C. H. McLeod, Ma. E., of McGill University, this compressor gives 62 per cent. of the actual power of the water used, and delivers over 155 H. P. in compressed air. This efficiency is secured in spite of the fact that 20 per cent. of the air is lost because of inefficient separation.

The inventor will undertake in all subsequent installations to obtain an efficiency of at least 75 per cent.

The air was first used in the engines on the 12th of August, 1896, and since that date it has provided power continuously for *seven* printing machines, each

FIG. 47.

of which is driven by a pair of engines with 8 in. x 12 in. cylinders. It also furnishes power at night for the feed pumps of the boilers, the machine shop, and other purposes. The air pressure uniform at all times, whether supplying one or more engines, is 52 lbs. per sq. inch. The compressor requires no attention other than starting and stopping it.

DESCRIPTION OF THE HYDRAULIC AIR COMPRESSOR.

The annexed perspective drawing shows a complete compressor, its details being as follows:

A. Penstock, or water supply pipe.

B. Receiving tank for water.

C. Compressing pipe.

D. Air chamber and separating tank.

E. Shaft, or well, for return water. (The required pressure is proportional to the depth of the water in this shaft.)

F. Tailrace for discharge water.

G. Timbering to support earth.

H. Blow-off pipe.

I. Compressed air main.

J. Head piece, consisting of—

a. Telescoping pipe, with

b. Bell-mouth casting opening upwards.

c. Cylindrical and conoidal casting.

d. Vertical air supply pipes. (Each pipe has at its lower end a number of smaller air inlet pipes branching from it towards the center of the compressing pipe.)

e. Adjusting screws for varying the area of water inlet.

f. Hand-wheel and screw for raising the whole head piece.

K. Disperser.

L. Apron.

M. Pipes to allow of the escape of air from beneath apron and disperser.

N. Legs by which the separating tank is raised above the bottom of the shaft to allow of egress of water.

P. Automatic regulating valve.

WORKING OF THE COMPRESSOR.

The water is conveyed to the tank B through the penstock A, where it rises to the same level as the source of supply. In order to start the compressor the head piece J must be lowered by means of the hand-wheel *f* so that the water may be admitted between the two castings *b* and *c*. The supply of water to the compressor, and consequently the quantity of compressed air obtained, is governed by the depth to which the head piece is lowered into the water. The water enters the compressing pipe between the two castings *b* and *c*, passing among, and in the same direction as, the small air inlet pipes. A partial vacuum is created by the water at the ends of these small pipes, and hence atmospheric pressure drives the air into the water in innumerable small bubbles, which are carried by the water down the compressing pipe C. During their downward course with the water the bubbles are compressed, the final pressure being proportional to the column of return water sustained in the shaft E and tailrace F. The accompanying diagram shows the relative sizes of the bubbles as they descend in a compressing pipe 116 feet in length.

When they reach the disperser K, their direction of motion is changed, along with that of the water, from the vertical to the horizontal. The disperser directs the mixed water and air towards the circumference of the separating tank D. Its direction is again changed towards the center by the apron L. From thence the water flows outward, and, free of air, passes under the lower edge of the separating tank. During this process of travel in the separating tank, which is slow compared with the motion in the compressing pipe C, the air by its buoyancy has been rising through the water and pipes M, M, from under the apron and disperser, to the top of the air chamber D, where it displaces the water. The

FIG. 48.—GRINDING ROOM.

air in the chamber is kept under a nearly uniform pressure by the weight of the return water in the shaft and tailrace.

The air is conveyed through the main I, up to the shaft to the automatic regulating valve, and from thence to the engines, etc. The air pressure in the main and air chamber increases 1 lb. per sq. inch for each 2 ft. 3½ in. that the water is displaced downwards in the air chamber by the accumulating air. The variation in pressure from this source will not be more than 3 lbs. per sq. inch in a working plant. As the automatic valve requires a change of only 1 lb. per sq. inch pressure to close it completely, it will be evident that, by properly adjusting the valve, some air can always be retained in the air chamber, and that the water can be prevented from ever reaching the inlet to the air main. If a large quantity of air has accumulated in the chamber, the valve allows of its free passage along the main; but when the air is being used more quickly than it is accumulating, and the pressure decreases below a certain point because the chamber is nearly emptied of air, the valve shuts partially, or completely, adjusting itself to the supply from the compressor.

When the air has displaced the water almost to the lower end of the compressing pipe, it escapes through the blow-off pipe H.

THE HARTFORD AIR COMPRESSOR.

Some years ago recognizing the demand for an hydraulic air compressor that would do quick economical work without getting out of order easily, the L. E. Rhodes Co., of Hartford, Conn., began a series of experiments to devise something more simple and efficient than the pumps on the market. A pump of the double acting form was finally adopted, the designers believing that that class of compressor would do much quicker and more efficient work than either the single acting pumps with their wasteful springs or weights and their inter-

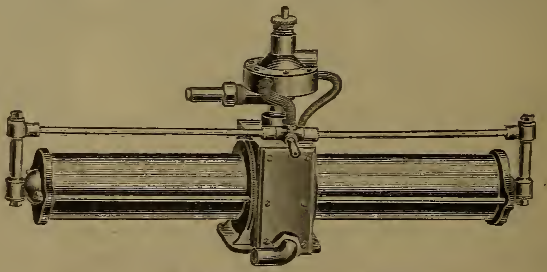


FIG. 49.—HARTFORD AIR COMPRESSOR.

mittent action, or the clumsy "tank" styles with their waste air space to consume power and their various floats and valves. The aim in the first place was to secure simplicity and next to prevent waste of water or air. How successful they have been in combining the advantages of the old pumps and eliminating their defects is realized when it is seen that in the Hartford Air Compressor there are less than half the parts usually necessary and no valve packings. The valve is a marvel of simplicity and efficiency, and the entire force of the water is utilized for there are no narrow ways to choke and cause friction, with no weights to work against nor auxiliary cylinders and waste air spaces to consume power. So it is claimed for this pump, that it will keep up the desired air pressure with less water than any other on the market. But the most noteworthy improvement to guard against waste is the system of regulating. The L. E. Rhodes Co. maintain that loss of speed must be the result where the ordinary practice is pursued of regulating down the pressure of the water (before it enters the compressor) to the desired air pressure and moreover that there is a great chance of leakage if the water is constantly bearing on the machine, whether air is being drawn or not. Consequently they have adopted a device whereby the water is shut off entirely when no air is being used. As air is drawn the regulator automatically opens and allows the maximum water pressure to bear on the pistons, insuring such a quick action that the desired air pressure is immediately regained, which in turn causes the regulator to close. The benefit of the maximum water pressure is thus obtained to drive the pistons rapidly, and constant strain on the pump is avoided with its consequent leakage, for when the pump is not working the water is shut off as if by a faucet. The regulator is simple and easily adjusted.

Long practical use has now substantiated the claims of the maufacturers that the Hartford Air Compressor gives a maximum co-service at a minimum cost for water and repairs. All the force of water is utilized, insuring speed and very high efficiency, and there is no annoyance waiting for a tank or cylinder to empty and no waste of water through leakage. Extremely simple in design; with the troublesome springs and valve packings done away with; high grade in construction, with a quick easy action and positive regulation, the Hartford Air Compressor truly seems an advance over anything yet devised.

HYDRAULIC COMPRESSION OF AIR.

At a recent meeting of the Manchester (England) Association of Engineers, Mr. H. D. Pearsall, of London, read a paper on "Hydraulic Plant for Compressing Air." Restricting the terms of his address to cases where water was the main agent—i. e., cases of the application of water power to the compression of air—he described various processes, the loss of energy in the application of which, he pointed out, had set back the development of that class of machine. Believing the principle to be right, he gave some consideration to the subject, and arrived at the conclusion that the imperfections were solely questions of design capable of rectification, and that the losses of power which were unavoidable were very small. He explained, by a series of drawings, an engine erected on the river Kent in Westmoreland, from designs he had prepared, the efficiency of which amounted to 80 per cent.—that was, that the work done measured in isothermic compression of air was 80 per cent. of the gross power of the water. When they compared that with the 30 per cent. or 35 per cent.,—and not that always,—which was commonly attained in piston compressors driven by water wheels, it must be admitted that the question of the use of compressed air assumed a totally new aspect. In a great variety of cases where with a low efficiency it was not worth while to use compressed air, or where electrical transmission, for instance, might be obviously preferable to transmission by compressed air, the case was entirely reversed if anything lik an efficiency of 80 per cent. could be attained, and attained in machines of simpler and less costly description than that which they superseded. Experience with the engine had revealed still further possibilities of improvement. Finality had not been reached, and he did not say that an efficiency of 80 per cent. could be bettered, but in other directions, such as making an engine of the same size do more work, the engine would be improved on in subsequent engines. Other developments of the same principle had also been suggested by it which were not yet carried out in practice.—*American Manufacturer.*

WAVE AIR COMPRESSOR.

Mr. R. Toennes, of Boonville, Mo., is the inventor of what he calls a "Wave Air Compressor." The power of the waves is utilized for the purpose of compressing air in a manner quite novel.

Briefly described the invention is as follows:

A shaft or tower, as shown in the larger figure, is constructed on or near the shore of a body of water where there are waves, or a tide. This tower is composed of one or more air-tight chambers (4), as circumstances may demand, and may be constructed of any substantial material.

The tower is built upon a solid foundation of rock. At its base (2) is an opening, with divergent top and side walls. Through this the waves enter the air

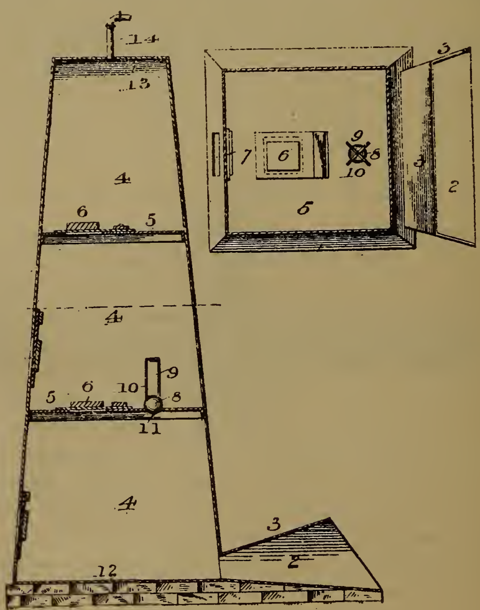


FIG. 50.—WAVE AIR COMPRESSOR.

chamber (4). This chamber is provided with a valve (6). The force of the wave opens this valve and admits the air to the compressing chamber (4). In this chamber is another opening, covered by a ball of some substance of a less specific gravity than water, kept in position by four vertical rods of metal, brought together at the top. As the waves recede, the valve (7) admits air from the outside, thus, by atmospheric pressure, forcing the water out of the chamber. The ball, floating upon the water, closes the opening as soon as the water has escaped. The air which was compressed by the action of the wave is admitted to the storage chamber by a valve (6). With each subsequent action of the water more compressed air is admitted to this storage chamber, thus in a short time affording a reserve force. This is utilized by means of a pipe, provided with a stop-cock (14), by means of which the concentrated power may be transmitted to the point at which it is desired to be used. The numerals (5) represent the horizontal partitions between the chambers; 12 represents the bottom, and 13 the top of the tower.

The smaller figure represents a horizontal section of one of the chambers, showing the manner in which the water valve and the ball (8) operate; 2 is the opening and 3 the outwardly inclined side walls for the admission of the waves.

This principle has never before been used in obtaining compressed air. Aside from the cost of construction, it requires but little outlay, and at the same time is capable of doing good work. It may be used on any body of water where the waves are of sufficient force. On the seashore the desired result may be obtained, where the coast is favorable, by constructing the shaft on the shore, or in the cliffs, and permitting the waves to enter by means of a tunnel, thus obtaining the advantage of cheapness of construction and stability. The tower may consist of one or more chambers, the number and height depending entirely upon the tide and waves.

HYDRAULIC PLANT FOR COMPRESSING AIR.*

The term "hydraulic plant for compressing air" may, of course, include all machinery for compressing air in which water takes any part. It should, however, certainly be restricted to the cases where water is the main agent—*i. e.*, to cases of the application of water power to the compression of air, and that is the sense in which the term is here used. The most usual way of applying water power to this purpose is to cause the water to produce rotary motion in some sort of a wheel, and by means of this rotary motion to drive reciprocating pumps in which air is received and compressed. This is obviously rather a roundabout process, involving the use of two distinct machines besides gear connecting them, and several conversions of energy. It is, of course, well known that though energy is indestructible it cannot be changed from one form to another without loss, and consequently, if there are several transformations of energy, there must be several losses. In converting the potential energy of water descending from a height into the rotary energy of a turbine, from 20 to 25 per cent. is usually lost. In the gear required to connect the wheel to the pumps there is also lost a percentage of the energy of the wheel, and in converting this energy to that of the reciprocating pistons, a third loss is suffered. The loss due to intermediate gear is frequently very considerable, because a turbine necessarily runs at a high speed and the pumps must run at a low speed. The consequence is that the net energy received by the pump piston is seldom more than half that of the original energy of the water, and is often much less. If, therefore the power of the water could be applied more directly, we should expect to attain a great economy of power; consequently, many efforts have been made to secure this object. Obviously, these considerations apply to the use of water power for any kind of pumping—*e. g.*, pumping water, as well as compressing (*i. e.*, pumping air)—but in the case of air-

*Paper read by Mr. H. D. Pearsall, M. Inst. C. E. of London, before Manchester Association of Engineers.

compression there is still another reason for desiring the direct application of the power. All the work done in compressing air is converted into heat, but when air is compressed under such conditions that all the heat is instantly and entirely absorbed by surrounding solid or liquid bodies, only about half as much net work is exerted (if, for example, compression is to one-fifth of original volume) as when no heat is thus absorbed. Therefore, it is obvious that it is of the highest importance to thus absorb heat during compression of air. In compressing air in reciprocating pumps, it is found practically impossible to absorb more than half the heat which is developed, and this is not surprising when we find that the greatest quantity of water which can practically be used, under the circumstances, for cooling is about two-thirds the weight of the air compressed, while the quantity of heat to be removed is very large indeed, amounting to fifty-eight heat units per pound of air when compressed to five atmospheres. But the quantity of water actually available when the motive power is water is never less than 1,000 times the weight of the air. Hence the strongest reason for applying the water used for power directly to the air—that if it can be done it should result in very much more thorough absorption of heat than can be accomplished in any other way. This analysis of the imperfection of air-compressing machinery is, of course, modern, but the practical result—that the inefficiency was very great—has been realized in a rough way ever since compressed air has been in common use, and, therefore, the attempts to apply the water directly have been many.

In this paper the author intends to confine his attention to those hydraulic air compressors which more or less perfectly attain this object. They may be divided into two classes:—In that which will be mentioned first the compression is effected by the weight of a column of water of a height equal to the maximum pressure of the air measured in feet of water. To obtain this pressure the water used as power is carried down a well or shaft and up again in an inverted siphon. The air to be compressed is diffused through the water in bubbles as small as possible, and part of it is then carried down to the bottom of the well by the stream. That which arrives there is, of course, then subject to the pressure of the water column above it and is accordingly compressed, and means are provided for allowing it then to escape from the water before it can again expand. This method is one of the very oldest known. One form of it is described by Pliny in the first century, and even then was old. In modern times several different inventors have revived it, and it is connected with the names of Upham, Mowbray, Frizell and C. H. Taylor. In this machine, as might be expected, the compression is isothermal, and it is a very simple machine and has few working parts. It is, however, rather an expensive one, as for a pressure of five atmospheres it requires the sinking of a shaft 150 ft. or more in depth, with an enlarged chamber and some of the apparatus at the bottom of the shaft. Moreover, when its principles are examined, it is found that the unavoidable losses connected with it are large, so that its theoretic efficiency is not very high. These may be chiefly embraced under the head of fluid friction due to the flow through a pipe 300 feet long and to eddies. The fluid friction is not merely that of water flowing through a pipe. The bubbles of air, although they descend with the water do not descend as fast as the water. Consequently the water is all the time passing the bubbles, and the rubbing surface causing fluid friction is, therefore, the whole surface of innumerable bubbles of air, in addition to the surfaces of the pipe. The co-efficient of friction is, therefore, very much greater than that of water in a pipe. The efficiency actually realized in practice appears to have been about 55 per cent. under the condition of using a very large pipe, a low fall and a pressure of only four atmospheres. Both a higher fall and a higher pressure diminish the possible efficiency.

In the other class of machines having the same object water acts as a piston, compressing the air in a chamber provided for the purpose. The earliest is probably due to Montgolfier, the inventor of gas baloons and of the hydraulic ram, about one hundred years ago, who described and patented a modification of his hydraulic ram to be used for the compression of air. It was quite a practicable machine, though possessing some complications which have been proved to be needless. But the reason why it has failed to come into use is the same reason which for so many years has confined the hydraulic ram for water raising to machinery of small and almost domestic size, viz., the construction of the main valve. In Montgolfier's machine the escape valve was similar to that of the Montgolfier water ram, and it was operated as that is, by the current of the escaping water. This necessarily limits these machines to a very small size, and, as when compressed air is wanted, it is nearly always wanted in considerable quantity, this alone would naturally prevent any use being found for these machines. That this construction was unsuitable for any large size one supposes should have been obvious; but, as for one hundred years, in nearly all attempts to improve the ram they insisted on retaining it, it seems it was not obvious. It was, however, abandoned in the next application of this principle which will be mentioned. This is the air compressor designed and used by Sommeiller in the excavation of the Mount Cenis tunnel. It consists of a pipe leading from the source of supply, two valves, a vertical pipe in which air is compressed, and a valve controlling the connection between this compression chamber and an air-vessel. The water does not act merely by its pressure. When it begins to flow, the air in the pipe offers very little opposition to it, and therefore the water acquires a high velocity and momentum. As the air becomes compressed it offers more and more resistance to the water, and this resistance absorbs the momentum of the column of the water. The compression is effected, therefore, more by the momentum of the column of water, than by its pressure. Hence it is essentially an hydraulic ram. The head of water was 85 ft., and the air was compressed to 6 atmospheres. Notwithstanding numerous defects of designs, these machines had considerable success. Ten of them were made, and after they had been in use three years at the Bardonneche end of the tunnel, six others were made for the Modane end of the tunnel, where the fall was only 35 feet. In this latter installation a most remarkable course was adopted, the history of which is very instructive. The natural fall being only 35 feet, the water was first pumped by water-wheels to a reservoir at a height of 85 feet, and then used with this fall in the compressors. But a little consideration shows that this was entirely needless. If, instead of doing this, the valves had been worked in a different way, a fall of 35 feet would have compressed the air just as well as a fall of 85 feet. The mean pressure due to compression to 6 atmospheres equals 61 feet of water. When the fall was 85 feet the water would give a mean pressure throughout the height of air column of 85 feet, less the loss of effect from fluid friction, etc. Hence if the efficiency was 75 per cent., the flow of the water would be adequate to compress all the air above the level. The gross energy developed would evidently be represented by 85 feet × height of air column. Now with a fall or head of 35 feet, suppose that after the chamber was emptied of water through the second valve, instead of then closing it before opening the first valve, the latter had been opened while the second still remained open. Water would then have flowed away through the second valve, and when the column had acquired a certain velocity the valve would be shut, and the compressing stroke would then take place. The energy available for compression would then be represented by length of column of water in pipe x head due to velocity + 35 feet × height of air column, and it is evident that by making the velocity a certain amount—that is, by keeping the second valve open a certain time—the amount of this energy can be made exactly as great (or greater if desired) than the energy that was developed under 85 feet head. In 1891, the author described in a paper in the *Proceedings* of the Institution of Civil Engineers an engine of considerable size for pumping water on the principle of the hydraulic ram, and then mentioned that he had also made experiments in compressing the air in the same manner. One of these engines has since been erected on the River Kent, in Westmoreland, from the author's design. This also consists of a pipe from the source of supply, and a chamber in which the air is compressed by the momentum of the water. But in this engine the method of using the water is that which the author suggested should have been used at Modane. The water runs freely away through the valve for a certain time in order that it may acquire a certain velocity and momentum. The valve is then closed and the energy available for compression is exactly as the author already formulated it. Consequently, such an engine may be used on a fall, however small. In this engine there is only one valve in place of Sommeiller's two. The air valve admits a fresh supply of air into the receiver after the compression is accomplished, and also allows of the escape of some of this air while the main valve is closing, so that part of the water which flows in the main pipe during this time can rise freely in the chamber instead of having to find an exit through the narrowing orifice of the main valve. The valve is closed by the water when it reaches a float attached to a lever in connection with the valve. There being but one water valve, there is but little gear required to operate it, but it is necessary that the valve should open and shut at certain definite intervals of time. The author has used several different forms of gear for this purpose. In the earlier engines it was a cam, in the Kent engine it is a crank motion. In all cases the power to operate the gear is taken from the air vessel. In the Kent engine water is used. In other cases an air motor has been used. In the Sommeiller engine it was only possible to make three strokes per minute, probably on account of the imperfection of the way of operating the large valves, and because apparently certain pauses were necessary between each stroke. In this engine, there are, of course, no pauses, and from fifteen to twenty strokes are made per minute, so that an engine of given size will develop a much greater power. The height of the chamber is also reduced one-half by making its diameter half as large again as that of the main pipe. The working of this engine has fully justified the author's expectations. In the compression of the air practically all the heat developed is absorbed as it is developed—as, indeed, it seems obviously must be the case, for the compression is effected in a chamber which is cooled at every stroke by being filled with a mass of cold water, and therefore, in the midst of a mass of cold wet cast iron on sides and top and of cold water below. The ribs of the valve plate further add to the mass of cold iron and to its surface. A registering thermometer was suspended in the air vessel, and after several hours running the highest temperature shown was about 2 deg. above that of the water. The engine runs with perfect smoothness and regularity without any noise (even as much as that of the ordinary pumps) or concussions of any kind. It is essentially an hydraulic ram, and the popular idea of a ram appears to be that the essence of its action consists in a blow. This idea has, of course, no scientific foundation, but practice is perhaps more convincing than theory, and the fact is very practically demonstrated here. It will be obvious that air is here compressed without any intermediate transformation of power, and therefore the three sources of loss of power referred to in the beginning of this paper are reduced to one. The other unavoidable sources of loss are also small. The fluid friction is merely that in a plain pipe of no considerable length and the moving parts are very few and such movement is slow. The efficiency, therefore, is, as a necessary consequence, very high, amounting to 80 per cent. That is, the work done measured in isothermic compression of air is 80 per cent. of the gross power of the water.

In a great variety of cases, where with a low efficiency it is not worth while to use compressed air, or where electrical transmission, for instance, may be obviously preferable to transmission by compressed air, the case is entirely reversed if anything like an efficiency of 80 per cent. can be attained and attained in machines of simpler and less costly description than that which they supersede. Experience with this engine has revealed still further possibilities of improvement. Finality has not been reached, and the author does not say that an efficiency of 80 per cent. can be bettered but in other directions, such as making an engine of the same size do more work, this engine will be improved on in subsequent engines, and other developments of the same principle have also been suggested by it which are not yet carried out in practice.

In the discussion following the reading of the paper,

Mr. W. J. Jenkins said the great drawback in connection with the compression of air by direct water-power was that which caused the compressors at the Mount Cenis tunnel to be thrown out—the very large expense in laying down plant, and the very small output obtainable from it. The total cost of two of the machines at Mount Cenis was £7,000, and the amount of air turned out about 8,000 cubic feet per hour in each, or an expenditure of £3,500 for 8,000 cubic feet turned out. That amount of air could be very well compressed by a steam engine costing not more than £400. He would like to know how Mr. Pearsall measured the amount of compressed air delivered, because on that point the question of efficiency depended. He had never been able to convince himself that any system will measure compressed air properly, except by pumping it into the receiver at a certain pressure. The great drawback to any hydraulic system of direct compression would, of course, be the immense weight of the water that must be dealt with. No doubt in the colonies and other places where large water-power was obtainable, the author's apparatus would meet with considerable success.

Mr. Constantine said he knew a case where there was a large compressing plant used for mine purposes, for driving rock-drills and hydraulic motors, and the engineer was often called to account by the mining captain for not keeping up the supply of compressed air, although the engineer held that his plant was working satisfactorily. What was wanted then, was some apparatus which could be fitted to the outflow pipe leading down the mine, to register, even if only approximately, the quantity of air which had passed from the compressor to the mine. Was there any apparatus for such a purpose?

Mr. Alfred Saxon asked the author in what direction was it likely that his apparatus for compressing air would be used—in places where there was the necessary water power—instead of the other forms of power application that were available, such as electricity, steam engines, and other kinds of motive power.

Mr. Pearsall, in replying, said the Sommeiller machine at Mount Cenis only made three strokes per minute, and the reason why there was so little work done was that between each stroke it had to make a long pause. In measuring the air he had often pumped it into a spare air-vessel in a simple way which gave the exact quantity of air compressed. Perhaps the best way was to fill a second air-vessel with water, and at a given instant turn the air into it, and open a tap at the bottom so that the air coming in drove the water out; the pressure in the second air-vessel was thus kept constant, and the measure of the air pumped in was simply the measure of the water that came out. In the case mentioned by Mr. Constantine, of course if they could conveniently establish a receiver for measuring the air, it was the very best plan, but this might be a little troublesome, and in such a case it might be better to be able to ascertain at any moment how much air was passing. He did not see why they should not put a little meter on the pipe which would tell the quantity passing at any moment. Of course, the field for hydraulic plant was much greater in countries where they had larger water power than in England. With regard to compressed air compared with electricity, his idea was that in a great number of cases, if the initial cost of compressing air, which had hitherto been so great, could be very largely reduced, the economy of transmitting power by compressed air would be greater than the economy of transmitting it by electricity. There were numerous incidental advantages in compressed air as compared with electricity. In mining, the advantages of compressed air hardly admitted of question.

A GASOLINE AIR COMPRESSOR FOR BRIDGE WORK.

The Illinois Central Railroad is at the present time engaged in an interesting piece of work in connection with the strengthening of its bridge at West Point, Ky. The chief interest attaches to the manner in which the conditions of shop work are made practicable upon a bridge already erected and under traffic by the use of a portable plant for generating compressed air for the operation of riveting tools. The power is supplied by a 12-horse power gasoline engine furnished by Fairbanks, Morse & Co., and the tools operated are riveting hammers of the Chicago Pneumatic Tool Co.

The bridge and the location of the plant upon it are shown by the accompanying engravings from photographs. The operations in question are confined to the draw span, 265 feet in length, supported on a stone center pier at a height

FIG. 51.—GASOLINE ENGINE AIR-COMPRESSING PLANT.

of 65 feet from the water. The end abutments of the trestle work forming the approaches are supported by two steel caissons tied together at intervals.

In the original construction the bridge had a wooden floor resting on the chords. It was considered of insufficient strength for the traffic and it was decided to put on a new floor structure. This was accomplished by hanging cross girders from the pins of the bridge, upon which should rest two sets of stringers the latter being built up and riveted. The stringers are 28 inches deep and placed about 18 inches apart. The inner set of stringers carries the ties and supports the track. Double sets of braces were riveted to the crossbeams for connecting the stringers, and also for attaching the lateral braces, and for this riveting.

requiring ⅞-inch rivets and passing through two and three thicknesses of plates, some experimenting was necessary.

It was found difficult to use the yoke riveter which would ordinarily have been put upon this kind of work, owing to the peculiar conditions of the structure. The space between the stringers was insufficient to admit the frame, and it became necessary to use the pneumatic hand hammer. Two kinds of hammers were furnished by the Chicago Pneumatic Tool Co., the numbers "o" and "ooo" Boyer, and good work has been accomplished. It was also impossible to use the pneumatic rivet holder-on, and the hand "dolly" was substituted.

The compressor plant is the direct-connected gasoline engine air compressor, which has been especially designed by Fairbanks, Morse & Co., for isolated

FIG. 52.—THE BOYER HAMMER DRIVING 1-INCH RIVETS.

and portable plants. It is located on one side of the track, being placed on two 6 x 12-inch timbers bolted together and lagged fast to timbers placed across the stringers underneath the rails. The compressing plant is located at the middle of the span and air carried by means of a pipe. Openings are provided in the pipe at short intervals, and hose connections made for operating the riveting hammers at any required position. The engine itself transmits power directly from the engine piston to the air piston. The air cylinder is single acting, having one set of valves, and a mechanically operated unloading valve relieves the compressor when the desired pressure has been reached. The engine is thus left under no load until the pressure has descended to a determined point, and under this condition the governor admits sufficient gasoline only to maintain speed. This feature has an important bearing on economy, since the fuel used is in direct proportion to the amount of work actually performed, and the automatic features reduce to a minimum the cost of attendance. In the present case the engine operates continuously all day without attention. The lubrication is by sight feed cups.

One of the engravings herewith shows the location of the compressor and also of the rivet-heating forges. These are run at present by hand blast, but it has

FIG. 53.—GASOLINE AIR COMPRESSING PLANT FOR PUMPING.

been suggested and planned to run a small jet of air to the forges for this purpose. The whole operation of setting a rivet consumes practically 15 seconds on an average. On account of the inaccessibility of some of the rivet holes the time consumed is considerably more than 15 seconds. It is estimated, however, that one of the riveting machines is doing the work of three hand operators and the 12-horse power gasoline engine compressor is of suitable capacity to supply three or four riveters.

The smaller of the two sizes of riveting hammers used was designed for ¾-inch rivets, but it was found that it did effective work on those of ⅞-inch diameter. It was, however, a little slower in the work on these rivets, and the large size hammers with pistol grip were fitted with an additional handle for holding in position. The work has thus been expedited by using two large hammers on the ⅞-inch rivets, and working the smaller hammers on the ¾-inch rivets on the upper structure of the bridge, which is being changed from lattice bracing to plate for giving additional strength.

The foreman and the entire gang engaged upon the work were accustomed to hand riveting only, and it was somewhat difficult to convince them that the

FIG. 54.—THE BOYER HAMMER ON BRIDGE RIVETING.

work could be done by air. Later the foreman expressed himself highly in favor of the pneumatic machines. It is stated also that the pneumatic tool is superior, especially for reaching down between the deep stringers, as in the case of hand riveting it would be necessary to use a riveting bar about 3½ feet in length, and it is almost impossible to keep the bar from jumping from the rivet at every stroke of the hammer. In this way time is lost and poor work the result.

The large hammer referred to as furnished by the Chicago Pneumatic Tool Co. is an entirely new device, recently designed by them for heavy work. It is constructed on the same principle as the lighter forms of the Boyer hammer, but has a capacity up to 1 inch, and has been used upon 1½-inch rivets. A hook bar is used for holding up rivets, and its speed is such that rivets can be driven faster than they can be made ready and put in place. Six to seven seconds are said to be ordinarily sufficient for driving a rivet. It has been designed especially for heading down staybolts, placing truck rivets, pipe riveting, etc. The Risdon Iron Works of San Francisco report in regard to the work of this tool on pipe riveting that they have driven 200 1½-inch rivets per hour at a cost of one-fifth that of doing the same work by hand. The tool is illustrated in one of the accompanying engravings, driving 1¼-inch rivets. While known as the large hammer, the term has relation to capacity rather than weight, the latter being 10½ pounds.

The gasoline air-compressing plant in use upon this bridge is in extensive use in mining work for operating rock drills, and in irrigating. The illustration shown on page 181 is of a plant installed by Fairbanks, Morse & Co. at Gardena, Cal., where a 12-horse power gasoline engine air compressor discharges 700 gallons of water per minute from a 7-inch bored well, with a total head of 29 feet. The air pressure is 45 pounds and the cost of running the plant ten hours is given as $1.35, using distillate at ten cents per gallon. The principal advantage, aside from that of economy in operation, claimed for the plant, is the fact that the machinery is entirely above ground and accessible. The adaptability of the same plant for the operation of pneumatic tools on bridge work may be considered as an important advance, affording in the field the facilities which have hitherto been available only in the shop.—*Railway Age.*

BELT-DRIVEN AIR COMPRESSOR FOR SHOP SERVICE.

The half-tone and accompanying drawings illustrate an air compressor especially designed for the constant maintenance of a working supply of com-

FIG. 55.—BELT-DRIVEN COMPRESSOR.

pressed air in machine shops, boiler shops, foundries and similar places where it is the growing practice to employ air-operated tools and facilities. The compressor is of the belt-driven type, with tight and loose pulleys, for easy stopping and starting. It is designed to be usually kept constantly running, a pressure governor automatically operating a run-around which stops the operation of compression when the pressure rises above a given point, and allows it to resume again when the pressure falls. One of the special features of this machine is that the governing action does not stop the flywheel, which is always ready to respond

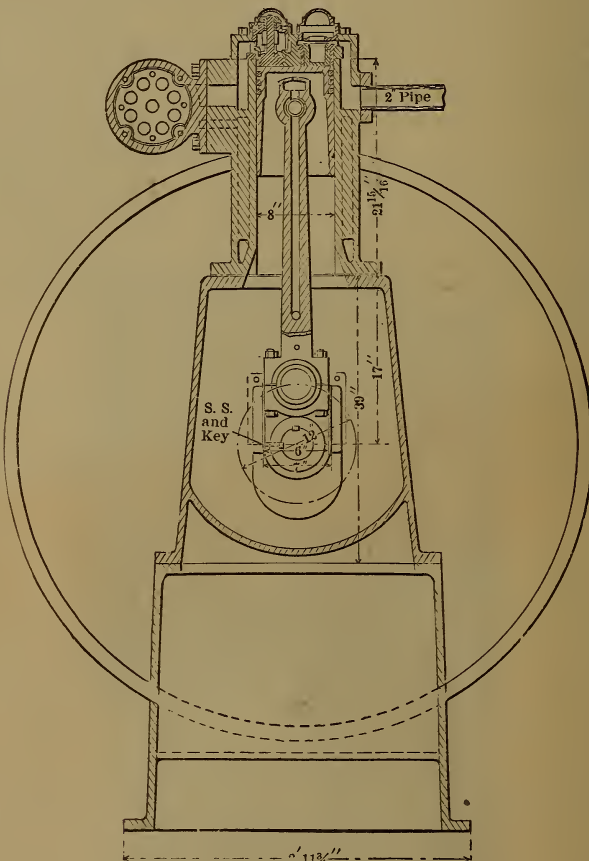


FIG. 56.—SIDE VIEW OF BELT-COMPRESSOR.

to duty. The compression is in two stages, with an efficient intercooler between the cylinders. The diameter of the cylinders, each single acting, are respectively 13 inches and 8 inches, with a stroke of 12 inches, and the free air capacity at 120 revolutions per minute is 100 cubic feet of free air, the permissible pressure being 110 pounds gauge, although 75 or 80 pounds is the more common practice. The pulleys are 60 inches x 10¼ inches, and the belt may be led off in any direction most convenient, the revolution being in either direction.

The same style machine is also built in size 16 inches in diameter, 10 inches diameter, 16 inches stroke. Flywheel 66 inches diameter, 15 inches face, having a capacity at 120 revolutions of 200 cubic feet of free air per minute. As will be seen, the compressor is entirely inclosed, but the working parts are easily accessible. By the hinged door at each side the connecting rods, cranks and main bearings are reached; all the valves are in the cylinder heads, each valve having its own cap and being independently removable. In the half-tone the high-pressure cylinder is nearest the observer, and the air is discharged at the side flange, to which the pipe to the receiver or line is to be attached. The free air enters at the side flange of the other cylinder, and if for any reason desirable an air pipe from the outside of the building or elsewhere may be connected. The provision for the lubrication of every working part is deserving of notice. There are chain oilers on the main journals and a pressure grease cup takes care of the upper pin. The base of the compressor is 6 feet x 3 feet and the total height is 7 feet. The drawings give very clear information as to the construction and operation of this compressor.

The design of this compressor is admirable, giving many points of advantage over other styles; the single-acting cylinders give 80 per cent. more cooling surface than the ordinary single cylinder, double-acting, increasing the efficiency in proportion, and doing away with troublesome stuffing boxes. This immense cooling surface is thoroughly water-jacketed, and partitions so arranged that there is a forced circulation of cooling water, so that all parts subject to excessive heat are kept cool. The advantage gained is readily understood.

This style of compressor is nearly double in weight of the same size of any other make.

These machines are now being manufactured in both single and double stage, either belt or steam driven, of sizes from 25 to 200 cubic feet of free air per minute, by the Curtis & Company Manufacturing Company, St. Louis, Mo.

We are also pleased to call attention to the very handsome catalogue which this concern has just issued, and it will be sent to all interested parties by applying to the manufacturers.

AUTOMATIC AIR PUMP.

A pretty little air pump just large enough to set almost anywhere is manufactured by the Auto-Electric Air Pump Co., 39 Cortlandt street, New York.

It consists of a one-sixth horse power electric motor, which can be arranged to operate by 110 volt continuous current, alternating current or storage battery as desired and an air compressing cylinder three inches in diameter by three inches stroke. Both the motor and the cylinder are mounted on a square cast iron base as shown herewith. The whole apparatus occupies a space of ten inches square and is enclosed in a glass case. When power is applied the motor operates the pump, producing a volume of air of 2.25 cubic feet per minute at 100 revolutions, enough to do a certain work such as operating dentists' tools, physicians' atomizers, pumping ale, beer or mineral waters, pumping tires, operating clocks and providing power for innumerable small works. Photographers, monumental designers, lithographers, architects and mechanical draughtsmen, also those who color photographs, lithographs, etc., will greatly improve their work and save time and annoyance by the use of this air pump. An illustration is given in the cover showing its use for artists. With the use of the foot pump to furnish air for the air brush, it has always been a matter of wonder how an artist could operate a pump with his foot and do good work with his hand. The Auto-Electric Pump operates automatically. It needs no attention beyond starting and it then starts and stops itself, maintaining a constant pressure at a desired point.

The use in which this apparatus finds its greatest utility is in pumping beer and other liquids in saloons, etc. It takes the place of carbonic acid gas and the

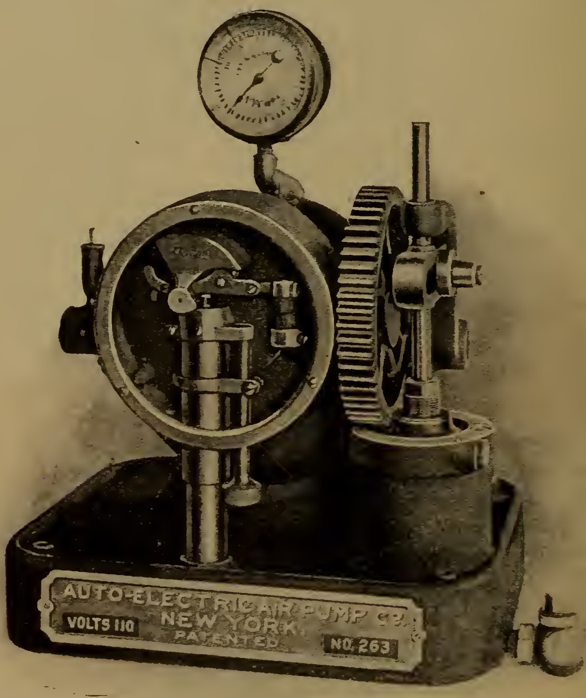


FIG. 57.—ELECTRIC DRIVEN AIR PUMP FOR SMALL DUTIES.

consumer is benefited by the change, as he gets only the natural effervescence instead of a highly charged gas in his beverages. The cost to the user is very much reduced and there is no refilling of reservoirs and consequent annoyance. Already numbers of saloons have adopted the air pump. One user says he draws from eight to ten barrels of beer and ale per day, and previous to running this pump his water bills for running the old style pump were from $18 to $24 per month. Since using this pump water bills run from $1 to $2 per month. To do the work mentioned the cost does not exceed 50 cents per month for electric current. The pump is capable of pumping from 20 to 30 barrels a day.

THE GLEASON-PETERS PUMP.

A variety of air pumps that would come in exceedingly handy for experimental purposes and would answer where only a small quantity of air was needed are made by the Gleason-Peters Pump Company, Houston street, New York. The

FIG. 58.

illustration shows an improved triple cylinder pump which can be operated by electric motor or from counter shaft. Requires but one-fifth h. p. at 75 revolutions and makes 150 lbs. pressure.

Dec. 12, 1899.

Editor COMPRESSED AIR:

I have a 24 x 18 power exhauster which operates satisfactorily at 40 R. P. M. with a port opening 20 x 1⅛ inches.

With 27-inch vacuum at what speed could this machine be operated to advantage? This machine has a simple slide valve, no lap, with eccentric 90 degrees ahead of crank.

If we desired to make a 9-16-12 D4 steam driven exhauster, at what speed do you think it would operate? It seems to me to be a question of velocity of gas through a variable port opening. If you can give me any idea it would be appreciated.

Thanking you for any information which you may give me, I am,

E. W. KING, M. E.,
Deane Steam Pump Co., Holyoke, Mass.

The data given by Mr. King is somewhat limited, and it is possible that we have not obtained a proper understanding of his purposes. To begin with, the engine described is a practical steam engine with a slide valve which is rigidly connected with moving parts and has a definite cycle which insures a certain relation between the piston and the valve at all times. The action is the reverse of the ordinary steam engine, in that air is admitted in what is usually the exhaust and is discharged from the steam chest, which is always the inlet in the usual engine. We will assume the piston at one end of its stroke just starting back, and we will assume that air is taken in for a full stroke on one side, and discharge for a full stroke on the other side. In the ordinary compressor of which this is the reverse, the valves remain fully open or fully closed, as the case may be, during the entire stroke. With a slide valve just described, the ports area is constantly changing from a very small opening through all ranges to the full size of the ports and again closing. However, the velocity of the moving piston, which is drawing in air on one side and expelling it on the other, is also changing. These two changes are, therefore, coincident, and properly related, that is, as the port opening of the inlet or outlet side of the cylinder is increasing or decreasing in area, the velocity of the inflowing or discharging air is increasing or decreasing as the case may be. It is usually true that these complimentary changes are not identical, and that the valve may close at a more rapid rate than the piston slows down, which causes an increased friction at the port; this point will be considered later.

For the present we will take the liberty of assuming the velocity of flow of air and the change of valve area as parallel variables. Another point to be considered is, that the pressure tending to fill the inlet side of air cylinder is that of the atmosphere or 15 pounds. Now it would seem that the limiting speed of such an engine would be for any given case that speed which would cause the air to flow through the full open port, neglecting now the resistance of pipes, elbows, etc., at the same velocity which air would have if allowed to flow through an orifice in a receiver, where the pressure is 15 pounds, and the outside pressure practically nothing, or from a receiver pressure of 30 pounds to an outside pressure of 15 pounds.

For practical purposes, however, it is better to assume a velocity of flow through the port of 100 ft. per second, which is the figure used for calculating port openings for steam engines.

To make this clearer take the exhauster mentioned by Mr. King.

The port area is $20 \times 1\frac{1}{8} = 22\frac{1}{2}$ sq. ins. or 0.156 sq. ft. $100 \times 60 \times 0.156 = 936$ cu. ft. per min.

The volume of the cylinder, 24×18 ins., is 4.75 cu. ft. Dividing 936 by 4.75, the volume of the cylinder, gives 197 strokes or 98 revolutions per minute.

COMPRESSED AIR CENTRAL PLANTS.

The enthusiasm and ingenuity being displayed in the application of compressed air for power purposes will no doubt bring to light many schemes for further advancing its use, now that it is in a fair way to be adopted in so many places where a few months ago it would have been rejected—not for the reason that it was not competent, but because it seemed new and untried. Many of these dormant schemes will be brought out and the fortunate inventor will reap a long delayed reward.

For transmission of power, compressed air perhaps has no equal. It is always ready, willing and obedient.There does not seem to exist any of the dangerous elements that are associated with other forces. Already the central plant idea is taking possession of the minds of the mechanical genius of the world, and a few of the many devices that may be operated from central plants will be of interest to engineers, in general, and will stimulate the adoption of compressed air in many places where it is not now applied. We have already told of the successful and highly economical operation of various appliances at Jerome Park, New York. It is simply a gigantic exhibition of the co-operative system in mechanics, where the judicious distribution of power effects good results and accelerates the completion of necessary work.

A proposition has been made wherein one air compressor will supply power to run several pumps that are widely separated, for pumping sewage to a level of the sewer line in the city of Chicago.

It seems in this case numerous steam-actuated pumps were to be employed, each one of which would require a boiler and an attendant to operate it. A progressive firm of pump manufacturers now propose to erect a central air

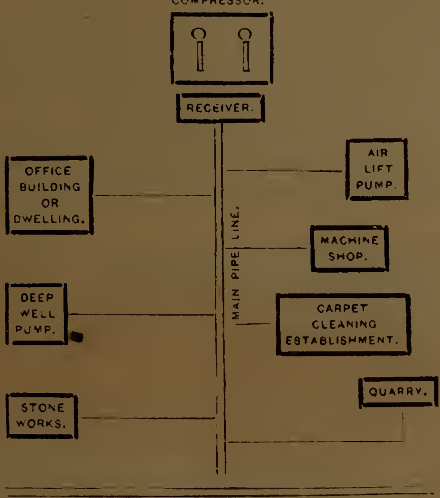


FIG. 59.

power plant, lay the pipe line to each pump and operate it by air instead of steam, and chances are that they will win the contract.

These two instances are only given to illustrate the importance to be attached to this method.

This little diagram will serve to illustrate the outlines of a central plant and its tributaries:

These and many additional places that may be added could readily be run from the one compressor plant, as they may all be within a half mile of each other.

As to the feasibility of this plan, there is no doubt. It has been demonstrated, time and again, that by using compressed air for the purposes for which it may be employed you will enjoy several advantages over steam and electric power. First of all comes safety and cleanliness, then reliability, and the simplicity with which it may be handled and made to do man's bidding. The cost is always dependent upon conditions, but in any case that we can think of it will be as cheap as either of the two agents mentioned, and if water power is available it will be much cheaper than either of the others.

COMPRESSED AIR VERSUS TROLLEY.

To the Editor—

In discussing the other day with a New York business man the advantages of the Compressed Air Motor over the Trolley, I referred to the safety of the former method and its freedom from delays and accidents. He asked me in a tone of triumph when I had ever heard of or seen any accident or delay caused by the Trolley?

I was surprised at this question, coming as it did from a man thoroughly well informed on current affairs, until I recalled the fact that he lived up-town in New York and had rarely "enjoyed" a ride on a trolley car. I am an unfortunate resident of trolley-ridden Brooklyn, and the very next day a practical answer was afforded me to his inquiry. While riding down Fulton street on a car filled with passengers, we were all startled by a sharp explosion directly at the side of the car—and a heavy wire blazing and sputtering with blue-fire fell to the ground striking the end of the seats, directly in front of me.

The passengers jumped to the other side amid the screams of women, the shouts of men, while every face paled with fright and the stoutest men trembled with fear.

Of course the papers contained nothing of this for it was "only" a daily passing occurrence, and my New York friend might say, "but no one was hurt." Apparently not, and yet it is now conceded by the doctors, that such frequent shocks and frights, leads to prostrations and complications of the nervous system, oftentimes most serious.

Previous to this occurrence I saw a live wire fall upon, and set fire to, the roof of the car, and for a hundred feet along the street emitting flames for a minute or two—a menace to the lives of those crowding the busy thoroughfare.

The old saying you might as well kill a man outright, as to frighten him to death, might with a slight modification be aptly applied to the erratic and terrible trolley.

Yours in the cause of public safety. J. S. TOBEY.

BROOKLYN.

TESTS OF A FOUR-STAGE AIR COMPRESSOR.

The *Engineering News* of November 4th contained a clear and valuable review of the two tests made on a four stage Ingersoll-Sergeant Air Compressor by seniors of Cornell University and Stevens Institute, the tests in detail having been published in the *Engineering News* on October 7th. The method of computing the efficiency of the Air Compressor defined as "the ratio of the useful work done by the air cylinders to the indicated work of steam cylinders," is interesting and as nearly correct, perhaps, as can be reached under the circumstances. It must be admitted, however, that the work done in the steam cylinders of this compressor was really more than the figures show, as it is stated in the beginning of the *Engineering News'* article that "the useful work done by the air cylinders was the storing in a receiver of 925 cu. ft. of air at a gauge pressure of 170 atmospheres." In order to do this, the supply pipe and the high pressure air cylinder were also filled with air at the same pressure. The second intermediate cylinder was filled with air at 780 lbs. pressure; the first intermediate was filled at 160 lbs., and the low pressure or initial cylinder at 55 lbs. In addition to these, the air was forced through the different coolers. It is evident that this represents work done, and that it should be taken into account when figuring the efficiency of the compressor. Each cubic foot of internal contents of conveying pipe required 1,500,000 foot pounds of work at 170 atmospheres. It is practically impossible to follow the air through the four stages of compression and the intercooling between each stage, comparing and computing the effects of each operation successively and obtaining definite results. The efficiency shown in the *Engineering News'* article is certainly as good as could have been expected, and it is probably better than has ever been shown before for such high pressures. In making theoretical deductions from a test of this kind, the indicated horse power of the steam cylinders at the beginning of the series and the volume pressure and temperature of the compressed air at the other end are safe lines on which to base efficiency.

It is to be regretted that this test is not conclusive and that the Air Compressor was not operated under the conditions of actual service. The filling of a receiver from atmospheric pressure up to any other pressure, however high, is not what a compressor is built for. It has usually to maintain a constant high pressure in a receiver while the air is being drawn off and used at that high pressure. The first operation is one of compression pure and simple, while the second involves not only compression but delivery of the air, which is a very different thing. The first operation, which is all that is represented in these tests merely brings the compressor to a point where it is ready to begin its legitimate work, and does not show its actual efficiency when at its proper work. It would not, therefore, be quite fair or proper to allow the statement of efficiency here obtained to go out as showing the actual efficiency of the compressor.

The results of our computations of the efficiency of the compressor in filling the storage receiver only are practically identical with those given in the *Engineering News*. In the first case—the test made by Cornell students—the steam cylinders developed 1,556,280,000 foot pounds; and 694 cu. ft. of air, at a pressure of 171 atmospheres, was compressed from atmospheric pressure. The formula for the mean effective pressure, absolute, in compressing air isothermally from any given pressure to any other pressure, we use in this form:

$$\frac{(\text{Hyp. log } R) \times P}{R - 1}$$

R being the ratio of the terminal to the initial pressure, and P the absolute terminal pressure in pounds per square inch. Substituting the figures we have

$$\frac{5.141663 \times 2513.7}{170} = 76.0268$$

The mean gauge pressure then will be

$$76.0268 - 14.7 = 61{,}3268, \text{ or say } 61.3.$$

The power required for the compression will then be 694 x 144 x 61.3 x 170 = 1,041,433,056 foot lbs., and 1,041,433,056 ÷ 1,556,280,000 = 66.91 per cent. as the ratio of the work done to the power expended, or the actual efficiency.

In the tests made by the Stevens Institute students, one-third more storage capacity was employed, and in the first test the work done was therefore 1,041,-433,056 (as above) x 1 1-3 = 1,388,577,408 foot lbs. The power developed by the steam cylinders being 2,029,500,000, we have 1,388,577,408 ÷ 2,029,500,000 = 68.40 per cent.

In the second test by the Stevens Institute students, the final volume and the total work done was the same as in their first test, with the exception that at the beginning of the second test the receiver was already filled with air compressed to 136 atmospheres, and the work of this preliminary compression is to be computed and deducted. The hyp. log. for 13.6 being 4.912655, and 136 x 14.7 = 1999.2 pounds, the absolute pressure, we use these in the formula above and we have

$$\frac{4.912655 \times 1999.2}{135} = 72.75. \text{ Then}$$

72 75 — 14.7 = 58 05 the m. e. p. Then 925 x 144 x 58.05 x 135 = 1,043,855,100 foot pounds, and 1,388,577,408—1,043,855,100 = 344,722,308 foot pounds, the work actually done. As the power developed by the steam cylinders was 527,710,000, that is to be used as a divisor, as in the preceding cases, so 344,722,308 ÷ 527,710,-000 = 65.3 per cent.

This is practically a recapitulation of the *Engineering News'* figuring, but it represents independent computation all through. The results differ only as the work of any one computor may differ from that of another on account of difference of practice in the retention of the decimals. It confirms in every particular the results arrived at.

A quite simple means of ascertaining the ultimate efficiency of the compressor, at any particular moment of its operation, would have been to take a simultaneous set of indicator diagrams, as was done repeatedly by the students, and note at the same time the temperature and pressure of the air delivered. The steam cylinder cards would, of course, show the power developed, and from the card of the first or low pressure air cylinder the volume of free air taken in could be ascertained. It would not be necessary to pay any attention to the work of the other air cylinders. The temperature and pressure at delivery would supply all additional data required, so far as the mere computation of the efficiency was concerned. The card from the high pressure cylinder could not be expected to be minutely accurate, on account of the small area of the piston and the friction and other interfering conditions. The entire set of cards is, of course, valuable, and especially suggestive and instructive to the compressor designer as showing the relative economy of each stage of the operation and the inter-dependency of the different parts of the apparatus.

ABSTRACT OF THESIS TEST OF COMPRESSED AIR POWER PLANT AT JEROME PARK, N. Y.

By George W. Vreeland and Charles M. Younglove.

To receive the degree of Mechanical Engineer at Cornell University, the above named gentlemen sought to satisfy the requirement for a graduation thesis by making an exhaustive test on the Compressed Air Power Plant at Jerome Park, N. Y.

The purpose of the test was to determine the various efficiencies of a central power plant of this kind and point out any line of improvement that may be necessary.

A complete description of the plant was given in Compressed Air, No. 7, Vol. I., and it will not be necessary here to go into details further than say that the plant consists of 2 Hogan boilers with an aggregate of 540 H. P., and one Ingersoll-Sergeant Corliss Cross-Compound Condensing Air Compressor, the equivalent of 3,400 cubic feet free air per minute at a pressure of 80 lbs.

The use to which compressed air is put to at Jerome Park represents a departure from old methods. Although the relative advantages are pretty well understood by those interested, any reliable information on any part of the plant is of importance, and great care was therefore taken in this test to give exact deductions.

We show samples of indicator cards taken from all cylinders of the compressor, and give the following abstracts, which no doubt will interest our readers.

A—Report of boiler test.

B—Engine data and results.

C—Compressor data and results.

REPORT OF BOILER TEST.

Duration of trial, hours, 10.

Dimensions.

Grate surface	Sq. ft.,	121
Water heating surface	"	5548
Superheating surface	"	None
Area for draft (Calorimeter)	"	
Area, chimney	"	19.73
Height, chimney	Ft.	93
Ratio heating surface to grate surface		45.8:1
Ratio air space to grate surface		

Pressure.

Barometer	Inches, Mercury,	29.70
Steam gauge	Pounds,	116.5
Absolute steam pressure	Pounds,	131.14

Temperature.

External air	Deg., Fah.,	65
Boiler room	"	70
Flue	"	483.5

Temperature—Continued.

Furnace	Deg., Fah.,	1918.
Feed water	"	105.8
Steam	"	259.05

Fuel.

Total coal consumed	Lbs.,	9284
Moisture in coal	Per cent.,	2.22
Dry coal consumed	Lbs.,	9078
Total refuse, dry	"	1102
Total refuse, dry	Per cent.,	12.1
Total combustible	Lbs.,	7976

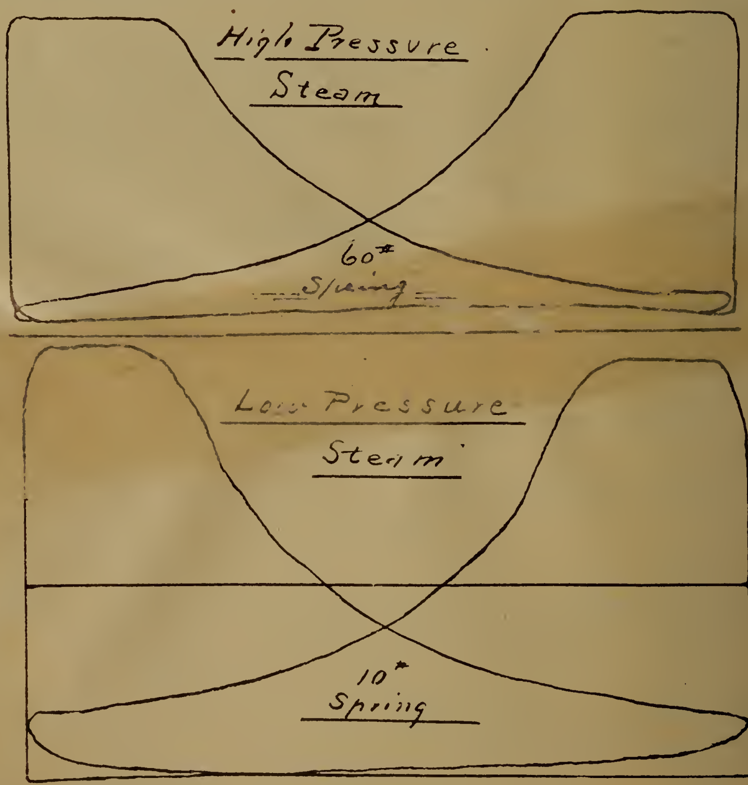


FIG. 60.—INDICATOR CARDS FROM CORLISS COMPOUND AIR COMPRESSOR AT JEROME PARK, N. Y., TAKEN APRIL 6TH, 1897.

Fuel per Hour.

Dry coal, per hour	Lbs.,	928.4
Combustible, per hour	"	797.6
Dry coal per sq. ft. of grate	"	7.67
Combustible, per sq. ft. of grate	"	6.59
Quality of steam	Per cent.,	97.9

Total Water.

Total weight water used....................................	Lbs.,	84,510
Total evaporated, dry steam.................................	Lbs.,	82,735
Factor of evaporation..		1.154
Total from and at 212°..	Lbs.,	95,476

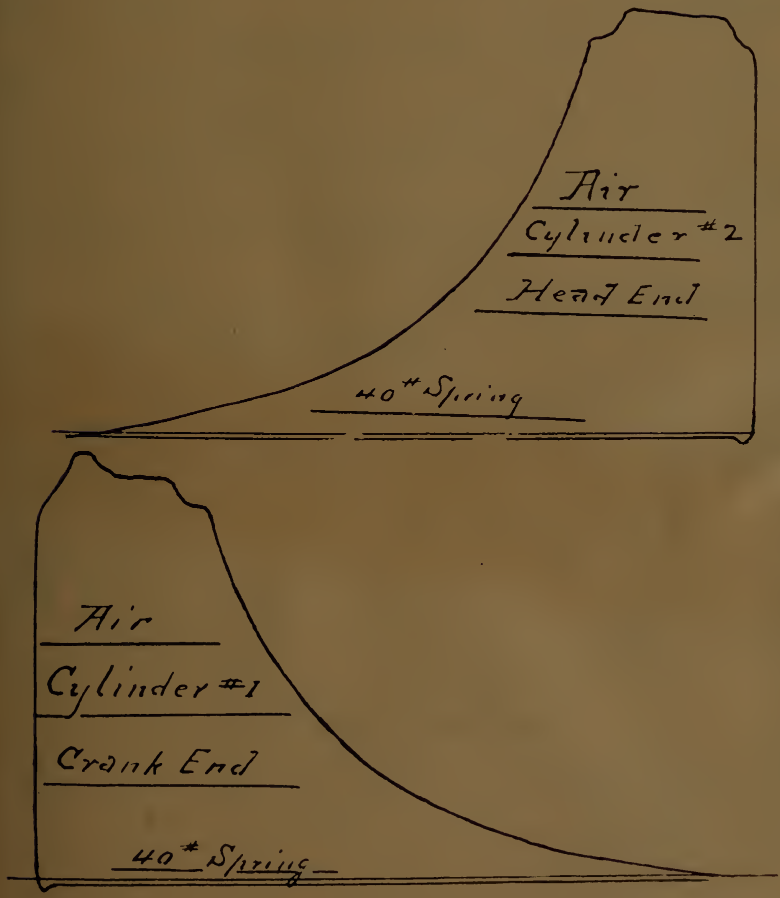


FIG. 61.—INDICATOR CARDS FROM CORLISS COMPOUND AIR COMPRESSOR AT JEROME PARK, N. Y., TAKEN APRIL 6TH, 1897.

Water per Hour.

Amount used..	Lbs.,	8451
Evaporated dry steam......................................	Lbs.,	8273
Evaporated from and at 212°...............................	Lbs.,	9547

Economic Evaporation.

Per pound of fuel.

Actual per pound, dry coal	Lbs.,	9.11
Equivalent from and at 212° (dry coal)	Lbs.,	10.51

Per pound of Combustible.

Actual	Lbs.,	10.37
Equivalent from and at 212°	"	11.95

Per sq. ft. Heating Surface per hour.

Actual	Lbs.,	14.9
Equivalent from and at 212°	"	17.19

From 100° Fah. to 70 lbs. by Gauge.

Per pound of fuel	Lbs.,	8.57
Per pound of combustible	"	9.5

Evaporation per Hour.

Per sq. ft. of Grate.

Actual from feed water temperature	Lbs.,	68.37
Equivalent from and at 212°	"	78.89

Per sq. ft. of Water-Heating Surface.

Actual	Lbs.,	1.49
Equivalent from and at 212°	"	1.71

Horse Power.

On basis 34½ lbs. equiv. evap. per hour (1)	H. P.,	277
Builder's rating	H. P.,	510
Ratio of commercial to builder's rating		50.5%
Heat generated per hour	B. T. U.,	11465740
Heat absorbed per hour	"	8960200
Heat lost per hour	"	2505540
Efficiency of boiler	Per cent.,	78.1
Efficiency of furnace	"	78

ENGINE DATA AND RESULTS.

Kind of engine, Cross Compound.

Duration of run	10 hours.
Revolutions per minute	57.06
Diameter of fly-wheel	22′
Weight of fly-wheel	50,201 lbs.
Temperature engine room	78
Temperature external air	65
Temperature condensing water, cold	74.3
Temperature condensing water, hot	113.8
Temperature boiling point (atmospheric pressure)	211.7
Boiler pressure, gauge	116.5
Boiler pressure, absolute	131.03
Barometer in mercury	29.73
Barometer pressure in lbs	14.58

(1) Standard Commercial H. P.

Condenser in mercury	23.3	
Condenser pressure in lbs	11.04	
Total condensing water per hour, lbs	160360.	
Weight condensing water per pound steam	19.7	
Total I. H. P.	467.7	
Total D. H. P.	402.4	
Mechanical efficiency	86.03%	
Moisture in steam	2.1%	
Steam per I. H. P. per hour, actual	17.36	
Steam per I. H. P., corrected for Cal	17.01	
Water rate of perfect engine	12.4	
Thermodynamic efficiency	23.4	
Ratio actual to theoretical water consumption	1.37	
Heat supplied per hour, B. T. U	9634245.8	
Heat discharged and radiation, B. T. U	8456808.8	
Heat utilized, B. T. U	1177437.0	

	High.	Low.
Diameter of cylinder in inches	24	44
Length of stroke	48	48
Diameter of piston rod, front	4	5
Diameter of piston rod, back	3⅝	3⅝
Piston displacement, crank end, cu. ft	12.211	41.64
Piston displacement, head end, cu. ft	12.221	41.92
Volume of clearance, head end, per cent	3½	4
Volume of clearance, crank end, per cent	3½	4
Make of Indicator	Thompson.	Tabor
Scale of spring	60	10
Cut-off, crank end, % stroke	24.82	16.83
Cut-off, head end, % stroke	22.14	16.32
Release, crank end, % stroke	100	100
Release, head end, % stroke	100	100
Compression, crank end, % stroke	100	100
Compression, head end, % stroke	100	100
Absolute pressure at point cut-off, crank	120.58	26.23
Absolute pressure at point cut-off, head	119.98	25.53
Absolute pressure at release crank	27.63	4.16
Absolute pressure at release cut-off, head	26.58	3.99
I H. P., head	123.3	104.74
I. H. P., crank	127.44	112.24
Total I. H. P.	250.74	216.98

Steam per I. H. P. at point of cut-off, per diagram, high pressure cylinder	11.3
Steam per I. H. P. at point of cut-off, per diagram, low pressure cylinder	7.25

COMPRESSOR DATA AND RESULTS.

	No. 1.	No. 2.
No. of cylinders, double-acting	1	1
Length of stroke, in inches	48	48

Diameter of piston	24¼	24¼
Piston area, head, sq. inches	429.28	429.28
Piston area, crank, sq. inches	451.49	451.49
Diameter piston rod, in inches	3⅝	3⅝
Diameter piston in inlet, inches	6 7-16	6 7-16
Piston displacement, per stroke, in cu. ft., head	11.924	11.924
Piston displacement, per stroke, in cu. ft., crank	12.54	12.54
Clearance, head, % volume	.289	.289
Clearance, crank, % volume	.287	.287
Displacement of piston, cu. ft., per minute	1395.68	1395.68
Developed H. P. mean	198.9	204.5
Absolute pressure at end of compression	80.76	82.20
Heat equivalent of work, steam end, per hour		1177437
Heat equivalent of work, compressor, per hour		1023910
Efficiency of mechanism, %		86.03
Work of compression per lb. air, in ft. lbs., Adia		7658.53
Work of compression per lb. air, in ft. lbs., Isoth		6286.44
Efficiency of compression		82.05
Combined efficiency, 86.03 × 82.05		70.58%

HEAT ACCOUNTS.

	No. 1.	No. 2.
Temperature of air at inlet	78	78
Temperature of air at exhaust	354.7	360.03
Rise of temperature of air	276.7	282.03
Temperature of entering jacket water	46.05	46.05
Temperature of exit jacket water	95.7	92.03
Rise of temperature of jacket water	49.65	45.98
Weight of jacket water per hour	2934.6	2934.6
Heat rejected in jacket water (B. T. U., per hour)	145705.	134935.
Heat rejected air leaving cylinder (B. T. U., per hour)	308063	313865
Radiation and unaccounted for	13701	18669
Total heat loss	467469	467469
Heat produced in compression	467469	467469
Calculated volume of air delivered in cu. ft. per stroke at atmos. pressure, allowing for clearance and by pass	12.11	12.11
Per minute, cu. ft	1395.68	1395.68
Per hour, cu. ft	83740	83740
Rated capacity of compressor at 60 revolutions per minute, in cu. ft. of free air	1467	1467
Per cent. of rated capacity delivered	95%	95%
Weight of comp. air per hour	12393.6	
Weight of comp. air per D. H. P		.517
Volume of air delivered per I. H. P. per hour at atmospheric pressure, in cu. ft		358.09
Volume of air delivered per D. H. P. per hour at atmospheric pressure, in cu. ft		416.2
Weight of water in cooling 1 lb. of air, in lbs		.31

In accounting for mechanical efficiency of 86.03%, allowance must be made for the work of the jet condenser, which is attached by means of bell crank and connecting rod to crank pin of low pressure engine—pumping about 200,000 pounds of water per hour with a suction of 5 feet, and also from a varying load as well as the condition of condensing water which enters condenser at a high temperature. This is occasional by a limited supply. The water being used over and over again, does not have time to cool, thus reducing the vacuum and decreasing the mechanical efficiency and increasing the steam consumption per H. P. per hour.

TESTS OF A KING-RIEDLER AIR COMPRESSOR, AT THE ROSE DEEP MINE, SOUTH AFRICA.

PAPER READ BY MR. L. I. SEYMOUR, BEFORE THE SOUTH AFRICAN ASSOCIATION OF ENGINEERS AND ARCHITECTS.

ENGINE.

A Vertical King-Riedler Compound Steam and Double Stage Air Compressor at the Rose Deep, Ltd., No. 1 Shaft.

Diameter of high pressure steam cylinder	19 inches	stroke	41·6875 inches
" " low " " "	30 "	"	41·9375 "
" " 1st stage air cylinder	30 "	"	41·9375 "
" " 2d " " "	17·5 "	"	41·6875 "
" " piston rods - - -		-	3·46875 feet

The two steam piston rods are connected by a short link to a triangular connecting rod, and the power from them transmitted through a crankshaft, fly-wheel and another triangular connecting rod and links to the two air cylinders.

The inter-cooler for the air is placed on the platform by the side of the air cylinders. (N. B.—This inter-cooler was not very effective and is now being fitted with baffle plates, which will reduce the temperature of the air in the inter-cooler to less than that drawn into the 1st stage cylinder.)

The circulating pump for inter-cooler and water jackets was driven directly by the engine.

The air pump and jet condenser was disconnected.

JACKETS.

The high pressure steam cylinder jacket was under boiler pressure, while the low pressure steam cylinder jacket was reduced to a pressure from 30 to 40 lbs. per square inch by a "Royle" reducing valve. The jackets were drained by a "Kieley" trap, and the discharge weighed.

CONDENSER.

A "Wheeler" independent condenser (capacity, 30,000 lbs. of steam per hour) with Admiralty tubes and attached horizontal air and circulating pumps, steam cylinder 16", air pump 16", circulating pump 18" x 24" stroke, was used during this trial entirely for the compressor; although ordinarily it condenses for the compressor, a 12½" and 19" x 42" Cornish pumping plant, a small temporary lighting plant and a pair of 10-½" and 17" x 28" horizontal tandem compound "Tangye" winding engine. The steam actuating the motive cylinder exhausted directly into the condenser, and all the steam used was charged against the compressor. The discharge from the condenser air pump was not measured the water pumped into boilers being weighed.

BOILERS.

The two boilers in use were of the horizontal return tubular type, (see annexed sketch).

Diameter of shell in inches	66
Length between tube plate in feet	16
Nnmber of tubes in each boiler	104
Outside diameter of tubes in inches	3
Number of square feet of grate surface	35
" " " " " heating "	1500
Ratio of grate to heating surface	1·428

No economizers were used with these boilers. A separator was fitted on the steam main to compressor and drained by a "Kieley" trap.

The water discharged from this tray was weighed.

COAL.

The coal used was "Clydesdale," having an evaporative value under the conditions of the trial of 5.815 lbs. of water per lb. of coal, (3 of rounds to 1 of nuts).

DRILLS.

One	2-1/2	inches value compared to 3¼ inches Ingersoll-Sergeant drill	445
Eleven	3-1/4	" " " " " " " " "	1·000
Seven	3-5/16	" " " " " " " " "	1 069
Twelve	3 3/8	" " " " " " " " "	1·123

Total 31 drills, equal in value to 32·4 3¼ inch drills.

TABLE 16.

Name of Drillman.	No. of Holes.	No. of Machines.	Footage.	Remarks.
J. Stephens	7	1	19 feet 7 inches	
D. McAvoy	2	1	8 " 2 "	stopped after about 2 hours
D. McAvoy	8	1	36 " 5 "	
R. Wilson	6	1	29 " 5 "	
G. Tonkin	9	1	51 " 9 "	4 dry holes
Walters	2	1	11 " 5 "	
Walters	1	1	3 " 0 "	stopped after about 1 hour
T. Mylroie	8	1	40 " 6 "	
J. C. Mylroie	4	1	19 " 5 "	
H. Temby	8	1	48 " 9 "	3 dry holes
R. Dellbridge	9	1	46 " 2 "	3 " "
S. Uren	8	1	44 " 8 "	
T. H. Trevillion	15	2	85 " 11 "	
J. H. Harris	8	2	42 " 4 "	
J. Cock	9	2	42 " 1 "	4 dry holes
H. Carnow	7	2	45 " 8 "	
Blain	10	2	50 " 8 "	4 dry holes
J. Carlson	6	1	32 " 9 "	
J. A. Harris	9	2	58 " 5 "	
Cock	8	2	44 " 7 "	
J. Harrison	8	2	42 " 3 "	
J. Handley	7	2	35 " 3 "	
Totals	159	31	230 feet 2 inches	18 dry holes

Thirty-one Ingersoll-Sergeant drills were started at 9:45 a. m. (Mine time), all being set up and ready to start simultaneously. The air pressure at the start was 46 lbs. per square inch, and as this could not be raised with the compressor running at about 90 revolutions per minute, two drills were stopped after drilling 8 ft. 2 ins. and 3 ft. respectively. The pressure then gradually rose 70 lbs. per square inch. Twice afterwards it fell to 48 lbs. and three times rose to 95 lbs. finishing at 80 lbs. (per square inch at 3:45 p. m. the average pressure was 69.83 lbs.)

The size of drills (all Ingersoll-Sergeant).

Two of the 3¼ in. drills ran 2 hours and 1 hour respectively.

This reduces the average time of running of the 32·4 3¼ in. drills from 6 hours (duration on trial) to 5·78 hours, which is equivalent to 30·9 3¼ in. drills running for an average time of 6 hours.

N. B.—The comparative values of the drills was measured by filling the cylinders, ports, etc., with water.

All holes not indicated were wet holes.

A bonus of £5 was given to C. Tonkin for drilling the most footage with his machine. The footage of 30.0 drills averages 26 ft. 10 2-5 in. per drill in 6 hours which is equal to 4 ft. 5 11-15 per drill per hour.

DATA.

Duration of trial in hours	6		
Average height of mercurial barometer in inches (corrected)		24·5	
" pressure in lbs. per square inch		12·04	
" " " steam by gauge		105·39	
" " " " (absolute)		117·43	
" vacuum in inches of mercury		21·24	
" pressure of air in intercooler		27·0	
" " " " receiver		69·83	
" temperature of air entering 1st stage air cylinder in degrees Fah.	52·0	543·0	abs
" " " leaving " " " "	292·8	753·8	"
" " " entering 2d stage " " "	131·9	592·9	
" " " leaving " " " "	243·5	704·5	
" " " at drills in mines in degrees Fah	65·0	526·0	
Percentage of volume taken by 2d stage air cylinder to that discharged by 1st stage air cylinder		78·65	
Percentage of volume taken by 2d stage air cylinder to that discharged by 1st stage air cylinder, if air had been reduced by proper inter-cooling to temperature used at drills		69 78	
Number of revolutions of engine during trial		29916·0	
Average number of revolutions per minute		83·1	
" temperature corresponding to absolute steam pressure in degrees Fah		339·37	
Average temperature of feed water		98·0	
B. T. U. in each lb. of the dry steam		1317·45	
" " " feed water		98·97	
" absorbed by each lb. of the feed water		1119·38	
Factor of evaporation		1·139	
Lbs. of water pumped into boiler		46873·8	
" moisture in the steam		422·85	
Factor of dryness of the steam		99·16	
Lbs. of dry steam used by steam jacket		3071·0	
" " " engine (including indep. condenser)		43380 25	
Total lbs. of dry steam used by engine (including steam for jacket and independent condenser)		46451·25	
Total lbs. of dry steam used by engine (including steam for jacket and independent condenser) per hour		7741·87	
Lbs. of water used by condenser (by meter)		1434500·0	
" " " per lb. of steam condensed		33·07	
Temperature of water entering condenser in degrees Fah		79·79	
" " leaving " " "		106·45	
B. T. U. in each lb. of water entering condenser		79 85	
" absorbed by each lb. of the circulating water		26·71	

RESULTS.

I. H. P. of steam cylinders	373·65
" " air and circulating pump	19·51
Total I. H. P. of engine	393·16
I. H. P. of air cylinders	338·77

Mechanical efficiency of engine per cent	86·17
" " " (without including air and circulating pumps) per cent	90·66
Lbs. of dry steam used by engine and independent condenser per I. H. P. per hour	8·39
Lbs. of dry steam used by jacket per I. H. P. per hour	1·30
Total lbs. dry steam used per I. H. P. per hour	19.69
Lbs. of coal used per I. H. P. per hour (assuming 1 lb. of coal will evaporate 6·74 lbs. of water from and at 212° Fah. cost of coal 13/9 per 2000 lbs.)	3·38
Cost of coal per I. H. P. per hour in pence	0·28
Heat efficiency of engine per cent	10·7
Average volume of free air entering 1st stage cylinder in cubic feet per minute	2505·5
Average volume of air leaving 2d stage cylinder at 69·83 lbs. gauge pressure and at the temperature used at drills (65° Fah.) in cubic feet per minute	368·46
I. H. P. at compressor steam cylinder per 3¼ in. drill	12·72
Cubic feet of free air required per 3¼ in. drill per minute including all leakages	81·08
Lbs. of coal required per drill per hour	42·99
Cost of coal per drill per hour in pence	3·55

SUMMARY OF MAIN DETAILS.

Diameter of high pressure steam cylinder 19 inch stroke	41·6875	
" low " " 30 "	41·9375	
" 1st stage air cylinder 30 "	41·9375	
" 2d " " 17·5 "	41·6875	
Average revolutions per minute	83·1	
" steam pressure (by gauge)	105·39	
" vacuum (by gauge)	21·24 ins.	
" intercooler air pressure (by gauge)	27·0	
" receiver " "	69·83	
" temperature of air entering 1st stage cylinder in degrees Fah.	82·0	(543 abs)
" " " at drills in degrees Fah.	65·0	(526 ")
Actual number of 3¼ inch drills working	30·9	
Duration of trial in hours	6·0	
Total footage of holes drilled	830 ft. 3 inches	
Average " " per machine	26 " 10 2-5 inches	
Cubic feet of free air compressed per minute	2505·5	
" " air at drills per minute at 69·83 lbs. pressure and 65° Fah.	368·46	
" " free air used per 3¼ inch drill per minute	81·08	
" " air used per drill per minute at 69·83 lbs. pressure and 65° Fah	11·92	
Average I. H. P. of steam cylinders (including air and circulating pump)	393·16	
Average I. H. P. of air cylinders	338·77	
Mechanical efficiency per cent	86·17	
Average steam I. H. P. per drill	12·72	
" feed water to boilers per I. H. P. per hour	19·69	
" cost of coal per drill per hour in pence	3·56	

Tested February 16th, 1898.

I believe the footage drilled during these six hours actual work is equal to the average work done per shift of drilling, which is usually of eight hours duration; on account of the drills being all set up ready to work and also the incentive, etc.

In other words I do not think the compressor would have made many more revolutions during eight hours ordinary working, than it did during the six hours trial. If this be true then the average steam horse power per drill would be reduced by $12{\cdot}72 \times 6 \div 8 = 9{\cdot}54$ or the probable steam horse power actually required per drill.

It must be borne in mind that this machine was specially designed for a high speed, with large valves having a high lift.

In addition to this, the air pipes at the Rose Deep, are remarkably free from leaks. Against this, the drill pistons are made a good fit in their cylinders and no packing rings are used.

Were the compressor only charged with its *pro rata* of the power required by the air and circulating pumps, as ordinarily used, the result would have been better.

Three other trials have been made since, which demonstrate that the total steam used per indicated horse power is 1·2 lbs. less, where the jackets are *not* used, than has been obtained on this trial.

I should not like to state this as being true under all conditions, inasmuch as the steam at the compressor is very dry, and were it moderately wet, no doubt the performance with jackets would be better than without.

Two boilers easily ran the compressor, and during a later trial which was non-condensing, the same two boilers ran the compressor but with hard firing.

The steam used in this latter trial was 25·75 lbs. per indicated horse power, over 31 per cent. more than when condensing.

The lbs. water evaporated into steam per boiler per hour was 3871 equal to 2·58 lbs. per square foot, heating surface, while on the non-condensing trial this was nearly 3·35 lbs. water evaporated per square foot per hour.

The cubic feet of free air compressed per minute was calculated from the first stage air cylinder card, the points at which the compression and re-expansion lines across the atmosphere, being taken as the volume of air actually delivered, which was 88·4 per cent. of the theoretical cylinder volume.

The compressor had been in constant use for three years, with few repairs, the only alterations being to substitute forged steel connecting rods in place of the original cast steel ones, which had proved defective.

The fluctuations in the air pressure were on account of the governor being disconnected and the speed regulated by hand.

The latter type of intercoolers supplied with these machines, in which the air is made to cross the cooling tubes three times instead of moving lengthwise, is a decided improvement and adds materially to the economy by reducing the volume of air discharged by the first stage cylinder and compressed by the second stage from 78.65 to 69.78 per cent.

Having proved that with this compressor running at a high rate of speed we compress 382·3 cubic feet of free air at 12 lbs. atm. pressure to a pressure of 69.83 lbs. per square inch, per steam indicated horse power per hour. I reserve for a future discussion and paper, the amount of air necessary under conditions existing on these fields, to again generate one brake horse power and I trust by this means we may obtain some reliable data of the efficiency of transmission of power by compressed air, for comparison with other methods more in use.

CENTRAL POWER PLANTS.

Central Power Plants for distributing any kind of power, either Compressed Air, Electric or belt power, are gaining daily in popularity, and it is only a question of time until small power consumers will derive their power from Central Power Plants instead of generating the power themselves. By doing so they will dispense with the following items: Expenses of installing boilers with

TABLE 17.—COMPARATIVE TABLE OF WATER AND FUEL CONSUMPTION, COST, ETC., FOR ONE 1000 H. P. CENTRAL POWER PLANT.

		No. 1 Single Cylinder Plain Slide Valve Engines	No. 2 Single Cylinder Meyers Cut-off Non-Condensing Engines	No. 3 Compound Non-Condensing Meyers Cut-off Engines	No. 4 Compound Condensing Meyers Cut-off Engines	No. 5 Single Cylinder Non-Condensing Corliss Engines	No. 6 Single Cylinder Condensing Corliss Engines	No. 7 Compound Non-Condensing Corliss Engines	No. 8 Compound Condensing Corliss Engines	No. 9 Triple Expansion Condensing Engines
Consumption of Dry Steam per H. P. per hour	Theoretical, lbs.	35 40	30–35	25–30	17–20	22–25	15–18	18–23	12–15	9–11
Consumption of Dry Steam per H. P. per hour	Practical, lbs..	45	40	35	25	28	20	25	17	13
Consumption of Dry Steam for 1000 H. P. per hour	Practical, lbs..	45,000	40,000	35,000	25,000	28,000	20,000	25,000	17,000	13,000
Consumption of Feed Water per day of 24 hours	Practical, gals..	135,000	120,000	105,000	75,000	84,000	60,000	75,000	51,000	39,000
Consumption of Feed Water per year of 360 days	Practical, gals..	48,000,000	43,000,000	37,000,000	27,000,000	30,000,000	21,000,000	27,000,000	18,000,000	14,000,000
Cost of Feed Water per year at 5c. per 1000 gals	Practical	$2400	$2150	$1850	$1350	$1500	$1050	$1350	$900	$700
Consumption of Combustible per H. P. per hour	Practical, lbs..	5½	4¾	4	3¼	3½	2½	2½	1 7-10	1 3-10
Consumption of Combustible per 1000 H. P. per hour	Practical, tons.	2.75	2.37	2.00	1.62	1.75	1.25	1.25	.85	.65
Consumption of Combustible per 1000 H. P. per day	Practical, tons.	66	57	48	39	42	30	30	20	15½
Consumption of Combustible per year of 360 days	Practical, tons.	23,760	20,520	17,280	14,040	15,120	10,800	10,800	7,200	5,580
Boiler Pressure in lbs. per square inch	Practical	60–100	60–100	75–100	80–110	75–110	75–110	90–125	100–140	125–180
Type of Boilers { R. T. Return Tubular / W. T. Water Tube... }	Practical	R T	R T	R T	R T	R T or W T	R T or W T	W T	W T	W T
Square feet of heating surface to the horse power	Practical	13–15	13–15	13–15	13–15	13–15	13–15	11	11	11
Evaporating capacity per sq. ft. of heating surface	Practical, lbs..	2½	2½	2½	2½	2½	2½	3	3	3
Boiler Horse Power required for plant	Theoretical	1100	1050	1075	725	1000	700	800	500	370
Boiler Horse Power required for plant	Practical	1200	1100	1100	875	1000	850	900	700	580
Proportion of Boiler to Engine Power	Practical	110%	105%	107%	72%	100%	70%	80%	50%	37%
Proportion of Boiler to Engine Power	Practical	120%	110%	110%	87%	100%	85%	90%	70%	58%
Average piston speed per minute in feet	Practical	300–400	300–400	300–400	300–400	400 600	400–600	400–600	400–600	500–700
Cost of plant all erected with foundations, piping, smoke stacks, pumps, etc., not including cost of building nor cost of apparatus for generating Compressed Air or Electric Power	Approximate...	$37,000	$40,000	$44,000	$52,000	$51,000	$57,000	$64,000	$67,000	$72,000
Cost of Fuel per H. P. per year, at $4 per ton.	Approximate...	$95,000	$80,000	$69,000	$56,000	$60,000	$43,000	$43,000	$29,000	$22,000

their expensive settings and piping, economy in space, dispensing with the services of expensive and many times unreliable engineers; and they will obtain their power at reduced prices from Central Power Stations operated in an economical manner.

The block system of distributing power has been tried in this city for the last few years, and while working under most unfavorable conditions it has proved to be a financial success to both owners and consumers.

The table which the writer publishes in connection with this article, and which is compiled not only from theory but from actual practical results, will demonstrate the adaptability and necessity of Central Power Plants. The larger the Central Plant is the greater will be the economy.

When a Company has decided to install a Power Plant the first problem which presents itself for solution is the selection of engines and boilers and other machinery to economically develop this power. Assuming that there is sufficient floor space to install the Plant to suit the best obtainable conditions and that the purchasers have enough business sagacity to make the first cost secondary to ultimate economy, then in order to make a proper selection the following points only should be considered: Whether to install single cylinder, compound or triple expansion engines, either condensing or non-condensing; whether, according to price of fuel, ordinary return tubular or high pressure water tube boilers would be most advisable; whether for condensing purposes, jet or surface condensers are preferable. For small plants up to 50 H. P. where the cost of fuel does not exceed $4.00 per ton, plain slide valve engines will generally do, as they hardly require any attention, but the fuel consumption per H. P. per hour for this class of engine is exceedingly high. For plants varying from 50 to 100 H. P. per unit Meyer's cut-off engines will fill the bill. For powers varying from 100 to 500 H. P. either single or compound Corliss engines, either non-condensing or condensing, are advisable, according to conditions, it being natural that the compound condensing Corliss engines will be most economical. A reference to the table of cost of plant will show conclusively that the first cost of a plant cuts a very small figure in comparison to the cost of its operation or economy, and that the extreme difference in price between the cheapest plant for 1,000 H. P. in engines of adequate sizes shown in column No. 2 to the expensive but economical plant shown in column No. 8 and amounting to $50,000, is more than recovered the first year in the consumption of fuel. As shown by the above table it is understood that the plant is in operation for 24 hours per day with cost of combustible at $4.00 per ton, the figures being based on regular mining or railroad work. The cost of operating such a plant in the Western States generally exceeds the above figures, as the price of fuel, labor and incidentals is higher than that named above, and thus a higher percentage of saving will be prevalent. Economical advantages of compounding and condensing contrasted with the old style of single cylinder non-condensing engines are so patent that no company could be oblivious to them and be prejudiced in favor of buying fuel-eating plants as a slightly smaller initial expenditure.

No reference is made in the above table regarding the cost of labor to operate plants, the cost of labor depending entirely upon the region where plant is installed; however, it should be understood that manual labor required to operate a 1,000 H. P. Central Power Plant will not exceed twice the labor required for a single 200 H. P. plant.

The table published in connection with this article ought to be of interest to any party contemplating the installation of a Compressed Air Central Power Plant for the distribution of power to small consumers.

Much has been said recently on the subject of distributing compressed air power for automobile vehicles and manufacturing purposes, but in all that has been published nothing has been said showing the cost or giving any data to guide the investing public in this matter. F. SCHMERBER.

A CENTRAL POWER SCHEME.

A company is at present in course of formation to be called "The Kalgoorlie Goldfields Electromotive Power Compressed Air and Electric Light Company, Limited." The object of the company is to establish a central power station on a site conveniently situated for the supply of electromotive power, compressed air, and electric light to the group of the larger gold mines on the Kalgoorlie goldfields. The Kalgoorlie miner speaks of the project in this manner.

There is probably no better field in the world for the successful carrying out of such a scheme than the Kalgoorlie goldfields, as the best mines are situated in a compact group, so that the distance of the mine most remote from the central station as suggested in this scheme will not exceed a mile, while the majority of them will be less than half that distance. Within a radius of two miles there are about fifty leases that are on payable gold, which in the near future will require power, at as cheap a rate as possible.

Mr. Sam Wilson, mechanical and mining engineer, Coolgardie and Kalgoorlie, is the chief promoter of the Kalgoorlie central power scheme. During the last twelve months he has been acquiring information and data respecting the same, not only here, but from all parts of the world, wherever accumulative power is being used. As the founder, managing director and largest shareholder of the Pioneer Foundry and Engineering Works in this place, Mr. Wilson has had special opportunities of becoming acquainted with nearly all the mine managers and electrical and mechanical engineers on the field, all of whom, without exception, recognize the fact that a large central power company will do more to develop and encourage the mining industry than anything else. Mr. D. C. Smith, electrical engineer of the Kalgoorlie Council, has given valuable assistance to the promoters of the Kalgoorlie central power scheme by his practical and technical knowledge.

It has been ascertained that, with one or two exceptions, there is no mine in the Kalgoorlie district able to produce power for less than from 6s. 6d. to 7s. per i. h. p., per 24 hours, and the average cost is usually higher than this. The proposed company does not intend to charge more than 4s. per 1 h. p., thus effecting a saving of at least 25 per cent. Fourteen mines are at present using about 3,600 i. h. p., so that the profit these mines would make by taking their power from the Central Power Company's works would be over £100,000 per 365 days working, still leaving a very handsome profit for the company.

The company proposes to at once erect a plant that will generate 3,000 i. h. p. for compressed air, to work 300 rock drills, and for underground hauling and pumping, 2,000 i. h. p. electromotor power, for winding, crushing, pumping and every other purpose; and 300 h. p. for electric lighting. It is thought that double this power will be required before the plant is completed. The capital of the company is £500,000, and it is proposed to call up £300,000 at once. Some months ago the promoters put this scheme, with all the required data and particulars, into the hands of Mr. William Griffith, the representative of Messrs. Bainbridge, Seymour & Company, the large mining engineers, St. Helen's place, London, who perceived its importance, and he at once forwarded all particulars to London. Through the able assistance given by Mr. Griffith and his firm, the scheme has been taken over and registered by a wealthy, influential syndicate in London, the chairman of which is also chairman of one of the largest electric lighting companies in London.

The syndicate has received very great encouragement from the largest mining boards in London, and it is thought that they will subscribe half the required capital, as they will be the most benefited by the company, and thus share half its profits, and secure equal representation on the London and local boards which will control the company. As the power will be registered by meter at the different mines, only what is used will be paid for. Each mine will provide its own receivers for compressed air; the electromotors will be the property of the power company, and a rent will be charged for their use and for keeping them in order.

In order to guarantee continuous power a reserve plant will be kept ready for use in case of a breakdown; accumulators will also be used for storing both compressed air and electricity for several hours, which can be drawn upon when required.

To the non-producing mines, to those which are being developed, and especially to those with small capital, the advantages are incalculable, as such mines will be saved the expense of putting down power and compressor plants, and will only be called upon to pay for the power and compressed air used. This should prove a great inducement to many developing mines that are at present closed. There is very little doubt that before the year is out all the power used about Kalgoorlie for lighting and other purposes will be drawn from the central power.

The scheme and plans are at present before a board of mechanical and mining experts in London, and it is expected that one or two of them will be here in a week or two to consult with the local promoters, and in a few weeks at most the company will be placed on the London market.

It has been ascertained from the local representatives of several of the principal mines that they would be willing to give their support to such a scheme, and it is proposed in the first instance to put down plant sufficient to supply their requirements, with a fair margin to meet any further demand. The following table gives a list of some of the principal mines, with the approximate power, number of lamps required for lighting, a probable number of compressed air drills either in use now or required in the near future:

It has therefore seemed reasonable to base the accompanying estimates on the following figures:

2,000 actual h. p. delivered on the mines for crushing, pumping, hauling, winding, etc., by means of electromotors.
300 actual h. p. in the form of electric light.
2,000 actual h. p. delivered on the mines in the form of compressed air.
4,300 total actual h. p. delivered.

But as the losses of transformation and transmission in the electric power and light circuits will amount to about 30 per cent., and the losses in air transmission to 50 per cent., the total h. p. generated in the central station will amount to 5,443 h. p., and this figure has been adopted in calculating capital and working expenses.

From these estimates it will be seen that the capital actually required is £235,500, but as it is anticipated that an early extension of plant will be necessary, it is proposed to have an authorized capital of £500,000 and to call up £300,000 at once, which will leave a sufficient margin for running expenses, while the plant is being filled up, the balance to be held in reserve toward duplicating the power, which more than probable will be necessary at an early date.

The annual running expenses will amount to £117,093, and the gross revenue, by charging 4s. 9d. per actual h. p. delivered, or 3s. 17d. per electric unit, will be £214,747 10s., leaving a profit of £97,654, equal to a profit of 32 per cent. on £300,000.

To give mine-owners a direct inducement to become consumers, it is proposed to give them the opportunity of subscribing conjointly one-half of the required capital, the other half being offered to the public, and it is further proposed to make the shares held by the mine-owners preferential to the extent of paying 6 per cent. on the capital held by them as a first charge on the profits.

TABLE 18.

	No. of Drills	No. of 16 C. P. Lamps	H. for other purposes	Total H. P.	For 274 days		Saving
					Present Cost at 6/6	Cost at 4/9	
Australia	30	200	700	870	£77,473	£56,614	£20,858
Lake View.............	25	200	240	385	34,284	25,054	9,230
Great Boulder.........	18	150	240	345	30.722	22,450	8,272
Ivanhoe	15	200	150	245	21,817	15,943	5,874
Golden Horseshoe.....	15	150	150	240	21,372	15.618	5,754
Kalgurli	12	100	100	170	15,138	11,063	4.075
Kalgurli North	12	100	100	170	15,138	11,063	4,075
Kalgurli South........	12	100	100	170	15,138	11,063	4,075
South Boulder.........	12	50	100	165	14,693	10,737	3,956
Hainault..	12	50	100	165	14,693	10,737	3,956
Brookman's Boulder...	12	50	100	165	14,693	10.737	3,956
Boulder No. 1..........	12	50	100	165	14,693	10,737	3,956
Perseverance	12	50	150	215	19,146	13,991	5,155
Oroya	12	50	100	165	14,693	10,737	3,956
Totals	211	1,500	2,430	3,635	£323,693	£236,545	£87,148

The ordinary shareholders will then receive 6 per cent., and the balance of the profits will then be divided evenly among all shareholders. It is also proposed to make a reduction in the price of power to the mines holding capital in the company, 4s. 6d. per h. p. being charged to them as against 5s. to mines holding no capital, and, further, a sliding scale of charges will be introduced whereby the largest consumer of energy will pay the smallest rate per h. p.

By this arrangement the mine-owning shareholders will get their power: (1) at 30 per cent. of the present cost, (2) will be guaranteed 6 per cent. on the money invested in the company, and (3) will still further reduce the cost of power by receiving the balance of profits in dividends, which collectively will reduce the cost of power to half the present expense. The ordinary shareholders, on the other hand, will be guaranteed a sufficient number of customers to ensure the success of the undertaking.

For the proper control of the company it is suggested that three mine managers represent the mine-owners' interests, while the other three directors will be appointed by the ordinary shareholders. It is further suggested that no director shall receive any remuneration until a dividend of at least 10 per cent. is declared. The method proposed for carrying out this scheme is to convey the electricity from the generating station at high pressure (2,000 volts) to sub-stations, placed in as close proximity to the various points where power is required as practicable. Those sub-stations will be furnished with accumulators capable of supplying the whole energy called for, for at least an hour. The power will be then taken from the accumulators at a lower and safer pressure to the various motors and lighting circuits.

The advantages of this method of distributing are:

1. The transmission is effected over the principal distances with a comparatively small main, and with small loss of pressure (about 2½ per cent.).

2. By the introduction of accumulators the pressure can be conveniently reduced to a perfectly safe point before being conveyed to the motor.

3. It is possible to keep the lamp at a perfectly steady c. p., notwithstanding the variations in the motor circuits caused by starting and stopping.

4. In the event of a breakdown in the generating machinery, the accumulators would act as a reserve for at least an hour, and so prevent a stoppage at the mines.

5. As the load of power circuits is always of a fluctuating nature, the use of accumulators will enable the engines to work steadily at their most economical point, the fluctuations being taken up and given off by the batteries.

6. That it is perfectly flexible in providing for variations in pressure for all purposes, as any pressure may be obtained from two to 2,000 volts, without any alteration to the existing arrangements, other than changing a wire.

With reference to the compressed air system, it is found to be more economical to compress the air direct at the central station, and convey it by pipes to the various mines, rather than simply to supply power on the mines to drive the various compressors, as thereby the cost of plant would be greater and the losses of transformation heavier; but in order to economize in the outlay of pipes, and also to preserve a uniform pressure at the mines, it is proposed to transmit the air at 300-lb. pressure per square inch to receivers capable of storing energy for 200 drills for an hour, placed at the sub-stations, and then to reduce the pressure before entering the service-pipes to the mines, to the usual working pressure of 80 lbs. by means of reducing valves.

Both the electric and compressed air energy will be measured by meter, so that only the power actually used will be charged for.

It is found in the Eastern colonies that a mine producing 5 dwt. of gold per ton crushed, can be made to pay dividends with care and economy, and while it would be rather rash to predict that the same state of economy would be arrived at here, by a saving in the cost of power, it is at all events safe to say that the introduction of the scheme just detailed would be a step in that direction, and in some cases, might make the difference between a dividend-producing and a call-producing mine.

This system has been introduced on the Rand in South Africa by two large companies with great advantage to themselves and to the mines utilizing the energy supplied by them, although the conditions there are not so favorable for economical running as in the Kalgoorlie goldfield, owing to the fact that the mines cover a much larger area, and the expense of labor is very much less.

In America the same method of generating power has been adopted in the large mining centres with most successful results, while such methods also are finding favor in Great Britain and on the Continent, where circumstances allow of a central generating power.

A machinery area has been secured adjoining the present railway (that will be an important consideration), in almost the centre of what is known as the gold-bearing belt, which embraces over fifty distinct companies or leases, nearly all of which have been proved payable mines, but will require power and light. It is, therefore, almost certain that by the time the plant is erected the whole of the proposed power and light will be applied for, and in the near future a large extension will be necessary.

There are at present a considerable number of mines that are in a forward state of development and will soon require machinery, and consequently they will be only too pleased to avail themselves of the proposed company's power, etc., if the scheme is carried out without delay.

Should any of the plant now in use by any of the mines which propose to take power from the central station be found suitable, the company would be prepared to take it over at a fair valuation and utilize it in the central station.

Letters expressing approval of and wishing success to the scheme have been received by Mr. Samuel Wilson from Mr. R. Hamilton, Great Boulder; Mr. T. Hewitson, Ivanhoe; Mr. William Dick, Golden Horseshoe, and the managers of all the leading mines in this district.

REPORT ON TRIALS MADE AT MAGOG, QUEBEC, TO TEST THE ECONOMY EFFECTED BY PREHEATING COMPRESSED AIR.

By Prof. J. T. Nicolson, D. Sc. (Edinburgh & McGill) M. Inst. C. E.

These trials were made during the month of April, 1899, at the Dominion Cotton Mill, Magog, Canada, where there is installed a 150 horse-power hydraulic air compressing plant on the system devised by C. H. Taylor, of Montreal.

They were made at the instance of Mr. John A. Inslee, of St. Louis, and conducted under the auspices of Mr. Inslee, the Taylor Hydraulic Air Compressing Co., and the Dominion Cotton Mill Co., jointly.

The trials were conducted by the undersigned, assisted by Professor R. J. Burley, B. Sc., etc., of McGill University, but a number of prominent engineers from the United States were invited to be present and took part in the experiments. Among others I may mention Mr. A. Langstaff Johnson, of Richmond, Va., Mr. Wm. O. Webber, of Boston, Mass., and Mr. John Birkinbine, of Philadelphia, Pa.

Experiments were made on five different methods of using compressed air in an ordinary steam engine of the Corliss type.

1st. The air was supplied to the engine cold.

2d. Steam was injected into the air in the main pipe before supplying it to the engine.

3d. The air was injected among the water in a steam boiler and heated by mixing with the water and steam of the boiler before being supplied to the engine.

4th. The air was blown upon the surface of the water in a steam boiler and heated, by mixing with steam in the same before being made to drive the engine.

5th. The air was passed through a tubular heating vessel and heated by a coke fire, afterward being used to work the engine.

For all the experiments the air was drawn at a pressure of 53 lbs. from the 5-in. main air pipe of the Taylor Air Compressor, which supplies power to the mill, and was piped to a 12-in. diameter by 30-in. stroke Corliss engine, supplied for the purpose of the trials by the Laurie Engine Company, of Montreal.

A friction brake was fitted on the fly-wheel of this engine and the engine in this way was worked up to its full power at about 75 revolutions per minute.

Connection was made to a Lancashire boiler 7 ft. diameter by 30 ft. long when it was desired to mix steam with the air for purposes of pre-heating.

When dry heating was resorted to the air pipe was led through a heater on its way to the engine, having been previously blanked off from the steam boiler. This heater was designed by the writer and built by Messrs. The Laurie Engine Co. for these experiments; but, as it was designed of such size as to heat the whole of the compressed air used in the mill, it was considerably larger than was required to heat the greatest quantity of air which could be used by the Corliss engine employed on the test. It was, therefore, a matter of some difficulty to prevent the heater and the small quantity of air passed through the same from becoming hotter than was desired.

For the experiments made without pre-heating, the observations made were as follows:

The temperature of the air before entering the engine.

The same on leaving the engine.

The pressure of the entering air, indicator cards from each end of the cylinder, readings of the revolution counter and of the rope brake weights.

A trial was conducted with cold air on April 27th, in the presence of Mr. Birkinbine, which gave the following results:

The air entered at 66.5 F. and was exhausted at—41 F., the revolutions being 74.6 and the cut-off about one-third of the stroke. The indicated horse-power was 27 and the weight of air used per hour was 1,671 lbs. This gives about 841 cubic feet of free air at 60 F. per I. H. P. hour.

On another trial made under same conditions 850 cu. ft. of free air were used per I. H. P. hour.

2. In the case of experiments made with the dry heating, the following observations were made:

The temperature of the air before entering the heater; after passing up the first row of tubes; upon leaving the heater; before entering the engine.

The temperature of the furnace and flue gases of the heater were also taken, the former with a Callendar's patent electrical promoter.

The amount of coke (Sherbrooke gas coke) used was carefully weighed and the trial only began when the conditions had become steady, i. e., about three hours from the time of beginning the run with heated air. Cards were taken; the brake horse-power and the revolutions were also observed.

With air entering the heater at a pressure of 53½ lbs. gauge and at a temperature of 58.2 F., it was raised to 225 F. after passing the first row of tubes, and to 363 F. upon leaving the heater. Owing to undue length of air pipe and lack of proper covering, the air fell in temperature to 287 F. before entering the engine. It was exhausted at 88 F. and the pressure at the engine was 52½ lbs. by gauge.

The temperature of the gases leaving the fire was only about 700 F.—and was reduced to 100 F. in the flue of the heater. It was difficult to use a small enough quantity of coke in such a large heater without letting the fire out altogether. A closed ash pit was used and the air for combustion supplied from the compressed air main and could be regulated in its amount to a nicety.

Under these conditions and with exactly the same cut-off as in trial of cold air, the indicated horse-power being 26.7 and the revolutions 70 per minute, there were used 1,310 lbs. of air per hour, this gives a consumption of 640 cu. ft. of air per I. H. P. per hour, a reduction of 850—640—210 cu. ft. of free air per I. H. P. per hour due to pre-heating. Thus 210-850, a saving of 24.7 per cent. is effected in the quantity of air used.

This saving was effected by the burning of 9.3 lbs. of coke per hour, or of 9.3-26.7 348 lbs. per H. P. per hour.

These results may be stated otherwise as follows:

To produce 100 H. P. with cold air, 85,000 cu. ft. of air were required in this engine; when pre-heated to 287 F., the horse-power yielded was 85,000—640—133 H. P., and as this heating was effected by the burning of $\frac{9.3 \times 133}{27}$ — 47 lbs. of coke per hour; the additional 33 H. P. were obtained by an expenditure of 47 lbs. of coke per hour, or at the rate of $\frac{47}{33}$ — 1.42 lbs. of coke per hour additional.

If we assume that this gas coke had ¾ of the calorific value of good coal, it is seen that we obtained an additional horse-power for every (1.42x¾) 1 lb. of coal burnt in the heater.

As an ordinary steam engine and boiler of this size would require from 4 to 8 lbs. of good coal per H. P. per hour, it is seen what a very economical mode of using the heat this is. Heat is used 4 to 8 times as efficiently in a compressed air pre-heater as it is in a steam engine and boiler.

With regard to the results of this trial it ought to be remarked that a large radiation loss per lb. of air used was taking place, both on account of the undue size of the heater and on account of its distance from the engine. Much more favorable results can be and in fact, have been obtained, when the size of the engine and heater are properly proportioned.

Professors Riedler and Guttermuth have obtained an additional horse-power in air motors for every ¾-lb. of coal burnt to heat the air: This is an economy far surpassing that of any prime motor in existence.

In large plants with first-class air motors, where double or triple pre-heating might be resorted to, a better result than even this can easily be obtained.

In a large transmission plant consisting of a Taylor Air Compressor, a five-mile pipe line, air engines and electric generators, with coke pre-heating stoves, the full or gross power of the water fall can be obtained at the terminals of the dynamo, at a comparatively insignificant cost for fuel.

No other system of energy transmission can compare with this for economy of first cost and maintenance.

3. Tests were made of the economy to be obtained by heating the air by mixing it with steam from a boiler before allowing it to do work in the engine.

The results are of the highest scientific interest, and show the adaptability of compressed air to almost any condition of employment. As regards economy, this method is, however, inferior to that of dry heating. By mixing from 10 to 13 lbs. of steam per H. P. with the air, the quantity of air required was reduced from 850 cu. ft. to 300 to 500 cu. ft. per I. H. P. per hour. Thus the air required for a 100 H. P. engine running with cold air would be sufficient to operate an engine of 85,000—400—210 H. P. if mixed with 12½x100—1,250 lbs. of steam per hour. This can be supplied by about 140 lbs. of coal per hour; so that 110 H. P. additional were obtained by the burning of 140 lbs. of coal or 140—110—1.3 lbs. of coal per I. H. P. per hour additional

Such a method of heating, economical as it may appear, would, however, be unsuitable except for powers of over 50 H. P., unless waste steam is available from a boiler plant at times of low demand.

COMPRESSED AIR AND ITS DISTRIBUTION FOR POWER PURPOSES IN THE CITY OF PARIS; HOW IT IS PRODUCED, ITS NUMEROUS APPLICATIONS AND ITS COST.

BY M. VICTOR POPP.

HISTORY OF THE ENTERPRISE.

The world renowned compressed air system for power purposes which is now in operation in Paris was started in a very small and modest way. Its point of departure was the installation of a small compressed air plant in 1879. This plant was installed in the basement of a dwelling house situated at No. 7 St. Anne street with a view of supplying compressed air to a small circuit for the operation of pneumatic clocks, and this was the first application of compressed air for this purpose. The machinery which was installed at that time consisted of two small steam actuated air compressors of 6 h. p. each.

The receivers, pressure regulators, standard clock controlling all the pneumatic clocks and other apparatus consistent with the plant were installed on the ground floor; the main standard clock controlling all the pneumatic clocks on the compressed air circuit, which was at that time about three miles long, gave each pneumatic clock a *compressed air impulse* every minute moving the minute hand 1-60 of a revolution. In addition to these clocks, which were placed on the principal thoroughfares, and the results being so satisfactory, a large number of them were installed soon after the beginning of operations in a number of public buildings and private houses.

In 1898 the compressed air installations of the Popp System comprised the following:

1st.—One compressed air central plant of 8,000 h. p., situated on the Quai de la Gare.

2d.—One central station for the operation of pneumatic clocks.

3d.—One main pipe line, having a total length of 138 miles, this pipe line being placed underground and located in a tunnel. Of these 138 miles of main pipe line 41 miles are operating the pneumatic clock service and 97 miles are for the supplying of compressed air for power purposes. In addition to the main pipe line, there are over 20 miles of branches. These branches conduct the compressed air to 955 power consumers and to 1,637 establishments in which compressed air is used for the operation of pneumatic clocks.

4th.—Compressed air furnished to consumers operate 1,600 h. p. of engines; is used in addition for 163 other purposes than power, and in addition, there are 180 passenger and freight elevators all operated by means of compressed air.

5th.—The company owns and operates 7,000 pneumatic clocks. As will be seen, great progress has been made since the installation of the small plant in St. Anne street.

QUALITIES OF COMPRESSED AIR.

The report of Mr. Humblot, General Inspector of Public Works in Paris. contains the following: "There is no reason why power could not be transmitted by means of compressed air, and the theoretical considerations on the subject have the tendency to give compressed air the preference above any other method of transmitting power. Compressed air is not a source of power, it is only a medium for the transportation of heat, which heat can be retransformed into power. Thus there is a great difference between this kind of power transmission and other methods such as the transmission and transportation of power by means of water or electricity. Water is nothing but a purely mechanical medium between the piston of the pump supplying same and the piston of the motor operated by same. It can be compared to a solid incompressible rod connecting two mechanical organs. Such manner of transmitting power presents many inconveniences and losses, and in no case can the power obtained by the motor operated by same be superior to the original power.

"Electricity is a form of energy, same as heat, and can be transformed into mechanical work, but here again the amount of power obtained at the further end of the line is always inferior to the power supplied at the starting point. As an electric conduit can receive nothing but electricity, the loss between starting point and final point must be made up by means of electricity, if such loss is made up. Now, in order to produce electric power heat has to be first produced; this heat transformed into mechanical work; mechanical work into electricity, and it is evident that this combination of transformations is inferior to a system which allows the making up of losses direct by the addition of heat, as can be done with compressed air. In order to fully understand the principles of distributing

FIG. 62.—BOILER ROOM OF THE PARIS PLANT.

compressed air, it is necessary to know the fundamental principles of the mechanical theory of heat and which are as follows:

"Any production of heat corresponds to the destruction of a power; any production of power corresponds to the absorption or destruction of a certain amount of heat.

"The unit of energy is the kilogrammetre, which represents the power necessary to elevate one kilogramme one metre in one second. The unit of heat is the calorie, and represents the necessary quantity of heat to elevate the temperature of 1 kilogramme of water 1° cent. This corresponds to the elevation of temperature of 4° cent. for 1 kilogramme of air. The absorption or suppression of one calorie corresponds always to 425 kilogrammetres of mechanical work produced; the absorption of 425 kilogrammetres of mechanical work corresponds always to the omission of one calorie.

"The above statement does not always exist in practice, and the role of the engineer consists in producing the above transformations from heat into work, and vice versa, with the least possible loss.

"Should this be obtainable in practice, the efficiency of compressed air apparatus would be 100 per cent.

"Example—One kilogramme of coal represents practically 5,000 calories; with 900 grammes of coal a steam engine will produce practically one h.-p. during one hour, the one h.-p. being equal to 75 kilogrammetres. As the hour is equal to 3,600 seconds, we can say $\frac{75 \times 3{,}600}{425} = 635$ calories, and then $\frac{635}{5{,}000 \times .9} = 14$ per cent.

"It is well known that 800 calories are lost through the smokestack; that 600 calories are absorbed in condensation, and that the balance of the loss comes from radiation and absorption in general. Thus we are in a position to say that for the present, and until better apparatus for the generation of heat and steam are produced, the steam engine in its present condition has reached an almost perfect stage; but, notwithstanding its low effectiveness of 14 per cent., it is at present the only method of obtaining primary power. For air, however, we are confronted with a different problem. Air must be considered only as a reservoir for heat and a vehicle capable of transporting same. When air is compressed it forms a resistance, it absorbs power, and consequently it increases in temperature. When this air, after being compressed, regains atmospheric pressure through expansion and mechanical work performed, its temperature will be decreased.

"Suppose that air, after being compressed, would not lose any of its heat between the compressor and the place where it is used; that there would be no loss by friction or leakage; that the number of calories absorbed by the compressor and the number of calories lost during the work of expansion would be equal, then the efficiency of the air compressor would be 100 per cent. This does not take friction of compressor into consideration. It cannot be obtained in practice, as we do not allow the air to absorb all the heat produced during compression. If this were done, the air would lose its heat by absorption and radiation in the pipe line and would decrease in volume and pressure. Excess of heat produced during compression is absorbed either by water injection or by water jacket circulation during the process of compression, and each calorie absorbed by the water corresponds to a loss of 425 kilogrammetres in the receiver, or an equivalent loss in weight of compressed air.

"According to Pernolet, the amount of heat produced by compression and which should be absorbed during the process of compression is as follows:

For two atmospheres—14 calories.
For three atmospheres—23 calories.
For four atmospheres—29 calories.
For five atmospheres—34 calories.
For six atmospheres—38 calories.
For seven atmospheres—41 calories.

"Suppose that we use water at 15 degrees cent., and, furthermore, that the water would be discharged at 30° cent., each kilogramme of water would absorb 15 calories, and for a pressure of seven atmospheres we would require 2.7 kilogrammes of water per kilogramme of air admitted to air cylinder.

"It will be seen later that one h.-p. being able to handle eleven kilogrammes of air, the practice and theory will agree. Thus, per nominal h.-p. of a steam engine, the amount of water required will be $2.7 \times 11 \times 15 = 445$ calories.

"In addition to the above loss of power during compression, there are several others which are secondary:

"1st.—The contraction of the air, which will be discharged at 30° cent. into the receiver and which will cool to 15° cent. in the main pipe line on account of radiation and absorption. This loss for 11 kilogrammes of air per h.-p. will be equal to $\frac{11 \times (30^\circ - 15^\circ)}{4} = 41$ calories.

"2d.—A certain amount of vapor remains in the compressed air and is carried with same into the pipe line. The quantity of vapor is hard to determine. We can, however, count on about 10 grammes of water per cubic metre of air at atmospheric pressure; this corresponding to about 100 grammes per h.-p., or, in other words, 61 calories.

"3d.—The quantity of water required for cooling, either by means of injection or otherwise, reduces the volume or capacity of the air cylinder. This is, however, of no consequence, principally when we consider that the injection water reduces the clearance to a minimum. Thus, we can say that the total loss of heat between the compressor and the terminal point of pipe line amounts to $445 + 41 + 61 = 547$ calories. As we have used 635 calories to compress the air and have a loss of 547 calories during compression, etc., we can deliver only 88 calories to the engine or other apparatus at the further end of the pipe line. We know, however, that compressed air is a valuable receptacle for calories and that it will give them up when required to produce mechanical work, we can add calories to produce compressed air, and these calories will be given up and transformed into mechanical power or energy in addition to the original calories stored in the compressed air. Practice has proved that compressed air will lose 65° cent. for a reduction in pressure of six atmospheres. Theory will bring the figures to 90° cent. We have thus for each kilogramme of air a reserve of $\frac{15 + 65}{4} = 20$ calories, and as each h.-p. handles 11 kilogrammes of air the number of calories stored would be 220. Adding to this the 88 calories added by the work of compression, we find that 1 h. p. of compressed air will amount to 308 calories at end of pipe line; thus, using 635 calories to do the work of compression, and obtaining 308 calories in work, the practical percentage of efficiency of the air compressor would be 48.6 per cent. If we consider, however, that the difference between the indicated and nominal h.-p. amounts generally to about 18 per cent., this loss being due to leakage, friction, dead-load of the engine, etc., for the steam engine itself, and that the air leakages in the air pipe line amount to about 5 per cent., we can only count on a practical efficiency of 37 per cent.

"This result being obtained without taking reheating into consideration.

"Practical tests made by a commission appointed by the Ministry of War have demonstrated that four 450 h.-p. air compressors have absorbed 38,000 kilogrammes of free air and have produced 16,000 kilogrammes of compressed air. The tests being made on short pipe lines without any leakages whatever, it will be seen that the practice agrees nearly with the theory, the effectiveness of the tests giving a result of 42 per cent., while the theory above mentioned should have called upon an effectiveness of 48.6 per cent.

"The difference between theory and practice is thus only 6 per cent. As air is a proper receptacle for the absorption and storage of calories at any stage during the compression before being used for power purposes, it is a very im-

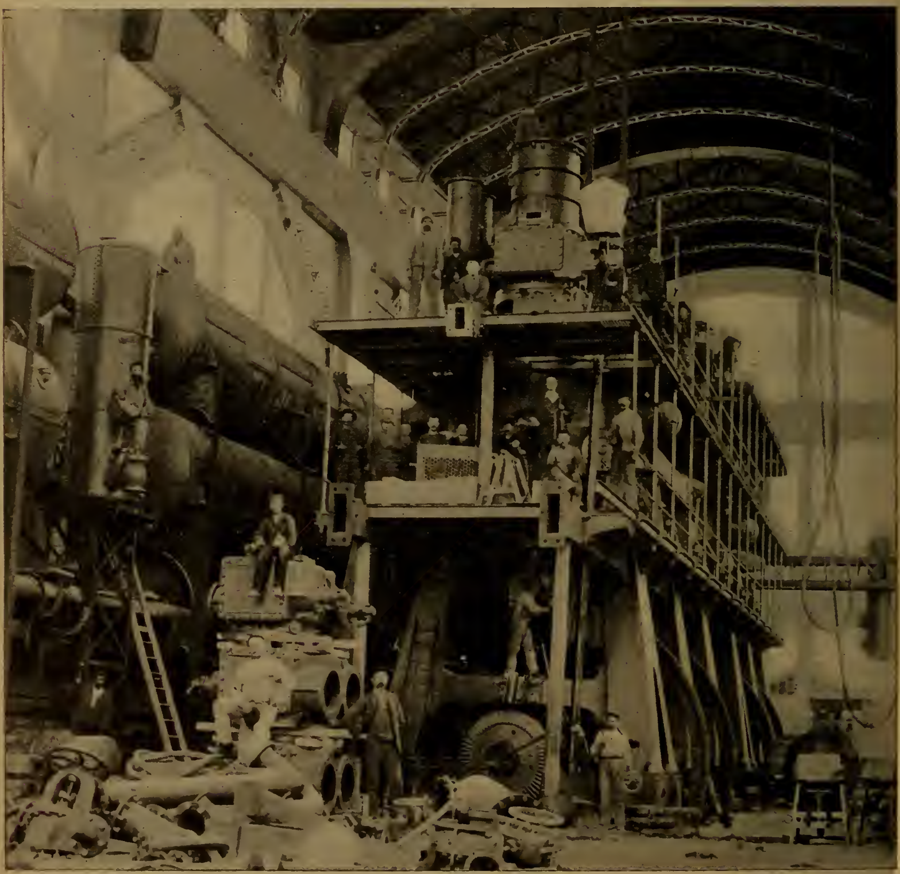


FIG. 63.—AIR COMPRESSORS AND AIR STORAGE RESERVOIRS.

portant subject to study as to how a certain number of calories can be given to the air after compression in order to make up for all the loss due to cooling, leakage, etc. There is no limit to the number of calories which can be added to the air except that a too high elevation of temperature wants to be avoided, as it would prove either inconvenient or dangerous. We have seen above that there are only 88 calories out of 635 available during expansion at the terminal point.

Thus, in order to obtain 100 per cent. of power we ought to restitute 547 calories per indicated h. p. Should we figure on nominal h. p. we should add about 20 per cent.

"This would bring the total number of calories required per nominal h. p. to 762. Now, having seen that 11 kilogrammes of compressed air will store 88 calories, or in other words, 8 calories per kilogramme, let us see in practice how many calories we can add to each kilogramme of compressed air by means of heat either in one, two or three stages before and during the work of expansion. It is easy while expanding to reduce the temperature of air 150° cent. (with two expansions, a decrease of 300° cent.) This decrease in temperature can be obtained while expanding the air in two cylinders, increasing its temperature 150° before letting it enter each cylinder. The total loss of temperature being 300° it represents a loss of 75 calories per kilogramme of air, which, added to the 8 calories which the air was ready to give up ordinarily, the total number of calories absorbed will be 83.

"We have said above that one kilogramme of coal represents 5,000 calories, and that to consume this coal, we have to lose 16 cubic metres of air at 400° in the smokestack, this being equivalent to 1,600 calories, the loss will be 32 per cent. In order to obtain the 5,000 calories with one kilogramme of coal, we will have to add 246/1,000 kilogramme of coal. Theory has demonstrated that the efficiency without reheating amounted to 37 per cent., thus it will be seen that for 1/10 of a kilogramme of coal consumed at the central power plant and 246/1,000 used for reheating at the terminal point one effective h. p. of compressed air can be obtained and a decrease of temperature at 300° cent. will be effected. Should the increase in heat furnished by reheating amount to only 150° cent., a larger amount of coal in reheating would be necessary. Tests which have been made confirm positively the above statement, and it is a remarkable proof that the hot air motor is a perfect thermic engine, where theory and practice differ the least.

"It is well known by all technical engineers that hot air engines are machines which show the best results theoretically, and that if these machines are not used in greater number it is on account of their complications in construction All the hot air engines are based on the following principle, which is to introduce a certain number of calories under the piston of the engine and then transform the heat into mechanical work by either of the two following processes:

"1st. The compression of air in the machine itself in order to expand same later on.

"2d. Direct expansion of heated air, using the power obtained direct on the crank.

"The above operations are explained by the following formula: The calories which are transformed into mechanical work are equal to the work of compression plus the work on the crank. The sum of these two energies, i. e., compression and power, which can be used, require a great number of calories, or, in other words, a great amount of energy on the piston of the engine; this piston, presenting only a small surface, is subject to great strains and also to deterioration on account of the great amount of heat prevalent.

"Thus it will be seen that the ideal is to compress the air in a different machine than the one which is used for producing the power, and for this purpose central compressed air power plants prove to be the best adapted where compressed air power can be obtained and produced cheaply, and then the con-

FIG. 64.—PLACE DE LA REPUBLIQUE, PARIS, SHOWING THE COMPRESSED AIR MAIN PIPE LINE.

sumer needs only to attend to the reheating, which amounts to very little regarding expense and attendance.

"To obtain a nominal horse-power at the end of the pipe line we have to use 1.50 kilogramme of coal, of whoch 900 grammes are used at the central station and 250 grammes at the terminal point for reheating. This gives us an efficiency of 78 per cent., and is under all conditions superior to the best results obtained by electrical power transmission.

"4th. The installation of a compressed air central power plant for distribution comprises:

"1st. One central power plant, comprising air compressors, boilers or other power medium, receivers, pressure regulators, etc.

"2d. A complete endless main pipe line starting from the central power station and returning to same. From this air pipe line a certain number of branch pipes run for the distribution of compressed air to the consumers; these branches furnished with automatic water traps in order to eliminate the condensed water.

"3d. Air meters placed at every outlet for measuring the amount of air used by every consumer, these meters varying to suit pipes from ¼ inch to 3 inches in diameter.

"4th. Apparatus for charging the receivers of compressed air cars or tramways, together with reheaters and all appurtenances connected with same."

CENTRAL POWER PLANT (QUAI DE LA GARE), ESTABLISHED IN 1891.

This is the most important central power plant not only in Paris, but in the whole world. The plant is installed and built of such size as to have an ultimate capacity of 24,000 h. p. The outlay is arranged for the installation of three rows of air compressors, each row amounting to 8,000 h. p. and comprising four 2,000 h. p. air compressors; thus the complete installation comprises twelve 2,000 h. p. air compressors.

The first row of 8,000 h. p., which has been in operation since 1891, consists of four 2,000 h. p. air compressors of the triple expansion Corliss type for the steam end, the weight of these four machines being 1,800,000 kilos, practically 4,000,000 lbs.

Each of the low pressure steam cylinders weighs 30,000 kilogrammes (66,00 lbs.).

The boilers are of the water tube type furnished with economizers, five for each compressor, thus making a total of twenty.

The four compressors are fitted with positive air inlet and outlet, and are of the three-cylinder type; two low pressure cylinders of same size fitted with intermediate receivers and intercoolers and one high pressure cylinder. That means the air compression is done in two stages. In addition to the above, part of the cooling is done during the period of compression by means of water injection in the cylinders.

The compressors are of the tandem vertical type, with three cranks setting at 120°, the steam cylinders being placed directly below the air cylinders.

The total height of each air compressor is 12½ meters (40 feet).

The steam ends of the compressors are of the triple expansion type and are controlled for the low and intermediate cylinders by means of variable cut-off Corliss valves, with trip motion, while the high pressure cylinder, which is fitted with the same kind of valves, is controlled by an automatic combined air pressure and speed governor in addition to a quick acting variable hand governor; this in order to stop the racing or running away of any air compressor and to control its speed and output at a steady working pressure of 8 kilogrammes (i. e., 120 lbs,).

These different methods of governing and controlling speed and pressure, and which are each independent of the other, act all on the steam distribution of the high pressure cylinder.

The valve motion for the air cylinders is actuated through a system of spur gears placed on the main shaft; each compressor is fitted with two heavy fly-wheels and the shafts of the four engines which are placed in line are con-

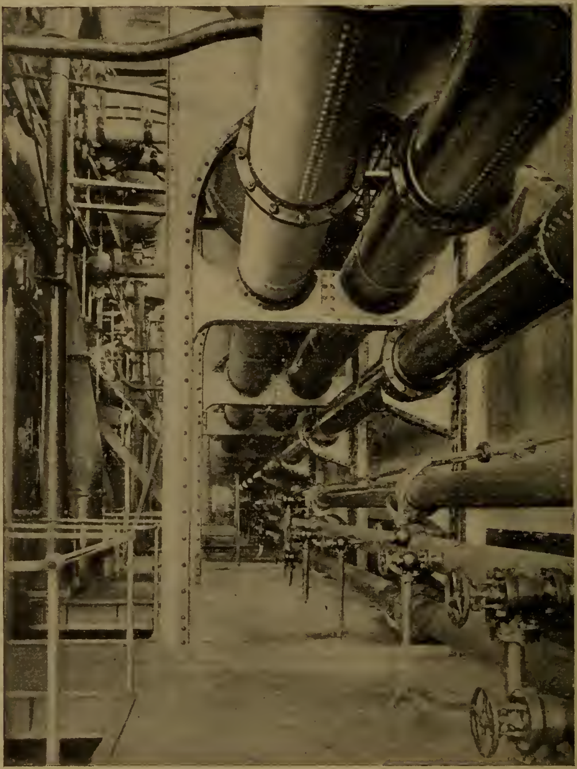


FIG. 65.—UNDERGROUND PIPES OF THE PARIS PLANT.

nected together with clutch couplings, thus allowing them all to work in unison. The four engines are besides rigidly tied together by means of heavy cast iron bed plates, thus insuring perfect alignment, the upper ends of frames being also tied together with heavy tie rods.

Access is given to all parts of the machines through four staircases and platforms extending the full length and on both sides of the four compressors.

The condensers, air pumps and water pumps are placed in pits next to the engines, these pits being 12 feet deep and reached by means of wrought iron stairs. Each compressor has its own condenser, air pump and water pump, the pumps being actuated directly from the crosshead of the high pressure cylinder through a beam controlled by same. The air valves of the two low pressure cylinders are of the positive inlet type and are fitted with rubber lined seats; the outlet valves are also of the same type, and it has been found that for low pressure cylinders these valves give very good results and dispense with shocks and jumping.

The two low pressure air cylinders are supplied with air direct from the atmosphere, discharging same into the combined receiver and intercoolers, which are placed on heavy cast iron columns; these receivers supply the air to the high pressure cylinder, where it completes its compression and is discharged into the terminal receivers.

In order to insure the best results it has been decided to admit the air for supplying the two low pressure cylinders direct from the atmosphere and passing through small longitudinal openings whereby this air will give up part of its heat and moisture.

Direct steam actuated fly-wheel pumps, entirely independent of the air compressors, furnish the injection and jacket cooling water for the compressors. In addition, these pumps furnish water for cooling the compressed air in the intercoolers between high and low pressure cylinders and in the high pressure receivers.

The drawings and sketches accompanying this article will give the reader a fair idea of the general arrangement of the plant and a conception of the provision made for future increase. The engines have been built for extra heavy duty and are amply strong in all their parts to develop much more power than required. All working parts, such as piston rods, crank pins, crosshead pins, etc., are made of hard crucible steel and removable. Main bearings, crank and crosshead pin bearings, valve rod pin bearings, etc., are fitted with adjustable, removable bronze quarter boxes.

Up to this date, after eight years of steady work, both day and night, it has not been found necessary to renew any of the working parts of any of the air compressors except the rescraping and regular readjusting incidental to general wear and tear.

All the engines run at a regular speed of 60 revolutions per minute, but the combined air and steam governors allow this speed to be increased to 72 revolutions if required.

The amount of air handled per hour by the four machines now in operation (8,000 h. p.), and which is compressed to 8 kilogrammes per square centimetre (i. e., 120 lbs. per square inch) amounts to 70,000 cubic metres (220,000 cubic feet) per minute. The above is based on a temperature of 60° F. and a barometric pressure of 29 inches.

Each of the 2,000 h. p. air compressors delivers its supply of compressed air at 8 atmospheres into two high pressure air receivers of 30 cubic metres capacity (i. e., 1,000 cubic feet each), from which it is distributed to the central main pipe line of 500 milimetres diameter (i. e., 20 inches diameter).

The boilers are of the water tube type manufactured by the Babcock & Wilcox Company, tested at 250 lbs. to the square inch, and furnish steam to the engines at 150 lbs. pressure. Each set of boilers is furnished with a steam reheater controlled in such a manner as to allow the steam from the boilers to pass through or around same. All steam pipes are installed in duplicates, thus allowing any engine or boiler to be put in or out of commission and to allow the cutting out of either of the main steam pipe lines in case of accident without interfering in any way with the operation of the plant.

Boilers to the number of 20 (i. e., 5 for each engine) are as follows:

Number of vertical sections for each boiler	12
Number of tubes per section	9
Number of tubes per boiler	108
Number of tubes—5.4 metres—equal	18 ft.
Diameter of tubes	4 in.
Heating surface for each boiler, 182 sq. metres, equal about	2,000 sq. ft.
Heating surface of economizers for the complete battery of boilers—500 sq. metres—equal	6,000 sq. ft.

Engines and air compressors are as follows:

Nominal h. p. of each engine	2,000 h. p.
Number of revolutions per minute	60
Pressure of compressed air in receivers, 8 kilogrammes	120 lbs.
Boiler pressure per sq. in., 12 atmospheres	180 lbs.
Diameter of high-pressure steam cylinder	36 in.
Diameter of intermediate steam cylinder	50 in.
Diameter of low-pressure steam cylinder	80 in.
Diameter of the two low-pressure air cylinders	44 in.
Diameter of high-pressure air cylinder	34 in.
Stroke of all the pistons	56 in.
Diameter of fly-wheels	18 ft.
Diameter of air pump	40 in.
Stroke of air pump	24 in.
Diameters of intercoolers and receivers	66 in.
Length of intercoolers	36 ft.

The following tests on the distribution of Compressed Air through main pipe lines have been made in Paris.

LOSS OF AIR.

The loss or decrease in pressure of compressed air in main pipe lines is due to either or both of the following causes: The loss in weight of air caused on account of leakage and the loss in pressure due to friction. Both of the above are of great importance and should be taken into consideration. The leakages, if properly attended to in due time, and if the main pipe line is kept fairly tight, do not require much attention as it is the duty and to the interest of any central compressed air power plant engineer to reduce them to a minimum. They remain a constant factor of loss in amount of air furnished.

The loss of compressed air through leakage is about proportional to the number of fittings, such as T's, elbows and valves installed on the main pipe line, and that it amounts to about 6 per cent. of the total capacity of the plant. As this is a constant percentage of loss for an even pressure, it will be readily seen that if the plant were of 24,000 H. P. capacity, the total loss of compressed air would be only 2 per cent., it being 6 per cent. for 8,000 H. P.

LOSS OR REDUCTION OF PRESSURE DUE TO FRICTION IN THE MAIN PIPE LINE.

The reduction in pressure due to friction is a question of the greatest importance, and in order to determine same and to avoid its being excessive, it is well for the owners of the central power plant to thoroughly investigate the following results.

A great many experts had formed an opinion that loss due to friction would not amount to much, and Mr. Arson's experiments had led the company to believe that the loss would be very small, but all these experiments and tests

FIG. 66.—HOUR SERVICE—CENTRAL CLOCK IN ITS CABINET.

were made with compressed air at low pressure and consequently low density. The company, however, decided to satisfy itself thoroughly, and engaged Prof. Gutermuth to make thorough tests, which were always made at night and on Sundays, when the traffic and supply were practically steady. These tests have proved that extraordinary loss of pressure was due to short bends, principally in the smaller branch pipe lines running uphill, notwithstanding the large diameter of 12 inches and the great number of receivers and automatic water traps connected with same. Thus it was decided to make thorough tests to determine the loss of pressure due to the receivers placed in pipes, and then in the main and branch pipes between the receivers. The table published below gives the results obtained.

LOSS OF AIR PRESSURE DUE TO FRICTION FOR ONE RECEIVER.

Pressure at entrance of receiver.	Pressure at outlet of receiver.	Loss.	Average speed of air per second through pipes.
92.84 lbs.	91.87 lbs.	0.97 lbs.	19.8 feet.
92.36 "	91.28 "	1.08 "	19.1 "
71.74 "	69.23 "	2.51 "	28.7 "
95.25 "	93.05 "	2.20 "	24.4 "
90.11 "	89.08 "	1.03 "	18.5 "

The figures show positively that for each receiver there is a loss of 15 per cent. of one atmosphere when the speed of air amounts to seven metres (23 feet per second), and that for 9 metres (30 feet per second), the loss due to friction amounts to 0.2 of one atmosphere. Thus it will be seen that five receivers placed one behind the other will cause a decrease of pressure of one atmosphere.

Twenty-three automatic water traps which were installed at different places on the main pipe line, did not result in any perceptible loss of pressure. The following table giving the number of tests and mentioning the places where they were made, will give the reader a fair idea of results to which reference has been made.

TABLE 19.

EXPERIMENTS IN DIFFERENT CONDUITS USED FOR THE TRANSMISSION OF AIR TO DETERMINE THEIR RESISTANCE.

SECTION OF CONDUIT	Length, Miles	No. of Tests
Total length from the Central Station at Saint Fargeau across the City and return.	10.28	7
From the Central Station to rue Fountaine au Roi	8.15	3
From Central Station to rue de Charonne	7.50	4
From Place de la Concorde to Saint Fargeau	5.75	5
From Station at Saint Fargeau to rue Fountaine au Roi	2.08	3
From Station at Saint Fargeau to Place de la Republique	1.066	2
Isolated tests conduits of different lengths	0.445 4.57	11
From rue de Charonne to rue Fountaine au Roi	5.44	..
From rue de Charonne to Saint Fargeau	2.74	8

The above table relates only to tests made at night while the distribution of air was practically at a standstill, and the whole compressed air plant at the disposal of the engineers in charge of the tests. Some tests, however, have been made while the plant was in full operation and while the compressed air reached the endless main pipe line experimented upon through both ends. The experiments were made at a place situated respectively four and five miles from the central power plant, and all readings were automatically registered by automatic recording pressure gauges placed at convenient places. All tests were thus made on a main pipe line having a total length of nine and one-half miles and fitted with four air receivers, twenty-three automatic water traps and forty-two gate valves. The resistance or loss ot pressure was made under different speeds of compressed air varying from zero to 50 feet per second.

I desire to emphasize that in the main pipe line of Saint Fargeau—Fontaine au Roe—which does not contain any receivers, it has been demonstrated practically that with a speed of 6½ metres (20½ feet per second), the loss due to friction amounts to 0.05 atmosphere per kilometre (3,300 feet) of main pipe line.

Thus admitting that the original speed of the air be 6½ metres (i. e., 20½ per second), and the original pressure 14.7 pounds above the atmosphere, a main pipe line of 20 kilometres length (i. e., 66,000 feet) would not be adequate to transmit any power.

A series of tests made on the main pipe line in Paris over a length of 16½ kilometres (i. e., 55,000 feet), with an average air speed of six metres (i. e., 20 feet per second), has demonstrated that the loss due to friction amounts to 0.07 of one atmosphere per kilometre. Thus, it is clearly proved that the forty-two gate valves, the twenty-three water traps and the four receivers do not represent a great percentage of loss and taking as a basis that any air pipe line will be fitted with about the same number of syphons, receivers, valves and traps as the

FIG. 67.—COMPRESSED AIR MUNICIPAL CLOCK.

above-mentioned line, it will be seen that a total length of main pipe of 14 kilometres (i. e., 46,500 feet) will produce the loss of one atmosphere. This result is the best obtained up to this time for such a length of main pipe line.

In addition to the above, it has not been mentioned that the main pipe lines in Paris contain a certain number of elbows and grades, which certainly increase the loss of friction to a certain extent. The tests having been made under different air pressures, it has been found that the practical loss of pressure due to friction does not proportionately increase with the pressure or with the density of the compressed air at least up to 60 pounds above the atmosphere, but it is demonstrated that in order to reduce the loss of pressure due to friction to a minimum, it is best to carry a high air pressure.

Several installations which have given very good results are transmitting compressed air at various pressures of from 30 to 50 atmospheres, and in one case 160 atmospheres. The mechanical work necessary for compressing to high pressures is in proportion to the increase of pressure; for instance, the mechanical work required to compress air from ten to twenty atmospheres, represents only 30 per cent. of the total mechanical work required to obtain the result.

It is thus possible to produce high pressure compressed air at a small cost, to convey same for long distances through small main pipe lines with less loss of pressure than if the pressure was low, and this can be done with less loss of power than any other motive power, such as water or electric power transmission. The transformation from high into low pressure for the operation of motors is effected without any difficulty at the place where the power is used,

FIG. 68.—APPARATUS FOR THE DISTRIBUTION OF TIME SERVICE. POPP SYSTEM.

this being done by an automatic pressure reducing valve. We will not, however, discuss here the very high pressure system, but confine ourselves to the medium pressure system, which is in practical use in Paris. The loss of pressure due to friction being one atmosphere for 14 kilometres (i. e., 46,500 feet), it will be easy to determine the loss due to friction in very long main pipe lines. As the resistance or loss of pressure due to friction decreases when the size of the main pipe line is increased, theory and practice have demonstrated that for doubling the diameter of the main pipe line and conveying the same amount of air at the same pressure through the larger pipe, the loss of one atmosphere would correspond to a length of about 40 kilometres (i. e., 132,000 feet); or, in other words, should the main pipe line be 100 kilometres long (330,000 feet), the pressure at the central station seven and one-half atmospheres, and the loss due to pressure one-half atmosphere, there would be a total loss of 7 per cent. between the central power station and the end of the pipe line.

Other experiments have decidedly demonstrated that a main air pipe line of 600 milimetres diameter (i. e., 24 inches), will be commercially fitted to transmit 24,000 H. P. without excessive loss, and it has been furthermore established that if transmission of power exceed 40 kilometres (i. e., 25 miles), compressed air will be a better medium than water or electricity.

COMPRESSED AIR MOTORS.

In order to utilize the full power accumulated in compressed air and to obtain all the energy possible, it is found necessary to reheat the compressed air and utilize same. The object of reheating is to expand the compressed air, or, in other words, to increase its volume while its pressure is kept constant. Prof. Reidler, who is considered as one of the best authorities on compressed air, mentioned in his lectures that M. Victor Popp was the first to successfully use the reheating system with good results. Reheating of compressed air, however, had been done for a long time in mining work, but had never given good results, and was used principally in order to avoid the freezing of exhaust pipes of the motors or other machinery operated by compressed air.

The reheaters used in the Popp Paris installation are of the cylindrical jacketted type, the air circulating through the jackets, while the heat derived from the fire inside of the cylinder is absorbed by the air after being deviated by means of a series of baffle plates. The results obtained have given very good satisfaction.

It has been seen above in relation to hot air motors that the amount of heat stored in the compressed air is almost entirely transformed into mechanical work. Even with cast iron hot air motors, it has been proved that 80 per cent. of the heat was practically used. The table below shows the efficiency of several kinds of reheaters.

TABLE 20.—TABLE OF AIR REHEATERS.

Nature of Reheater.	Surface of the Heater in sq. meters	Volume of Air heated per hour in cu. meters	Temperature of the Air in the Heater C°		Number of Calories transmitted per hour		
			When Entering	When Leaving	Total Calories	Per sq. meter of Surface Calories	Per kilo. of Coke Calories
Cast Iron Tubular Heater.	1.3	576	7°	107°	17900	13760	4470
Wrought Iron Heater....	1.3	313	7°	184°	17200	13230	4530
Stove	4.3	1088	50°	175°	39200	9200	5600

The experiments from which this table was compiled were made by Prof. Gutermuth and show that one kilogramme of combustible will, under good circumstances, give up as much as 5,600 calories in an air reheater. This result being superior by at least 500 per cent. to the result obtained by the best triple expansion compound condensing engine, the question of reheating the air using same, is entitled to serious consideration.

The amount of coal required for reheating air (for large motors) being about 0.09 of one kilogramme (i. e., 0.2 of the pound per H. P. per hour) 0.2 of

FIG. 69.—AIR REHEATER.

one pound is so small that it hardly needs to be taken into consideration, and thus in transmitting heat directly to the compressed air, the decrease of net efficiency of the fuel burned for reheating same is more than six times as efficient as that used to produce the compressed air. Thus 0.1 of one kilogramme (i. e., 0.22 of one pound), will produce the same mechanical work in reheating as 0.6 of one kilogramme or 1.3 pounds of coal through the medium of boilers and economical engines.

If the reader wanted to thoroughly investigate the above assertions and results of experiments, it will be seen that for a very small increase of com-

FIG. 70.—AIR REHEATER.

bustible it will be possible to transmit large quantities of compressed air a great distance and make up not only the loss incurred through friction, etc., but obtain at the end of the pipe line a larger power than that originally pumped into same. For ordinary length of pipe lines and with reheating to 250 degrees C. above the atmospheric temperature, the power obtained at the end of the line was 30 per cent. above the power originally required to compress the air.

In gas motors as they exist to-day, the heat developed by the explosion may be transmitted directly or partially to the compressed air. The heat lost in the jacket of the cylinder may be absorbed by the compressed air and utilized in this way. When arrangements suitable to this end shall have been discovered, the affirmation, based upon scientific experiments, may be made that one horse-power can be produced with an expenditure of from 0.65 to 0.89 pounds of fuel, that is to say, with one-half of what the best steam engines consume.

The little rotary Popp motors used in Paris have been made the subject of new study on the part of M. Gutermuth. The table below contains an abstract of

FIG. 71.—COMPRESSED AIR ROTARY MOTOR.

these experiments. The rotary motors, with automatic regulators to indicate the expansion necessary, without reheating the air, a volume of 1044.6 cubic feet per indicated horse-power per hour; and with reheating the air to about 122 degrees F. (50 degrees C.), an expenditure of 835.7 cubic feet 24 m. of air per horse-power per hour.

These little motors, from those of the power of a sewing machine, one-eighth horse-power, up to those one horse-power, are very well suited to light manufacturing and to the production of refrigeration in residences.

The total efficiency of these little motors, in which the air is first heated to 122 degrees F. (50 degrees C.), is 43 per cent.

The following is an abstract made from experiments upon piston motors:

TABLE 21.

MOTOR	Number of Revolutions per minute	Pressures	Temperature of the Air at Motor		Air Consumption per H. P. per hour, cu. meters	
			Admission	Exhaust	Without Heating	Heated
Piston Machines...............	....	....	....	....	....	....
Journaux, 2 H. P...............	169	2.1	10°	....	34.1	....
" 2 "	148	....	150°	0°	....	19.7
Boulet, 1 H. P................	283	....	150°	34°	....	24.3
" 1 "	149	....	165°	18°	....	23.13

It must be noted that the results in this table were obtained with old motors of one or two horse-power, bought in the market, and of very ordinary construction. The back-stroke presented considerable resistance.

Thus in the Journaux machines of two horse-power, the actual efficiency was only from 65 to 75 per cent. The loss of energy due to friction was thus unusually great. The motors of good construction showed a mechanical efficiency of 91 per cent.

If we suppose for the machines of which the table above treats, an efficiency of 85 per cent. and a better construction, the amount of air consumed per horse-power with a load would be 602.4, 741.7, and 710.4 cubic feet. The foregoing is an experiment with an old steam engine of 80 horse-power. This was a single cylinder machine, which had been used during six consecutive years as a steam engine, and which had been made to serve without any change as a compressed air motor with an air reheater in which the temperature of the air did not exceed 338 degrees F. (170 degrees C.). The minimum amount of air supplied to the machine was 452.7 cubic feet per horse-power per hour with air at 320 degrees F. This corresponds to a total efficiency of 80 per cent. The consumption of coke was 0.176 lbs. (.08 kil.), per horse-power per hour.

The following table contains an abstract of different experiments relating to this machine:

TABLE 22.—CONSUMPTION OF AIR BY AN ENGINE OF 80 H. P.

MOTOR	No. of Rev. per Min.	Efficiency	Temperature of Air		Consumption of Air per Hour in Cubic Feet	
			Admission	Discharge	Per H.-P.	Per H.-P. with Free Brake
Farcot's Machine of 80 H.-P., with a Single Cylinder.	54.3	72.3	1.29°C 264.2°F	21.°C 69.8°F	462.77	512.13
	54.3	72.3	152.°C 305.6F	29°C 84.2F	431.09	468.35
	54.0	72.3	160°C 320°	35°C 95°F	418.55	458.24
	40.0	65.0	170°C 338°	49°C 120.2°F	432.12	470.09

Considering the results of experiments made with old reciprocating steam engines, those obtained with old style motors, the conclusion can be drawn that modern air motors show an efficiency which has never been attained by any other motor, or with any other system of transformation of power.

The smallest motors, below one horse-power, with a slight reheating of the air (to about 122 degrees F., 50 degrees C.), give a total efficiency of almost 50 per cent.; and the more powerful motors, such as the steam engine previously cited, with a moderate reheating, has a total efficiency of at least 80 per cent.

In all this, exception is made of all improvements which may be brought about in the reheater and in the motors.

The information relating to old machines is purposely given, since it shows that the total efficiency and the supply of air are at the extreme lowest limits; the efficiency could not be less, but it might be sensibly increased with better motors.

The total efficiencies include all the losses, and the actual quantity of air necessary to the production of one useful horse-power, and are based on the actual work which is required for the compression of the air at the central station. The loss of pressure in the conduit has been estimated at one atmosphere, although it might average less in the entire Paris plant.

The figures given may, therefore, be considered as the minimum of efficiency in the working of compressed air, and we may adopt these figures, which are results obtained from old machines adapted to the use of compressed air, as a certain basis.

The scientific principles of the work and of the action of heat in air motors can not be contested and are generally known; they have often been examined in these later days. In spite of that, I will give one glance at these scientific principles because all the experiments made with air motors establish a very close agreement between the volume of air given by the theoretical calculations and that really furnished to the machine in actual practice.

Disagreeing results have been found only in certain cases when, by reason of the wire drawing of the air before entering the motor, the exact tension could not be given to a certainty, or when the measurement of the exact temperature at the beginning of a stroke of the piston was doubtful. But, whenever, these data can be furnished exactly, the volume of air given by calculation, and that actually supplied, agree.

The effect of preliminary heating is to expand the air if the pressure remains constant; for example, the unit volume of air that is raised from the temperature of 59 degrees F. to 302 degrees, 392 degrees and 572 degrees, becomes:

$$V\,59 : V\,302 : V\,392 : V\,572 =$$
$$1.0 : 1.46 : 1.64 : 2.$$

Therefore, by heating the air to 572 degrees (300 degrees C.), its volume is double what it was at 59 degrees (15 degrees C.), the pressure remaining constant, and the work which this air can do is increased in the proportions:

$$A\,59 : A\,302 : A\,392 : A\,572 =$$
$$1.0 : 1.45 : 1.53 : 1.90.$$

The work can therefore be almost doubled by the heating of the air to 572 degrees (300 degrees C.). The heating of the air at a constant volume and with an increasing pressure is still more favorable. The work which it can do, by heating it to 302 degrees (150 degrees C.), is increased in the proportion of 1 to 1.7.

This fact is made more striking by a graphical representation.

The work absorbed in the compressor in order to compress the air is compared with that furnished by this same air in the motor, after reheating. In all these diagrams there has been used as a base the work of compression, using this law of expansion:

$$p\,v^{1.3} = \text{constant}.$$

In reality, the resistance in the compressor is sensibly less than this figure, even in the machines of the Paris plant. The theory is, therefore, unfavorable in comparison to the practice.

The compressed air loses heat in the pipes, and the volume of air decreases from ac to al; besides, there has been admitted a loss of pressure in the city system indicated by the decrease from a to a_1 in the diagrams, the corresponding loss of work is represented by the surface a, l. a_1 l_1 a covered with cross hatching. The compressed air, because of the decrease of the pressure, occupies a more extended space, and extends to a. l. We admit that this expansion is made according to an isothermic law.

Before its entrance into the motor, the pressure and the volume of the air are indicated by a_1 l_1; then, the air is heated, and, the pressure remaining constant, the volume is increased to m. The expansion of air in the motor and the production of work are made according to the law:

$$(p\ v)^{1.4+} = \text{const.}$$

This adiabatic expansion is supposed to be less favorable than that which is really produced. The curve of expansion rises higher than the adiabatic curve, because of the heat communicated from the walls of the cylinder.

This graphical representation shows on one side the loss of work caused by the absorption of heat during compression, and by the friction in the conduit. This loss is compensated for by the reheating. There results from this:

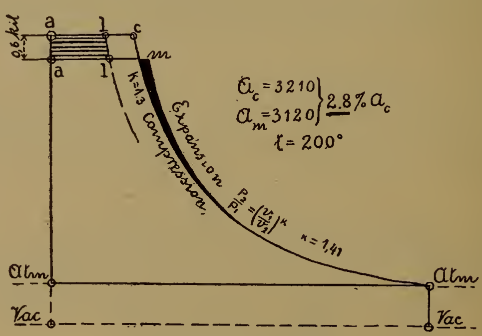


FIG. 72.—DIAGRAM.

for a loss of pressure of 0.06 atmospheres in the city conduit.

We shall have, then, if the distribution is made over a radius of 7.46 miles (12 k.), and with a reheating of the air to 392 degrees F. (200 degrees C.), a loss of work of 2.8 per cent.

That is to say, of the work expended in the central station, 2.8 per cent. is lost by transmission, and is not compensated for by the reheating; but it must be noted that the total loss in friction in the compressor and the efficiency of the motor are supposed to be less favorable than they really are.

When the loss of pressure in the conduit is 1.3 atmospheres (in transmitting to a distance of 16.16 miles), and when the temperature to which the air is heated is 392 degrees F. (200 degrees C.), the losses are compensated for by this reheating of the air, to the amount of 8.7 per cent.

For a loss of pressure of 2 atmospheres (distance of 24.86 miles), the loss of work is 13.2 per cent.; and finally,

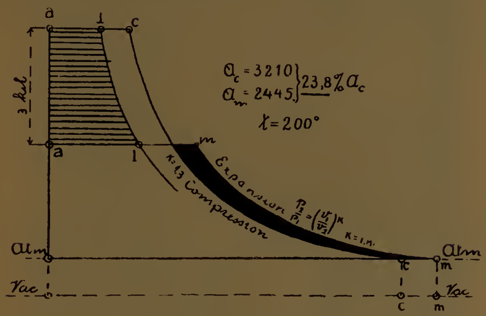


FIG. 73.—DIAGRAM.

For a loss of pressure of 3 atmospheres (in transmitting to a distance of 37.28 miles), the loss of work is 23.8 per cent.

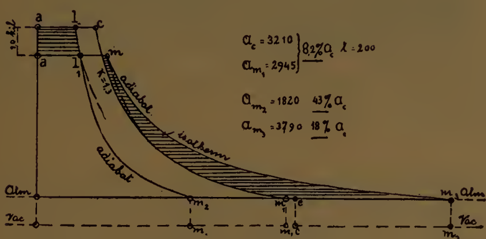


FIG. 74.—DIAGRAM.

In the diagram (Fig. 3), we have comparatively represented:

The work absorbed in the compressor (curve c c),

The loss of work due to cooling (c l),

And that due to the loss of pressure in the conduit c (a-a_1; l-l_1) ; the pressure being decreased by one atmosphere. (System of 12.43 miles long.)

WHEN THE COMPRESSED AIR ENTERS THE MOTOR.

1. Without having been reheated, the expansion follows l_1, m_2, and the work that may be utilized is represented by the surface a_1, l_1, m_2, of the diagram Fig. 3.

The loss of work is then 43 per cent. of the work of compression.

2. After having been heated to 392 degrees F. (200 degrees C.). In this case, it will occupy the larger space l_1, m, the expansion is made accordingly to the adiabatic curve m, m_1, and the loss of work not compensated for is 8.2 per cent.

3. After having been heated to 392 degrees F., and after the injection of water, in such a way that the expansion of the air mingled with vapor follows m, m_3, the work done exceeds the work of compression by 18 per cent.

The diagram (Fig. 75) indicates a different result; the work expended in the compressor during a compression approximately isothermic, the increase of temperature being 72 degrees, which is the case for the more perfect compressors; this work is compared to the useful work produced in the motor, supposing that

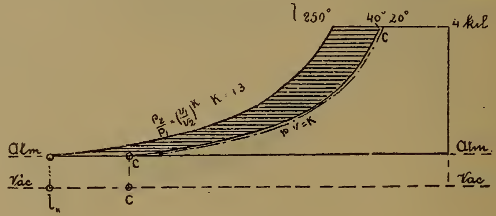


FIG. 75.—DIAGRAM.

the air has been heated to 482 degrees F., and that the expansion operates according to the law: $p\ v\ 1.3 = \text{const.}$

Fig. 75 indicates this relation, the pressure of the air being 4 atmospheres.

The relation between the work of compression as shown by the curve (Ac) and the work furnished by the motor (Al) is the following:

For 8 atmos. of pressure: Ac : Al = 1 : 1.34 = 34 per cent. inc.
For 6 atmos. of pressure: Ac : Al = 1 : 1.39 = 39 per cent. inc.
For 4 atmos. of pressure: Ac : Al = 1 : 1.44 = 44 per cent. inc.

The limits that may be practically reached by reheating the air and particularly by the double heating, are given in the following table:

TABLE 23.

SUPPLY OF AIR WITH DOUBLE EXPANSION AND DOUBLE REHEATING.

	Temp. of reheating.	Air consumed per ind. H. P. per hour.	Efficiency Ne. / Nc
With reheating	392° F	320.8	=0.85
pv^k=const., k=1.41	572°	271.6	
With reheating and injection of hot water	392°	254.2	=0.90
k=1.2	392°	208.9	

If we except the function of the injection of water, there could be reached a supply of air per horse-power per hour of from 280 to 314 cubic feet, supposing an efficiency of 85 per cent. With this supply of air from 280 to 314 cubic feet, let us compare the work necessary to take in, per hour, 365.6 cubic feet of air, and to compress it to six atmospheres, work corresponding to one horse-power per hour. The excess of work is then 25 per cent. and the practical efficiency reaches 125 per cent.

APPLICATIONS OF COMPRESSED AIR IN PARIS.

After having arrived, through the system of distribution, to the different points where it may be utilized, and after having passed through the air meters

FIG. 76.—HUGHES AUTOMATIC POWER ACCUMULATOR—POPP SYSTEM.

FIG. 77.—PRESSURE REGULATOR—POPP SYSTEM.

to the subscribers, compressed air is applied to a host of employments, of which we will confine ourselves to enumerating the principal ones.

Silk finishing machines.
Embroidering machines.
Scrap shears and tinsmith's shears.
Turbines and ventilators.
Lace machines.
Machines for carding, calendering and scouring wool.
Comb manufactories.
Motors for dynamos; electricity.
Machines for physicians, pharmacists and dentists.
Machines for seltzer water.
Machines for making, kneading and chipping dough.
Woodworking machines and tools.
Sifting and polishing machines.
Machines for boarding books and sealing envelopes.
Shoemaking machines.
Motors for hot air furnaces.
Motors for ventilators.
Motors for dynamos and cold storage rooms.
Pumping of beer and wine.
Elevators and hoists.
Blow pipes.
Works of the Exposition of 1900, construction of the piers of the bridge of Alexander, beneath the Seine, etc., etc.

COST OF PRODUCTION OF COMPRESSED AIR IN PARIS.

M. Bourdon, professor of the course in steam engines at l'ecole centrale des Arts et Manufacturers, and M. Meker, inspector in chief of machines for the city of Paris, were assigned to make the tests for admission of the machines.

This test, the result of which we give hereinafter; was made Jan. 19, 1893, upon the machine No. 4; it must be noted that this machine had already been in service since December, 1891, and had thus been used for about thirteen months before the test.

Average No. of revolutions per minute	59.635
Average pressure of the steam in the boilers	157.16 lbs.
Average pressure of the steam in the regulating valve of the small cylinder	146.16 lbs.
Average vacuum in the condenser, in inches of mercury	28.20 lbs.
Pressure of air in the compressors—	
Low pressure	32.71 lbs.
High pressure	102.40 lbs.
Temperature of the air on entering the compressors—low pressure.	40.7° F.
Temperature of the air on leaving the compressor—high pressure.	69.1°
Average temperature of the feed water after leaving the economizer	140.°
Average temperature of the feed water before entering the economizer	62.6°
M. e. p., per sq. in., upon the steam pistons according indicator cards—	
High pressure cylinder head	43.02 lbs.

High pressure cylinder crank	43.45 lbs.
Intermediate cylinder head	17.11 lbs.
Intermediate cylinder crank	17.19 lbs.
Low pressure cylinder, head	8.99 lbs.
Low pressure cylinder, crank	8.135 lbs.
Indicated work, in horse powers, upon the steam pistons—	
High pressure cylinder, head	304.5
High pressure cylinder, crank	305.5
Intermediate cylinder, head	335.3
Intermediate cylinder, crank	335.4
Low pressure, head	61.5
Low pressure, crank	326.4
Total indicated work, in horse powers	1978.5
Coal burned during the experiment of 8 hours	11.49 tons
Slag and cinders, 5.32 %	.61 tons
Coal (net) consumed during experiment	10.88 tons
Coal (net) consumed per hour	1.36 tons
Steam lost per hour in the pipe and by condensation	1255.9 lbs.
Corresponding amount of coal lost per hour	139.5 lbs.
Coal (net) consumed per hour for the running of the machine	2580.5 lbs.
Coal (net) consumed per indicated horse power per hour by the cylinders—	
$\frac{2580.5}{1978.5}$	1.30 lbs.

The work of compression developed by the machinery of l'Usine du quai de la Gare is deduced from the two following experiments, made towards the end of the year 1892, with three months between them:

	Number of revolutions per minute.	Total mechanical efficiency.	Final pressure of air Pounds per sq. ft. (effective).	Vol. of air taken into steam cylinders per H. P. per hour.	Relation of real work of compression to theoretical work.
First experiment made by the engineers of Popp Co	50	84%	1.08	10.21	1.281
Second experiment made by Professor Gutermuth	40	89%	1.23	10.22	1.192

The average of these last two ratios is 1.237.

The real efficiency of the work of compression of the air compressors in question, which are, as has ben stated, of 200 horse-power each, is $\frac{1}{1.237} = 80.84\ \%$

Numerous other studies have been made of the same compressors when they were in full operation. We relate hereafter the results of some of them, giving an illustration of each of the four following cases:

1. A day of average production.
2. A day of least production (Sunday).
3. A month.
4. A quarter.

STATION QUAI DE A GARE.

Production and expenses for one day—

Number of revolutions of the machines	125,922
Cubic feet of air taken in	22,456,561
Horse power developed—	
This includes all that relates to the lighting by electricity of the factory, to the water pumps and to divers pieces of accessory apparatus of the establishment	58,452
Coal burned for the air compressors and their accessories	1,326,782 lbs.
Per cubic feet of free air	2.1 lbs.
Per indicated horse power	2.25 lbs.
Total expenses of the day	$556.74
Cost of 3531.55 cubic feet of free air and compressed to 17.64 lbs. (effective)	.09

Total production for a quarter—

Summary of the number of cubic feet of free air compressed by the compressors at the Saint-Fargeau and Quai de la Gare stations—

	Cubic feet.
Month of January—Saint-Fargeau and Quai de la Gare	668.792,755
Month of February—Quai de la Gare	548,483,406
Month of March—Quai de la Gare	532,506,886
Total cubic feet of free air for the first quarter, 1892	1,749,783,047

WORKS OF THE QUAI DE LA GARE—APRIL,—SUMMARY OF QUANTITIES.

Number of cubic feet of free air compressed (at 77° F.—during the month		652,651,629
Average per day		21,755,054
Number of horse power developed—during the month		1,696,135
Average per day		56,537
Average per hour		2,356
Gross weight of coal burned for the compression of air	3,644,506 lbs.	
For electric lighting	42,227 lbs.	
Per cubic feet of free air		.0056 lbs.
Per 1 horse power		2.1493 lbs.
Per 1,000 revolutions		991.6000 lbs.
Waste of coal—for the compression of air		557,762 lbs.
Amount per 100 lbs. of coal		15.33 lbs.
Weight of pure carbon burned—for the compression of air	3,085,743 lbs.	
Per cubic feet of free air		.0047 lbs.
Per 1 horse power		1.8193 lbs.
Per 1,000 revolutions		839.6 lbs.
Difference between pure carbon and gross weight of coal burned —per cubic feet of free air		.0009 lbs.
Per 1 horse power		.3300 lbs.
Per 1,000 revolutions		152.016 lbs.
Consumption per 100 cubic feet of free air of—Valve oil		.0004 lbs.
Lubricant		.0013 lbs.
Tallow grease		.0001 lbs.
Grease		.0001 lbs.
Cotton waste		.0008 lbs.

Cost of coal—per cubic foot of free air—

Coal—3,686,733 lbs. at $5.40 per ton (2,000 lbs.)	$9,963.36
11,023 lbs. at $7.31 per ton (2,000 lbs.)	40.28
	$10,003.64

which is $0.000015 per cubic foot of free air.

Summary of costs—

Coal—3,686,733 lbs. at $5.40 per ton (2,000 lbs.)	$9,963.36
11,023 lbs. at $7.31 per ton (2,000 lbs.)	40.28
Water	96.50
Lubricants and cotton waste for wiping	819.31
City taxes	579.00
Sundry expenses	1,065.55
Total amount of pay rolls (officers and labor)	3,228.37
	$15,792.37

Total cost per cubic foot of free air, $0.000024.

TABLE 24.—SHOWING EVAPORATION FROM THE BOILERS.

No. of hours of operation of the boilers	Gross weight of coal burned		Loss of carbon per hundred lbs.	Carbon burned		Average pressure P of the steam	Average temperature of water in economizers		No. of gallons of water evaporated				Fuel burnt per hour		Carbon burnt per hour		No of gals. of water evaporated per hour		Average cost of one ton of coal	Cost of 1000 lbs. of steam at pressure P
	During the month	Average per hour		During the month	Average per hour		At entrance	At exit	During the month	Average per hour	Per pound of fuel	Per pound of carbon	Per sq. ft. of heating surface	Per sq. ft. of grate surface	Per sq. ft. of heating surface	Per sq. ft. of grate surface	Per sq. ft. of heating surface	Per sq. ft. of grate surface		
648	2,887,907 lbs.	4,457 lbs.	15.3 lbs.	2,448,894 lbs.	3779 lbs.	149.33 lbs.	71.6° F	165.2° F	3,062,791 gal.	4,727 gal.	1.0616 gal.	1.2507 gal.	30.48 lbs.	1667.10 lbs.	25.84 lbs.	1413.65 lbs.	32.32 gal.	1768.05 gal.	$5 40	$1.48

REMARKS :—The apparent difference between the weight of coal burned as shown in this table and the total weight of coal consumed at the works, is accounted for by the fact that the coal burned in the first boiler is not included in the table; this boiler is not yet provided with a water meter.

Itemized list of the costs per cubic foot of free air—

Coal	$0.000015
Water, taxes, oil, and sundry expenses	0.000004
Pay rolls	0.000005
	$0.000024
Total cost of free air—per cubic foot	$0.000024
Per horse power	0.129311
Per day of 24 hours	526.41

Total production for a quarter—

Summary of the number of cubic feet of free air used by the compressors of the factories "Saint Fargeau" and "Quai de la Gare"—

January—Saint Fargeau and Quai de la Gare	668,792,755
February—Quai de la Gare	583,798,906
March—Quai de la Gare	532,506,886
Total number of cubic feet of free air	1,785,098,547

Engine, Steam—

Diameter of high pressure cylinder	2 ft. 9.47 in.
Diameter of intermediate cylinder	4 ft. 7.12 in.
Diameter of low pressure cylinder	6 ft. 6.74 in.
Stroke (length)	4 ft. 7.12 in.
Number of revolutions per minute	60
Initial pressure of steam in the high pressure cylinder	142.22 lbs.

Air cylinders—

Diameter of low pressure cylinder	2 ft. 9.47 in.
Diameter of high pressure cylinder	3 ft. 7.31 in.
Pressure of the air	113.78 lbs.

COMPRESSED AIR PLANT AT AINSWORTH.

The first drill ever run by compressed air derived direct from falling water, under the Taylor patents, was started in operation in April at the camp of Ainsworth, the plant having been installed by the Kootenai Air Supply Company, of Nelson, B. C.

The plant is now completed, and the compressed air automatically made, is being distributed throughout the ramifications of the camp and in the great variety of uses in mining camp work it is of more than passing interest to the great army of mine owners to whom compressed air is the necessity of their daily business, and no one can go to Ainsworth and see the novel features of the installation there—the water collecting the free air from nature, carrying it into the bowels of the earth, and leaving it tightly boxed in a chamber compressed to 87 lbs. pressure ready for the drill, and passing on down the creek to find its tortuous way to the ocean—without being impressed with the simplicity and effectiveness of this great invention.

The whole process of converting the raw energy into manufactured power ready for delivery through the pipe lines, is absolutely automatic, with no machinery of any kind, and so long as the water comes from the flume the compressed air is being made.

DETAILS OF THE WATER POWER PLANT.

The plant is located on Coffee Creek, to the south of Ainsworth, and about 2½ miles from the principal operating mines. The creek has a flow varying from 2,500 cubic feet per minute to several thousand, and the flume used is stave barrel construction, round steel bands being bolted around it every three feet. The flume is 1,350 feet in length, 5 feet diameter in the clear, the available head at the compressor being 107½ feet. The water at the compressor tower is received in a wooden tank 12 feet in diameter, height 20 feet; a downflow pip passes from the water level through the bottom of this tank down perpendicularly and at the creek level a shaft was sunk 210 feet deep. The downflow pipe (which is 2 ft. 9. in. in diameter, outside measurement, of stave pipe construction throughout, the stay bands being set from 6 inches to 3 feet apart, dependent on the pressure to which the particular section is subjected) passes on down in the middle of this shaft, terminating in a great steel bell-shaped chamber at the bottom. The downflow pipe discharges into a deep groove, being open to the chamber in about its middle, the so-called groove being open to the chamber. The dimensions of this chamber are: height 17 feet, diameter 17 feet, the bell-shaped bottom standing about two feet from the bottom of the shaft, thus allowing the water to pass out. The discharge of the mingled water and air from the downflow pipe into this groove causes it to swirl around the whole circumference of the chamber, some 51 feet,

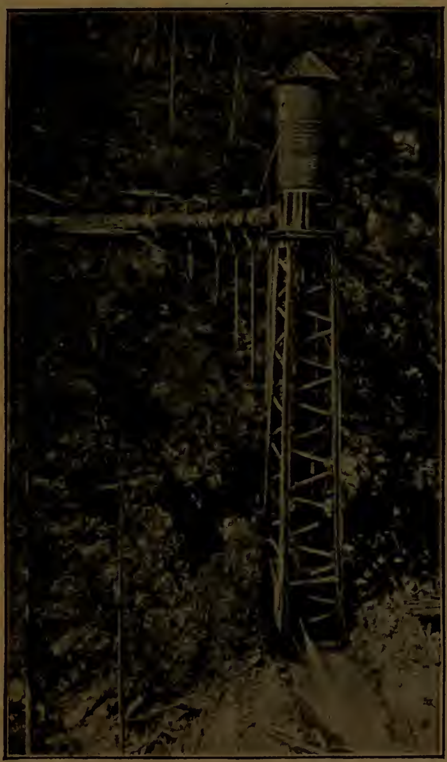


FIG. 78.—TOWER OF COMPRESSOR PLANT ON COFFEE CREEK, AINSWORTH DISTRICT.

giving the air an opportunity to leave the water and to rise into that portion of the chamber which is above the line of the channel, while the water drops below to the rock bottom of the shaft, and the water in the supply tank at the head rises in the shaft on the outside of the bell and the downflow pipe to the level of the creek. This back water column is an important factor in this system of compression; its weight on the falling water in the downflow producing the pressure, every 27½ inches of height of column of backwater increasing the pressure of air and water in the downflow pipe one pound: Thus, the shaft being 210 feet in depth, and the depth of the groove, which is the effective back head, being 200 feet, the air pressure roughly will be 200 feet divided by 27½ inches, or 87 pounds, which the gauge on the compressor records. The air in the chamber has been isothermally compressed, the moisture has been absorbed from it by the water which surrounds each globule in its passage down, and it goes to its useful work three times dryer than the original air that was entrained cold and pure. A gooseneck pipe reaches from the surface of the creek to the level of the dividing line between the air and water in the chamber, and whenever more air is being made than is being used, the air displaces the water, and the surplus passes out of this

FIG. 79.—PIPE-LINE AIR COMPRESSOR PLANT AT AINSWORTH.

pipe. It is discharging into nature through the pipe at the foot of the trestle in the accompanying photograph; on the other hand, when more air is being drawn than is being made, a pressure valve on the surface of the ground shuts off the flow until the automatic air-maker catches up to the demand. In other words, by this device the pressure cannot vary to exceed one pound, or 27½ inches of water column, and the compressor plant can be left alone to do its work perpetually.

THE AIR-MAKER.

The accompanying sketch plan shows the elevation and plan of the tank at the head of the trestle, where the water is received from the flume and the air is entrained. The air-maker is an inverted iron tanked funnel of the downflow pipe, It is seven feet in diameter, and arranged with a screw lift, so that the amount of water allowed down the downflow pipe can be regulated. Around the circumference of this tank are inserted 3,000 pieces of ¾-inch gas-pipe, the upper orifice of which is open to the air, the lower orifice being in the water, all of which must pass these lower orifices in rushing down the downflow pipe. The speed of the water in the downflow pipe is approximately 34½ feet per second, and the speed with which the air is drawn in with it will be nearly the same. The air is received by the water in millions of globules which retain their individuality, gradually becoming smaller in their passage down until finally liberated in the chamber below.

THE EFFECTIVE WORK OF THE PLANT AT THE COMPRESSOR.

The flume has a fall of 4 feet to the mile and the velocity of flow is figured at 3.72 feet per second, and the volume at 70 cubic feet per second. The actual

FIG. 80.

effective head is 107½ feet, and the available horse power allowing 75 per cent. efficiency is 620 H. P. The area of the downflow pipe being 4½ square feet and the area of the shaft 32 square feet. The speed of the water in the penstock or downflow pipe is 34½ feet per second. The amount of free air taken in under these conditions is 85 cubic feet per second, or 12 cubic of air compressed to 87 lbs. The motor air horse power will be 465. The efficiency of the plant will vary with flowage. At a later date complete data will be available under a variety of different conditions.

THE PIPE LINE.

In all the construction a light lap-welded pipe with screw joints has been used. The air leaves the compressor in a 9-inch pipe, branching some little distance out, one branch being left for later construction, the main branch running north parallel to the Kootenai Lake to the mines round Loon Lake. This branch is of the following dimensions: 6,200 feet of 7¼-inch pipe to the Dictator, 4,000 feet of 6¼-inch pipe along the west side of Loon Lake serving the Lady of the Lake and Mamie mines, and 1,100 feet of 5-inch pipe branch northeast to the Tariff, Highlander, and the big tunnel of the Philadelphia Mining Company. The total length of straight line is 11,300 feet. The properties reached by the pipe line at present are: The Eden, Crescent, Last Chance, Dictator, King Solomon, Krao, Lady of the Lake, Mamie, Little Donald, Black Diamond, Little Phil, Tariff, Highlander, Albion, Spokane and Trinket, and the intermediate claims.

The tunnel of the Philadelphia Mining Company is now in 700 feet, and is being driven from the bench above the Stevenson concentrator to tap the various ledges of the camp. This tunnel will give a depth of 900 feet at the highest point

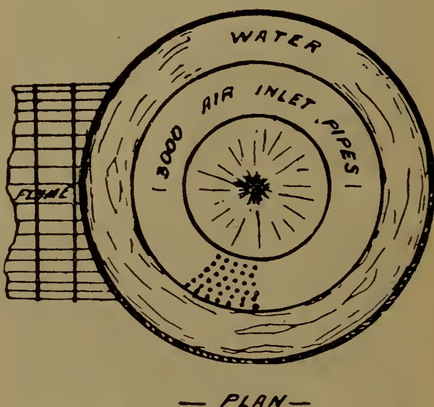


FIG. 81.

of the hill; it has already intercepted the Tariff vein, and drills supplied from the Taylor plant are driving the cross-cut tunnel ahead and drifting to the ore body on the Tariff ledge.

ITS USEFUL WORK.

Air was turned on to the pipe lines in the early part of April, and the first machine drill ever run by air direct from a column of water was started in the big tunnel of the Philadelphia Mining Company on the 16th of that month. Mr. E. E. Knowles, the mechanical engineer in charge of the plant, in writing of the plant, says:

"The machine drill first started was a ¾-inch Rand, and is 12,000 feet from the compressor at Coffee Creek. It started without a hitch and with 85 pounds air pressure at the drill. This pressure is absolutely maintained at all times. I will venture the statement that there is not another machine in the world to-day working with as dry and pure air as this one, and I will also add that there is none giving better results. Manager Henry Stevenson, of the mining company above referred to, who is using the air, has expressed himself as being highly pleased with the air, and the pressure at this distance from the compressor was a surprise to him. Here is an instance of what the capabilities of this system of compressing air will do. The company referred to has a developed water power with a working head of 1,000 feet, and are using a Pelton wheel belted to a mechanical compressor; yet this cheapest of plants to operate has been shut down for the simple reason that they are getting their power furnished them at their very door for just one-half what it was costing them for labor to run their plant, to say nothing of their investment, interest, oil and repairs. The compressor is running fine with not a soul nearer to it than three miles. At least it is presumed to be, as it is breathing into this machine drill at a rate that pleases the men who are running it and causes the muckers to get a hump on themselves. The work

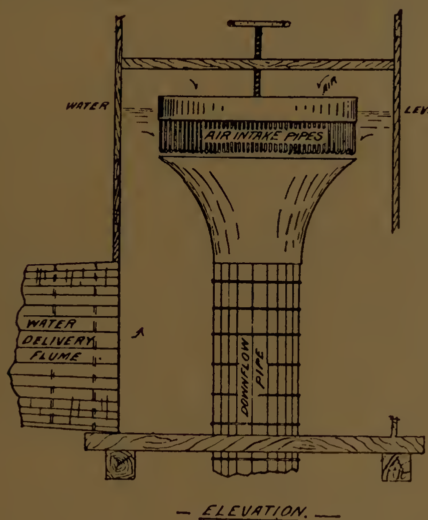


FIG. 82.

at the Philadelphia tunnel is in charge of Mr. Sherwin, and in conversation with him he made the statement that the effective work of the air could not be heat; after shooting a round of eight holes the men go back to work in from 15 to 20 minutes with the tunnel perfectly clear of impurities, and as clear as a bell in every way. Mr. Sherwin says that with all his experience with mechanical compressors, and some of them have had a capacity of 50 drills, he has never used air that is equal to the Ainsworth Air for clearing out smoke and impure air, and he also dwells on the fact that this air is an infinitely better power factor, inasmuch as it is always at constant pressure, and thereby the machine men are able to do better work and to break more ground. Mr. Stevenson, the general manager of the company, is equally well pleased with the air.

THE COST OF THE PLANT.

The installation at Ainsworth has cost in the neighborhood of $60,000, including incorporation, water power development and pipe line. Of this investment

$20,000 will cover the pipe line cost, $10,000 the water-power improvements, and $30,000 the compressor cost. The latter cost was especially heavy in Ainsworth by reason of the fact that the shaft was sunk in an unusually hard formation and involved a cost of nearly $50 per foot.

On the basis of a gross air power of 600 the output when 4,200 cubic feet per minute is used of the capacity of the water flume, this would represent a capital investment of $100 per horse power, or upon a motor horse power of 465 (allowing loss in delivery and loss in engines) the capital cost per horse power would be 130.

The company is now selling the power delivered at the mines at $4 per drill, with a liberal reduction where more drills are used. The power is being used for pumping, hoisting, blacksmith forges and ventilation, the drill charge including ventilation.—*The Mining Record.*

IS COMPRESSED AIR DESTINED TO BECOME THE RIVAL OF ELECTRICITY?

Many and marvelous are the inventions which have grown out of electrical discoveries and research, until it seems, from their multiplicity and present state of perfection, that the spirit of invention which animated these creations must soon slumber. Mighty, indeed, has been the revolution in the affairs of man wrought by electricity; under the command of genius, even though its march has been in the wake of that other potent force in civilization—steam. Notwithstanding these achievements, the commercial and industrial world is fast becoming conscious of the fact that its future rapid strides and ultimate commercial supremacy, as a motive power, will depend on cheapening the production of this form of energy, so as to oust steam, which feeds wastefully on costly coal. If this problem remains much longer unsolved, its toiling in the field of transportation, and in the workshop, will be shared by some other of nature's forces, for investors have begun to seriously realize that the millions which have been expended for franchises, dynamos, copper wire, etc., are not fruitful in dividends. It is stated that only one-fifth of the electric lighting stations in the United States are paying 4½%. Is it the uneconomical process of generating electricity by the initial power, steam, that is responsible for seventy-four electrical railroads, representing a billion and a half of dollars, being now in the hands of receivers? It is true that dynamos, in their present state of development, give out a high percentage of the engine's power imparted to them, and though we find the latter supplying in mechanical energy only 10% of that represented by the furnace heat, yet this wasteful process is not directly chargeable to the engine's incapacity to transform power delivered to it; but the trouble is due to the inability of the boiler to absorb and convert the major portion of the heat energy liberated in its fire-box. These significant facts have already influenced the recent course of electrical investments, and now the selection of a cheap initial power for generating electricity is the all-important question of the day. Eminent engineers and scientists are at work upon this problem, some endeavoring to produce electricity direct from coal or chemicals by rapid decomposition, or other methods of electro-chemistry, with a view of locating power plants in the coal-fields, or by the sea, and telegraphing the currents so derived to the cities for cousumption, while others are seeking sources of energy to be found in water-powers, or in the fitful but giant forces of nature, as tides and winds—and the promise recently given that Niagara would soon be a captured Pegasus and harnessed, so as to become a useful wheel-horse, instead of a prancing, plunging steed, is now fulfilled.

This development of power in the bosom of nature, many miles distant from industrial centers, presents other problems, requiring skill of the highest order, in their solution, namely: the economical transmission and distribution of currents of great magnitude and intense energy over long distances. When large accumulations of electric current are concentrated and prescribed to flow over a conducting wire, it becomes elusive and intractable as it flows forth, and rather than follow the pathway appointed for it to travel, it wastes itself, or passes to other substances and is dissipated so rapidly, that if it is transmitted any great distance the loss becomes so great as to render its transmission impracticable. Thus it can be seen that while electricity has not yet succeeded to its estate, the solution of these problems will mark a new era in the history of this subtle element. The applications of electric energy to industrial and commercial uses are so numerous and varied, and this singular phenomenon has received so much attention at the hands of the scientist, the engineer and the capitalist, that the world has become fascinated by its conquests, till now the impression prevails that electricity must necessarily become the motive power of the age. The writer does not claim that this, the above tendency, is a false one, but simply is set forth to show the reasons why other available forces in nature have received so little attention and consideration. Among these neglected forces, compressed air may be mentioned as a means of power transmission that has not received the attention it deserves.

EARLY ATTEMPTS TO USE COMPRESSED AIR.

The application of compressed air to industrial purposes dates from the close of the last century, although before this we find isolated attempts were made to apply it in a variety of ways.

To the fertile brain of Dr. Papin, of France, we are indebted for the first suggestion of conveying parcels in a tube by compressed air, and he was the first to suggest the use of compressed air as a means of transmitting power. This distinguished Frenchman went to the expense of putting his ideas into wood and metal, but the results of his experiments were not encouraging. This was about A. D. 1700.

About a hundred years later, a Welsh engineer contrived an apparatus to utilize a water-power to work a blast furnace and machinery, a mile and a half distant, by compressed air, but the resulting blast was feeble.

For a century or more water elevators operating by compressed air have been used in the mines at Chemnitz in Saxony. Vague descriptions of apparatus for using compressed air in the mechanical arts are found in early English patents and publications, but none, so far as known, were practically applied. In 1810, Medhurst, of England, patented means for conveying parcels by compressed air.

There is no authentic record that his project was reduced to practice, and it stands simply as a mile-post on the road toward the advancement of knowledge in this direction. In 1824, Vallance revived the idea of Medhurst. Contributions to this science were also made by such pioneers as Pinkus, Cleeg, and Pilbrow.

In 1837, the Italian government ordered experiments to establish the laws that govern air transmission, and improvements in methods and appliances have followed, resulting in the practical use of air for tunneling, in conveying parcels in tubes, and that valuable adjunct to railway trains—the air-brake.

Along about 1857 an American, Dr. Gorrie, exhibited in London and elsewhere cold-producing machines, in which air was compressed in one cylinder, cooled whilst compressed, and re-expanded in another cylinder, in a manner to utilize its expansive force. In 1859, a company was formed in London, and permanent pipes laid down for conveying parcels by air; these lines of pipe were extended in 1865. During the same year Ericsson operated eighty sewing-machines by compressed air in a factory in New York.

Experimental sections of pneumatic dispatch tube for carrying passengers were built at Sydenham, England, and in New York in 1867. The line at Sydenham was 600 yards long, and was traversed in fifty seconds with a pressure of 2½ ozs. per square inch. In 1872 Congress appropriated $15,000 for a pneumatic dispatch tube between the Capitol and the Government Printing Office in Washington.

Other systems have been multiplied by telegraph and express companies in Vienna and Berlin. The Western Union Telegraph Company conveys messages from lower Broadway to Twenty-third Street in New York, a distance of about three miles. They employ a vacuum, and the parcel travels between the terminals ordinarily in five minutes. Air was used for rock drilling in tunneling Mount Cenis, Hoosac, Arlburg, and other mountains. In 1879 air was used to propel cars on the Second Avenue Railroad, in New York.

This was briefly the state of the art up to 1880, but the dreams of Papin and the hopes of Medhurst were but partially realized. The disappointments of the past are, however, no cause for apprehension of final successful application of air for transmitting power. Many of the grandest successes of the present were absolute failures in the early attempts. Previous to 1880 the waste of energy in the compression of air, and the sickly design and faulty construction of mechanism for using air, due largely to the ignorance of the principles of thermodynamics, retarded the introduction of air as a mode of transmitting power. At Mount Cenis tunnel, the loss in compression was fully 90%. In the modern compressors the loss is less than 16%.

While compressed air has been used over and over again in a small way, and generally in a rough and uneconomical fashion, it was not until within a few years that any systematic attempt has been made to transmit and distribute this form of power for general consumption. To-day this is being successfully done in Paris and Birmingham, England, where the installations have given birth to applications and utilizations for purposes heretofore unthought of, with valuable economic results, and a realization of high efficiency in its workings.

In Paris the power is distributed not only to factories and electric lighting stations, but also finds domestic use, being sold to householders, restaurant keepers, etc., keeping them supplied with an available power which is turned to account in many useful ways, in producing the conveniences and comforts of life, while proving a welcome substitute for steam-power, with its heat, smoke, danger and waste.

The commercial advantages derived from these air systems have resulted in their rapid extension, and in Paris elaborate provision is being made to increase the size of the plant with a view of supplying an aggregate of 25,000 H. P.

THE POWER YIELDED.

The general efficiency of this mode of transmitting power in these two systems is conservatively put at from 80% to 85%, a showing that puts to flight the idea that the transmission of compressed air over a distance of several miles necessarily entails enormous losses. The attainment of this efficiency is gained by the help of another physical agent, in connection with the observance of certain simple laws, and an explanation in regard thereto may be readily understood without wading too deep into the water of science; and when understood will make clear the reasons why heretofore the progress in the introduction of a power so rich in possibilities has been impeded, while the truth becomes apparent that there is very little loss of power through its transmission if properly manipulated. In order that the reader may understand the elements involved in the solution of this problem it is necessary to gain a few preliminary ideas as to the behavior of air under prescribed conditions. Air under compression when impelled to move in a certain path is governed by laws quite different from those affecting electricity. As the air flows through the pipes the resistance of the surface of the same has to be overcome, and whenever compressed air meets resistance the pressure falls slightly, but this moderate reduction in pressure does not involve a loss of transmission, because what the air loses in pressure it gains in volume, so that its mechanical effect may at any point be easily restored to initial capacity by the application of a small amount of heat, and it has been found that by this simple expedient its capacity to do work at the points of consumption many miles from the power-station is enhanced with but a nominal cost, and that no more economical effect of the application of heat has ever been found than this method of annihilating the effects due to friction in the air's transmission. An eminent English engineer declares that a quarter of a pound of coke per hour per indicated horse-power is sufficient to heat the air required in a moderate sized engine. Nor does this fairly illustrate its economic value, when we come to consider that it is capable of another important service (as alluded to in Dr. Gorrie's discovery) at the points of consumption, in the use of the by-product, the exhaust from the motors—for the purposes of ventilation and refrigeration. In Paris the restaurants and beer cellars are supplied with refrigerant in this manner, and which proves highly satisfactory in every respect and displaces the ice-melting method altogether, and in some cases is so sought after for cold storage that power is consumed essentially for its exhaust to use to this end.

In this country compressed air is being pressed into service in small ways in every branch of industry, but the use to which the public is most familiar is probably in its application to railway trains in its adaptation to applying the brakes; but its utility and operation in this connection are scarcely appreciated until we come to consider the conditions of its use. While we have all noticed that trains cannot be gotten under way until the locomotive has run some distance, to work up speed, it is doubtful if we have ever stopped to think of the tremendous momentum that is being piled up as that speed increases and the energy that must be destroyed in bringing a train to a sudden stop after it has gotten under way. It is estimated that the vast amount of energy that must be called into action at a moment's notice is greater than can be imparted to a projectile by the largest of modern guns. Its triumph in this direction is daily evidenced, and is the one important factor that has made speed in railway travel reconcilable with safety. How few of us have realized the importance of this daily performance. A train running 40 miles an hour traverses 59′ in each second—lurking danger appears in sight—the loss of one second through the lack of vigilance on the part of the engineer means its hastening on an errand of destruction by just 59′. By the touch of a lever the brakes are applied and the train that was rushing along at almost lightning speed is brought to a standstill in a minimum of time and within a distance of 400′ from where the danger was sighted, and this prodigious power that is brought to bear on the brakes is so ingeniously distributed and applied as to relieve the cars of all strain, while the train is promptly arrested in its flight without creating any commotion among the passengers or giving rise to a disagreeable shock.

JOSEPH W. BUELL, in *Inventive Age.*

Editor COMPRESSED AIR:

DEAR SIR:—Knocking about the mines where compressed air is being used, I hear a good deal said about the deleterious effect of compressed air upon the health; only recently one foreman going so far as to say that compressed air was very bad to breathe, as the result of compression gave a quality of air very different from that of the atmosphere. He went on to say that a *chemical change* took place in the air as the result of compression.

Upon investigation, I found that they were using a very inferior quality of oil, and, running the compressor very hot, the result naturally followed that a certain amount of gas from the decomposition of the oil found its way into the headings, and naturally affected the men.

It might be wise, therefore, that this matter should be discussed a bit in your admirable publication, and thoroughly explained to the unitiated. There seems to be a belief among miners that compressed air is a bad thing to breathe, or rather that the exhaust from drills in some way affects the health of the miner.

Am I not right in my surmise that it is simply the use of a poor quality of oil in the compressor? Yours very truly,

BENJ. B. LAWRENCE,

Mining Engineer.

Denver, Col., March 13, 1897.

In compressing air for the ordinary purposes of mining, temperatures between 200 and 400 degrees are obtained in the air cylinder, notwithstanding the cooling jackets. This tends to volatilize the oil, carrying gases into the mine with the air. A high grade oil will be comparatively free from objection in this respect, but in no case is it likely that a chemical change takes place in the air, or that there is anything unhealthy about it. Many of the germs or organisms which exist in free air are destroyed by the heat of compression. A process has been recently introduced for the preservation of fruits and meats by confining them in dry air which had previously been compressed and dried, the purpose of compression being mainly to kill the germs. Compound compression or compression in stages aids in preventing the smell from oil. This is natural, because in compound compression the heat does not reach as high a point as in single stage compression.

The effect upon men working in a confined space where pure air is continually being exhausted, should have a tendency to make a model workman out of the laziest man.

There is no reason to believe that heat (even intense heat) should cause a chemical change in the two gases composing the mechanical mixture, air. The heat of compression in the average compressor does not rise much above 350 deg. F.; and if any foreign substance is present, such as oil (in excess often), there will be a tendency for it to volatilize at that temperature unless the *quality* is such that the 350 deg. F. will have no volatilizing effect upon it.

It is only necessary to refer to the use of compressed air in caissons to prove that the air undergoes no chemical change by virtue of the heat of compression. The only difficulty met with there is on account of the effect of the pressure on the human body; the extra amount of oxygen present in a caisson has the most exhilarating effect upon the workmen.

Referring to the deleterious effect of compressed air on human life, I asked Professor Hart, the chemist, if air underwent any change in compressing and heating, and he said not, and that if there was any odor in compressed air it was caused by the oil. This was what I supposed to be the case. From my own experience, I must admit that there is an odor to compressed air which it undoubtedly receives partly by some of the oil becoming volatilized owing to using poor oil, and where excessive heat is in the air due to poor cooling, but mostly by the air passing through the receiver and pipe line which are more or less coated with oil—the air, even when cold, being able to take up odors. A good example of this would be the delightful odor one meets when passing through a pine forest. It does not follow that air in which an odor is perceptible is unhealthy, for in the case of a pine forest the odor is both agreeable and healthy, while with many antiseptics the odor is disagreeable, but still healthy. I do not think compressed air any exception to the rule, for the slight odor it has is not disagreeable, and as the air was pure when it entered the compressor and had nothing to mix with except the small amount of oil that was fed to the air cylinder for lubrication, this only amounting to about one pint of oil for every 1,000,000 cu. ft. of free air, or such a small percentage that the air itself should not be appreciably changed.

Wherever the odor of compressed air becomes objectionable, it must be due to the air being excessively hot and poor oil used, that the oil is turned into a gas which mixes with the air, and also that a great excess of oil is used; but even with the most unfavorable conditions, the percentage of oil would be so small that the large amount of air with which it was mixed should have no deleterious effect on the life of people who were inhaling same. With good oil, of which only a small quantity is necessary, a good compressor with good cooling, no oil should ever be turned into a gas.

TRANSMISSION.

THE USES AND ADVANTAGES OF A PUBLIC SUPPLY OF COMPRESSED AIR.*

BY FRANK RICHARDS.

It occurs to me that it will be of interest to many readers of the "American Machinist," and that I will be doing an actual, practical service to many of them, if I try to put in easily readable shape some statement of what could be done—say in any of the large cities—if a supply of compressed air should be established and maintained, and the air distributed to all customers who should want it, as water and gas are now so universally provided.

There are no difficulties or uncertainties whatever in the way of establishing a general compressed air supply. Air compressors of considerable capacity are now made, and nearly as well understood as the steam engine, and their performance can be computed and guaranteed with great accuracy and reliability. The conveyance and distribution of the compressed air involve no difficult problems, no experimenting, no risks, no enormous expenses. Comparatively small pipes will convey a great amount of power, and they can be cheaply laid, and made and kept tight, by the resources of everyday mechanical skill. No expansion strains of any importance occur, as with steam pipes. The air, as delivered to customers, can be metered as accurately as gas; so that everything can be conducted upon a thorough business basis.

It may be better at the latter end, rather than at the beginning, to go into a detailed consideration of the cost of the compressing plant, and of its maintenance and operation, with the details of its construction and arrangement. It will be better first to see whether the service would be worth anything to us—and if so, how much—before proceeding to consider the cost of it.

It is necessary at the outset to determine what pressure of air shall be maintained in the system, as the scope and mode of its employment must, to a certain extent, be limited or controlled by that. We may assume, then, a pressure of 100 pounds, gauge, which, upon the whole, and at this stage of the game, may be better adapted to an all-around service than any other pressure, although much might be said in favor of a pressure much higher.

Although, as I said above, we will not now consider in detail the cost of compressing and delivering the air, still, in order to have some practical idea of the cost—and, therefore, the saving or the loss in the use of the air, under the various conditions which we may mention—it will be desirable to have some ap-

* "American Machinist."

proximate figures for a standard by which we may measure the economy of the air service as compared with other means applicable to each individual case.

It is generally found to be most convenient in making computations or comparisons, or in keeping records or accounts pertaining to compressed air practice, to conduct all such transactions upon a free-air basis. Free air is the volume that we have at the beginning and at the termination of compressed air operations; but during the use of the air, the volume will be less and will vary at different stages. Supposing the air to be compressed at or near the sea level, and at normal barometric pressure, the volume actually delivered at 100 pounds gauge pressure, and at normal temperature, will be only .1304 of the volume of free air; or, 1,000 cubic feet of free air will, as actually delivered to the customer, be only 130.4 cubic feet.

Let us assume, then, for the sake of keeping the cost feature before us in our compressed air practice, that the air is delivered to the consumer at an established and uniform rate of five cents per thousand cubic feet of free air—the pressure maintained being, as before assumed, 100 pounds by the gauge. This estimate of cost is, for the present, to be taken entirely upon trust; although I could easily show that the rate would be a perfectly safe and profitable one for a company who should undertake the compressing and furnishing of the air and develope sufficient business in it. With coal at $5 per ton (and not talking any nonsense about utilizing idle water powers, where the water is running to waste, and where consequently it would cost nothing), the total fuel cost for compressing the air under the above conditions would be decidedly less than two cents per thousand feet of free air.

The establishment of a public supply of compressed air could not fail to open for it a wide field of usefulness. It is an undeniable fact that it can boast a range and variety of applicability, a Briarean dexterity, possessed by no other transmissible medium. To some extent, in the single function of power transmission, it would find itself in competition—or, rather, in comparison—with the hydraulic system, with steam, and with electricity. Water transmitted under pressure of 1,200 pounds or more, is in use in various cities of Great Britain, and though the range of its usefulness is restricted to power transmission alone, and that only under narrow conditions of application, it is still an established success, and moderately remunerative to its promotors. Steam, though excellent in the development of power when it gets at its work, and though also available as a conveyor of heat, is not a good traveler, and its inability in this particular is fatal to its extensive employment. Electricity, upon the other hand, is the most sprightly and ubiquitous of travelers, and a ready distributor of both light and power—the latter almost exclusively by means of whirling motors and trains of reducing mechanism, while air may communicate its power in various ways—by the motor or engine at high speeds, or by slow, dead pressure when so required; and in addition to its universal adaptability for power transmission, it has numerous other modes of making itself useful which are possessed by it alone; and it has, above all, the unique advantage of costing nothing, except as it is used, and that it charges only for its actual services when employed.

ADVANTAGES OF COMPRESSED AIR FOR TRANSMITTING POWER.

In a communication to the Société de l'Industrie Minérale of France, M. Mortier made a critical examination of the advantages and disadvantages of compressed air as an agent for the transmission of power, showing clearly by mathematical calculation, that the advantages far outweigh the disadvantages. We have not sufficient space to reproduce this valuable treatise, but we select the more practical portions and also the conclusions arrived at by the eminent inventor of the diametral ventilator.

While compound air compressors have already been adopted to a certain extent, the use of multiple expansion has hitherto been limited to a compounding of the motors, the reason of which limitation must be sought in the fact that compound engines cost more than those not compounded, while it is difficult, without warmed intermediate receivers, to restore its initial temperature to expanded air. Instead, however, of compounding each compressed air motor independently, it would be better to compound them mutually, the exhaust air from one series of motors being collected for supplying another series in a pipe under moderate pressure, laid side by side with the high pressure mains.

There is, moreover, nothing to prevent various lengths of this supplementary pipe from being connected, first with one another, and afterwards with the receiver of the successive compressors, in which case a series of compoundings would be obtained, notwithstanding differences in the volumes of air exhausted from the two series of motors, and in this manner something akin to the system of electric distribution with three conductors would be effected, without, however, its complication.

Besides great saving in the first cost of the motors, a mutual compounding would give them considerable elasticity of power without loss in yield, because with two pipes under different pressures, a moderate effective pressure, double or triple, according to the method of connecting the admission and exhaust, may be applied to the same cylinder. Advantage may thus be taken in the same cylinder with normal dimensions of the original economy afforded by low compression, because the possibility of admitting a threefold pressure would permit of overcoming a special resistance of making unusual efforts. In this manner successive stages of compounding introduced into the utilization apparatus would greatly increase the useful effect of moderating or governing, by permitting the dimensions of the motors to be reduced and the wire-drawing of the compressed air in the cylinder to be diminished.

The co-efficient of general yield, taking into consideration the imperfect general yield, the losses of work corresponding with losses of pressure, and the advantages of multiple compressions at the beginning and end of the operation, is calculated mathematically by the author, who concludes that if only the adiabatic method—that at equal pressures—be adopted, which most nearly approaches the ordinary conditions of practice, the following useful effects will be obtained: With a single compression, 0.533; with a double compression, 0.681; and with quadruple compression, 0.753.

These figures suppose the most unfavorable conditions that can occur, *viz.*: no cooling down in the compressing cylinders and no reheating in those wherein the air is again expanded; but at the same time they suppose the favorable condition of the air returning to its initial temperatures after each stage in the multiple compression. Although a quadruple compression may be obtained perfectly well, a double expansion is all that can be hoped for in practice. Taking everything into account, it will be very near the truth to regard the original yield or useful effect as varying between 55 and 75 per cent.

Simple air compressors of good construction show a ratio of 0.85 between the work indicated on the air pistons and that on the steam pistons, or 0.93 for the yield of the air system and 0.93 for that of the steam system, while for the receptor motors only a rough mean can be given, probably near upon 75 per cent. The maximum value of the general useful effect, supposing the pipes absolutely tight, will therefore be $0.75 \times 0.93 \times 0.75 = 0.523$; but without multiple compressions this figure will be only 0.384, supposing the work of expansion to be completely utilized, which is practically impossible with a single expansion without reheating.*

As is well known, the compression of air in a space which exerts no action upon it causes heating, while expansion in a similarly inert space causes cooling, and with production or utilization at constant pressure the variation of temperature may be obtained in centigrade degrees by dividing the work (expressed in kilogrammetres* per kilogramme of air) by 102.7 F.

To give an example for an expansion at constant pressure corresponding with a ratio of 6.25, the theoretical lowering of temperature will be 120° cent., while for a ratio of 2.5 it will only be 60° cent. In the former case, working would be impossible owing to the oil becoming solidified, and the watery vapor in the air being frozen; but in the second case admissible conditions may be obtained, especially if the exhaust be allowed to commence at a pressure slightly greater than the back pressures.

Thus, not only does the use of multiple expansions improve the useful effect, but even renders it possible, which would not otherwise be the case. If the initial temperature of utilization be not the same as that of production, the useful effect found for identity of initial temperature must be multiplied by the ratio of the temperatures.

The yield may be increased (1) by lowering the initial temperature of production, although little more can be practically done in this connection than to draw the air for compression from a cool cellar and (2) by raising the temperature of the compressed air immediately before it is utilized. The available energy is then, as it were, expanded under the action of heat, just like air itself, and with the same co-efficient of expansion, the improvement thus obtainable having theoretically no limit, so that the yield of a power transmission by compressed air may be considerably greater than unity; and it is in this respect that compressed air differs widely from the other agents for transmitting power such as electricity and water under pressure, which admit of no such increase, and always yield less work than what has been entrusted to them.

It is evident that this "expansion," or increase of energy, cannot be obtained without the consumption of fuel, but this supplementary work is obtained so cheaply and simply that no other is more economical, not even the natural

* A kilogrammetre (7.233 foot-pounds) represents the effort required to raise a kilogramme (2.2 lbs.) the height of 1 metre (3 ft. 3⅜ in.).

forces, which are regarded as gratuitous. In any case, whether the expansion leaves the air at a relatively high temperature or whether it determines an intensely refrigerating action, a difference will be set up that may be utilized mechanically so that some of the heat imparted will be recovered, thus reducing expense.

Indeed, there is a case in which the saving that may be obtained is absolutely integral, viz.: when the expansion supposed forms one of a multiple series in which the initial temperature becomes raised by the reheating every time to the same figure, and in that case the residual temperature of the air at the end of each partial expansion constitutes a net gain for the next reheating.

For a multiple utilization, comprising a certain number of stages, each corresponding with the same ratio of compression, with the same initial absolute temperature reheated, and consequently with the same sum of work produced, the mean thermic yield, which in this case is the arithmetical mean of the partial yields, may in any case rise above 50 per cent. even, under ordinary circumstances.

Considering that the cylinders of gas engines readily accommodate themselves to high temperatures, an exact doubling of the energy available at the end of the operation, *i. e.,* an integral reconstitution of the energy furnished at the commencement may be obtained—and this with a very slight expenditure of heat units, inasmuch as the operation of reheating has a thermic yield ten times that of good engines.

The multiple compression of air by the natural forces, its transmission at high pressure, and its expansion in a series of stages after considerable and repeated heating, afford a very welcome solution of the problem of the economical production and transmission of power; and this system, economizing the natural forces, the effect of which it multiplies, and the fuel which it consumes, offers nothing but what is very acceptable, provided the pipes be perfectly tight, which, however, is unfortunately not yet attained in practice. The following is a summary of the conclusions arrived at by the author:

Compressed air, regarded as an agent for transmitting power, is just what it is made, its value being exactly proportioned to that of the mechanical and calorific conditions which preside at its production and utilization. With high adiabatic compressions, rendering illusory all effective expansion, the yields obtained are miserably small; and on the other hand, although with low pressures this original defect is absent, the dimensions of the pipes and apparatus then become so large as to be prohibitive.

With a series of successive compressions, however, even at constant pressure, and especially with a mutual compounding between motors, sufficiently far apart for the air partially expanded in passing between them to acquire the surrounding temperature, a useful effect of 50 per cent. may easily be obtained, and that with pipes and cylinders of moderate dimensions.

While the other agents of power transmission, such as electricity and water under pressure, correspond with a strictly defined amount of energy available, compressed air, in addition to the amount of work which it is capable of giving out at a constant pressure and at the surrounding temperature, carries with it a credit, theoretically unlimited, for transforming into power the artificial heat which may be communicated to it; and this transformation is effected with so high a thermal yield that the supplementary work thus obtained is almost gratuitous.

In other words, the purchaser of a given weight of compressed air acquires at the same time the right of obtaining, without complication of any consequence, and with a very slight expenditure of fuel, an artificial quantum of energy at least equal to that of the natural energy imparted to it directly.

This special faculty added to absolute elasticity of speed, both of the compressors and the motors, and also to the possibility of regulating or storing up compressed air, constitutes an individual feature of the highest importance, which may often justify a preference being given to this agent of power transmission.

J. W. PEARSE.

AIR VS. ELECTRICITY IN LONG DISTANCE TRANSMISSION.*

By W. S. Norman.

The high efficiency now obtainable by the Taylor system of hydraulically compressing air which develops 75 per cent. of the horse power of any given water power in compressed air, the excessive dryness and low temperature of the air so compressed, thus reducing to a minimum the loss in delivery, brings compressed air forward as the most economic form of delivering power in long distance transmission; and I propose to show in this article that for the uses of a mining camp, compressed air under the Taylor system is the cheapest in its first cost of installation, and immeasurably the cheapest in its cost of operation in comparison with electric power.

The Taylor system of hydraulically compressing air was fully explained in an article which appeared in the May number of the *Mining Record,* and the accompanying plan of the plant now in process of installation at Ainsworth, B. C., will refresh the memory of the reader as to the principle involved. The Ainsworth plant will develop 75 per cent. of the horse power of the stream in actual compressed air, at a pressure of 90 pounds, and the air so delivered will be three times drier than the external atmosphere, and of the same temperature as the water which compresses it.

In comparing any two systems of power transmission, relative comparisons must be made upon the following points:

1. Original cost of installation.
2. Cost of maintenance and operation, including their relation to load factor.
3. Efficiency of systems.
4. Relative simplicity of systems, and the superior advantages of operating with simple machinery.

Starting with the acknowledged condition of all mining operations, namely, that a large portion of the ultimate power required must be compressed air, whether it is mechanically compressed by steam or from turbines, or from electricity transmitted by electric wires and converted by electric motors and mechan-

* British Columbia Mining Record.

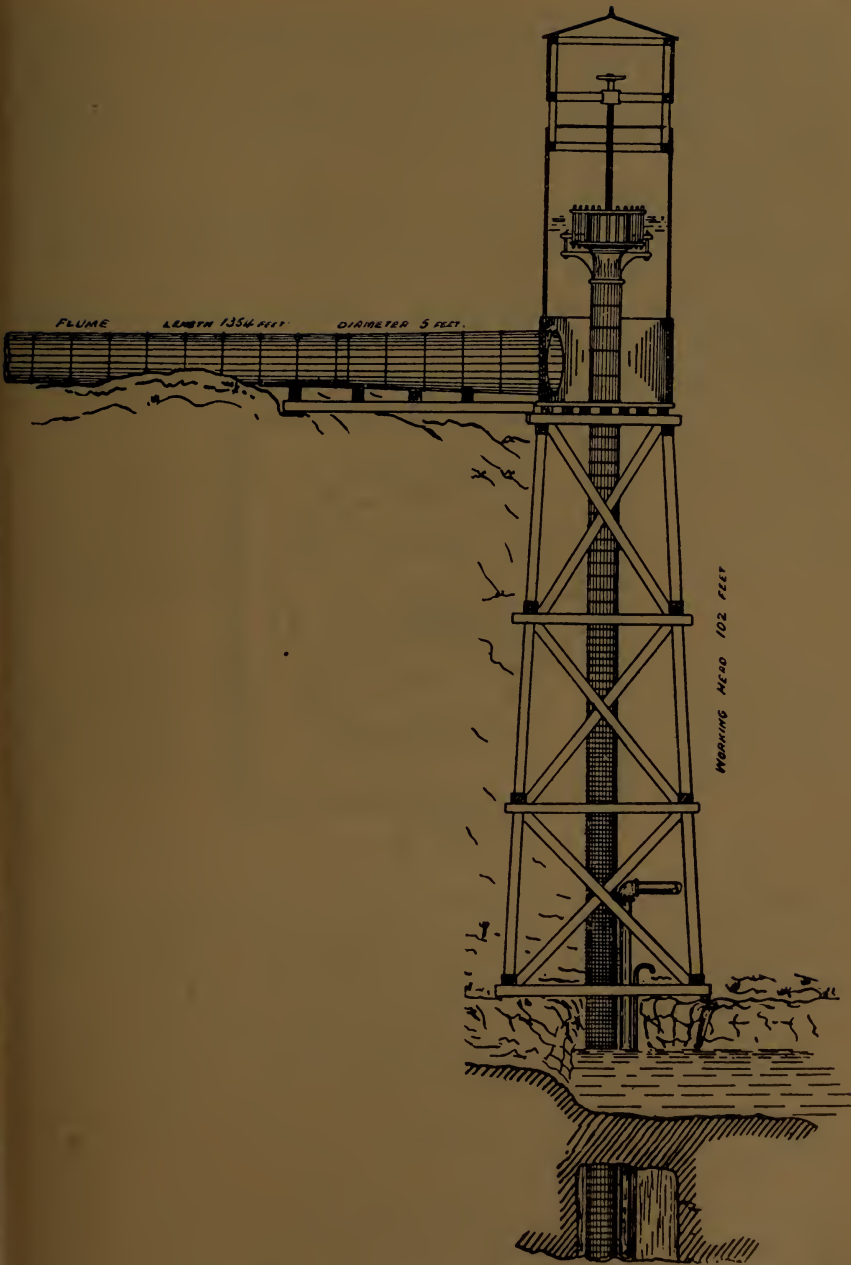
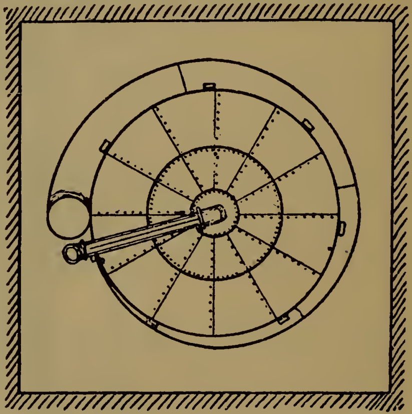


FIG. 83.—AIR COMPRESSOR PLANT INSTALLED AT AINSWORTH.

ical compressors, or by the Taylor system, the absolute demand of the camp for a large share of its power must be air to drive the percussion drill, to ventilate the underground workings and to actuate the pumps; and since the major portion of the work to be done in the mine has to be performed by air, the general custom is to run all motive power by air, thus bringing the generating station under one roof.

For the purpose of comparison, we will assume the existence of a water power eight miles from a group of mines, where the head is high and the cost of development is relatively low, the conditions to be fulfilled being the delivery of 10,000 cubic feet of free air at six atmospheres pressure, or sufficient free air to represent 1,000 net air h. p. delivered, and to actuate say 150 drills in ordinary rock. We shall consider the case of an electric plant at a water power actuating motors in the heart of a mining district, the motors driving mechanical compressors in a central station, the air being delivered by mains to the various mines,



PLAN

FIG. 84.

though a very common practice throughout the United States and Canada is the use of small separate mechanical compressors at the various properties, each actuated by its own separate motor, and each employing its own separate force of operators, thus materially increasing the cost of the air h. p. delivered at the drill. The air h. p., however, which the conditions laid down above call for is not the air h. p. read from the indicator card of the compressor, which tells us nothing of the temperature of the air nor of the amount of moisture therein contained, but the air h. p. at its working conditions at the drill, where the moisture has been drawn off and where its temperature has been reduced almost to atmospheric conditions. To reach this degree of perfection, the mechanical compressors must deliver an air efficiency of 1,000 h. p., or 10,000 cubic feet of free air per minute at the mine, and our mechanical compressors, therefore, should have at least 1,500 gross h. p. capacity, and be actuated by electric motors of at least 2,000 h. p. capacity, and our water power must possess 3,000 gross h. p., which will give 2,400 net h. p. on the wheel shaft, and will give a dynamic force of 2,200 h. p., delivering 2,000 h. p. over the line at the electric motors. With the Taylor system there is but the one transformation, that from the water to the compressed air, and no moving mechanism is used in the transformation. The water rapidly flowing down the downflow pipe entrains the air, which is compressed in the receiving tank by the returning column of water, and from this tank it is automatically delivered absolutely free from moisture ready for use at the drill. The amount of loss in transmission is almost inappreciable if we care to invest a sufficient amount in pipe line. In the West, however, where freights are high and the pipe line cost is greater than the sinking of shaft cost, we will figure on a wider drop of pressure in the pipe line. At the compressor we will have a shaft sunk deep enough to produce 125 pounds pressure and allow 45 pounds loss of pressure in the line, delivering at the terminal at 80 pounds. This would be equivalent to a loss of 12 per cent. Reduction of pressure increases the volume of the air, and by using a 15-inch wrought iron pipe we can deliver at the terminal end 10,500 cubic feet of free air per minute, isothermally, and not adiabatically compressed, as in the case of all mechanical compressors, the h. p. of which would be rather more than 20 per cent. greater than the same volume of air adiabatically compressed. With these losses we should, therefore, require 1,250 h. p. at the compressor, and a gross h. p. in water of 1,700 h. p. By raising the initial pressure to 200 pounds, and making a drop of pressure of 100 pounds in the pipe line, which would represent a loss of about 19 per cent. due to friction, the 1,000 h. p. could be carried in a 12-inch main, thus saving one-tenth in weight of iron in the plant.

I—ORIGINAL COST OF INSTALLATION.

The cost of water-power development varies with the local conditions, and for the sake of camparison we will take a water power having a high head, where the power can be developed, exclusive of the waterwheel cost, at $20 per h. p. The following will be the cost of the electric plant, according to the figures given in Dr. Louis Bell's "Electrical Power Transmission," 1897:—

Electric plant, 3,000 gross h. p., at $20 per h. p.	$ 60,000
2,200 h. p. electric generators, at $12 per h. p.	26,400
2,200 h. p. in transformers, at $10 per h. p.	22,000
Pole lines and wires, eight miles	35,000
2,750 h. p. in water-wheels, at $15 per h. p., set in place	41,250
Station building and equipment	10,000
2,000 h. p. step-down transformers	22,000
2,000 h. p. in motors, at $12 per h. p.	24,000
1,500 h. p. compressor plant, set up in place	75,000
Miscellaneous	20,000
Total	$335,650

The following will be the cost of the air plant under the Taylor system:—

1,750 gross h. p. water power to develop, at $20	$35,000
275-foot shaft, 8 x 8	10,000

Down-flow pipe and compressor tank	5,000
8 miles 15-in. pipe line, all set in place, at $1.50 per ft.	63,360
Sundries	10,000
Total	$123,360

2.—COST OF MAINTENANCE AND OPERATION.

The following are the expenses of the electric plant:—

Superintendent of whole plant	$ 3,600
4 men at power generating station, at $3 each per day.	4,380
4 men at compressor station and sub-electric station, at $3 each per day	4,380
Repairs to plant, 4 per cent. on capital cost	13,483
Insurance, 2 per cent. on $150,000	3,000
Taxes, 2 per cent	3,000
2 linemen at $3 and team at $1 per day	2,555
Interest on investment, at 6 per cent	20,235
Sinking Fund, at 4 per cent	13,488
Clerical work and office expenses	4,000
Total	$72,126

Should the power transmission plant be at a distance greater than ten miles, then the investment cost would be greater, as a step-down transformer station would be rendered necessary, entailing additional capital and additional operating charges. This brings the annual charge per air h. p. delivered at the drill up to $72.12, and it is very questionable to-day whether in practice, under the most favorable conditions, a rate as low as this has ever been realized. It should be remembered that in almost every mining camp where electricity is used for the driving of compressors, numbers of small compressors are used on each different property, driven by their own separate motor, each entailing a separate operating force, and this, of course, adds largely to the cost of the air h. p. delivered at the drill. If, for instance, the electric h. p. is rented from a central company at a charge of say $50 per h. p. per annum, delivered at the motor in the camp, it can be seen from the above figures that the air h. p. delivered at the drill will cost between $150 and $200 per annum.

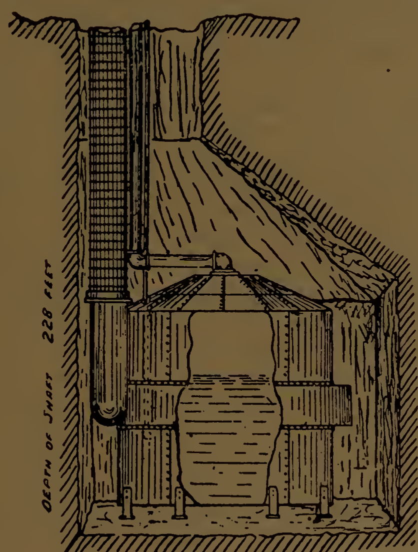
The following are the maintenance and operating expenses of the Taylor air plant:—

Maintenance of pipe line, at 4 per cent	$ 2,534
One man at station to keep racks clean	1,000
Depreciation in plant taken at 2 per cent. on account of absence of machinery	2,267
Management and interest	10,801
Total	$16,602

Or a h. p. cost of $16.60 per annum delivered at the drill.

An important point to consider is the relation of the load factor in a power-generating plant. The load factor in a plant reaches its maximum of 100 per cent.

when it operates at its full maximum capacity during the whole twenty-four hours. If it operates at less than its maximum capacity, or less than the twenty-four hours, then the load factor cannot reach 100 per cent. The great object in all electric plants is to raise the load factor, because it is found in actual experience that the operating expenses do not increase as the load-factor increases, nor do they diminish as the load factor diminishes. Very few electric plants attain a load factor exceeding 50 per cent. In the case of the electric plant given above by Dr. Bell, he considers that if it runs on a load factor of 38 it attains all that can be expected. The point is just this: As has been mentioned, the operating expenses in an electric plant do not fall as the load factor falls. If the load factor falls down, say as much as 60 below its maximum, the operating expenses will



ELEVATION.

FIG. 85.

only fall about 10 per cent. In the case of the Taylor air system, the operating expenses are merely nominal, being in the case considered only $1,000 for a man to keep the water racks clean, so that this factor of loss due to a low and variable load factor is almost entirely eliminated in the Taylor air plant.

EFFICIENCY OF SYSTEMS.

In the case of the electric proposition there is a series of eight losses from transformation before the drill is actuated in the face of the stopes of the mine: First, from the water to the water-wheel; second, from the water-wheel to the dynamo; third, from the dynamo to the transformer; fourth, from the transformer to the line; fifth, from the line to the step-down transformer; sixth, from the transformer to the motor; seventh, from the motor to the compressor, and eighth, from the compressor to the drill. In the hydraulically compressed air plant under the Taylor system we just have two transformation losses—first from the water to the air in the receiving tank, and from the receiving tank to the drill. The Magog, Quebec, plant is actually running with an efficiency of delivered air of 62 per cent., and Professor Nicholson, of McGill College, Montreal, in a very able treatise on the plant, shows that the efficiency should have been 81 per cent. instead of 62, the difference being largely accounted for by a loss due to ineffective separation, 20 per cent. of the air taken down having escaped with the up-cast water. This was due to the small capacity of the separating tank; and, as Professor Nicholson points out, "all future plants will avoid this loss, and we may expect as high an efficiency from this system as when the power is given off at a turbine jack-shaft, when it is not by any means in such a fit state for transmission as it is in the shape of compressed air." Professor W. C. Unwin, F. R. S., author of "The Development and Transmission of Power," says: "I expect that an efficiency of 75 per cent. can be reached when the proportions of the apparatus have been better adjusted. This comparatively large compressor (referring to the Magog plant), is therefore, an example of a very successful application of Mr. Taylor's system. It works almost automatically, and with very little supervision. It has no moving parts and nothing requiring adjustment, and the apparatus will cost very little for maintenance or repairs."

We come now to consider the respective losses in both systems due to transmission. It is generally believed that electricity has a much superior advantage over compressed air for transmission purposes, that is, that there is a much smaller loss of energy over electric wires than through pipe lines. Compressed air has been badly misrepresented in this respect; this loss has been greatly exaggerated, and the catalogues of air-compressing machinery companies have not improved matters any; in fact, they have done more harm than good as regards the interests of compressed air. The tables published in air compressor catalogues usually speak only of the loss of pressure; they fail to tell us that the loss of pressure is not necessarily, or to the same extent, a loss of power. As Frank Richards, in his work on "Compressed Air," page 33, says: "The actual truth is that there is very little loss of power through the transmission of compressed air in suitable pipes to a reasonable distance, and the reasonable distance is not a short one. With pipes of proper size and in good condition, air may be transmitted say ten miles, with a loss of pressure of less than one pound per mile. If the air were at 80 pounds gauge or 95 pounds absolute upon entering the pipe, and 70 pounds gauge or 85 pounds absolute at the other end, there would be a loss of little more than 10 per cent. in absolute pressure, but at the same time there would be an increase of volume of 11 per cent. to compensate for this loss of pressure, and the loss of available power would be less than 3 per cent. With higher pressures still more favorable results could be shown." As a competitor with electricity in long distance transmission, it seems almost like scientific heresy to claim for it equal if not greater efficiency; nevertheless the writer claims that within the 20-mile limit compressed air will compare in efficiency with electric transmission, while so far as operating and maintenance expenses are concerned, the electric proposition is not to be compared for a moment with that of air. Over 15,000 h. p. of mechanically compressed air is distributed to-day throughout the city of Paris, France, being transmitted from a series of stations from three to fifteen miles distant, with a loss of 10 pounds pressure in transmission. This compressed air is used for all kinds of purposes; and additional intallations are constantly being made to meet the ever-increasing demands.

Professor W. C. Unwin in his work on "The Development and Transmission of Power from Central Stations," page 186, says: "In comparatively short distance transmissions such as those in towns, the loss of pressure in the mains is so insignificant that it may be neglected. In long distance transmissions an accurate estimate of frictional loss is necessary. The author believes that he has shown, using data derived from careful experiments on twenty miles of main in Paris, that long distance transmission of power by compressed air is perfectly practicable." In the work referred to Professor Unwin gives the figures on a 10,000 h. p. plant, where the initial pressure is 132 pounds, and the transmission pipe is 20 miles in length and 30 inches in diameter, and shows that the loss of pressure in such a case would be only 12 per cent., which means a loss of power of less than 6 per cent.

It is not the purpose of the present article to institute a comparison between the work done by mechanical air compressors and the Taylor air compressor, its object being to show the comparison of the latter with electric transmission. As, however, the mechanical compressor becomes a part of the system in the electric proposition, being necessary at the distribution end of the line to convert the electric energy into compressed air, this is the proper place to say a few words as to the relative efficiencies of the product turned out by the mechanical compressor and the Taylor air compressor respectively. The Taylor compressor turns out absolutely dry air—a feat which is impossible of accomplishment by any known mechanical compressor. The great advantages of dry air are sufficiently well known to all air users, so it will not be necessary to dwell on this point here. From the very nature of mechanical compressors, it will never be possible for them to turn out dry air. Owing to the rise of temperature which accompanies all mechanical compression, mechanically compressed air will always contain a higher percentage of moisture than the surrounding atmosphere; in this sense the mechanical compressor acts like a moisture collector, and this moisture is discharged and freezes up in the machinery upon the expansion of the air when used. From actual tests it is found that the Taylor compressor turns out compressed air which is three times drier than the free air of the atmosphere from which it is drawn. This may appear somewhat surprising, but it is nevertheless true. It leaves the compressing tank absolutely dry and cool, its temperature being the same as the water which it carries down. This is the ideal condition to which all compressed air users and manufacturers of air compressing machinery have been striving to attain, and particularly in its application to mining, where compressed air is required for constant use by the drills, will this advantage of obtaining absolutely dry and cool air be found to be an inestimable boon.

4.—RELATIVE SIMPLICITY OF SYSTEMS AND THE SUPERIOR ADVANTAGES OF OPERATING WITH SIMPLE MACHINERY.

In long distance electric power transmission the apparatus used is of a highly unstable character, necessitating as it does constant supervision by skilled men. The multiplicity of transformers, high potential insulators and other high potential devices in long distance electric propositions renders them exceedingly liable to break-downs, particularly if the transmission line passes through a rough and wooded country. A break-down generally occurs just when the power is most wanted, and when the heaviest load is on. Trouble on the outside line from storms, falling timbers, lightning and other causes is immediately felt at the generating station, with very often disastrous results to the high potential machines and apparatus. If by machinery is implied moving mechanism, such as wheels, shafts, pulleys, belting, gearing, etc., then there is no machinery whatever involved in the Taylor system of air compression. There is not one single moving piece of mechanism in the whole compressing outfit. There is no other system of power generation in the world where these conditions exist; and of all the factors which enter into the consideration of the economic production of the power at the present day, the one involved in moving machinery parts is the most important. The aim of modern machinery practice is to obtain the utmost possible simplicity of moving parts consistent with efficient operation. What does the absolute absence of moving machinery mean in a system of power generation? It means the absolute elimination of all repairs and stoppages in the system; and those who have had to do with the management of power machinery can realize what this means from an economic point of view, and can also realize the trouble and annoyance dispensed with by the breaking down of moving machinery very often at the most critical times. In the Taylor air compressing system there is not a single moving axle or shaft, not a single moving wheel or gear, and not a single rod or piston of any kind. The system is, as stated, absolutely devoid of anything whatever in the way of moving mechanism; and yet it develops and delivers any quantity of compressed air in a more efficient and perfect condition than if engines and compressors turned it out.

UTILIZATION OF SMALL MOUNTAIN POWERS.

There is one factor in this new form of hydraulically compressing air which will prove to be of great value in the utilization of the numerous comparatively small streams found in the mountainous mining districts of the west. It often occurs that in the course of a stream extending over a distance of five miles a series of falls can be obtained, aggregating about 1,000 feet, the stream gathering to itself as it flows downward additional supplies of water from various gulches. To improve these small powers by turbines involves, if the whole head is to be taken advantage of, the loss of the drainage area below the point of diversion, which ofttimes amounts to a large percentage of the whole, or the installation of three or four operating stations, the expense and maintenance of which make the power cost prohibitive. With the Taylor system every pound of water in the whole length of the stream can be used, because compressors can be installed at every few hundred feet, and the air generated by these compressors delivered into a common pipe line for distribution to the mining camp; or, in order to save expense in the sinking of shafts the upper compressors can make the air at a low pressure and this air can be carried to the lowest compressor, the lowest compressor being used as a "booster" to raise the pressure so that it can be economically transmitted. In this way the entire h. p. of the stream on every foot of its length can be utilized without any addition to the operating expenses and with only a comparatively small increase to the installation cost. The system in other words has all the elasticity of electricity with elimination of its operating and maintenance expenses, and the volume of air transmitted in the pipe line can be doubled even after the compressors are built, by the construction of a second compressor to "boost" up the air made by the first compressor to a higher pressure.

It will also be observed that the Taylor system is by far the more economical in the use of water in the cases we have been considering; and this is an important item with the mountain streams of the West, whose water supply is limited, and for the use of which certain fixed charges are made by the Government according to the quantity used. Every year adds to the industrial value of the streams, and therefore any system of power development which involves the more economical use of the water is the system to which preference must be given.

Compressed air is the ideal applied power and particularly is this the case under the Taylor system. The plant where is it installed is like a part of nature herself, the water being simply directed to flow through an iron or wooden pipe instead of through its former channel. There is practically no wear upon the system, and the power materials are drawn from nature's inexhaustible storehouse. It is incomparable in its simplicity, and is destined to bring compressed air as an applied power to its deserved and proper place—the very front rank in the mechanical world—a consummation impossible of attainment with any known system of mechanical compression at the present day.

DISCHARGE OF AIR FROM PIPES UNDER HEAVY LOSSES OF PRESSURE.

BY WILLIAM COX.

It is generally supposed that the volume of "air" discharged from a pipe increases with every increase of pressure absorbed in overcoming friction. Thus, if the initial pressure is 100 pounds, more air will be discharged with a final pressure of 80 pounds than with a final pressure of 90 pounds. That a limit to this useful absorption of pressure exists hardly seems to have been considered, except such limit as would be imposed by the extra consumption of fuel, etc. Yet upon due reflection it would almost appear natural that such a limit should exist; but why, where? The important question therefore arises: What, if any, maximum proportion of the initial pressure may in any given case be absorbed in overcoming friction in the pipe before this limit, if it exists, is reached?

One great difficulty in dealing with all problems relating to the flow of air in pipes is that all the practical users of this valuable commodity always calculate according to volumes of free air. Now, free air does not circulate in pipes, does not run rock drills, pumps, hoisting engines, etc. Hence much confusion of ideas. The supposition that free air flows through a pipe implies that there is in it constant volume, constant density and constant velocity of flow. But the fact is that each of these is varying at every step of the current's passage. This general consideration of free air instead of compressed air leads also to the application to it of laws which affect compressed air, whereas the laws governing free air and compressed air, as specially related to flow in pipes, are in most cases entirely opposite.

In order to have clear ideas on this subject, and to arrive at correct conclusions, it is therefore necessary that we should deal with what actually flows through a pipe and is discharged from it. Thus, to return to the supposition with which this paper opens, that 100 cubic feet of air, compressed to 100 pounds gauge pressure, enter into a pipe per minute from the receiver, it would appear evident that with every subsequent reduction of the terminal pressure, or pressure of discharge or egress from the pipe, the volume of air (compressed) discharged will by reason of its expansion be greater and greater until the maximum reduction of the terminal pressure (in this case 100 pounds) expands it to the point of free air, or air at atmospheric pressure, when its volume will also be a maximum. Such increases for a constant volume of compressed air, and for various reductions of pressure would be as follows:

100 cubic feet of air at 100 pounds gauge pressure is equivalent to 121 cubic feet at 80 pounds; 153 at 60 pounds; 209 at 40 pounds; 330 at 20 pounds; 464 at 10 pounds and 780 at atmospheric pressure.

As the volume increases therefore toward the outlet of the pipe, the velocity of flow must also clearly increase; and as the greater volume is under a lower pressure, its density must consequently be less, hence as stated, what flows through a pipe is by no means free air.

The assumption, when applied to compressed air, that the volume of air discharged from a pipe increases with every increase of pressure absorbed in overcoming friction, is therefore, we may say, correct. The case given above does not, however, represent the flow of air in a pipe, as it supposes that the same volume of air enters the pipe, and consequently that the same equivalent volume of air, but at a lower pressure, is discharged from the pipe, whatever variations there may be of the terminal pressure.

The laws governing the flow of air in pipes show that the discharge of air (compressed, not free) from a pipe varies as the square root of the loss of pressure, when the diameter and length of the pipe and the initial pressure are constant.

The formula for the flow of compressed air in pipes given by the writer in COMPRESSED AIR, January, 1898, page 359, is:

$$\text{Discharge in cubic feet per minute.} = c\sqrt{\frac{d^5 \times (p_1 - p_2)}{w_1 \times l}} \quad \ldots\ldots\ldots\ldots(1)$$

which may also be put in the form

$$\text{Discharge} = \frac{c\sqrt{d^5}}{\sqrt{w_1} \times \sqrt{l}} \times \sqrt{p_1 p_2} \quad \ldots\ldots\ldots\ldots(2)$$

The first factor on the right hand of this equation represents the diameter and length of pipe and the initial pressure, and if in any number of cases this is a constant quantity, then clearly the discharge of compressed air will vary as $\sqrt{p_1 - p_2}$, or the square root of the loss of pressure. And examination will show that according to the formula there is no limit to this absorption of pressure until the air is discharged without pressure into the atmosphere. But then *cui bono?* Considerations, commercial, mechanical or scientific, or all combined, will find it essential that some limit to such wasteful absorption of pressure be imposed; and the cost of compressed air at its initial pressure, and its effective value at any given terminal pressure will be in a broad sense the factors which will determine at what figure this limit shall be placed.

In the example of the discharges given on page 270, supposing that

$$\frac{c\sqrt{d^5}}{\sqrt{w_1} \times \sqrt{l}} = 100^*$$

then we should have the following volumes of compressed air discharged at the different terminal pressures noted, namely:

80	lbs.	final	pressure,	$100 \times \sqrt{20} = 447$	cubic	feet.
60	"	"	"	$100 \times \sqrt{40} = 632$	"	"
40	"	"	"	$100 \times \sqrt{60} = 775$	"	"
20	"	"	"	$100 \times \sqrt{80} = 894$	"	"
10	"	"	"	$100 \times \sqrt{90} = 949$	"	"
Atmospheric			"	$100 \times \sqrt{100} = 1000$	"	"

But on page 270 we see that 100 cubic feet of air at 100 pounds pressure is the equivalent of 780 cubic feet of free air. Now, if the air were at atmospheric pressure at the exit or in the nozzle of the pipe, it would not flow out of it, as the front and back pressures would balance each other, and the whole volume of air in the receiver would remain there, being balanced by the pressure absorbed in the pipe to overcome the enormous friction produced by the great velocity of flow at the end of the pipe. To force it out, therefore, the pressure in the receiver would have to be increased, and likewise the initial pressure in the pipe, which would then be shown by a somewhat increased volume of $\sqrt{w_1}$ in Eq. (2).

Or may it not be that if the pressure in the receiver is kept constantly at 100 pounds, that a somewhat less quantity of air would be discharged from the pipe than 1,000 cubic feet? Unfortunately in this examination we have only a theoretical expression of the laws of nature, in the shape of a formula, to guide us, and no series of data based upon actual experiments to help us.

This is, however, taking a very extreme caśe, where such refinements of calculation would probably never be required, and also one to which perhaps the formula, although an excellent one, may not apply. But it must be remembered that the formula does not deal with the quantity of air that enters into the pipe, but only with what is discharged from it. The first factor on the right hand of equation (2) does not indicate what volume of air would enter the pipe except theoretically upon the supposition that no friction whatever exists. It is only when in conjunction with the second factor that the volume of air discharged is obtained. It may, therefore, be that the real discharge at atmospheric pressure would be 1,000 cubic feet, as also at 90 pounds final pressure 949 cubic feet, and so on.

D. K. Clark, in his work on the steam engine, says: "The flow of steam of a greater pressure into an atmosphere of a less pressure increases as the difference of pressure is increased, until the external pressure becomes only 58 per cent. of the absolute pressure in the boiler. The flow of steam is neither increased

* This is correct for a 3-inch pipe, 141 feet long, with $p_1 = 100$ pounds.

nor diminished by the fall of the external pressure below 58 per cent. of the inside pressure, even to the extent of a perfect vacuum."

Is it not possible that some such law may be found to exist in the case of compressed air? Be this as it may, the formula seems to show that the discharge of compressed air continues to increase with every successive reduction of the final pressure, or increase of pressure absorbed in friction, although this increase of discharge is a continually decreasing one in proportion to the increase of pressure loss. Thus for 20 pounds loss of pressure, from 80 to 60 pounds final pressure, there is an increase of discharge of 185 cubic feet, whereas for 20 pounds loss of pressure, from 20 pounds final to atmospheric pressure, there is a gain of only 106 cubic feet.

But what interests the compressor builder and, in accordance with the way he has been educated, the compressed air user, is the amount of free air which is supposed to be discharged from the pipe. The compressor builder and user figure only on free air because the compressor at the very commencement of the cycle of operations for which air is to be used, takes in free air, and its dimensions, speed, etc., have all reference to this quantity of free air taken in. So, further on in the cycle of operations, the builder calculates that a given quantity of free air will be required to run a certain number of rock drills, or a hoisting engine, or a pump, or to perform some other work. Therefore as much as possible the views of the builder and user have to be met. That form of the formula which deals with equivalent free air will therefore now be examined.

Some time ago I was asked to solve the following problem:

What volume of free air will pass through a 3-inch air line, 6,000 feet long, the initial air pressure being 125 pounds and the terminal 80 pounds? Also how much will pass if the terminal pressure is 60 pounds, other conditions remaining the same?

Here, then, we have the following data to work from:

3 inch pipe, $c\sqrt{d^5}=876$

6,000 feet, $\sqrt{l}=77.46$

125 pounds pressure $w_1=0.7230$, and $\sqrt{w_1}=0.85$

80 pounds final pressure $=p_2$, then $p_1-p_2=45$ lbs., and $\sqrt{p_1-p_2}=6.71$

Also 60 pounds final pressure $=p_2$, then $p_1-p_2=65$ lbs., and $\sqrt{p_1-p_2}=8.06$

Now, inserting these in equation (2) we get in the first case

$$\text{Discharge of compressed air in cubic feet per minute} = \frac{876}{0.85 \times 77.46} \times 6.71$$
$$=13.3 \times 6.71$$
$$=89.243 \text{ cubic feet air at 80 pounds terminal pressure.}$$

and in the second case

$$\text{Discharge of compressed air in cubic feet per minute} = \frac{876}{0.85 \times 77.46} \times 8.06$$
$$=13.3 \times 8.06$$
$$=107.198 \text{ cubic feet air at 60 pounds terminal pressure.}$$

To find the equivalent in free air of any volume of compressed air we have

$$\text{Equivalent free air} = \text{Compressed air} \times \frac{G+14.7}{14.7} \quad \ldots\ldots\ldots\ldots(3)$$

where G is the gauge pressure of the volume of compressed air.

The writer has simplified this by reducing it to the form.

$$f = \frac{G+14.7}{14.7} = 1+0.068\,p \quad \ldots\ldots (4)$$

where f is a factor to reduce compressed air at pressure p to its equivalent volume of free air.

Inserting the values of p_2 in Eq. (4) we get for terminal pressure 80 pounds

$$f_2 = 1 + (0.068 \times 80) = 6.44$$

and for terminal pressure 60 pounds

$$f_2 = 1 + (0.068 \times 60) = 5.08.$$

Equation (3) may now be put into the form

$$\text{Equivalent free air} = \text{Compressed air} \times f_2 \quad \ldots\ldots (5)$$

which gives us in the first case for 80 pounds final pressure,

Discharge of free air $= 89.2 \times 6.44 = 574$ cubit feet per minute,

and in the second place for 60 pounds final pressure,

Discharge of free air $= 107.2 \times 5.08 = 544$ cubic feet per minute.

It results, therefore, that with a reduction of the final pressure by 20 pounds, we actually obtain a smaller discharge of equivalent *free* air, although, as already shown, we have a larger output of compressed air. And how do we know that with 80 pounds final pressure we do not obtain a smaller discharge of equivalent free air than we should do with a final pressure of 90 pounds? In other words, *Where is the limit?* WHAT IS IN ANY GIVEN CASE THE LOWEST USEFUL FINAL PRESSURE? This is a very important point for the compressor builder and for the compressed air user, who always calculate on the basis of free air. It is shown by the solution of the above problem that with very heavy losses of pressure in a pipe line, a smaller equivalent volume of free air can be forced into the pipe than with more moderate pressure losses, the initial pressure remaining the same. How many pipe lines have given results below what was expected, through ignoring this fundamental principle, and how often has the cause for the failure been accounted for in any way but the correct one?

Combining equations (1) and (4) we now obtain the following general formula for the discharge of equivalent free air from pipes:

$$\text{Discharge free air in cubic feet per minute} = c\sqrt{d^5}\,\frac{f_2 \times \sqrt{p_1 - p_2}}{\sqrt{w_1} \times \sqrt{l}} \quad \ldots\ldots (6)$$

In those cases (such as the problem under consideration) where the diameter and length of a pipe, as well as the initial pressure, are constant, and the final pressure only varies, the formula may be put

$$\text{Discharge free air in cubic feet per minute} = \left(\frac{c\sqrt{d^5}}{\sqrt{w_1} \times \sqrt{l}}\right) \times (f_2 \times \sqrt{p_1 - p_2}) \ldots\ldots (7)$$

it being then at once seen that as the first factor on the right hand of the equation is constant, the discharge of equivalent free air varies exactly in proportion to

$$(f_2 \times \sqrt{p_1 - p_2}),$$

that is, in a certain degree, according to the final pressure. By this arrangement of the formula we are enabled to examine easily the effects produced upon the discharge by variations of the final pressure, as the only factor with which we have to deal is the second one on the right hand of equation (7). By calculating values of

$$(f_2 \times \sqrt{p_1 - p_2})$$

for a number of terminal pressures in a given case, we can at once and easily campare them, and select a limit which should not be exceeded in order to obtain results such as may be desired.

And here it is important to note that as p_2 increases in value, f_2 decreases in value, and *vice versa,* so that there must be a point at which the value of

$$f_2 \times \sqrt{p_1 - p_2}$$

is a maximum, and consequently the discharge of equivalent free air from the pipe is also a maximum, and any further pressure absorbed in friction beyond this maximum value of $p_1 - p_2$ or minimum value of p_2, produces a diminution of the discharge, which is absolute loss of economy.

Suppose an air compressor to be rated to compress 574 cubic feet of free air per minute to 125 pounds, and that this air is forced through a pipe of such diameter and length that the terminal pressure is 80 pounds. Now, if that terminal pressure is reduced to 60 pounds, the compressor will only have to compress 544 cubic feet of free air per minute to 125 pounds, so that it is not working up to its full capacity by 30 cubic feet a minute, or more than 5 per cent. And yet who will affirm that the real work done by the compressor is not as great in one case as in the other?

What is in any given case the Lowest Useful Final Pressure, and how is it ascertained?

Taking the problem before us, and leaving out of consideration the factor

$$\left(\frac{c\sqrt{d^5}}{\sqrt{w_1} + \sqrt{l}}\right)$$

which has no effect upon this question of final pressure, let us take a few different final pressures and tabulate them thus:

TABLE 25.

p_1	p_2	f_2	$p_1 - p_2$	$\sqrt{p_1 - p_2}$	$f_2 \times \sqrt{p_1 - p_2}$
lbs.	lbs.		lbs.		
125	85	6.78	40	6.3246	42.88
125	80	6.44	45	6.7082	43.20
125	75	6.10	50	7.0711	43.13
125	70	5.76	55	7.4162	42.74
125	65	5.42	60	7.7460	42.00
125	60	5.08	65	8.0623	40.94

Here we see that the maximum value of

$$f_2\sqrt{p_1-p_2}$$

is somewhere about where $p_2 = 80$ pounds that is, in any case, when the value of p_2 lies somewhere between 75 and 85 pounds. It may be more or it may be less than 80 pounds. We, therefore, now tabulate a little further as follows:

TABLE 26.

p_1	p_2	f_2	p_1-p_2	$\sqrt{p_1-p_2}$	$f_2 \times \sqrt{p_1-p_2}$
lbs.	lbs.		lbs.		
125	82	6.576	43	6.5574	43.1215
125	81	6.508	44	6.6332	43.1689
125	80	6.440	45	6.7082	43.2008
125	79	6.372	46	6.7823	43.2168
125	78	6.304	47	6.8557	43.2183
125	77	6.236	48	6.9282	43.2043

From this we see that the highest value of

$$f_2\sqrt{p_1-p_2}$$

is 43.2183, which is obtained when the terminal pressure is 78 pounds. This is then the limit sought, or the lowest useful final pressure for an initial pressure of 125 pounds. For other initial pressures the limit can be found in the same way. It must be admitted that it is somewhat tedious, but the result in any given case may far more than compensate for the time and labor bestowed. The writer has worked out these limits for a full range of initial pressures from 10 to 1,000 pounds.

Applying now the limit of 78 pounds, as found above, to the problem under consideration, we have by inserting the known values in equation (7)

Discharge of free air in cubic feet per minute $= 13.3 \times 43.2183 = 574.80$ cubic feet.

The exact discharge for 80 pounds terminal pressure is $43.2008 \times 13.3 = 574.57$ cubic feet. The difference is so slight that 80 pounds may be practically considered as the lowest limit beyond which, for the sake of economy, the terminal pressure should not be allowed to fall.

From a careful consideration of this problem it will be evident that all use of the simple term "air" should be accompanied by a clear comprehension of what is meant, and what it involves. Confusion may lead to serious consequences.

Viewed in the light of what is here shown it would be both interesting and profitable to reduce the volumes of compressed air given on page 271 to their equivalent volumes of free air. A certain point will then probably be found which is not the "lowest useful final pressure," but rather the most *economical* one, when the cost of the compressed air at its initial pressure and the amount of effective work which may be obtained from it at terminal pressure are duly considered.

LOSS OF LOADS IN AIR-PIPES.*

STATE OF THE QUESTION.

A great many authors have dealt with the loss of energy sustained by a certain volume of air in its passage through metal pipes; but the coefficients published, correct enough when applied to the pipes experimented with, no longer hold good when extended to those of sheet-iron or tin-plate, and there is great interest in determining the constants to be introduced into the general formula expressing loss of load in the air-pipes used in mines. The author's method of experimenting was suggested by the remarkable labors of M. Murgue, who in the *Bulletin* of the Societe de l'Industrie Minerale, has shown in such a striking manner the influence exerted by the nature of the sides on the resistance opposed to the air's motion through mine workings; and the former's researches, which may be regarded as the complement of M. Murgue's, permit of solving beforehand with sufficient exactitude the problem:

"Calculate the energy necessary to draw through a line of pipes, included in a given circuit, a given volume of air for ventilating the face of a heading;" or inversely, "Given a pipe line of known length, nature and dimensions, forming part of a circuit, calculate the air volume that will be drawn to the face by a given power."

MODE OF EXPERIMENTING.

The time-honored formula expressing the loss of load due to the motion of air through pipes is

$$h = a \frac{L\, p\, v^2}{s} \delta_2$$

in which a is a coefficient varying with the nature of the sides, L the length of the pipe, b and s the mean perimeter and sectional area, v the mean speed, and δ the density of the air; and generally the numerical value given to a depends upon a depression (water-gauge), h, expressed in millimetres (say inches) or kilogrammes per square metre (say pounds per square inch) of surface. Finding the value of coefficient a, that characterizes a pipe of known form and dimensions, is connected with a simultaneous determination of the motive depression, h, producing a current of mean speed, v; and the following are the instruments that were used in the author's experiments, with the methods employed for measuring the intensity of the air-current and the loss of load corresponding with a given distance passed through.

Pressure-gauge.—The remarkably correct instrument used by Mr. Murgue, and lent by M. Marsaut, which permits of reading a difference of level correct to

*From a paper by M. Paul Petit, Chief Engineer of the Saint-Etienne Collieries, Loire, France, prepared for the International Congress on Mining and Metallurgy, held in connection with the Paris Exhibition.

within one hundredth part of a millimetre, consists essentially of two glass flasks of very different diameters, connected below by an indiarubber tube. It is only in the small flask that the difference of level due to the diminished pressure is observed, and that with the aid of a microscope, the simultaneous fall of the water level in the large flask not being regarded; and the result of the readings is corrected by calculation. The great sensitiveness of this instrument requires that it be placed on a strong and massive table, for preventing the water-level from being influenced by trepidations; and, for experiments on the surface the pressure-gauge was placed on a thick surface (setting-out) plate, while a portable cast-iron table was made for receiving the instrument in the underground workings.

Anemometers.—For measuring the air volume drawn along by a known depression three small Casartelli anemometers were used, M. Murgue's ingenious method of instantaneously throwing the wheel in and out of gear being adopted.

Atmospheric Observations.—The temperature of the air-current was measured above and below each line of pipes experimented with, or each length of underground road, by thermometers graduated to one-tenth of a Centigrade degree; the pressure being read off from an aneroid barometer; and the humidity

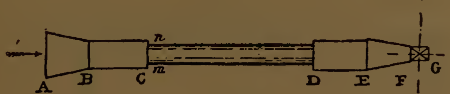


FIG. 86.

in the atmosphere was taken by a very correct hygrometer, the weight of air in motion being calculated by the convenient tables appended to the work by Herr Althans, president of the Prussian sub-committee on ventilators.

Air-pipes.—In the first series of experiments sheet-iron pipes of 27 mm. (1 1-16 in.) inside diameter with screw socket connections were used; but, owing to their joints not being found tight notwithstanding every precaution, lead pipes of 17 mm. (21-32 in.) inside diameter and 3 mm. (⅛ in.) thick, soldered together if necessary, were used for the second series—that metal, which affords absolute tightness, being suitable on the surface where these experiments were made, although its softness would be an objection under ground.

Production of the Air-current.—The various lines of pipes experimented with were in turn laid out in the yard of the workshops, near the boilers; and an exhausting fan at the down-stream end set up an air-current, the intensity of which could be varied at pleasure. For straight lines of pipes a Rateau fan of 70 cm. (2 ft. 3 in.) diameter, driven directly, was used; but in subsequent experiments, for obtaining more intense currents, and consequently greater difference of pressure than could be more correctly measured by the gauge, a Mortier diametral fan of 90 cm. (2 ft. 11 in.) diameter and the same width, also driven directly, was utilized. The trials with curved lines of elliptic pipes and those of large diameter were made in the locomotive running-shed, an arrangement which permitted of the experiments being continued uninterruptedly in all weathers.

Measuring the Air-current.—The annexed diagram, Fig. 86, shows the general arrangement adopted, in which the pipe, C D, to be experimented with is inserted between two adjutages, B C and D E, the former receiving the air-current drawn in by the fan through a convergent inlet-piece, A B, while the latter delivers it to the exit-piece, E F, also convergent, connected with the fan inlet, G. The adjutages, and also the inlet and the outlet, are made of ploughed and tongued boards, carefully fitted; and the air volume was measured near the inlet and outlet in the cross-sectional plane of their adjutages. The gauging station was placed at such a distance from the inlet and outlet of pipe C D that the flow might be considered as taking place by parallel currents, uninfluenced by the contraction due to the air's motion, between the larger sectional area of the adjutage and the more or less reduced sectional area of the pipe experimented with. By simultaneously measuring, in the entrance and exit adjutages, the air volume passing

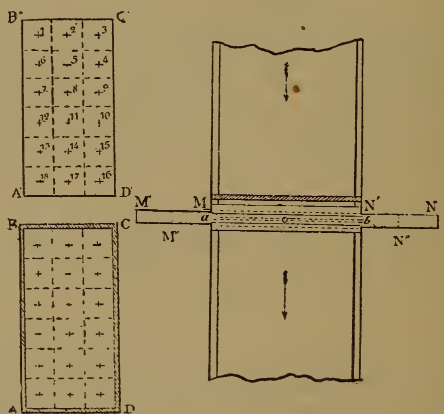


FIG. 87.

at each of the stations, it was possible to estimate the quantity of air infiltration and check the degree of tightness in the whole arrangement.

In all the series of experiments the sectional area of the adjutage D E remained practically constant; and the inlet with its adjutage was adapted to the size of the pipe to be experimented with. As the energy that could be set up by the fan was limited, it became necessary, for measuring the volumes of relatively slight intensity circulating through pipes of small diameter, to reduce the sectional area of the inlet adjutage to the value corresponding with a speed of current that could be exactly measured by the anemometer. The connection of the various pipes with the entrance and exit adjutages required great care, for avoiding the infiltration of air that might escape being registered by the anemometer, and thus falsify the measurements of the volume; and on that account the pipes were allowed to project slightly inside each adjutage so as to bear against partitions, carefully constructed of thick boards ploughed and tongued, forming part of the adjutage, luted with putty and having an aperture of the same diameter as the pipe.

For measuring by the anemometer the intensity of an air-current passing through pipes so small as those experimented with, a difficulty arose that does not present itself in the gauging of mine workings; and it is evident that the dimensions of the entrance adjutage cannot be too much increased without a risk of excessively diminishing the speed of a weak air-current. Now, for a moderate section of adjutage the presence of an experimenter may greatly invalidate the observations; and it would become impossible to simultaneously measure the air volume passing through the pipe and the depression of the current. For getting over this difficulty, the following arrangement, due to Herr Althans, was adopted:

Referring to Fig. 87, the rectangular sectional area of the gauging station was represented full size by a tablet, A′ B′ C′ D′ placed above the adjutage, A B C D, and divided into the squares, 1, 2, 3...... 17 and 18 corresponding with the anemometer stations. A slot, *a b*, was made in the top cover, B C, of the adjutage, and closed by a wooden slide, moving with easy friction in a guide screwed to the cover, the minimum travel being equal to double the width, B C, of the adjutage. In the movement from left to right or from right to left given by hand to this slide, its extreme positions will be M N and M′ N′, the mean position being M″ N″; and at no point of its travel can there be penetration of the outer air into the inside by the slot *a b*, which is constantly covered by the moving slide.

As shown in Fig. 88, the anemometer being hung from the end of a small but rigid rod, of such a length that if one of its ends occupies point 1 (see Fig. 87) in the upper tablet the other will occupy station No. 1 of the adjutage, it will penetrate into the interior through a hole in the slide. If the slide is at rest, all that will be required is to lower in a vertical direction the upper end of the rod, bringing it in succession opposite stations 1, 6, 7, 12, 13 and 18 of the tablet, for the centre of the anemometer to occupy the corresponding stations; and if the instrument is to be displaced horizontally it will be sufficient to move the slide in the proper direction by maintaining it at a station for a preconcerted space of time, after the manner of a pantagraph, although in this case there was no reduction or enlargement.

In order to permit of throwing the anemometer in and out of gear from a distance without entering the chamber, it was hung from the end of a light but rigid copper tube; and a copper wire inside the tube was held by one of the experimenters standing on the adjutage opposite the numbered tablet, a spring fastened to the stand of the instrument acting through a small chain on the engaging lever to which the wire is attached on the side opposite the spring. When the wire is stretched the anemometer is thrown into gear, but at other times the spring, acting on the lever, throws the instrument out of gear, an arrangement that gave every satisfaction.

In 1897 each series of observations made on a given pipe was preceded by a gauging that comprised measurement of the speed at each of the eighteen stations marked on the tablet, one minute being occupied at each. During this protracted gauging the fan's speed was kept perfectly constant; and, for taking into account slight variations in the engine speed, the fan revolutions were taken simultaneously with the gauging, the speeds observed being all reduced to a given fan speed supposed constant. The experiments following the first of each group only comprised a gauging for one minute each at three points in the sectional area; and the total number of revolutions made by the anemometer during this space of time was registered. In accordance with M. Murgue's remarks as to the constant ratio between the mean speed of the air-current for the whole of the sectional area and its speed at three given points, the result was arrived at by a simple proportion sum.

In 1898 this manner of making the observations was modified for the following reasons: The prolonged gauging before beginning each group of experiments took up too much time for recording so many observations as those re-

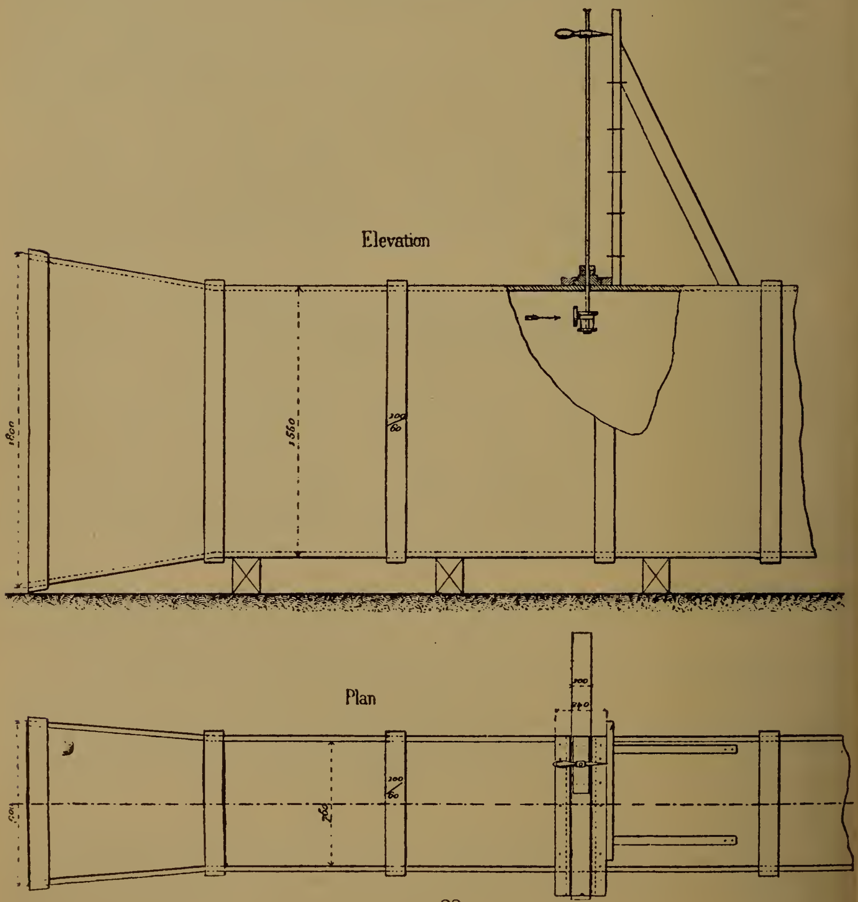


FIG. 88.

quired; but the chief reason consisted in the difficulty of keeping the fan at a constant speed, especially when setting up a comparatively high watergauge, the boiler though fired hard, not being able to make sufficient steam.

There are, however, grounds for believing that the second method was quite as correct as the first. One permitted, which could not be obtained with the other, of tracing curves of equal speed; but this advantage was slight, because a knowledge of the distribution of the different speeds is only useful if it relates to the pipe experimented with, and the gauging was effected in an adjutage the sectional area of which was always far greater than that of the pipe. The time during which the anemometer was kept at each station has never been less than six seconds, which is considered sufficient by all who have taken up this question; and the rectangular form of the adjutage, 1.5 m. by 0.75 m. (4 ft. 11 in. by 2 ft. 5½ in.) lends itself readily to a division into equal squares, their centres corresponding with the stations.

Influence of Air Infiltrations.—However carefully the joints be made, it is difficult to entirely avoid the errors resulting from slight air infiltrations over the distance with respect to which the loss of load is to be measured; but for reducing this cause of error to a minimum the author made a point, before beginning each series of observations, of gauging the entrance and exit adjutages at the maximum fan speed, so as to better appreciate the extent of the leakage, although with metal pipes an almost entire concordance between the inlet and outlet volumes was attained.

TAKING THE WATER-GAUGE.

In all the observations made under the author's superintendence, the difference of the total pressure was measured by two Pitot tubes placed along the centre line, the pipe facing the air-current; and here began the difficulties. These tubes ought to have been placed at the points of the stations, up-stream and down-stream, where reigned the mean speed; but this was not done, for want of time, the tube being always held in the middle as if the total pressure were the same over the whole sectional area. The Murgue apparatus was set up, at the up-stream end, on one of the side faces of the air inlet; and a slight shelter protected the pressure-gauge arranged on the heavy cast-iron plate already mentioned. Indiarubber tubes from the cocks connected the pressure tubes above and below with the large and small flask of the gauge respectively. In the experiments on pipes of slight diameter these tubes were laid along their length entering at two points comprising between them the length to be observed; and the two tubes were bent to a right angle so as to constitute a Pitot tube.

Referring to Fig. 89 in the observations on straight pipes, the tubes, T T′, starting from the Murgue pressure gauge, proceeded one to the up-stream station, A, and the other to the down-stream station, B, F being the fan and the arrow showing the direction of the current. In the observations on separate straight portions connected by various bends the tubes might be arranged so as to permit of measuring at will the total loss of load, as well as the partial loss of load in each portion of the pipe line; and it is thus that, in the case shown by Fig. 90, the water-gauge may be taken if desired between the points 1 and 4 of the total distance traversed, or between the points 2 and 3 of the partial distance.

CONDUCT OF THE OPERATIONS.

The six observers were placed—the first near the exhaust fan for recording its speed; the second on the top cover of the up-stream adjutage facing the tablet above mentioned, for moving (as has been described) the rod of the anemometer, which he threw in and out of gear from a distance; the third moved horizontally, from left to right and from right to left, the slide covering the upper slot of this adjutage, and the fourth, holding a chronometer, gave the signals for beginning and finishing the observations, while the fifth and sixth respectively took the water-gauge and booked the number of revolutions made by the anemometer. The extreme stations, up-stream and down-stream, were connected by electric-bell apparatus, so that the signals agreed upon could be exchanged.

So soon as the fan acquired the determined speed, the down-stream observer notified those up-stream; and at a stroke from the bell the anemometer was released and moved about in the different stations, where it was kept for a given number of seconds signaled by the chronometer man; and during this time as many readings as possible (at least ten per minute) were taken of the depression. At the end of the observations the operators formed into two groups, each read-

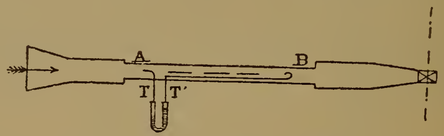


FIG. 89.

ing in turn the tachymeter and anemometer figures, this checking of the observations, strongly recommended by M. Murgue, being indispensable for avoiding errors.

GENERAL FORMULA EXPRESSING LOSS OF LOAD.

After describing the numerous experiments with both straight and curved pipes, carried out in the above-mentioned manner, and quoting Herr Althans' simple formula for expressing loss of load, the author states it as follows:

$$h = 0{\cdot}0007489 \times \frac{L}{D^{1\,373}} \delta^{\frac{2}{3}} v^2 \ldots\ldots\ldots\ldots \quad (1)$$

h being the loss of load, L the length of pipe, D its diameter, δ the weight of a cubic metre of air, and v the mean speed of the fluid. He was able, thanks to the many and various observations made, to determine the true power which connects the loss of load with the mean speed, finding it equal to 1.916. As regards only the passage of air through pipes used for ventilating preparatory workings, a case which supposes for δ a value near upon 1.2 kilogr. (3 lb.), he feels justified in stating a = 1; and he was led empirically to modify the formula to the following:

$$h = 0{\cdot}000765 \times \frac{L}{D^{1{\cdot}506}} \delta\, v^{1\,916} \ldots\ldots\ldots\ldots \quad (2)$$

A table is given (in the original paper) of the values calculated by formulæ (1) and (2) with the experimental results obtained for a whole series of diameters comprised between 0.259 and 1 metre; and a comparison of these values leads to the following

CONCLUSIONS.

1. For slight diameters the non-concordance between the calculated and observed results is sufficiently marked, and more so with the Althans formula (No. 1) than with that proposed by the author (No. 2).

2. For pipes rough inside, such as those of 0.45 m. (1 ft. 6 in.) and double that diameter, comparable with the state of a cast-iron surface, the Althans formula expresses the results observed with very slight divergence; but for smooth

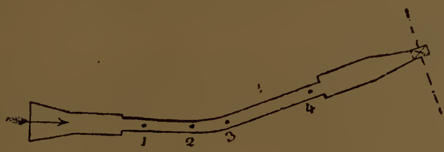


FIG. 90.

pipes of galvanized sheet iron or painted with red-lead, and having a diameter larger than 0.338 m. (1 ft. 1 in.), it gives the loss of load as rather high.

In fine, the author considers that the general formula proposed by him embraces the collective results with a very near approximation.

COMPRESSED AIR FOR TRANSMISSION OF POWER.*

By J. H. RONALDSON.

The transmission of power, to a greater or less distance, is frequently a subject for the serious consideration of a mining engineer, and thanks to the advances in scientific and mechanical knowledge made during recent years, the choice of method is varied and the possible efficiency is considerable. The means of transmitting power are steam, water, wire rope, electricity and compressed air, and the advantages and disadvantages of each of these systems vary with the distance to be bridged and the conditions attending their application.

Steam.—Within moderate distances and under certain conditions, steam is at once the most economical and satisfactory means of transmitting power, but the limitations to its use are too familiar to require enumeration.

Water.—There is no more valuable agent than water for actuating hoists and for certain pumping operations in mines, where excessive lifts over long distances have to be overcome. One of Moore's pumps has been in use at South Bulli Colliery, Illawarra, for some years.

Wire Rope.—For the general purposes of haulage, wire rope transmission of power is unexcelled, and it has in many instances been used for other purposes, such as pumping in mines. For the latter purpose it has, however, received a limited application, a result due, it is to be feared, to defective installation, through a frequent ignorance of the properties of ropes and pulleys. When one remembers the admirable work done in the way of haulage, pure and simple, by modern ropes, it is inconceivable to think that this method could not be applied to pumping in mines, in many instances with favorable result. As an

* A paper read before the New South Wales Chamber of Mines, June, 1900.

example it may be mentioned incidentally that at the Metropolitan Colliery in New South Wales, a band rope of crucible steel 1¼ in. diameter, taken down a shaft 1,100 ft. deep, and transmitting at least 100-horse power regularly for ten hours per day, worked without change for five years and was then only taken off to insure perfect safety in an important service. The rope was far from being worn out when changed.

Electricity.—As a competitor with compressed air, electricity occupies the first place. Its use as a means of transmitting power has of recent years been widely extended, and in mines we have it now applied to pumping, haulage per medium of locomotives, and fixed rope haulage engines actuated by electricity, winding above and below ground, to rotary and percussive drilling, and most successfully to coal cutting machinery.

Compressed Air.—For the transmission of power this agent has therefore in certain directions serious competitors, in favor of which there has frequently been urged greater economy in first cost, in working cost, in efficiency and in applicability. These claims have, however, been keenly contested by the advocates of compressed air who, on the other hand, contend that it supplies a means of power transmission at once safe, economical and efficient for general mining work. The force of this contention has been much increased by the improvements effected during the last twenty-five years, in the methods of generating compressed air and of using it, as will be shown later on. There is little need to dwell on the importance of compressed air as a factor in the economy of many mines, an enumeration of its uses making this sufficiently apparent. It is used to actuate rock drills, underground haulage and hoisting engines, pumps, underground ventilating fans, Körting's air injectors, and coal cutting machines. It is necessary to an intelligent appreciation of the subject to consider the laws relating to air as a gas, and the mechanical causes which render its economical use more difficult than would at first sight appear. It is proposed, therefore, to consider the subject in the following order:—(1) The laws affecting the compression of air; (2) the various styles of compressors; (3) the causes of low efficiency in air compressors; (4) air conduits; (5) methods of using compressed air; (6) dangers attending its use.

I.—LAWS AFFECTING THE COMPRESSION OF AIR.

Air is an elastic fluid which, when free from vapor, behaves as a perfect gas; 13.09 cubic feet at ordinary atmospheric pressure, and at 60 degs. Fahr., weighs 1 lb. According to Boyle's law, the volume of a gas varies inversely as the pressure affecting it so long as the temperature remains constant; consequently in doubling or trebling the pressure the volume becomes one-half or one-third respectively. According to Charles' law, if the volume of a gas be kept constant, the pressure varies as the absolute temperature, and if the pressure be kept constant the volume varies as the absolute temperature. By the law of the transmutation of energy, work performed on a body, whether solid, liquid or gaseous, is evidenced by a definite increase of temperature in that body, and we are familiar with that fact as shown in the simple laboratory experiment of exploding a small charge of guncotton in a strong glass cylinder through the rapid heating of the air contained in it by a sudden jerk of a tightly fitting piston. Consequently when air is compressed it is heated; when heated it expands and the volume of air to be compressed is proportionately increased with a corresponding expenditure of the power required to compress it. Could the temperature of the air undergoing compression be kept constant (isothermal) during the process, and the heat taken up from it returned to the air during its expansion in the motor while doing work, all loss from this source would be avoided. This, however, is impossible, and the aim of modern compressors is to prevent an increase in the volume of the air by keeping down the temperature during the period of compression; that is by approximating to what is termed the isothermal process. It is clear that the least efficient compressor is the one in which no provision is made for cooling the air during the actual period of compression, that is one working on what is termed the adiabatic process.

2.—AIR COMPRESSORS.

Although compressed air had been used to a small extent previously, it was not till 1850, when the Mont Cenis tunnel was constructed, that its use became general. Two forms of compressors are in use, in each of which a reduction of the temperature of the air is aimed at; in one case by the use of a liquid piston in the cylinder, and in the other by a water-jacket round the cylinder, or by an internal spray of water. The former is termed a "wet" and the latter a "dry" compressor.

Wet Compressors.—Of these, there are two types: (a) where the water piston owes its energy to the fall of water from a height; (b) where the water piston is actuated by a steam driven piston. At Mont Cenis, Mons. Sommeiller made use of water with a fall of 86 ft., and by utilizing the momentum of the falling water he was able to obtain an air pressure of 75 lbs. per square inch. Though extremely low in efficiency (not more than 6 per cent.) and necessitating clumsy plant, the arrangement gave results sufficiently good. This principle has been applied in other cases, and one arranged by Hathorn, Davey & Co., Leeds, was successfully used for many years in Mexico. The application of the principle is simple, and where an abundant water supply exists, excellent results are obtained. The second form of wet compressor has attained a wide application on the continent of Europe where, particularly among the highly educated Belgian and French engineers, the principles of air compression are more thoroughly understood than in Britain. It is, however, a question if their adherence to this method is not an instance of the length to which a desire to reach an ideal perfection may lead one from the best practical solution of a problem. As will be shown later on, the dead space at the end of the air piston stroke is undesirable, and it was largely to eliminate this defect and to keep the air cool that liquid pistons had such a vogue on the Continent. The water forced back and forward in the cylinder and up the pipe at each end, carrying the necessary valves, filled the dead space. But unfortunately for this ideal, there are a number of inconveniences attendant on the system. The cooling of the air is insufficient because it is only on the surface of the water. The speed of the piston is extremely limited and cannot exceed forty to fifty feet per minute, on account of the mass of water to be moved; consequently the number of compressors required for a given work is large. The water agitated by the motion is frothed and causes an excessive moisture in the air. Various devices more or less successful have been used to lessen these defects, but, in spite of all, the fact remains that in other countries these compressors have not found favor.

Dry Compressors.—This type of compressor has a cylinder and piston similar to those of a steam engine, with suitable outlet and inlet valves at the cylinder ends. The temperature of the air is kept within reasonable limits by the constant flow of cold water through the water jacket of the cylinder from the bottom upward. It is, however, doubtful if this process of cooling, even under the most favorable conditions, does more than keep the cylinder from becoming excessively heated and so imparting heat to the incoming air. A more thorough method of cooling is obtained by injecting a fine spray of cold water into the cylinder near the outlet valves. To this the objection has been strongly urged that the presence of water with its non-lubricating properties causes an undue wear and tear in the cylinder and loss in power.

3.—CAUSES OF LOW EFFICIENCY IN AIR COMPRESSORS.

These causes briefly stated are the heating of the air during compression, mechanical defects in the inlet and outlet valves, and leakage past the piston. It has been already shown that air when subjected to compression is heated, and that as the volume is thereby increased, much power is uselessly expended in dealing with the heated air. The most efficient compressor therefore, in this regard, must be the one presenting the best cooling arrangement for the air as it is being compressed. That form of compressor in which the piston is represented by the falling water supplying the power, such as Sommeiller's, permits of a very thorough cooling, as the water piston is renewed each stroke, and the cylinder is kept perfectly cool.

But in the second form of wet compressor, such as Dubois' of Mariehaye Colliery, Belgium, in which the water, only slightly renewed per stroke, becomes considerably heated, the cooling is not more perfectly effected than in the dry compressor. As the pressure to which the air is raised becomes greater, the losses from this source become serious, and as the efficiency of the motors increases with the pressure, and the size of the conduits can be correspondingly small it is desirable, particularly in large installations, to use high-pressure air. The most satisfactory results in this direction have been obtained by stage compression—that is, by pressing the air to a certain pressure in one cylinder and further compressing it in a second, and, if desired, in a third, or even a fourth. By this system the air is cooled between each stage, and the losses from this source are minimized. For low pressures it is doubtful if any practical economy would result from stage compression, but it is now fully demonstrated that for pressure above 60 lbs. the advantages of stage compression are very marked. To diminish losses caused by resistance to the passage of the air through the inlet and outlet valves many devices have been resorted to. In the ordinary valves held to their work by springs the valves rattle or chatter if the springs are weak. On the other hand, if the springs are made very strong, a resistance to the passage of the air is set up, resulting in a loss of power which in some cases becomes serious. To obviate this defect the valves are occasionally devised to open mechanically. In a short paper such as this it is impossible to enter into the details of the various valves used. It is not uncommon to hear much stress laid on the losses caused by the unavoidable dead space occupied by compressed air at the end of each stroke, and it may be pointed out at once that the loss is not in power, but solely in the volumetric capacity of the compressor. To diminish this inconvenience, the air piston is usually run as close to the cylinder ends as practicable, and care is requisite to avoid sailing too close to the wind in this direction and damaging the mechanism. The best plan is to arrange trick passages or grooves on the inside of the cylinder, for a short distance back from each end, to allow the air in the dead space to pass the piston to the end in which compression is about to begin. The inside pressure against the suction valves is thereby relieved, and compression on the other side of the piston begins at once. To prevent knocking, through the sudden relief caused thereby at the end of the stroke, a certain amount of cushioning in the steam cylinder is required. The low efficiency, due to leakage of the pistons, can only be effectually reduced by carefully attending to their condition. Naturally the higher the compression the greater the leakage; but stage compression greatly lessens this evil.

4.—AIR CONDUITS.

Two considerations are of importance in determining the pipes to be employed; these are the size of the pipes and the character of the joints. The frictional loss in the passage of the air through the pipes increases very rapidly as the diameter decreases, as shown by the following example. If a volume af air at 60 lbs. pressure, equivalent to 18,000 cubic feet per hour at atmospheric pressure, be passed through 1,000 ft. of pipes the loss of pressure of air for 2½ in., 3 in., 3½ in. and 4 in. pipes would be 5¾ lbs., 2 lbs. and 1½ lbs. respectively. Leakage at the joints, through the expansion and contraction of the pipes, is a fruitful and at times a serious source of loss of power. A receiver of suitable size should always be placed alongside the compressor, and where a considerable length of pipes is used, it is an advantage to have a receiver as near the motor as practicable.

5.—METHOD OF USING COMPRESSED AIR.

When air is compressed it is heated, and when it expands it is cooled. The latter fact gives rise to the inconvenience so frequently met with in air motors, of ice being formed in the ports, through the freezing of the moisture in the air. Where the air is admitted to the motor practically during the whole stroke there is little danger of ice being formed, but there is a terrific waste of power, for it is as important for economy to use air expansively as it is to use steam expansively. While a little moisture in air used expansively results in the formation of ice in the ports, it may be pointed out that aqueous vapor has a specific heat nearly double that of air, and consequently cools less rapidly under expansion than dry air, and the tendency of an excess of moisture is to reduce the cooling. The specific heat of water being still greater, a spray of water may be effectively used in the motor cylinder to prevent cooling to the freezing point. The writer was familiar many years ago with an instance where, in the case of large haulage engines placed underground, the inconvenience caused by freezing was so serious that compressed air was abandoned, and steam, though inconvenient, was substituted. Reheating the air is, however, the most effective method of allowing air to be used expansively, without the formation of ice in the ports, and this can best be done by passing the air near the motor, through a coil of pipes heated by a small furnace; and a further elaboration, permitting the highest degree of expansion, is effected by introducing a small quantity of water into the heater, where it is converted into steam. A move in the latter direction was made years ago by the use of a jet of steam in the air pipe, near the motor. In practice it is found that reheating the air not only prevents freezing, but results in a very great economy in the use of compressed air at a small cost both for plant and fuel.

6.—DANGERS ATTENDING ITS USE.

These are so slight as to be scarcely worth considering but their existence is worthy of passing notice. A few cases are known where an explosion, more or less marked, has occurred in the receiver placed near the compressor. In these instances combustion has been set up apparently in the carbonaceous matter, deposited from the lubricants used in the compressor. The readiness with which a piece of old oily waste takes fire at comparatively low temperature is well known, and it is possible that a similar action may take place in the deposited carbon, if subjected accidentally to abnormal heating by a failure in the cooling apparatus of the compressor.

The use of compressed air seems at first sight an extremely simple one, and consequently the principles surrounding its use are seldom inquired into. The results obtained from it are, in consequence, at times appallingly poor, and its reputation as a means of transmitting power suffer proportionately. In the worst forms of machines 10 per cent. only of the power expended may be obtained, and the writer has a distinct recollection of the care with which his Belgian professor demonstrated the impossibility of obtaining more than 33 per cent. of useful effect from compressed air. But to quote from Professor Goodman: "In the best cases, without reheating about 55 per cent. and with reheating 75 per cent. of the total power is given out by the motor." The extensive use made of compressed air in metalliferous mines, particularly for rock drills, should naturally induce an intelligent interest in its use in Australia, and a discrimination in the proper and improper methods of employing it.

COMPRESSED AIR TRANSMISSION PLANT AT THE NORTH STAR MINE.

The paper read by Mr. Arthur De Wint Foote, C. E., at the meeting of the American Society of Civil Engineers, recently convened in San Francisco, elicited much interest and no small amount of discussion.

The paper referred to makes a very elaborate and exhaustive report upon the operation of the compressed air transmission plant of the North Star Mine in Grass Valley, Cal., a brief description of which, compiled from this report, we here present.

The power station consists of a Pelton Wheel, 18 ft. 6 in. in diameter, attached direct to the shaft of a Rix Duplex Air Compressor, compound tandem type. The initial cylinders are 18 inches, and the second cylinders 10 inches diameter, with a 24-inch stroke.

The wheel is built up of angle iron plates riveted together to break joints, and is held concentric with the shaft, with 12 pairs of radial spokes of 1¼-inch rod iron secured by nuts to the cast iron hub. The driving force being applied to the rim, is transferred to the hub by four pairs of 2-inch iron rods so arranged as to form a truss.

The wheel weighs 10,500 pounds, and runs at 110 revolutions under 750 feet head, developing upwards of 300 H. P. It is made of this large diameter for the purpose of giving proper speed to the compressor under the high head in this case available. The water is applied to the wheel through a variable nozzle controlled by a hydraulic regulator which maintains a uniform speed on the wheel with a variation from full load down to 25 per cent. of same, making its operation absolutely automatic, as well as economizing the water supply, no more being used at any time than required for the work.

The construction of the wheel, as will be seen, forms an ingenious mechanical combination, altogether novel and without precedent, affording an ample factor of safety with a very high peripheral velocity. The water supply is brought to the wheel through 2½ miles of 22-inch riveted pipe, affording sufficient capacity to develop 800 H. P. A 6-inch lap-weld pipe conveys the air at a pressure of 90 pounds from the power house to the company's shaft, 800 feet distant and 125 feet elevation. This is at present running a 100 H. P. pneumatic hoisting engine and a 75 H. P. compound pump, beside other pumps, drills, forges, etc.

The report above referred to shows that repeated tests on this wheel, made by the most approved methods and checked up very closely, give the remarkable efficiency of 93 per cent. at full load; also an average efficiency of something over 90 per cent. for ¼, ½, ¾ and full loads. The suggestion has been made that the extraordinary efficiency here shown is accounted for in part by the unusual dimensions of the wheel. This, however, was shown to be incorrect, as equally high efficiencies have been obtained on Pelton wheels of much less than one-third this diameter.

The efficiency of compression and transmission from water wheel to motors, not including cost of reheating, is given as 79 per cent., making a most favorable showing for the plant as a whole, under the conditions installed. The application here described is also of interest as showing the remarkable flexibility of the Pelton system and facility of adaptation to all varying conditions.

ECONOMY OF COMPRESSED AIR POWER TRANSMISSION.

BY WM. O. WEBBER.

The recent great interest in compressed air for power transmisision suggests that a few figures on the possibilities of this method of storing and converting energy might be pertinent. It has recently been found possible to compress air directly by falling water without the necessity of using water wheels, with the consequent loss in friction of from 15 to 20 per cent., and also the loss in transforming the rotary motion by means of displacement compressors, with the further consequent loss due to the raising of the temperature of the air compressed and the condensation of the water vapor from the air. In fact, this last feature has been one of the chief obstacles to the use of compressed air.

It is a well-known fact that water vapor contained in air may be condensed by falling temperature and also by an increase in pressure. The atmosphere holds varying amounts of water vapor, depending almost wholly upon its temperature. At 75 deg. Fahr. 1 cu. ft. of air can hold 10 grains of water vapor. Under average conditions it would hold 7 or 8 grains. Suppose 1 cu. ft. of air to be compressed from atmospheric pressure—that is, 14.7 lbs. per square inch—to 100 lbs. gauge pressure. The volume of the air and vapor will be reduced to about one-eighth. The effect of the rise of temperature upon the vapor contained in the air when no cooling device is used, exceeds the effect of the increase in pressure, and no condensation of the contained vapor takes place during compression; but the air must, during transmission, lose heat and return to about the same temperature as before compression, consequently from three-fourths to seven-eights of the vapor will be condensed, because 1 cu. ft. at the higher temperature holds eight times as much vapor as 1 cu. ft. of the atmosphere. Hence the water will constantly collect in the air mains, and in cold weather will freeze and obstruct the passage of the air.

In short transmission the air may not suffer a great fall in temperature, and may carry the larger portion of the vapor with it; but the sudden and considerable fall in temperature caused by the air expanding against the resistance of the pistons is sufficient, not only to condense, but also to freeze the moisture in the cylinder and exhaust ports of the engine. This is a continual source of trouble in many instances where air has been compressed by cylinder compressors. An attempt is made, with only partial success, to overcome this difficulty by having a large receiver where the air may cool down and deposit its moisture, after compression and before it is used. The above device, however, will not in most cases free the air of moisture sufficiently to insure absence of freezing in engines when there is no reheating.

In compressing air directly by falling water, the bubble of air while passing down the compressor pipe is kept cool by a body of water surrounding it. The time of compression is comparatively slight, being from fifteen to twenty seconds. The bubble of air is compressed at a constant terminal pressure, being that due to the depth of the water, and the excess of water caused by the gradual increase of pressure is deposited on the walls of the bubble. A test made of air hydraulically compressed to 52 lbs. gauge pressure showed that it only contained one-fifth of the vapor usually contained in atmospheric air during fine weather, or 14 per cent. of saturation.

If air at 35 deg. Fahr. is heated under a constant pressure, its volume will be increased one four hundred and ninety-fifth for each degree over 35 degs. Air at a temperature of 70 deg. Fahr., if heated to a temperature of 340 deg. Fahr., will increase in volume 50.94 per cent. If, when so heated, this air is thoroughly saturated with moisture by being passed through a tank of water at about the same temperature, each 50 cu. ft. of free air is found to absorb about 1 lb.

of water in the form of steam; hence the steam adds more than 50 per cent. to the volume of air. Thus the expansion by saturating with steam and reheating increases the volume more than 100 per cent., or, in other words, doubles the amount of work that any original quantity of compressed air will do. The cost of the reheating is trifling.

The coal required to reheat and secure double efficiency is less than one-eighth of the coal required to do the same amount of compressing with a cylinder compressor, or, reconverting this back into efficiency of work done, it is safe to say that the cost of reheating would represent 8 per cent. of efficiency.

To note what this all means, taking the figures obtained from the tests made in Paris in compressed air transmission, the results to be obtained by compressed air are as follows:

PERCENTAGES OF EFFICIENCY.

Air compressor	75
Pipe line	98
Reheating and saturating which equals the addition of	100
Then the use of air motors which will give	81
Would give a total of	119

But as the cost of this reheating equals a net result of 87 per cent., the actual net economy is about 103 per cent. This economy of course is limited to conditions in which the cost of pipe for distributing the compressed air and the reheating apparatus would not eat up all the profit. It would then be preferable to compress the air at 75 per cent. efficiency, reheating and moistening it, which would add 100 per cent., convert this air directly into rotary motion by the air motors giving 78 per cent., then through step-up transformers at 96 per cent., wire line at 95 per cent. and step-down transformers at 96 per cent., giving 96 per cent. of the original power, or, taking the loss of heating into effect, 90 per cent. of the original power instead of a net efficiency of about 60 per cent. to 65 per cent. if the same amount of water was used in water wheels and converted directly into electricity and transmitted.

I have gone into some pretty careful figures recently regarding the cost of development under these different conditions, assuming the quantity of water to equal 5,000 h. p., to be transmitted four miles, and have figured out that by water wheels and electrical transmission we would obtain a net of 3,000 h. p. at the end of the line, at a cost of installation of $46 per h. p. The cost of compressing the air, reheating it, and then converting it into electricity and sending it over a wire comes to about forty-three dollars ($43) per h. p., and I believe it would be possible, with a water power situated not more than two miles from the edge of a town, to transmit the compressed air to that point by pipe, and then convert and distribute the power and light by electricity for forty dollars ($40) per h. p.

In a recent publication I saw a reference made to the utilization of the water at the Iron Gates of the Danube, and it struck me at once that it would be a feasible proposition to use this power in the form of compressed air for the purpose of propelling the boats up the river and through the canals which are to be constructed, thus making the power of the falling water passing down through that famous gorge, do the work of propelling the boats up against its own current. This, of course, seems somewhat impractical, but upon careful thought, I do not see that it is any more so than water pumping itself up hill, as it certainly does in a hydraulic ram.

THE FLOW OF COMPRESSED AIR IN PIPES.

BY WILLIAM COX.

The volume of a fluid discharged from a pipe is very easily ascertained by means of the formula

$$D = \frac{v \times 0.7854\, d^2 \times 12 \times 60}{1728}$$

$$= v \times d^2 \times 0.32725 \quad \ldots\ldots (1),$$

Where D = discharge in cu. ft. per minute,

v = mean velocity of flow in feet per second,

d = internal diameter of the pipe in inches.

With this formula it, however, generally happens that the velocity v is an unknown quantity, as the application of indicating instruments is either difficult or altogether impossible in existing pipe installations and out of the question in the case of new ones when being designed. Recourse must, therefore, be had to some other means to ascertain the actual or required rate of flow of the fluid, and to this end scientists and engineers have long directed their best energies.

It is well known that if it were possible to eliminate all kinds of friction and other opposing forces, the velocity of flow of water in a pipe would be the same as the velocity acquired by a heavy body which has fallen from a height equal to the head of water; that is—

$$v = \sqrt{2\,g\,h} = 8.02\sqrt{h} \quad \ldots\ldots (2)$$

Where v = final velocity in feet per second of the falling body,

h = head of water, or space fallen through in feet,

g = the force of gravity = 32.16.

In the case of fluids flowing through pipes there are, however, various opposing forces and other influencing circumstances, all of which (as they produce friction and affect the velocity or rate of flow, and materially diminish the practical value of the head), must be taken into consideration. These may be briefly classified as follows:

1. Friction induced by the fluid entering the pipe. This is comparatively small so that it need not be taken into account when considering pipes of a length equal to 400 or 500 times their diameter, or what are termed *long pipes.*

2. The friction caused by the flow of the fluid in the pipe. This is proportional to the length of the pipe, when the velocity is the same throughout, also to the circumferential area of the inner surface of the pipe. It also varies in intensity in proportion to the internal condition of the pipe, and is likewise affected by the

density of the fluid. This latter cause of velocity is not apparent in the case of water, as being an almost incompressible body, its density is not appreciably affected by changes of pressure, but in the case of elastic fluids such as air, steam or gas, this factor is an important one and must always be taken into account.

A general formula applicable to the flow of water in clean pipes, deduced from these considerations, is

$$v = c \sqrt{\frac{d \times h}{l}} \qquad (3)$$

Where v = velocity of flow in feet per second,
d = diameter of the pipe in inches,
h = total head of water in feet,
l = length of pipe in feet,
c = a variable co-efficient to be determined by experiment.

It was found by D'Arcy and some others that the co-efficient c was not a constant one to be used for all sizes of pipes. D'Arcy devoted much time to the working out of a series of co-efficients applicable to various diameters of pipes, and this formula so modified has been generally accepted as giving approximately correct results.

It has also been affirmed by some engineers of authority that this formula is also applicable to the flow of an elastic fluid in a pipe by the insertion of a term denoting the density of the fluid. Replacing in Eq. (3) the term head of water by its equivalent pressure in pounds per square inch, we then obtain

$$v = c \sqrt{\frac{d \times (p_1 - p_2)}{w_1 \times l}} \qquad (4)$$

Where p_1 = initial gauge pressure in lbs. per square inch,
p_2 = final gauge pressure in lbs. per square inch.
$p_1 - p_2$ = difference of pressures, or pressure required to overcome friction and produce the velocity of flow, equivalent to the loss of head,
w_1 = density or weight in lbs. per cu. ft. of the fluid at the initial pressure p_1.

The other letters represent the same terms as in previous equations.

If the value of v as given in Eq. (4) is inserted in Eq. (1), we obtain

$$D = c \sqrt{\frac{d^5 \times (p_1 - p_2)}{w_1 \times l}} \qquad (5)$$

which gives the discharge of compressed air in cu. ft. per minute from a pipe of any diameter and length, with any initial and final pressures, the volume of discharge thus obtained being under the terminal pressure p_2. To apply this formula to practical use, D'Arcy's co-efficients for different actual diameters of pipes, modified to suit the conditions of elastic fluids, are here given.

TABLE 27.

Diam.	Co-effic't.	Diam.	Co-effic't.
1 inch	45.3	4 inches	57.8
2 inches	52.7	5 "	58.4
3 "	56.1	6 "	59.5

Diam.	Co-effic't.	Diam.	Co-effic't.
7 inches	60.1	12 inches	62.1
8 "	60.7	14 "	62.3
9 "	61.2	16 "	62.6
10 "	61.8		

To further simplify calculation, the following table gives the values of $c\sqrt{d^5}$, and if we call this term **x**, we then obtain the simpler formula

$$D = x\sqrt{\frac{p_1 - p_2}{w_1 \times l}} \qquad (6).$$

The values of $x = c\sqrt{d^5}$ in this table are slightly modified so as to make them conform to a perfect curve.

TABLE 28.

Diam'r	C.	$x = c\sqrt{d^5}$
1 inch	45.3	45.3
2 inches	52.5	297
3 "	56.2	876
4 "	58.0	1856
5 "	59.0	3298
6 "	59.8	5273
7 "	60.3	7817
8 "	60.7	10988
9 "	61.2	14872
10 "	61.6	19480
11 "	61.8	24800
12 "	62.0	30926
13 "	62.2	37898
14 "	62.3	45690
15 "	62.5	54462
16 "	62.6	64102

It must of course be understood in connection with all pipe calculations that the diameters referred to are always the actual ones and not the nominal ones, otherwise considerable divergences may be obtained between the calculated and the real discharges. Thus the actual inside diameter of a 1-inch pipe, "Standard" dimensions, is 1.048 inches, giving a sectional area of nearly 10 per cent. more than the nominal one. The following table gives the nominal and the actual diameters and areas of "Standard" steam, gas and water pipes. It is taken from "Book of Standards," issued by the National Tube Works Co.:

TABLE 29.

Nominal.		Actual.	
Diam.	Area.	Diam'r.	Area.
1 inch	0.7854	1.048	0.8626
2 inches	3.1416	2.067	3.356
3 "	7.0686	3.067	7.388
4 "	12.5664	4.026	12.73
5 "	19.635	5.045	19.99

Nominal. Diam.	Nominal. Area.	Actual. Diam'r.	Actual. Area.
6 inches	28.274	6.065	28.888
7 "	38.485	7.023	38.738
8 "	50.266	7.982	50.04
9 "	63.617	8.937	62.73
10 "	78.540	10.019	78.839
11 "	95.033	11.25	99.402
12 "	113.10	12.00	113.098
13 "	132.73	13.25	137.887
14 "	153.94	14.25	159.485
15 "	176.71	15.25	182.655

These real diameters should always be taken into account when using the formulas, and if not actually inserted in them, the differences existing should be allowed for.

To further facilitate the investigation of this formula, Table 30 is added, giving the values of w_1 and $\sqrt{w_1}$ in equations (5) and (6) for pressures up to 100 pounds, calculated from the formula

$$w_1 = 0.0761 \ (0.068 \ p_1 + 1) \qquad (7)$$

where p_1 = the initial gauge pressure of the air in lbs. per square inch, at the entrance to the pipe.

TABLE 30.

Gauge Pressure.	w_1	$\sqrt{w_1}$
0 pounds	0.0761	0.276
5 "	0.1020	0.319
10 "	0.1278	0.358
15 "	0.1537	0.392
20 "	0,1796	0.424
25 "	0.2055	0.453
30 "	0.2313	0.481
35 "	0.2572	0.507
40 "	0.2831	0.532
45 "	0.3090	0.556
50 "	0.3348	0.578
55 "	0.3607	0.600
60 "	0.3866	0.622
65 "	0.4125	0.642
70 "	0.4383	0.662
75 "	0.4642	0.681
80 "	0.4901	0.700
85 "	0.5160	0.718
90 "	0.5418	0.736
95 "	0.5677	0.753
100 "	0.5936	0.770

When, as is generally the case, it is required to know the equivalent volume of free air corresponding to the volume of compressed air discharged, this latter, or D, must be multiplied by the density of the air at terminal pressure as related to the density of the atmosphere. We have for this purpose the following formula:

$$F = D \times W_2 \quad \text{.........} \quad (8).$$

in which D = volume of compressed air discharged at final pressure,
F = equivalent volume of free air,
W_2 = density of the discharged air in atmosphere, = $(0.068\ p_2) + 1$,
p_2 = final gauge pressure in lbs, per sq. in. of the discharged air.

The following table of values of w_2 will be found of use in solving such problems:

TABLE 31.

P_2	W_2	P_2	W_2
0 pounds	1.00	55 pounds	4.74
5 "	1.34	60 "	5.08
10 "	1.68	65 "	5.42
15 "	2.02	70 "	5.76
20 "	2.36	75 "	6.10
25 "	2.70	80 "	6.44
30 "	3.04	85 "	6.78
35 "	3.38	90 "	7.12
40 "	3.72	95 "	7.46
45 "	4.06	100 "	7.80
50 "	4.40		

In Compressed Air the application of D'Arcy's formula to the flow of compressed air (an elastic fluid) in pipes was shown in detail. In this number a copyrighted table of values of $\sqrt{\frac{p_1 - p_2}{w_1}}$ is given, which both facilitates and simplifies very considerably the use of the formula. Making a separate term of the above we obtain the complete formula in this simpler form

$$D = \frac{c\sqrt{d^5}}{\sqrt{l}} \times \sqrt{\frac{p_1 - p_2}{w_1}} \quad \text{.........} \quad (9)$$

in which

D = volume of compressed air discharged at final pressure in cubic feet per minute.
d = actual diameter of the pipe in inches,
l = length of the pipe in feet,
c = a co-efficient varying with the diameter of the pipe (see Table 28),
p_1 = initial gauge pressure in pounds per square inch,
p_2 = final gauge pressure in pounds per square inch,
w_1 = density or weight in pounds per cubic foot of the air at the initial pressure p_1 when entering the pipe (see Eq. (7) and Table 30).

Values of $c\sqrt{d^5}$ for various sizes of pipe are given in Table 28, and values of $\sqrt{\frac{p_1 - p_2}{w_1}}$ for any final pressure p_2 from 20 to 100 pounds, and for any loss of pressure from 1 to 10 pounds are given in Table 32, as follows:

TABLE 32.

* *Table of Values of* $\sqrt{\frac{p_1 - p_2}{w_1}}$ *in D'Arcy's formula*

$$D = c\sqrt{\frac{d^5 \times (p_1 - p_2)}{w_1 \times l}}$$

, for terminal pressures from 20 to 100 pounds, and for pressure losses from 1 to 10 pounds.

Compiled by William Cox.

Final Pressure. p_2	Losses of Pressure, equals $p_1 - p_2$. 1 lb.	2 lb.	3 lb.	4 lb.	5 lb.	6 lb.	7 lb.	8 lb.	9 lb.	10 lb.	Final Pressure. p_2
20 lbs	2.325	3.241	3.918	4.466	4.930	5.336	5.693	6.014	6.309	6.574	20 lbs
21 .	2.293	3.198	3.868	4.410	4.870	5.272	5.627	5.946	6.237	6.502	21 .
22 .	2.262	3.157	3.819	4.356	4.812	5.211	5.564	5.878	6.168	6.432	22 .
23 .	2.233	3.117	3.772	4.304	4.756	5.152	5.501	5.814	6.102	6.362	23 .
24 .	2.205	3 079	3.727	4.254	4.702	5.093	5.440	5.752	6.036	6.296	24 .
25 .	2.178	3.042	3.684	4.206	4.649	5.036	5.381	5.688	5.973	6.233	25 .
26 .	2.152	3.007	3.642	4.158	4.597	4.981	5.323	5.630	5.913	6.173	26 .
27 .	2.127	2.973	3.601	4.112	4.548	4.928	5.268	5.572	5.856	6.113	27 .
28 .	2.103	2.939	3.561	4.068	4.499	4.877	5.215	5.518	5.799	6.056	28 .
29 .	2.079	2.907	3.523	4.024	4.452	4.828	5.164	5.466	5.745	5.999	29 .
30 .	2.056	2.876	3.485	3.982	4.408	4.781	5.114	5.414	5 691	5.942	30 .
31 .	2.034	2.844	3.448	3.942	4.365	4.735	5.066	5.364	5.637	5.888	31 .
32 .	2.012	2.815	3.414	3.904	4.323	4.690	5.019	5.312	5.586	5.834	32 .
33 .	1.991	2.786	3.381	3.866	4.282	4:646	4.971	5.264	5.535	5.782	33 .
34 .	1.971	2.759	3.348	3.830	4.242	4.603	4.926	5.216	5487	5.733	34 .
35 .	1.952	2.733	3.317	3.794	4.202	4.561	4.881	5.170	5.439	5.686	35 .
36 .	1.933	2.707	3.286	3.758	4.164	4.520	4.839	5.126	5.394	5.639	36 .
37 .	1.915	2.682	3.255	3.724	4.126	4.480	4.797	5.084	5.349	5.594	37 .
38 .	1.897	2.656	3.225	3.690	4.090	4.441	4.757	5.042	5.307	5.550	38 .
39 .	1.879	2.632	3.196	3.658	4.054	4.404	4.717	5.002	5.265	5.509	39 .
40 .	1.862	2.608	3.168	3.626	4.020	4.368	4.680	4.962	5.226	5.468	40 .
41 .	1.845	2.585	3.140	3.596	3.987	4.333	4.643	4.924	5.187	5.426	41 .
42 .	1.829	2.563	3.114	3.566	3.956	4.299	4.609	4.858	5.148	5.385	42 .

Final Pressure. p_2	Losses of Pressure, equals $p_1 - p_2$. 1 lbs.	2 lbs.	3 lbs.	4 lbs.	5 lbs.	6 lbs.	7 lbs.	8 lbs.	9 lbs.	10 lbs.	Final Pressure. p_2
43 lbs	1.813	2.542	3.088	3.538	3.924	4.267	4.575	4.852	5.109	5.344	43 lbs
44 "	1.798	2.521	3.064	3.510	3.895	4.235	4.540	4.814	5.070	5.306	44 "
45 "	1.783	2.501	3.040	3.484	3.866	4.203	4.506	4.778	5.034	5.268	45 "
46 "	1.769	2.481	3.017	3.458	3.837	4.171	4.471	4.744	4.998	5.230	46 "
47 "	7.755	2.462	2.995	3.432	3.808	4.139	4.439	4.710	4.962	5.192	47 "
48 "	1.742	2.444	2.972	3.406	3.779	4.109	4.408	4.676	4.926	5.155	48 "
49 "	1.729	2.426	2.950	3.380	3.752	4.080	4.376	4.642	4.890	5.120	49 "
50 "	1.716	2.407	2.927	3.356	3.725	4.051	4.344	4.608	4.857	5.085	50 "
51 "	1.703	2.389	2.906	3.332	3.698	4.022	4.313	4.578	4.824	5.050	51 "
52 "	1.690	2.372	2.886	3.308	3.671	3.993	4.283	4.546	4.791	5.015	52 "
53 "	1.678	2.355	2.865	3.284	3.645	3.965	4.254	4.516	4.758	4.983	53 "
54 "	1.666	2.338	2.844	3.260	3.620	3.938	4.225	4.484	4.728	4.952	54 "
55 "	1.654	2.321	2.823	3.238	3.596	3.911	4.196	4.456	4.698	4.920	55 "
56 "	1.642	2.304	2.804	3.216	3.571	3.885	4.169	4.428	4.668	4.889	56 "
57 "	1.630	2.289	2.785	3.194	3.547	3.860	4.143	4.400	4.638	4.860	57 "
58 "	1.619	2.273	2.766	3.172	3.524	3.835	4.117	4.372	4.611	4.832	58 "
59 "	1.608	2.258	2.747	3.152	3.502	3.811	4.091	4.346	4.584	4.803	59 "
60 "	1.597	2.242	2.730	3.132	3.479	3.787	4.066	4.320	4.557	4.775	60 "
61 "	1.586	2.228	2.712	3.112	3.458	3.764	4.042	4.294	4.530	4.747	61 "
62 "	1.576	2.214	2.695	3.092	3.437	3.742	4.019	4.268	4.503	4.718	62 "
63 "	1.566	2.200	2.678	3.074	3.417	3.720	3.995	4.244	4.476	4.693	63 "
64 "	1.556	2.186	2.662	3.056	3.397	3.698	3.971	4.220	4.452	4.668	64 "
65 "	1.546	2.173	2.647	3.038	3.376	3.676	3.948	4.196	4.428	4.642	65 "
66 "	1.537	2.160	2.631	3.020	3.356	3.654	3.926	4.172	4.404	4.617	66 "
67 "	1.528	2.147	2.615	3.002	3.337	3.634	3.905	4.150	4.380	4.592	67 "
68 "	1.519	2.134	2.600	2.984	3.318	3.615	3.884	4.128	4.356	4.566	68 "
69 "	1.510	2.122	2.584	2.968	3.300	3.596	3.863	4.104	4.332	4.541	69 "
70 "	1.501	2.100	2.570	2.952	3.283	3.576	3.842	4.082	4.308	4.516	70 "
71 "	1.492	2.098	2.556	2.936	3.265	3.556	3.820	4.060	4.284	4.494	71 "
72 "	1.484	2.086	2.543	2.920	3.247	3.537	3.799	4.038	4.263	4.471	72 "
73 "	1.476	2.075	2.529	2.904	3.229	3.517	3.778	4.018	4.242	4.449	73 "
74 "	1.468	2.064	2.515	2.888	3.211	3.498	3.759	3.998	4.221	4.427	74 "
75 "	1.460	2.052	2.501	2.872	3.193	3.480	3.741	3.978	4.200	4.405	75 "
76 "	1.452	2.041	2.487	2.856	3.177	3.463	3.723	3.958	4.179	4.383	76 "
77 "	1.444	2.030	2.473	2.842	3.162	3.446	3.704	3.938	4.158	4.361	77 "
78 "	1.436	2.019	2.461	2.828	3.146	3.429	3.686	3.918	4.137	4.339	78 "
79 "	1.428	2.009	2.449	2.814	3.130	3.412	3.667	3.898	4.116	4.317	79 "
80 "	1.421	1.999	2.437	2.800	3.115	3.395	3.648	3.878	4.095	4.294	80 "
81 "	1.414	1.989	2.425	2.786	3.009	3.377	3.630	3.858	3.074	4.272	81 "

Final Pressure, p_2	Losses of Pressure, equals $p_1 - p_2$. 1 lbs.	2 lbs.	3 lbs.	4 lbs.	5 lbs.	6 lbs.	7 lbs.	8 lbs.	9 lbs.	10 lbs.	Final Pressure, p_2
82 lbs	1.407	1.979	2.413	2.772	3.084	3.360	3.611	3.840	4.053	4.253	82 lbs
83 "	1.400	1.969	2.401	2.758	3.068	3.343	3.593	3.820	4.035	4.234	83 "
84 "	1.393	1.959	2.388	2.744	3.052	3.326	3.575	3.802	4.017	4.215	84 "
85 "	1.386	1.949	2.376	2.730	3.037	3.310	3.559	3.786	3.999	4.196	85 "
86 "	1.379	1.939	2.364	2.716	3.022	3.294	3.543	3.768	3.981	4.177	86 "
87 "	1.372	1.929	2.352	2.702	3.008	3.279	3.527	3.752	3.963	4.158	87 "
88 "	1.365	1.920	2.340	2.690	2.994	3.265	3.511	3.734	3.945	4.139	88 "
89 "	1.358	1.910	2.330	2.678	2.981	3.250	3.495	3.718	3.927	4.120	89 "
90 "	1.351	1.901	2.319	2.666	2.967	3.235	3.479	3.700	3.909	4.101	90 "
91 "	1.345	1.893	2.309	2.654	2.954	3.221	3.463	3.684	3.891	4.082	91 "
92 "	1.339	1.884	2.298	2.642	2.940	3.206	3.447	3.666	3.873	4.064	92 "
93 "	1.333	1.876	2.288	2.630	2.927	3.191	3.432	3.650	3.855	4.048	93 "
94 "	1.327	1.867	2.278	2.618	2.914	3.177	3.416	3.634	3.840	4.032	94 "
95 "	1.321	1.859	2.267	2.606	2.900	3.162	3.401	3.618	3.825	4.016	95 "
96 "	1.315	1.850	2.257	2.594	2.887	3.148	3.387	3.604	3.810	4.000	96 "
97 "	1.309	1.842	2.246	2.582	2.873	3.135	3.373	3.590	3.795	3.984	97 "
98 "	1.303	1.833	2.236	2.570	2.862	3.123	3.360	3.576	3.780	3.969	98 "
99 "	1.297	1.825	2.226	2.560	2.851	3.110	3.347	3.562	3.765	3.953	99 "
100 "	1.291	1.817	2.217	2.550	2.840	3.098	3.334	3.548	3.750	3.937	100 "

Intermediate Values can be obtained by Interpolation.

A few practical examples are now given to show the application of the formula, and also the use of Table 32. The simplicity by which solutions are obtained of what would otherwise be very tedious calculations, will be seen to be most striking.

Example 1. How many cubic feet of compressed air will be discharged from an 8-inch pipe, 10,000 feet long, the initial pressure being 80 pounds, and the loss of pressure not to exceed 4 pounds? Also what will be the volume of equivalent free air?

Here $p_2 = 76$ lbs.

$$c\sqrt{d^5} = 10988 \text{ (Table 28)}$$

$$\sqrt{\frac{p_1 - p_2}{w_1}} = 2.856 \text{ (Table 32.)}$$

$$\text{and } \sqrt{l} = \sqrt{10000} = 100.$$

Therefore by Eq. (9) we have

$$D \; \frac{10988}{100} = 2.856$$

= 314 cubic feet compressed air per minute at 76 lbs. final pressure.

Now by Eq. (8) and Table 31 we have

$F = D \times 6.168 = 314 \times 6.168$

= 1936.7 cubic feet equivalent free air.

Example 2. It is required to transmit through a pipe 7056 feet long, the equivalent of 800 cubic feet of free air, the initial pressure being 60 lbs., and the loss of pressure not to exceed 5 lbs. What must be the diameter of the pipe?

Here $p_2 = 55$ lbs.,

$$\sqrt{\frac{p_1 - p_2}{w_1}} = 3.596 \text{ (Table 32)}$$

$$\text{and } \sqrt{l} = \sqrt{7056} = 84.$$

Now by transposing Eq. (8) and by Table 31,

$$D = \frac{F}{w_2} = \frac{800}{4.74}$$

= 169 cubic feet compressed air discharged at 55 pounds final pressure.

Then by transposing Eq. (9) we have

$$c\sqrt{d^5} = D \times \sqrt{l} \div \sqrt{\frac{p_1 - p_2}{w_1}} \quad \text{(10).}$$

$$= \frac{169 \times 84}{3.596} = 3947$$

We now see from Table 28 that this value 3947 corresponds to a pipe about 5½ inches diameter. A 6-inch pipe should therefore be selected.

Example 3. It is desired to lay a 9-inch pipe, 10,000 feet long, which shall discharge 400 cubic feet of air per minute compressed to 60 lbs. final gauge pressure. What will be the loss of pressure? Also what must be the initial pressure?

Here $D = 400$,

$d = 9$,

$c\sqrt{d^5} = 14872$ (Table 28.)

$p_2 = 60$,

$\sqrt{l} = \sqrt{10000} = 100$

whence it is required to find $p_1 - p_2$ and also p_1.

This problem is the most tedious one which presents itself in connection with the flow of compressed air in pipes, seeing that, as has been shown in connection with Eq. (4) p_1 and w_1, which are unknown quantities, are inter-dependent, each one having a different value as the value of the other one varies. By the usual method we cannot proceed directly but must adopt an indirect or tentative method of solution. With Table 32, however, the problem is exceedingly simple. Thus, transposing Eq. (9) we have

$$\sqrt{\frac{p_1-p_2}{w_1}}=\frac{D\times\sqrt{1}}{c\sqrt{d^5}} \quad \text{(11).}$$

$$=\frac{400\times 100}{14872}$$

$$=2.690.$$

Now looking at the table along final pressure $p_2 = 60$ lbs., we see that

$$\sqrt{\frac{p_1-p_2}{w_1}}$$

is equal to 2.242 for a loss of 2 lbs.,
and 2.730 " " " " 3 "

so that for 2.690 the proportionate loss $p_1 - p_2$ will be 2.9 lbs., thus making the required initial pressure p_1 to be $60 + 2.9 = 62.9$ lbs., or say 63 lbs.

If it should now be desired to find the equivalent volume of free air necessary to supply the required volume of compressed air, so as to ascertain what should be the capacity of the compressor, we have from Table 31

Free Air required at Compressor $= 400 \times 5.08$
$= 2032$ cubic feet of free air to be compressed to 63 lbs. initial gauge pressure. Dividing this by 5.284 (the relative value of w_1 for $p_1 = 63$ lbs., according to Eq. (8) gives 384.5 cubic feet per minute as the volume of compressed air required to enter the pipe at 63 lbs. initial gauge pressure, and which, owing to the loss of pressure caused by the friction in the pipe, expands to 400 cubic feet per minute at 60 lbs. final or exit pressure.

Of course it must be understood that in these calculations no allowances are made for losses other than those caused by friction in the pipe. Should the existence of leakage or any other losses be known, such as between the compressor and the receiver, or the receiver and the entrance to the pipe, bends, etc., they must be ascertained and allowed for separately, by the introduction into the compressor of a proportionately greater volume of free air.

A few more examples will be given in the next article, as also some deductions which a closer study of the formula brings to our notice.

Equation (7).

$$w_1 = 0.0761\ (0.068\ p_1 + 1.)$$

where w_1 = density or weight in lbs. per cu. foot of the fluid at the initial pressure p_1.

EQUATION (8).

$$F = D \times w_2$$

in which D = volume of compressed air discharged at final pressure, p_2.
F = equivalent volume of free air,
w_2 = density of the discharged air in atmospheres, = $(0.068\ p_2) + 1$,
p_2 = final gauge pressure in lbs. per sq. in. of the discharged air.

TABLE 28.

Diam'r.	$c\sqrt{d^5}$
1 inch	45.3
2 inches	297
3 "	876
4 "	1856
5 "	3298
6 "	5273
7 "	7817
8 "	10988
9 "	14872
10 "	19480
11 "	24800
12 "	30926
13 "	37898
14 "	45690
15 "	54462
16 "	64102

TABLE 30.

Gauge Pressure.	w_1	$\sqrt{w_1}$
0 pounds	0.0761	0.276
5 "	0.1020	0.319
10 "	0.1278	0.358
15 "	0.1537	0.392
20 "	0.1796	0.424
25 "	0.2055	0.453
30 "	0.2313	0.481
35 "	0.2572	0.507
40 "	0.2831	0.532
45 "	0.3090	0.556
50 "	0.3348	0.578
55 "	0.3607	0.600
60 "	0.3866	0.622
65 "	0.4125	0.642
70 "	0.4383	0.662
75 "	0.4642	0.681
80 "	0.4901	0.700
85 "	0.5160	0.718

Gauge Pressure.	w_1	$\sqrt{w_1}$
90 pounds	0.5418	0.736
95 "	0.5677	0.753
100 "	0.5936	0.770

TABLE 31.

P_2	W_2	P_2	W_2
0 pounds	1.00	55 pounds	4.74
5 "	1.34	60 "	5.08
10 "	1.68	65 "	5.42
15 "	2.02	70 "	5.76
20 "	2.36	75 "	6.10
25 "	2.70	80 "	6.44
30 "	3.04	85 "	6.78
35 "	3.38	90 "	7.12
40 "	3.72	95 "	7.46
45 "	4.06	100 "	7.80
50 "	4.40		

EXAMPLE 4.—It is required to discharge from a 6-inch pipe, 6400 feet long, the equivalent of 1166 cu. ft. of free air at a terminal pressure of 60 pounds. What must be the initial pressure?

Here $F = 1166$, $d = 6$, $c\sqrt{d^5} = 5273$, $l = 6400$, $p_2 = 60$, $w_2 = 5.8$.

Then, by Eq. (8) transposed

$$D = \frac{F}{w_2} = \frac{1166}{5.08} = 229.5 \text{ cu. ft. at 60 lbs.}$$

By Eq. (11)

$$\sqrt{\frac{p_1 - p_2}{w_1}} = \frac{229.5 \times 80}{5273}$$
$$= 3.482.$$

Now running the eye along the line in Table 32 of 60 lbs. terminal pressure, we find under 5 lbs. loss the value of

$$\sqrt{\frac{p_1 - p_2}{w_1}} = 3.479$$

This is therefore the resulting friction pressure, whence the initial pressure must be 60 + 5 = 65 lbs.

EXAMPLE 5.—Take the same case as Example 4, but limit the loss of pressure to 2 lbs. How much air will be discharged at 60 lbs. final pressure?

From Table 32 under 2 lbs. loss, and opposite 60 lbs. final pressure, we find

$$\sqrt{\frac{p_1 - p_2}{w_1}} = 2.242$$

Inserting this in Eq. (5) we obtain

$$D = \frac{5273}{80} \times 2.242$$
$$= 147.76 \text{ cubic feet air at 60 lbs. final pressure.}$$

Supposing now that this quantity does not suffice, what diameter of pipe will be required to discharge the 229.5 cu. ft. air at 60 lbs. with a loss of 2 lbs. only, making the initial pressure = 62 lbs.?

By Eq. (10)

$$c\sqrt{d^5} = \frac{229.5 \times 80}{2.242}$$
$$= 8185.$$

From Table 28 the diameter of the pipe would have to be about 7¼ inches.

EXAMPLE 6.—It is desired to discharge from a 4-inch pipe 150 cu. ft. air at a final or exit pressure of 60 lbs. How long can the pipe be so that the loss of pressure shall not exceed 5 lbs.?

Here D = 150, d = 4, $c\sqrt{d^5} = 1856$, $p_1 = 65$, $p_2 = 60$.

Transposing Eq. (9) and by Table 32, we have

$$1 = \left(\frac{c\sqrt{d^5}}{D} \times \sqrt{\frac{p_1 - p_2}{w_1}}\right)^2 \quad \ldots\ldots(12)$$

$$= \left(\frac{1856}{150} \times 3.479\right)^2$$

= 1853 feet long.

EXAMPLE 7.—Supposing that in Example 6, the initial pressure remains at 65 lbs., and that the pipe is 3706 feet (or twice as long); what will be the final pressure, the volume of discharge being still 150 cu. ft. of compressed air?

Here D = 150, d = 4, $c\sqrt{d^5} = 1856$, $p^1 = 65$, $l = 3706$; $\sqrt{l} = 60.877$.

Required to find p_2.

By Eq. (11).

$$\sqrt{\frac{p_1 - p_2}{w_1}} = \frac{150 \times 60.877}{1856}$$
$$= 4.92.$$

Now by Table 32 we see that 4.92 is the value of $\sqrt{\frac{p_1 - p_2}{w_1}}$ for a final pressure of 55 lbs. with 10 lbs. loss, making the initial pressure 65 lbs. as required.

It will be noticed that in Example 7 the length of the pipe and the loss of pressure are each *twice* as much as in Example 6, the discharge in each case being 150 cu. ft. of compressed air. BUT:—*and this is the great point to be noted*—we have in the former case 150 cu. ft. of air discharged at 60 lbs. final pressure, the equivalent volume of free air being 762 cu. ft., whereas in the latter case we have 150 cu. ft. of air discharged at 55 lbs. final pressure, whose equivalent volume of free air is only 711 cu. ft., or 51 cu. ft. less, being equal to a diminished discharge of 6.7 per cent. Hence, *when the initial pressure and the volume of compressed air discharged from a pipe remain constant, the loss of pressure will be proportionate to the length of the pipe.*

For further exemplification of this most important truth, which has been so often misstated, see Table 36 following, and also deductions therefrom.

A formula is like a theorem in logic. If no important truths can be deduced from it, it is of doubtful value. It may therefore in the present case be useful to see what this formula teaches regarding the flow of compressed air in pipes. It will also certainly be interesting to know from those who have had practical experience in the matter, if these deductions have had their fulfilment in the case of existing installations.

It seems to the writer that the best method of examining the formula with this object in view will be by means of short tables, designed to show the changes wrought in certain of its factors by slightly varying conditions of the other factors, and then deducing from each table the truths thus exposed to view.

In Tables 33, 34 and 35 following, it is assumed that we are dealing with a 6-inch pipe, 10,000 feet long, thus giving the value of

$$\frac{c\sqrt{d^5}}{\sqrt{l}} = \frac{5273}{100} = 52.73$$

TABLE 33.

Take $p_1 = 60$ lbs. gauge, constant, and $p_1 - p_2$ as increasingly variable.

p_1	$p_1 - p_2$	$\sqrt{\frac{p_1 - p_2}{w_1}}$	p_2	Discharge Comp. Air.	w_2	Equivalent Free Air.
lbs.	lbs.		lbs.			
60	1	1.608	59	84.8	5.012	425.0
60	2	2.273	58	119.8	4.944	592.3
60	3	2.785	57	146.8	4.876	715.8
60	4	3.216	56	169.6	4.808	815.4
60	5	3.596	55	189.6	4.740	898.7

It will be noted here that the initial pressure remains constant at 60 lbs., so that the density of the entering air will be likewise constant. The discharge of compressed air will be seen to increase with each increase of loss of pressure, but in a decreasing ratio, that is, *as the square root of the loss of pressure.* Thus, with a loss of 4 lbs. the discharge is only twice as great as with a loss of one pound. It will also be seen that the discharge of equivalent free air increases with the increasing loss of pressure, but in a still greater decreasing ratio than that of the compressed air discharge, seeing that the ordinary values of w_2 are used (See Eq. 8) and not their square roots.

It is also evident that although the initial pressure is maintained at 60 lbs., and the loss of pressure increases from one to five pounds, *the cost of running the compressor with the higher loss will be greater,* as the increased loss must be counterbalanced by the intake of a greater volume of equivalent free air, in order that the initial pressure may be maintained at 60 lbs. This condition also applies more or less to Tables 34 and 35.

TABLE 34.

Take $p_1 - p_2 = 5$ lbs. gauge, constant, and p_1 and p_2 as uniformly variable.

p_1	$p_1 - p_2$	$\sqrt{\frac{p_1-p_2}{w_1}}$	p_2	Discharge Comp. Air.	w_2	Equivalent Free Air.
lbs.	lbs.		lbs.			
65	5	3.479	60	183.4	5.080	931.7
66	5	3.458	61	182.3	5.148	938.5
67	5	3.437	62	181.2	5.216	945.1
68	5	3.417	63	180.2	5.284	952.2
69	5	3.397	64	179.1	5.352	958.5
70	5	3.376	65	178.0	5.420	964.8

This table shows that although the initial and final pressures correspondingly increase, the loss of pressure remaining constant, the volume of compressed air discharged decreases in a uniformly decreasing ratio, that is, inversely as the square root of the density of the air at its initial pressure. On the other hand the volume of equivalent free air entering and being discharged from the pipe increases continually, but in a decreasing ratio.

TABLE 35.

Take $p_2 = 60$ lbs. gauge, constant, and p_1 and $p_1 - p_2$ as corresponding variable.

p_1	$p_1 - p_2$	$\sqrt{\frac{p_1-p_2}{w_1}}$	p_2	Discharge Comp. Air.	w_2	Equivalent Free Air.
lbs.	lbs.		lbs.			
61	1	1.597	60	84.2	5.08	424.5
62	2	2.242	60	118.2	5.08	600.4
63	3	2.730	60	143.9	5.08	731.0
64	4	3.132	60	165.1	5.08	838.7
65	5	3.479	60	183.4	5.08	931.7

In this table the initial pressure and the loss of pressure increase uniformly, while the final pressure remains constant. It will be seen that the volume of compressed air discharged increases with the increase of the initial pressure and the loss of pressure but in a decreasing ratio, that is, as the square root of the loss of pressure divided by the square root of the initial density. The discharge of equivalent free air increases exactly in the same ratio as the discharge of compressed air, seeing that the value of w_2 is constant throughout, being dependent upon the final pressure p_2, which is also constant.

TABLE 36.

Take a 4-inch pipe 1853 to 3706 feet long, whence $c\sqrt{d^5} = 1856$. Assume $p_1 = 65$ lbs. gauge, constant, and D = 150 cubic feet constant.

p_1	Discharge Comp. Air.	l	$\sqrt{\frac{p_1-p_2}{w_1}}$	p_1-p_2	p_2	w_2	Equivalent Free Air.
lbs.				lbs.	lbs.		
65	150	1853	3.479	5	60	5.080	762
65	150	2224	3.811	6	59	5.012	752
65	150	2594	4.117	7	58	4.944	742
65	150	2965	4.400	8	57	4.876	731
65	150	3335	4.668	9	56	4.808	721
65	150	3706	4.920	10	55	4.740	711

Here the discharge of compressed air is constant throughout, and the loss of pressure is exactly proportionate to the length of the pipe. As the final pressure, and consequently w_2, diminish with the length of the pipe, the volume of equivalent free air discharged must diminish in the same ratio as w_2, as also obviously the equivalent volume of free air entering the pipe. If on the other hand the volume of equivalent free air entering the pipe at a uniform initial pressure were constant, it is clear that the loss of pressure would be greater proportionately than the increase in the length of pipe.

TABLE 37.

p_1	Comp. Air entering the Pipe.	Equivalent Free Air.	l	p_1-p_2	p_2	Discharge Comp. Air.
lbs.	c. ft.	c. ft.	feet.	lbs.	lbs.	c. ft.
65	140	762	1853	5	60	150
65	140	762	2162	6	59	152.1
65	140	762	2460	7	58	154.2
65	140	762	2730	8	57	156.3
65	140	762	2988	9	56	158.5
65	140	762	3226	10	55	160.7

In this table the initial pressure and the volume of compressed and equivalent free air entering the pipe are all constant, but the loss of pressure and the length of pipe increase, although not correspondingly. Thus, for increasing losses of one pound, the length of pipe increase as follows:

	Length of pipe.	Prop'te length.	Difference.
Loss of 5 lbs.	1853 feet	1853 feet	.....
" 6 "	2162 "	2224 "	62 feet.
" 7 "	2460 "	2594 "	134 "
" 8 "	2730 "	2965 "	235 "
" 9 "	2988 "	3335 "	347 "
" 10 "	3226 "	3706 "	480 "

whence it is clear that when referring to the flow of free air (equivalent) in pipes, the loss of pressure *isnotproportionate to the length of the pipe,* the volume of air entering the pipe being constant, as also the initial pressure.

TABLE 38.

Particulars of pipe, pressure, discharge, etc., the same as for Table 34.

Area of pipe = 28.27 square inches, which gives for a 6 inch pipe $v = \frac{D}{11.78}$

p_1	Comp. Air Entering.	Veloc-ity.	p_2	Comp. Air Discharged.	Veloc-ity.	Equivalent Free Air.	Veloc-ity.
lbs.			lbs.				
60	83.66	7.10	59	84.8	7.20	425.0	36.08
60	116.60	9.90	58	119.8	10.17	592.3	50.28
60	140.90	11.96	57	146.8	12.46	715.8	60.76
60	160.50	13.62	56	169.6	14.40	815.4	69.22
60	176.90	15.01	55	189.6	16.09	898.7	76.29

From the above it may be noticed that two different velocities have to be taken into account. Of these, the velocity of equivalent free air is constant throughout the length of the pipe when the initial pressure and the loss of pressure are maintained at the same point. On the other hand the velocity of the compressed air is continually varying, being the lowest at entry, and increasing by degrees as it flows along to the point of discharge. The formula clearly explains the reason of this, seeing that it shows:

1st. As the compressed air flows through the pipe, friction takes place, producing an increasing loss of pressure as the compressed air advances.

2nd. By reason of this loss of pressure, the pressure to which the air is compressed decreases as it flows along.

3rd. Diminished pressure involves diminished density of the compressed air, hence,

4th. The original volume of compressed air entering the pipe becomes continually greater, and as the entry pressure remains constant, this greater volume must pass any given point in the pipe in the same time as the original smaller volume, whence

5th. To accomplish this, the rate of speed or velocity of flow must constantly increase to the end of the pipe.

Other interesting deductions from this formula could have been made, and will suggest themselves. What has been set forth in these articles will, it seems to the writer, show that the formula is applicable to the flow of elastic fluids, such as air and steam, in pipes; that it is logical, and that with the help of Table VI. it enables the solution of any practical problem to be quickly and very easily obtained.

Further experience may of course go to show that D'Arcy's co-efficients require somewhat modifying, but it should be remembered that no two series of experiments can be expected to be undertaken under precisely similar conditions, so that slightly varying results must be looked for, but they will not for this reason affect the reliability of the formula.

A MUNICIPAL POWER PLANT.

The following paper on the "Transmission of Power by Compressed Air" was recently presented by Richard Hirsch, before the Engineers' Society of Western Pennsylvania, Pittsburg, Pa.

In papers presented to this Society at different times, various methods of transmitting power in the city of Pittsburg have been advocated. Up to the present time, however, the only agent which has been utilized for this purpose is electricity, unless we mention our city water supply, which has been used for hydraulic elevators, and in a few instances for motors operating light machinery.

It has been unfortunate for the reputation of compressed air that so little attention has been given to its development as an efficient transmitter of power. In most applications its peculiar advantages, such as safety, non-condensation during transmission, and unobjectionable exhaust, have been features of first consideration. Little attention was given to economical operation, inefficient compressors and wasteful motors being used. Compressed air has many advantages which entitle it to a more general recognition as an efficient means of transmitting and distributing power in cities.

In the use of steam, the loss by condensation in the pipe lines, the necessity for expensive pipe coverings and expansion joints, and the objectionable exhaust, either as steam or hot water, are disadvantages not met with in the use of compressed air. The high cost of hydraulic power, and the limited possible applications of the same, place it in an unfavorable light, when brought into competition with pneumatic transmission. The ease with which electric wires can be strung on poles, over housetops, and through buildings, and the low cost of such work, have been great factors in the rapid increase in the use of electrical machinery—much more so, in fact, than the cost of electric power. But vigorous protest should be made against the disfiguring of house fronts and interiors by the promiscuous array of wires, insulators and transformers. The conversion of our streets into veritable forests of unsightly poles, carrying net-works of highly charged and uncovered wires, should not be tolerated. When electric conductors are laid underground, and interior wiring concealed in the walls and floors of buildings and securely insulated, the cost of such work equals, if not exceeds, the cost of piping required for transmitting power by other agencies.

Compressed air is used at pressures varying from that of a more or less perfect vacuum up to 5,000 lbs. per square inch. There is a power transmission system in Paris where motors are operated by the pressure of the atmosphere and exhaust into mains in the streets, in which a more or less perfect vacuum is maintained by air pumps situated at a central station. Pressures of from 60 lbs. per square inch to 90 lbs. per square inch are used for ordinary power purposes; from 400 lbs. per square inch to 800 lbs. per square inch for pneumatic locomotives; 2,000 lbs. per sq. inch for street cars, and from 1,000 lbs. per sq. inch to 5,000 lbs. per sq. inch for pneumatic dynamite guns and other purposes on war vessels.

The gratifying results obtained in the use of compressed air for operating locomotives and shop machinery, and the high efficiency that could be obtained in a properly designed plant for the general transmission of power, lead the author of this paper to believe that such a plant could be successfully operated in the city of Pittsburg, considered both from an engineering and business point of view. The following is a description of a proposed plant capable of transmitting 1,100 indicated horse-power, developed in the motors where used, with the cost of building and operating the same.

In a fire-proof building situated on the banks of one of our rivers, and as near the business portion of the city as possible, will be installed the necessary boilers and air compressors. Water for feeding boilers and cooling purposes will be pumped from the river, thereby saving water tax. Coal will be received by rail or boat, and handled by machinery. Ashes will also be handled by machinery, and loaded into boats or cars as required. Boilers will be of the water tube type, fitted with mechanical stokers, and capable of developing 2,000 indicated horse-power in the steam cylinders of the compressors. There will be two air compressors, with triple expansion condensing engines of the Corliss type, having steam cylinders 20″, 34″ and 50″ diameter, by 42″ stroke. The air cylinders will be compound, two for low pressure, each 26″ diameter, and one for high pressure, 30″ diameter; all 42″ stroke. The air will be taken at atmospheric pressure through a cooling apparatus and specially adapted Corliss valves into the two low pressure cylinders, and discharged through an inter-cooler into the one high pressure cylinder; the air will there be compressed to 100 lbs. per square inch, and delivered through a cooler into the pipe line. Each compressor will be capable of delivering about 6,000 cu. ft. of free air per minute, compressed to 100 lbs. per square inch gauge pressure. The compressor will be fitted with automatic valves which will reduce their speed when the pressure in the pipe line runs up to a little more than 100 lbs. per square inch and speed them up again when the pressure falls. It might, however, be advisable to subdivide the compressing machinery into three or more units to facilitate repairing and lessen the liability of seriously crippling the plant in case of accident or breakdown. There is no necessity for large storage tanks or reservoirs, as the air mains provide sufficient capacity to permit the air to be pumped directly into them. Moisture will be withdrawn from the mains by suitably arranged traps and delivered into the sewers. These traps need be but comparatively small affairs, connected to the air mains by pipes of small diameter and enclosed in the street boxes with the shut-off valves. For the reason that watery or other vapors can not be compressed to a density greater than that due to their temperature, the watery vapor in the air would condense soon after compression, and most of it would be drawn off near the power house.

The main pipe line from the power house will consist of 12″ wrought iron pipe coupled together by bolted flanges. It will extend to where the next work of street distributing mains begins, and will there be reduced in size as the carrying capacity and frictional resistance of each branch of pipe permits. The street distributing mains will consist of 6″ and 8″ wrought iron pipe coupled together by threaded sockets. No expansion joints will be required, as the mains being laid below the frost line, and the air being cooled after compression in the power house, there will be no more variation in the temperature of the air mains than there is in water or gas mains, neither of which are provided with expansion joints. The expansion joints on the underground steam lines of the New York Steam Heating Co. are quite elaborate and very expensive affairs, and are placed at close intervals. In connection with pneumatic locomotives, wrought iron mains with screwed sockets and without expansion joints are used, carrying pressures of from 400 lbs. per square inch to 700 lbs. per square inch. The satisfactory results obtained in the use of these lines furnish a precedent for advocating street distributing mains of practically the same description, although various other kinds of joints have been used in Paris and elsewhere for this purpose.

In the Paris system, steel mains 20 inches in diameter are used, having perfectly plain ends and connected together by the so-called Normandy joint, which is described in Unwin's Development and Transmission of Power.

In estimating the cost of construction it has been assumed that the power station could be located within 8,000 feet of Eleventh or Grant streets, and allowance has been made for that length of 12 inch main. Provision has been made for laying pipes on all the principal streets of Pittsburg situated between the Monongahela and Allegheny rivers and on and below Grant and Eleventh streets. Stop valves inclosed in suitable street boxes will be provided at frequent intervals in the mains, by means of which the air supply can be shut off from any section of pipe undergoing repairs, or while service connections are being made. At such times the air can be made to pass the portion of the main thus cut out, through the pipes in the adjoining streets, causing inconvenience to but few users of the power. Much annoyance could be averted by making service connections at night, or if made by day, appliances could be used which permit making connections to pipe lines without shutting off the supply. The estimate does not cover the cost of service connections, as they will be paid for by the consumers of the power, but does cover the cost of meters. Liberal margin has been allowed in the various items, and the following figures would undoubtedly cover the actual cost of construction. Allowance has been made for dividing the boilers and compressors into such units as to provide reserve power, available in case of accident or while repairs are being made.

COST OF CONSTRUCTION.

Real Estate	$30,000.00
Buildings	20,000.00
Compressors erected on foundations with Condensers and attachments	55,000.00
Boilers	21,000.00
Stack and Britchen	3,750.00
Mechanical Stokers	4,375.00
Circulation and Feed Pumps, Injectors, etc	4,000.00
Cooling Apparatus	2,000.00
Water Tanks	1,500.00

Coal and Ash Conveyors	4,000.00
Pipe Lines and Distributing Mains	70,000.00
Meters	5,000.00
Engineering and Expenses of Organization	25,000.00
Miscellaneous Items, including electric light plant and crane for power station	10,000.00
Contingencies	19,375.00
Total cost of plant	$275,000.00

COST OF OPERATION PER ANNUM.

Interest on investment of $275,000 at 6 per cent	$16,500.00
Deterioration 4 per cent. of $275,000	11,000.00
Taxes	3,500.00
Fuel	5,000.00
Salaries and Wages	16,500.00
Repairs and Supplies	5,000.00
Office Expenses	2,500.00
Total annual cost of operation	$60,000.00

It is estimated that the plant will deliver 1,100 H. P. for 3,000 hours, and 200 H. P. for 5,760 hours per annum, or a total of 4,452,000 H. P. hours per annum. The annual cost of operation, divided by 4,452,000, gives 1.35 cents per H. P. per hour, or $40.50 per H. P. per annum of 3,000 hours.

The cost of power to consumers would be graded somewhat, according to the amount used. This would not be a hardship to small users of power, because to such consumers the power would be cheap at any reasonable price. To users of power in moderate quantities, the cost per H. P. per annum, including attendance, cost of heating and interest on cost of motors and heaters would not be more than $50.

For deterioration there will be laid aside each year out of the earnings, 4 per cent. of the total investment, and this money placed at 3 per cent. compound interest will, in about 19 years, equal the capital invested, or sufficient to rebuild the plant entire. It will be noted that the cost of operation would increase but slightly with considerable increase in the capacity of the plant, and also that the cost of construction would not increase in direct proportion to such enlargement of the plant. If the building of a larger plant would be justified, the cost of power to consumers would be less than given.

To compare the cost at which power could be furnished by compressed air with the cost as furnished by other means, I extract the following from our proceedings, being estimates given in papers read by members of this society at different times:

Amount per H. P. per annum paid to the City of Pittsburg for operating hydraulic elevators (about)	$700.00
Cost of power per H. P. per annum in a large store having its own plant, 15 hour service	128.44
Cost in same plant corrected for 10 hour service	89.92

Estimated cost per H. P. per annum at which power could be furnished by a proposed hydraulic power company, with no allowance made in operating expenses, for taxes, or deterioration of plant............	77.70
Cost in same plant corrected for above omissions....................	100.20
Estimated cost per H. P. per annum at which power could be furnished by an electric power company capable of delivering 20,000 H. P......	50.00

The low cost at which power can be furnished by compressed air can only be approached by electricity working under the most favorable conditions. The rates paid for power to the electric companies in Pittsburg at the present time are excessive.

EFFICIENCY OF THE SYSTEM.

It can be shown theoretically, and has been proven in practice, that one cubic foot of free air, when compressed to about 90 pounds per sq. in., is capable of performing from 2,600 ft. lbs. to 3,000 ft. lbs. of work, when used cold. From actual tests it has been found that by heating the air this can be increased 40 per cent. Prof. Unwin states that the experiments of Reidler and Gutermuth show that heat thus applied is used five or six times more efficiently than if used in a good steam engine. The compressors, as above specified, have a combined capacity of 12,000 cu. ft. of free air per minute. Deducting 15 per cent. of this for loss by leakage and friction in pipes, we have 10,200 cu. ft. of free air available for useful work; or expressing it in foot pounds per minute, we have 10,200+2,600+1.4=37,128,000; or in horse power, we have 37,128,000÷33,000=1,125 H. P., which is 56 per cent. of the indicated H. P. in the steam cylinders of the compressors; assuming the efficiency of the motors where the power is used to be 90 per cent., we have an efficiency of over 50 per cent. in the entire system, from the indicated horse power in the steam cylinders to the brake horse power in the motors. This compares favorably with electric transmission, which, under average conditions, is about 58 per cent. Much higher efficiency than 50 per cent. have been given by writers on this subject, but the figures here given are based on the actual capacity of the compressors after due allowance has been made for internal friction and other unavoidable losses, such as leaking stuffing boxes, valves and pistons, and more especially the loss occasioned by the heating of the air during compression. Moreover, the builders of the compressors will guarantee the capacity as here given, and the estimates from two different firms showed practically the same indicated horse power in the steam cylinders of the compressors to produce the amount of air required.

One thing to be noted in the use of compressed air is the fact that the loss caused by the fall in pressure resulting from friction in the mains, is partly made up by the increase in volume. In a hydraulic system a fall in pressure, caused by friction in the mains, results in a loss in direct proportion to the fall in pressure; the volume remains the same. The efficiency of the system can be considerably increased by using compound motors, in which the air would be heated before entering the motor and reheated between the first and second expansions; the motor being somewhat similar to a compound steam engine with a receiver between the high and low pressure cylinders, the receiver in this case being a reheater. When the air is heated to increase the economy, the most efficient results are obtained when moisture is added, which, by giving out its latent heat in the motor, materially increases the efficiency. For this reason heaters are generally of the hot water style, wherein the air passes through hot water under pressure, and part of it goes to the cylinder of the motor in the form of steam.

USES OF COMPRESSED AIR.

Compressed air can be applied to such a wonderful variety of uses that a ready market for the entire power of the plant is almost assured, and the project would undoubtedly be as profitable in a financial way as it has been elsewhere, notably in Paris. The power would be used for the operation of elevators, electric light plants, ventilating apparatus, pneumatic tools, and motors. It would also be used for parcel and cash conveyors, cleaning and cooling purposes; for the latter purpose either air direct from the mains, or exhaust air from the motors, would be used. For comparatively small addition to the cost of building the plant, a system of regulating clocks could be installed, and but very little power would be required to operate it. Some of the new office buildings in the East have been piped for delivering compressed air to the tenants, the same as they would be provided with hot and cold water. Compressed air only lacks the capacity to supply heat, to enable it to operate the entire mechanical plant of the modern office building. Heat would be supplied by the boilers in the building, but not being called upon for lighting or power purposes, would be operated only during the cold months of the year. In the ideal plant, however, heat would be furnished by the hot water system, and power and light by air—the cost of operation being thereby reduced to the minimum.

The project could be still further enlarged upon. While laying the distributing main, ducts could be laid for a parcel delivery system. Stations would be located in different portions of the city, where parcels would be received and sent through the chutes to the station nearest to the destination of the package, and the delivery be completed by messenger.

It would be practicable to have street connections in close proximity to the fire plugs, and operate fire engines by air, which could then be built much cheaper, lighter in weight, less complicated in detail, and would be ready for immediate service at all times. In fact, the practicable applications of the power are almost unlimited, and the project would certainly meet with success and pay handsomely on the capital invested. It would increase our business and manufacturing facilities and assist greatly in making Pittsburg a cleaner city and more desirable as a place of residence. These are factors in the making of a truly Greater Pittsburg. The building of a metropolis must consist of a more healthy and substantial growth than accrues from the annexation of surrounding villages and pasture fields.

PNEUMATIC LOCOMOTIVES.

Compressed air has been used with great success in the operation of locomotives. When used for operating street cars or for hauling trains through tunnels or city streets, all the advantages of an independent motor are obtained, with none of the objectionable features of steam locomotives or electric cars. It is especially applicable in locations where sparking electric wires, fire and fumes of combustion must be avoided.

The following is a very brief description of the plant of the Susquehanna Coal Co. at Glen Lyon, Pa., where there are two motors in operation. The air is supplied by a compressor of the three stage type, having steam cylinders 20 inches + 24 inches, and air cylinders 12½ inches, 9½ inches and 5 inches + 24 inches, with water jackets and intercoolers, compressing the air to 600 lbs. per square inch. The air passes through a line of 5 in. special strong pipe 200 ft. to the head of the shaft, down the shaft 800 ft. and then along the gangway about 3,400 ft., a total length of 4,300 ft. This pipe line has a capacity of 580 cu. ft., and acts as a reservoir for the compressor. It is coupled together with threaded sockets which are counter-bored for a lead filling which is caulked. At intervals of about 200 feet, and at all valves and charging stations, flange couplings are used with lead gaskets, and the line is perfectly tight, being tested to 1,500 lbs. per sq. in. Charging stations are placed where required, and consist of a universal metallic coupling, which is attached to the check valve of the locomotive air tanks when a fresh supply of air is required. It requires about 1½ minutes to complete the operation of charging the locomotive, and reduces the pressure in the main pipe line from 600 lbs. per sq. in. to about 570 lbs. per sq. in. A charge of air weighs about 380 lbs. The locomoitve is of the 4 wheel type, having cylinders 7 in. diameter by 14 in. stroke; drivers, 24 in. diameter; weight, 18,500 lbs.; length over all, 17 ft. 6 in.; width, 5 ft. 2 in.; height, 5 ft. 0 in. The air for propelling the locomotive is stored in two cylindrical steel tanks with a combined capacity of 130 cu. ft., and are supported by cast iron saddles resting on the frames of the locomotive. The air flows from the main tanks through a specially designed reducing valve into an auxiliary reservoir, and from thence through a throttle valve to the cylinders. The pressure in the auxiliary reservoir can be regulated anywhere from 30 lbs. up to 140 lbs. or 150 lbs. per sq. in., as required. The air in the auxiliary reservoir is maintained at a constant pressure, while in the main storage tanks it may vary from 570 lbs. per sq. in. down to the pressure at which the reducing valve is adjusted; when this pressure is reached in the main storage tanks, the air passes through to the cylinders without further reduction in pressure.

The locomotive hauls 16 empty cars a distance of 3,700 ft. into the gangway and returns to the shaft with 16 loaded cars with one charge of air, starting with a pressure of 575 lbs. per sq. in., and ending with about 100 lbs. per sq. in. The train of empty cars, including the locomotive, weighs 60,000 lbs., and the train of loaded cars, including the locomotive, weighs 166,000 lbs. The grades favor the loads. The locomotive runs from 25 to 50 miles per day, depending upon the length of the trip and time consumed in making up the trains at the terminals. This locomotive was lowered down the mine shaft a vertical distance of 800 feet without dismantling in any manner. Sometimes the circumstances are such that it becomes necessary to take the locomotive apart, lower it piece by piece, and reassemble them in the mine.

Where it is practicable to use a heater on a locomotive, the efficiency is increased about 40 per cent. These heaters take the place of the auxiliary reservoir, and consist of a tank containing hot water under pressure at a temperature of about 300 deg. F., through which the air passes before going to the cylinders.

The heaters are charged with steam while the storage tanks are being charged with air.

Compressed air is also used for the propulsion of street cars, the air being stored in nests of Mannesman tubes. There are four of these tubes under each car seat, and are 9 inches in diameter by 15 ft. long, and are charged to a pressure of about 2,000 lbs. per square inch. The air is reduced in pressure by a reducing valve to about 140 lbs. per sq. in., and then passes through a hot water heater and throttle valve to the cylinders. The cars are of the four-wheel type, have the ordinary street car body, and are provided with the usual locomotive machinery, reversing gear, balanced valves and air brakes. They can be controlled from either platform by means of a fixture similar in appearance to a trolley car controller, and very compact. They are independent motors, have all the advantages claimed for storage battery cars, and compare favorably with the overhead trolley system in cost of operation.

PRACTICAL APPLICATION OF HIGH RANGE COMPRESSED AIR POWER TRANSMISSION.*

BY FRANK RICHARDS.

I use the term high range to designate the system here referred to for convenience as it seems to fit the case, whether it has been used before or not. The system is called also the two-pipe system, on account of the return pipe, made necessary to convey the air which has done its work back to the compressor, the exhaust pressure being constantly maintained very much higher than that of the atmosphere. The system has been put into practical operation in California and elsewhere in the far western portion of the United States, being known there as the Cummings system of compressed air transmission, the apparatus there employed being under United States patents granted to Charles Cummings, of Oakland, Cal.

Under this system the compressor in full operation receives the air returning from rock-drills, pumps, hoists, motors, or whatever it is employed to drive, at a pressure considerably above that of the atmosphere, compresses it to a still higher pressure, and then sends it out again to do more work. The operation as thus stated is as simple as that of the ordinary air compressor, which takes in free air, or air at atmospheric pressure, and sends it out again at a pressure of, say, six or seven atmospheres. In compressing from one to seven atmospheres or in compressing from seven to 14 atmospheres there is no essential difference in the operation involved.

If the compressor is to work at anything like the pressures last indicated there must, however, be some provision for first charging the system to the high initial pressure required, and also some means of governing or controlling the speed and output of the compressor according to the rate at which the air may be used at the other end of the system. The arrangements by which these results

* *American Machinist.*

are accomplished are worth looking into. Fig. 91 is a side elevation, Fig. 92 is an end elevation and Fig. 93 a plan of a duplex steam driven compressor. Of the general design of the compressor it is not necessary to speak. It will scarcely be maintained that it represents the best possible arrangement. The steam cylinders are at the left, Fig. 91, and the pull and thrust of the steam piston is transmitted directly through the yoke in which the connecting rod plays to the air cylinder. The body of the air cylinder is water jacketed and the valve chambers on each end have each a vertical partition, the inlet valves and pipes being on one side and the discharge valves and pipes on the other. The air being at normal atmospheric pressure throughout the apparatus we may start the compressor, referring principally to Fig 92, and as we proceed the functions of the pipes and connections will reveal themselves. Both compressing cylinders are alike in construction and operation. At the beginning of operations we may assume the globe valve *M*

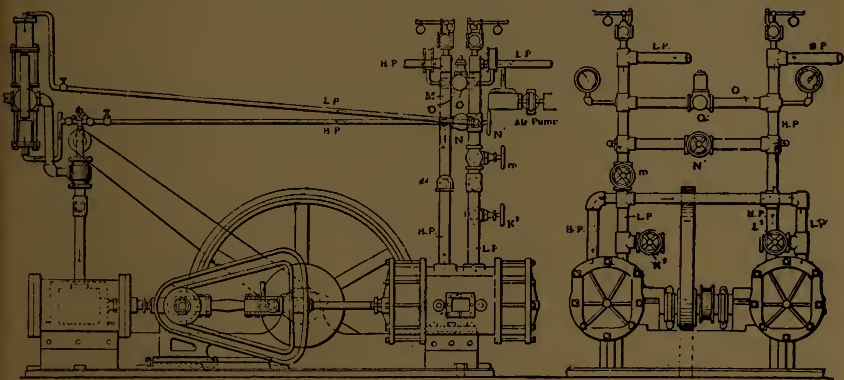


FIG. 91. FIG. 92.

SIDE AND END ELEVATION OF HIGH RANGE AIR COMPRESSOR.

to be closed and all other valves to be open. The free air will enter through valves K^2 and L^2 and the compression will continue until the pressure rises to, say, 100 pounds, if we assume that pressure for the lower limit of our working range. When the pressure of 100 pounds is reached valve N^1 is closed by hand, separating the high pressure and the low pressure pipes, and the operation of compression then continues until the high pressure pipes are filled to the high pressure required, say 200 pounds, while the low pressure system remains charged at 100 pounds. The air inlet valves K^2 and L^2 are closed by hand and valve *M* is opened, allowing the 100 pound air to be delivered to both cylinders. The entire apparatus is now a closed system, with both the high and the low pressures as required, and ready for continuous action. A small pump *U*, shown in Fig. 91 up at the right, replaces what air may be lost by leakage. This pump may be placed wherever most convenient and may be operated by connection with the main compressor or otherwise, and here requires no further mention.

Attention is now called to cross pipe *O*. This pipe directly connects the high pressure and the low pressure pipes. Somewhere between the two pipes is located the valve *O′*. This is an adjustable pressure valve which may be set to open at any pre-determined difference of pressure, in this case 100 pounds, and it will not open until that difference exists, when any excess of air in the high pressure pipes is automatically discharged into the low pressure, thus constantly maintaining the required difference. The compressor may be charged or put in condition for continuous operation by the use of this automatic valve instead of by the hand operated valve N^1.

The operation of governing an air compressor, either under the system we are considering or any other, is distinctly different from that of governing a stationary steam engine. The amount of power required may fluctuate in either case, but in that of the steam engine it is still usually necessary to maintain a constant rate of speed. In the case of the air compressor it is necessary to vary the speed according to the work. With our closed circuit of piping, and assuming the compressor at one end and the motor at the other, each running at such relative speeds that the difference of 100 pounds is just maintained between the two pipes, if it should then happen that the motor should be run slower, or in any way should

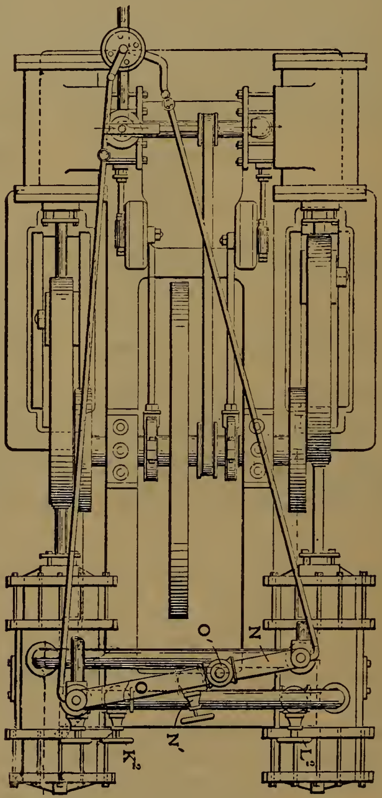


FIG. 93.—PLAN OF HIGH RANGE AIR COMPRESSOR.

require less air to pass through it, then if the compressor still maintained its speed, the pressure in the high pressure pipes would become too great, while in the low pressure pipes the pressure would fall too low. The reverse operation would result as badly in the opposite direction. A centrifugal governor is provided, as shown, to control the speed of the compressor when the demand upon it is up to its full capacity and prevent it from running away. This governor may also come into play in the earlier stages of the initial charging of the system, but is of no use at other times, the differential pressure governor being the usually operative controlling device. This governor, which it is scarcely necessary to describe in detail, is indicated in outline up at the left of Fig. 91. It consists of two

FIG. 94.—HIGH RANGE AIR COMPRESSOR IN SERVICE.

cylinders of different areas, say one twice that of the other, the two pistons being connected and moving together and by their movement operating a sliding steam valve and controlling the flow of steam to the steam cylinder. These governor cylinders standing vertical, and that of the larger area being above, with the smaller cylinder below, a small pipe connecting with the low pressure system is led into the top of the large cylinder, while a pipe from the high pressure system enters the bottom of the lower and smaller cylinder. The differences in pressures being compensated by the differences of piston areas, the piston and the steam valve are stationary when the difference in pressures is normal, while if the high pressure increases the steam valves closes and slows the compressor, and if the high pressure falls while the low pressure increases then the steam valves moves in the other direction, more steam is admitted and the compressor runs faster. The compressor being duplex, with cranks at right angles, it will, of course, start itself from any position. The compressor for this system, it will thus be seen, requires little complication above that of the ordinary compressor.

It is proper to say a little as to the actual practical workings of the system. As is well known, the use of compressed air is perhaps better developed and better appreciated upon the Pacific coast than anywhere else in the United States. Some admirable installations of the ordinary type are in operation there and some notable instances of large plants and long distance transmission. It is not strange that the two pipe system also should find its first employment in the same section. It can scarcely be claimed for it that its possibilities have yet been all developed or that its applications have been other than crude and cheap. The half-tone herewith speaks for itself as to the conditions under which it has been tried (or it would have so spoken if the engraver had not taken such pains to make the scene respectable). The compressor here shown is of different construction from that which I have described, but it embodies the same two pipe principle. As to the results attained, there are not as yet any thorough, careful and precise tests to be referred to, and we must be content with statements such as the following:

"Two tests were made of three hours each, one with the machinery run under the two pipe system, and the other with the same machinery run under the ordinary system. In each one the same machinery was used throughout. This consisted of a duplex air compressor with air cylinder 5 x 9 inches, and steam cylinder 6½ x 9 inches, and a water pump with air cylinder 4½ x 7 inches, and water cylinder 5 x 7 inches." These dimensions are not altogether clear and satisfactory, but I give them as I have received them. The statement of comparative performance which follows is more intelligible.

"The machinery was run for three hours under the two-pipe, high range system. One of the pipes was then disconnected and the same machinery was run under the ordinary system. That is to say, instead of exhausting into the return pipe, the exhausting was done into the atmosphere. The pump was employed in elevating water 80 feet. The first three hours under the two-pipe system the pump made 23,877 revolutions while the compressor made 16,735 revolutions. In the second three hours, running under the ordinary system, the compressor made 22,735 revolutions and the pump 5,380." There was, of course, no such advantage as the figures given seem to indicate, but that there was a great advantage seems clear. "In the two-pipe system we ran the pump about as fast as is consistent with good practice, while the compressor had to be run comparatively slow. In the ordinary system we could hardly run the compressor fast enough to give sufficient air to the pump to turn over. We had great difficulty in running three hours under the ordinary system, owing to the fact that the temperature in the exhaust ports of the pump came below the freezing point of water. We had to use petroleum to make the pump work. Of course, under the two-pipe system there is no chance of any ice being formed from the expansion of the air."

Hans C. Behr, in a bulletin of the California Mining Bureau, says: "The incidental advantage in the two-pipe system is that the pump engines, particularly if direct acting, can be operated under water until they wear out." He says also: "To properly estimate the value of this system it must be compared to the reheating system as to mechanical efficiency, first cost and simplicity of construction and manipulation." I have seen also enough other letters to probably convince any ordinary person that this system gives quite astonishing results.

A SPECIAL STOP-COCK FOR COMPRESSED AIR PIPES.

We illustrate herewith a special stop-cock that has met with great favor of late among the mines, for use in compressed air pipe lines. This cock is being manufactured and sold by the American Engineering Works of Chicago. It is made with iron body and brass plug ¾ in., 1 in., 1¾ in. and 1½ in. in sizes for

Fig. 95.—Special Stop-cock for Compressed Air Pipes.

use in air pipes. A 1-in. all brass cock is made for use in connection with air drills. The great advantage of this stop-cock over the ordinary form is that there is no possibility of workmen leaving it loose, with consequent and often considerable loss of air. In many forms of stop-cocks the plug is larger at the top than at the bottom, and is held in place by a nut at the bottom. Workmen will frequently loosen this nut, knock the plug up slightly in order to loosen it, to enable them to open or close the cock, and then leave it in a leaky condition. The stop-cock, as illustrated herewith, has the plug reversed, being larger at the bottom than at the top, and is held tightly in place by a spring. If it does not turn easily a slight knock on top of the square head will loosen the plug and enable it to be turned, but it will not be left in a leaky condition, for the spring will keep the plug well seated.—*Engineering and Mining Journal.*

MANNESMANN STEEL BOTTLE TEST.

The public in general appears to have the idea that using compressed air stored at high pressures on street cars is dangerous. To prove how unfounded is this view, one of the bottles or tubes that is used in street cars was tested to destruction by hydraulic pressure on the 10th inst. by Chas. G. Eckstein & Co. of New York, at the works of Messrs. Watson & Stillman, of this city. Prof. Jacobus, of Stevens Institute, assisted by Mr. Curtis W. Shields of our staff, conducted the test, the results of which are given below. Among those interested present were Mr. Alfred Mannesmann, president of the Mannesmann Cycle Tube Co., Adams, Mass.; Frank Richards, of the "American Machinist;" John J. McCutcheon, Ass't Engr. American Air Power Co.; Rudolph Allert, Sup't Consumers' Brewing Co. and Dr. Wm. Mettenheimer.

The bottle was marked off into 7 equal parts and the measurements taken without pressure beginning at the bottom, were as follows: 2′ 5 1-16″, 2′ 5 1-16″, 2′ 5 1-16″, 2′ 5⅛″, 2′ 5 3-32″, 2′ 5 3-32″, 2′ 5 1-32″, outside diam. respectively. Length 5′ 6⅛″ over all between perpendiculars.

Under a pressure of 2,500 lbs. the greatest expansion was a little over 1-16″; at 4,000 lbs. 3-32″. When this pressure was removed the bottle returned to its original measurements. At 4,350 lbs. the greatest expansion was ⅛″; at 4,550 lbs. 7-32″, and the greatest permanent set noticed was 6-32″.

At 5,000 lbs. the length of the bottle had increased nearly ⅛″, and the expansion was 7-16″; at 5,280 lbs. ⅝″, at 5,730 lbs. 13-16″. The bottle burst under a pressure of 5,760 lbs. The fracture was very clean, and not even a minute particle of the metal flew. The fracture extended from the neck a distance of 2′ ¾″ down the side of the bottle.

STORAGE OF AIR IN BOTTLES.

A good deal has been written of late in the newspapers about the danger to which passengers may be subjected when riding in cars propelled by compressed air because of the storage of air under high pressure. Until recently experiments in the line of pneumatic traction were confined to air at moderate pressures, mainly because a safe bottle or receiver was not available. In designing a vessel in which to store the air, it is necessary to consider the question of weight, and as the air pressure was increased, the weight of common receivers became so great as to be prohibitive. Pipes of wrought iron or steel were all right when made of extra thickness, but the weak point was in the cap or joint at the end of the pipe. During recent years there has been imported a weldless, cold-drawn steel tube which has served the purpose very well. This tube is known as the Mannesman bottle and is made in Germany. Its safety lies in the fact that it is drawn from a solid billet of steel, hollow throughout with rounded ends forming a vessel of uniform strength and with no joints or welds of any kind. One end of the Mannesman bottle is tapped for a pipe of small diameter which connects with the interior and which serves as an outlet or inlet for the compressed air. This form of bottle is a safe vessel for air at pressures of 3,000 pounds per square inch, and it is so designed that a number of these bottles, each about the length of the space under the seats of a street car, are laid side by side and connected at one end, thus storing enough air, as in the case of the Hardie car, to run approximately 25 miles.

Some experiments have been made with cold-drawn bottles made of nickel steel, which it is claimed will store air at 5,000 lbs. pressure per square inch, and as the tensile strength of nickel steel is high, bottles made of this material should be able to safely carry large volumes of compressed air in a small space and without the handicap of serious weight. Now the safety of a steel bottle carrying compressed air is a simple question of engineering. A boiler carrying steam at a pressure of say 100 lbs. per square inch is less safe than an air bottle, because the boiler is composed of joints and rivets, and carries superheated water, all of which being subject to variations of temperature, thus increasing the uncertainty as to the factor of safety. The reserve force contained in superheated water in a boiler is enormous. Should a break occur and the steam be released, this water is converted into steam almost instantly, and acts in a sense like gunpowder or dynamite producing destruction in its path. The air bottle is practically at all times subject to a uniform temperature. It is designed to stand a certain pressure, and if properly tested before use and a factor of safety established beyond its working strains, there remains but little uncertainty or danger in its use. As a matter of fact, these bottles are easily tested before use, and engineers agree that in a vessel of this kind it is not necessary to establish so great a factor of safety as with boilers or other vessels which are subjected to changes of temperature and more or less varying strains. In a boiler, for instance, the feed water may run low and by sudden contact of cold water on hot plates the normal pressure may be momentarily very much increased. No such conditions can exist in the case of the steel bottle.

A better comparison with the air bottle is the strain upon a floor beam or the truss of a bridge. One might claim that a bridge is dangerous because it is subjected to hundreds or thousands of tons strain, yet this bridge when properly designed is intended to carry this strain and its strength of material is proportioned accordingly. It is customary in bridge construction to allow a wide margin or liberal factor of safety, because of vibration and other conditions which cannot be foreseen or estimated and which do not exist in the case of the air bottle. A cast iron column, even with a liberal factor of safety, is less likely to be safe than an air bottle, because blow holes may exist in cast iron beneath the surface, while with soft cold-drawn steel the material is uniform throughout. It should not be claimed, of course, that steel air bottles cannot be broken or that they are absolutely safe against explosions. Nothing in engineering is safe to a point of certainty, but it can safely be claimed that in the steel bottle the elements of uncertainty are small and easily controlled; that the bottles are not subject to deteriorating influences, as they are surrounded by free air on the outside and compressed air on the inside; that when made properly and carefully tested they may safely be used to carry air pressure strains of one-half the figures at which they are tested, and as it is quite possible to provide these vessels with blow-off valves they may be made practically safe.

Even though an air bottle should explode when carrying air at pressures of several thousand pounds to the square inch, it is not likely to be as destructive as is usually supposed. These bottles are arranged in a series in some respects like the water tube boiler, which is considered to be the safest form of boiler made. Water tube boilers do not explode. There have been instances where one or more of the tubes has been disrupted, but the effect is only local, while with common cylindrical boilers, explosions have been frequent and the results serious.

Air when released shrinks rapidly in volume, because of a rapid lowering of temperature. This tends to reduce the force of explosion. The effect would very likely be local and of very short duration, as the air once released is soon discharged.

FREEZING IN COMPRESSED AIR.

Freezing in compressed air pipes and passages is more frequent in winter than in summer, not entirely because of the low temperature in winter, but because of the increased density and saturation of the atmosphere. On a cold day in January which follows warmer weather, the steam discharged from exhaust pipes rises and floats for a considerable distance before it becomes dissipated. It acts in this respect like smoke. This condition is due to an excess of moisture in the atmosphere because of a shrinkage of volume produced by reduced temperature. When the atmosphere is dry it soon takes up and carries in suspension the steam globules. The same reason accounts for the long wake or foam following a ferryboat in crisp, cold weather, the foam being nothing more than aerated water, which is soon scattered, and partly absorbed by the atmosphere, in dry weather. In a compressed air installation the air-discharge pipes are usually exposed, and are like surface condensers, reducing the temperature of the air which passes through them. If this temperature is reduced below the intake temperature, or the normal atmospheric temperature, there will be a coating of frost deposited on the interior walls of the conduit. The same causes which deposit frost on a window-pane, or which condense moisture on an ice-pitcher, are responsible for the clogging up of the interior of a compressed air pipe. It is well to cover the pipes, and it is still better to enlarge them. A cheap trough, carrying sawdust or manure, preferably the latter, is a good preventive. A large pipe will last longer without clogging through frost for reasons that are obvious. When it is practicable it is best to place all air-receivers out of doors in order to effect as much condensation as possible before the air reaches the conduit. This helps to dry the air, and in some cases more efficient drying can be accomplished by passing the air through a comb or radiator of pipes submerged in cold water, and provided with proper means by which the condensed water is drained off. The aim in all cases should be to reduce the temperature of compressed air to as low a point as possible before it is started on its journey.

Freezing in exhaust passages is more difficult to overcome, but if the air is properly dried at the compressor station, the difficulties about the exhaust will be minimized. All exhaust passages should be large and free of access. It is well not to use exhaust pipes except such as are bell-mouthed or funnel-shaped. As far as practicable, use wood or other non-heat-conducting substances around the exhaust. In pumps, a little water admitted from the column to the valve will prevent freezing in the exhaust, because the water gives off its specific heat, and mechanically aids in cutting away the frost.

FREEZING.

LEHIGH & WILKESBARRE COAL CO.

Wilkesbarre, Nov. 18, 1898.

GENTLEMEN:

In reply to your inquiry relative to the use of compressed air for operating pumps, we beg to state that we have no trouble whatever to keep them from freezing, as we insert a small pipe, or jet, in the pump close to the valve and inject hot water or steam, which effectually prevents freezing. In the summer time we use water just as it comes from the reservoir. Trusting that this will be of service to you, we remain, yours very truly,

W. J. RICHARDS,
General Superintendent.

The foregoing letter was addressed to a manufacturer of air compressors and is published here because it is practical. At this season of the year when freezing is common and when so many people are using compressed air to run pumps, it is of interest to know how to prevent freezing in the exhaust. This is a subject which the readers of COMPRESSED AIR will recognize as rather prominent in our thoughts, because we know that compressed air has been "turned down" on many occasions because of the complaint that it gives trouble through freezing. As it is generally admitted that compressed air as a power is supreme in mines and as pumps are largely used in mines, it is natural that the miner should wish to operate his pumps by compressed air. He is doing this in many cases under disadvantages because of freezing. In the piston pump the chief trouble from freezing is usually in the exhaust, which is gradually choked by ice. Of course, the first thing to do is to provide a free exhaust for the pump which uses compressed air; by free exhaust we mean do not connect any pipes to it and have the exhaust as large as is practicable.

In England they advise bell-mouthing the exhaust, that is, inserting in the exhaust a fitting or pipe which is shaped like a bell. Our experience has taught us that it is best to insert nothing in the exhaust, but to have it as free and open as possible and to turn one's attention to preventing the accumulation of ice by either reheating the air before it enters the pump, or by inserting water or steam.

Reheating is obviously the best plan to follow, because it adds to the efficiency of the air by increasing its volume, due to expansion through heat. The objection to reheating in the mine is that the products of combustion are discharged in the mine and interfere with the ventilation. This is true only where the reheating is done on a large scale, but it is seldom necessary to reheat on a large scale, as what is wanted is simply an addition of 25 or 30 degrees of temperature, and if this is done properly it will require but a small quantity of fuel and will produce no more hurtful results than the burning of half a dozen miners' lamps.

If electricity is used in the mine it will serve a useful purpose by putting in resistance coils in contact with the air, thereby heating it electrically. It costs, of course, more to heat electrically than to heat directly by fuel, but compressed air is sensitive to heat; a little heat adds largely to its volume, and when other conditions are considered, it is safe to say that reheating electrically pays.

A candle burning in a compressed air pipe will burn with greater intensity and will give off a larger heat effect than when burning in free air. The theoretically perfect reheater is that which burns a candle or some other substance within the air. A miner's lamp has been placed in a four-inch pipe and has warmed a considerable volume of air. It is difficult, of course, to arrange an apparatus by which this form of reheating is made practical, but that some one will devise such an apparatus, we have no doubt. There is no such thing as burning the air by internal reheating. The effect is simply to change the conditions by adding carbon and producing air and gas both of higher temperature, hence both more efficient when used as power.

External reheating, that is, simply applying heat to the external surfaces of vessels containing compressed air, is the commonest form of reheating, and may be used even in mines. Small reheaters are now furnished by builders of air compressors and are placed near the valve of the pump, these heaters being so arranged that the products of combustion are carried off, or in some cases they are simply discharged in the mine, but little fuel being required. These reheaters are sometimes arranged to burn gasoline and other oils. Where pumps are used without reheaters good results may be obtained by injecting water or steam on the plan mentioned in Mr. Richards' letter. Both water and steam carry a good deal of heat, that is, the specific heat is high compared with the specific heat of air, hence small quantities injected into the air directly at the valve or inlet serve a useful purpose in giving out heat and thus preventing freezing. It is not always, of course, convenient to get hot water and steam down into the mine at the point where the pump is located, but one may be surprised to know how far steam and hot water may be carried. If convenient, the pipe carrying the hot water or steam should be inserted within the compressed air pipe, so that the heat given off through condensation will be imparted to the compressed air. If the pump is too far away use cold water, for it is strange to say that even cold water will prevent freezing in pumps using compressed air; this is because the water gives off its heat to the air during expansion, and in addition to this, it acts as a mechanical scourer in washing away the ice as it accumulates in the exhaust passages.

FREEZING.

In a recent conversation with Mr. Geo. E. Ames, Supervising Engineer of the Anaconda Copper Mines in Montana, the question of freezing in compressed air pipes was brought up. Mr. Ames is a practical man, having recently taken charge of the Anaconda mines after an experience of 18 years with the Union Iron Works, San Francisco. Large volumes of air are used in the Anaconda mines, compressors being installed at different points, with an aggregate capacity of 50,000 cubic feet of free air per minute, delivered at 80 pounds pressure per square inch. Among the installations is one where the compressed air after leaving the generating station is conveyed over ground a distance of several thousand feet and then carried down a shaft into the mine.

During the winter months it was found that at times it was difficult to get air pressure in the mine, and Mr. Ames set about to discover the cause. Being an engineer he looked at the case from a theoretical as well as a practical standpoint, and discovered that the air pipe was in fact a surface condenser, the cold Montana winds keeping it at a low temperature, and the hot compressed air on the inside coming in contact with the cold surface of the pipe was reduced in volume and temperature, and as it went along it deposited its moisture on the interior surfaces. Air at all times contains moisture. It is called comparatively dry when the humidity is 50 per cent., which means 50 per cent. of the quantity of water required to saturate a given quantity of air. At times it is as high as 90 per cent., and even more. This water is in the air, though we cannot see it, and it is just as certain to be condensed to a visible and a troublesome liquid when the temperature is lowered, as steam may be converted into water. It is altogether a question of temperature. Steam is in a condition of vapor only because it is held up by heat. The air we breathe passes over water surfaces and absorbs moisture, just as the water is taken from wet clothes while hanging on the line. and the warmer this air is the more moisture does it take up.

This water is carried around with the air and up into higher regions. where it meets with cold currents and is condensed into clouds. These clouds represent nothing else but the visible moisture which is present in the air drawn into a compressor, and it is certain to form a cloud and rain, either in the air receiver, the pipe line or the rock drill or pump that uses the air. This is a process of nature, and knowing the cause, as Mr. Ames did, it was not difficult to find a remedy. This he found by putting in a series of old boilers outdoors near the engine room. The air at 80 pounds pressure and hot was passed from one of these boilers to the other until its temperature had been lowered to the initial point, and when it started up the hill it was practically of the same temperature as the pipe line, and it had left its moisture, or a large portion of it, behind. Old boilers when strong enough are especially well suited for use as compressed air condensers, because of the large metallic surface exposure through the shell and the flues. The compressed air passes around the tubes and the free winds of winter blow through them. It is best to so place these boilers that they will get plenty of wind. It is better to put them in a horizontal than in a vertical position, and if wind is not available, use a blower, or better still, a cold stream of water. If practicable submerge the receivers. Suitable means should, of course, be provided for trapping the water. Pet cocks or globe valves are sometimes used, but water traps working automatically will serve the purpose better. It is not necessary, however, as some suppose, to take the water out as fast as it is formed, for as long as the temperature of the water is lower than that of the air there can be no absorption of water by the air. This simple remedy, which Mr. Ames has applied at the Anaconda mines, might save time and money at other places, and it is mentioned here hoping that it may have this result.

FREEZING.

As the cold weather approaches we wish to call attention to certain precautions which may be applied to compressed air installations, and which will prevent the annoyance and expense of freezing. Makers of air compressors of the compound type furnish intercoolers, which are placed between the air cylinders, and which serve to reduce the temperature of the air, as it passes between stages of compression. These intercoolers are nothing more than tubular condensers, commonly called surface condensers, the water circulating around the tubes, through which compressed air passes. In some of these the air passes on the outside of the tube and the water on the inside. However this may be, the principle involved is the same.

These intercoolers require about 1 pound of water for each cubic foot of free air, the air passing at a pressure of 60 pounds per square inch. These coolers serve just as important a purpose as after coolers, as they do as intercoolers, and there is quite as much reason for after cooling compressed air as for cooling it between stages, because the after cooler, when properly installed, should bring down the temperature of the air to the original point; that is, to the temperature of the atmosphere, and in this way moisture will be deposited before the compressed air is started through the line pipe to the work. If the air is started on its journey hot, and it traverses a line of pipe long enough and sufficiently exposed to reduce its temperature, we will have the conditions of a long drawn out condenser, moisture collecting on the inside of the pipe to form water and ice, at times completely closing the tube, through the incrustation on the inside. Now, in order to get this condensation, the temperature of the air must be reduced, and if we reduce the temperature at the receiver as low or lower than it is on the outside, there will be no chance for further reduction until the air is expanded. It is quite possible at certain seasons of the year to obtain such thorough after-cooling as to prevent freezing even in the engines during expansion, for we may safely say that if the temperature of the air never goes below that to which it is brought in the after-cooler, there will be no trouble from freezing, and it is quite impossible to get too low a temperature in the after-cooler, because no matter how we may shrink the air by cooling, we are all the time drying it, and when we start it through the service pipes and it meets there higher temperatures, we will then be reheating under natural conditions, the air taking up heat from the atmosphere without expense and after having been dried.

West New Brighton, S. I.
October 29, 1899.

Editor Compressed Air:

Will you kindly publish in Compressed Air a feasible method of testing a pipe line for leakage?

The line in question supplies a dozen or so of Pedrick & Ayer Hoists, and it comprises a two-stage compressor 12 in. x 8 in. x 12 in. stroke, has no reservoir, but compresses directly into the pipe line.

C. Lee Straub.

There are a number of factors which should be given before an accurate answer can be made. Using the data mentioned, it seems that the most satisfactory method would be about as follows:

If the pipe line has valves at all branches, and a valve between the compressor and the beginning of the pipe line, the branch valves should all be closed and the compressor run until the air pressure in the transmission line is at the maximum for which the machinery was designed. The valve between the compressor and the pipe line should then be closed, and the full pressure in the pipe line noted.

If there are no leaks it would seem that the pressure would hold up for a considerable time, and the time required for the pressure to drop from maximum to, we will say half pressure, will be a measure of the amount of leakage.

Another way, although not as satisfactory, would be to shut the system down, or make the test when it can be shut down without inconvenience, and pump the transmission line full of water up to the maximum pressure. Leaks would then be indicated by wet spots. If there are no valves at the branches and the air is allowed to pass through flexible connections to the hoist, and is shut off by the hoist valves, this method would not be advisable. The air method, however, could be used in exactly the same way, or the flexible air pipes could be disconnected and cups screwed on the branches.

Another method in very common use is to place oil around the seam or joint in question and in case of a leak the air will blow bubbles of oil. Application is easily made by means of the ordinary "squirt oil can" used around machine shops.

The soapsuds method is perhaps the simplest. Take a strong solution of soap and water and with a clean paint brush apply the suds to the pipe, beginning at the compressor and following to the last appliance. Wherever there is a leak, bubbles will appear. Mark these places with chalk for future attention.

Editor Compressed Air:

The volume of discharge of compressed air at terminal pressure from a pipe varies inversely as the square root of the density of the air at initial pressure.

The volume of discharge of compressed air from a pipe decreases when the initial pressure is increased, and increases when the initial pressure is decreased; the loss of pressure being maintained constant in both cases.

The volume of free air equivalent to the discharge of compressed air from a pipe increases with the increase of the initial pressure, and vice-versa, the loss of pressure being maintained constant throughout.

It is very important in the case of problems relating to the flow of air in pipes to bear clearly in mind whether the flow of free or of compressed air is being considered, as many of the conditions and effects are absolutely reversed in the two cases.

"Free air" does not flow in a pipe, therefore the discharge from a pipe cannot be said to be such or such a quantity of "free air."

It is often said that the loss of pressure in a pipe is proportional to its length. This is true only when it refers to the discharge of air under pressure (not free air) from a pipe. When the equivalent volume of free air discharged is taken into consideration (as is usually done), the loss of pressure caused by friction in the pipe is much greater in proportion as the length increases. Thus, if the loss of pressure at the end of 1000 feet of pipe, with an initial pressure of 60 lbs., is 5 lbs., it will be 20 lbs. at the end of 2500 feet, and not 12½ lbs., which would be the proportionate loss. WILLIAM COX.

New York.

Editor COMPRESSED AIR:

Could you give me any information about water getting in the air of a compressed air pipe line? We drain our receiver every three or four days, but do not get any water to speak of. The air is piped about 300 feet. T. R. H.

WILKESBARRE, PA.

To thoroughly deposit the moisture from the air of your compressed air pipe line before it leaves the receiver, you will find it necessary to cool the air in the receiver to at least a temperature of the surrounding atmosphere. A simple illustration of why this is so would be the falling of dew during still evenings in the warmer seasons; during the day the air becomes heated and at all times has more or less moisture in it; during the evening this same air becomes cooled to what is known as the dew point and the moisture is condensed and deposited as dew. To apply this to compressed air: the air becomes heated during compression and the moisture is held in a form of vapor; if the air is cooled before leaving the receiver this moisture will be condensed and deposited there in an amount directly proportional to the lowering of temperature. If you desire to avoid all water in the pipe line, you should cool the air in the receiver lower than the temperature of any surface it may come in contact with in passing along the line.

In laying a compressed air pipe line it is highly advisable to select the coolest possible position for a receiver, say where it is shaded and the wind can pass around it or when water is at hand immerse it. By putting additional receivers into the line and so locating and constructing them as to cool the air below its initial temperature, you will be able to overcome your difficulty.

An editorial in the November, 1898, issue of COMPRESSED AIR (page 326 of this book) describes the cooling system in the Anaconda Copper Mines, where numerous receivers in the form of old boilers are used with a success.

Compressing air by the Compound system makes the discharge into the receiver at a much lower temperature than in single stage compression. This would also help you to overcome your difficulty.

USE.

HISTORY.

From historical research it appears that compressed air for conveying passengers has always been under consideration. Nearly all experiments have served to prove the mechanical power of the atmosphere, and the question, how it could be converted into a motive power, available for the conveniences of so-

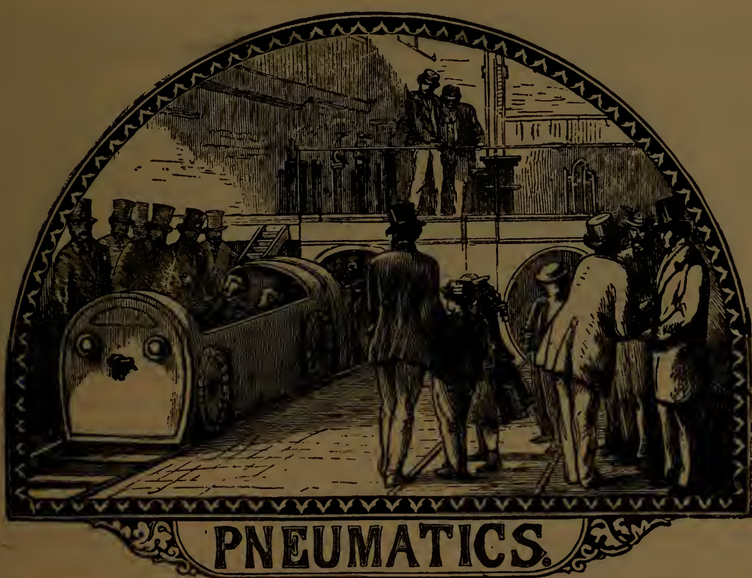


FIG. 96.

ciety, has been a problem of great interest to engineers. More than two centuries ago the notion was entertained of producing motion economically for the purpose of transit by means of the pressure of the atmosphere. The original thought may at least be traced back with certainty to the celebrated Dr. Papin. In the year 1810, a proposal was made by Medhurst, the Danish engineer, to put letters and goods and passengers in a canal, 6 ft. high and 5 ft. wide, and containing a road of stone and iron, and project them by means of atmospheric rarefaction and condensation.

In 1824, an Englishman, Mr. Vallance, made a similar suggestion. His daring plan was to connect Brighton and London by means of an enormous tube, through which, by pumping out the air, carriages were to be propelled with the velocity of a cannon ball. Other plans of equally novel character were considered at various periods.

The Pneumatic Parcel Despatch Company, of London, about the year 1865, successfully worked a pneumatic line while it was designed for parcels, was capable of carrying passengers. (See Fig. 96.)

The construction of the tube between Euston Square Station and the Northwestern Post Office in Eversholt, is described as most simple, cheap and effective, and reflected great credit upon its engineer, Mr. Rammel, for the ease and certainty with which the air from the *fans* sends one or more carriages, heavily laden, from one end to the other. Other demonstrations were made on this same line. At the Polytechnic of London, a little model of wood was constructed about 20 feet long. There were two carriages, the passengers consisted of a party of white mice, and they were blown from one end to the other by means of a blast of air.

MEN PROMINENT IN COMPRESSED AIR DEVELOPMENTS.

Two conditions are always prominently connected with the development of every new and useful thing, whether it be a machine or the useful application of a new science— men and money. It is usual for use to talk of the lack of means as the excuse for failure to bring a new thing to the paying point, but the right kind of a man, the genius to handle each particular subject is of greater importance than money. Good and useful things have been produced by men working practically without means, but money has never built up a good thing without the aid of the man of brains.

Compressed air, though as old as the hills, is a new thing in its usefulness to mankind. This century, and we may also say this decade, is the compressed air era, and yet the useful application of this power has become so general, that we appear to be only beginning to enter this wide field of usefulness. American men and engineers are responsible for a large share of this. French, German and English engineers and professors are greater theorists, and have built for us the foundations on which practical work has been laid. The Popp system in Paris, deficient as it is from our standpoint, has pointed the way to better things. It was was this system which first attracted Professor Riedler's attention to compressed air. The writings and inventions of Professor Reidler entitle him to rank at the top among pneumatic engineers. He has been spoken of as the highest authority on pneumatics in Europe.

This title might perhaps be disputed by Professor Unwin, of England, who though less inventive than Riedler, is quite his equal in knowledge of pneumatics, and whose thoroughness and exhaustive capacity for work entitles him to rank among the greatest of living engineers. Professor Kennedy has also taught us much that we know about compressed air.

The reader of this publication will be glad to see the portraits of those who have accomplished so much, and who are already well known by reputation. Our gallery is necessarily not complete, notably so in that it does not contain the picture of Mr. Ebenezer Hill of Norwalk, Conn., our highest authority on this subject. Mr. Hill is a rare combination of the engineer and business man and an inventor who has designed standard machinery. He has been intimately connected with compressed air for perhaps twenty-five years, and in the development of the compound air compressor he is entitled to the first rank. Mr. Hill long ago saw the importance of compound compression, and he adhered to it at a time when he stood alone. To-day every engineer who knows anything about the subject recommends compounding, and all makers of the first class furnish compound machines.

Mr. Addison C. Rand was born in Westfield, Mass., in 1841. He early became interested in the practical applications of compressed air through his connection with a powder manufacturing concern, which naturally gave him an

FIG. 97.—ADDISON C. RAND.

FIG. 98.—B. C. BATCHELLER.

acquaintance with the needs of improved drilling and mining machinery. This interest took him into the field of manufacturing rock drills and later air compressors. The large experience gained in this field made him one of the best known compressed air men.

Mr. Rand died on March 9th, 1900, and at that time was President of the Rand Drill Company and a Director of the Laflin Rand Powder Company.

Mr. B. C. Batcheller has been called the Edison of pneumatic sciences. He is, as his portrait indicates, a young man of determination and ability. He is best known in connection with the pneumatic despatch system of the Batcheller Pneumatic Tube Company, which has been adopted by the United States Government. The details of this system, designed by Mr. Batcheller, show that practical originality which usually denotes the successful mechanical engineer.

Mr. H. D. Cooke has fought compressed air battles as a gallant knight: Compressed air has been his shibboleth. His work has been mainly of a business nature in connection with the promotion of pneumatic traction companies, and it

FIG. 99.—HENRY D. COOKE.

is probably due more to his personality and strength than to anything else, that the use of compressed air for street cars has been kept alive in America.

Mr. F. A. Halsey is a well known engineer and inventor. Shortly after graduating from Cornell University he began work with the Rand Drill Company, where he invented the "Slugger" rock drill. Among other things he has invented

FIG. 100.—F. A. HALSEY.

a mechanical valve motion for air compressors and a pneumatic pump. He has published two works, "Slide Valve Gears," now in its fifth edition, and "Locomotive Link Motion." His paper entitled "The Premium Plan of Paying for Labor," read before the American Society of Mechanical Engineers in 1891, has been widely quoted. He is, perhaps, our best authority on valves. He is a close student, thoughtful and accurate and an acknowledged authority on pneumatics.

Mr. Robert Hardie, the inventor of the Hardie Air Motor, is a Scotchman by birth, though in all other respects an American. Air, especially in its use for

FIG. 101.—ROBT. HARDIE.

traction, has been Mr. Hardie's hobby. He designed the motor which was used on the elevated road in New York in 1879, and has recently built air motors for street car work. Mr. Hardie had much to do with the design of the De Larvergne Refrigerating Company's machinery: His mechanical ideas are marked by much individuality, the element of simplicity being prominent. It is doubtful if any one

FIG. 102.—GEN. HERMAN HAUPT.

has had as much experience as Mr. Hardie in pneumatic traction, and he is an acknowledged authority on the subject.

General Herman Haupt is a well known engineer. Graduating from West Point as a military engineer, the General has had a most extended career in field work, railroad construction, bridge work, as professor of mathematics and civil engineering, general superintendent and chief engineer of railroads, etc. His attention was first attracted to compressed air in 1879. Since then he has been identified with pneumatic traction, as president of the General Compressed Air

FIG. 103.—GARDNER D. HISCOX.

Company. He has published several works, among them "General Theory of Bridge Construction," and "Haupt on Motors."

Mr. Gardner D. Hiscox, is a distinguished hydraulic and pneumatic engineer, and is at present on the staff of the *Scientific American*. Mr. Hiscox has had a most extended experience in mechanical construction, is very fertile in expedients and has a fund of information at his fingers' ends, based on practical

FIG. 104.—J. H. M'CONNELL.

contact with work. As an engineer he combines the theoretical and the practical, and is well posted and a safe adviser on pneumatic and hydraulic subjects.

Mr. J. H. McConnell is the efficient superintendent of motive power of the Union Pacific Railroad at Omaha, Neb. His paper read before the Western Railroad Club (COMPRESSED AIR, Vol. I, No. 2) showed a knowledge of the practical application of air, which has entitled him to rank as one of the most useful students of this subject. Mr. McConnell saw the possibilities that were dormant in compressed air, and he went to work to develop machinery for its use. This he has done in a most extended way on the Union Pacific road.

Mr. R. A. Parke, is a well known mathematician and engineer, young, able and progressive. He is especially prominent among railway men, because of his connection with the Westinghouse Air Brake Company. He is a recognized authority on compressed air and especially in connection with air brake service. Mr. Parke has designed and patented a system of air brake traction which has been worked experimentally at Albany, N. Y. As an inventor he is extremely conservative, but for this his traction system might have been pressed forward by capitalists. A paper read by Mr. Parke before the New York Railroad Club in

FIG. 105.—R. A. PARKE.

FIG. 106.—WILLIAM PRELLWITZ.

1894, entitled "Economy in Compressed Air Transmission for Commercial Purposes and for Air Brake Purposes," has been widely quoted and is an able contribution to our literature on this subject.

Mr. William Prellwitz is in charge of the engineering department at the shops of The Ingersoll-Sergeant Drill Company. His training in connection with air compression, especially in the design of pneumatic machinery, has been thorough and extensive. Engineering comes natural to him, and he belongs to that class of thinkers on the subject, whose ideas inspire confidence. Mr. Prellwitz thinks to the bottom of every subject brought to his attention; a ready and expert free hand draughtsman and one of our best authorities on pneumatic engineering. His paper entitled "Compressed Air; Its Production, Transmission and Use," published in Vol. II., No. 7, of COMPRESSED AIR (page 67 of this book), is a compendium on the subject and an education to a student of compressed air literature.

Mr. Whitfield P. Pressinger was formerly Secretary of the Clayton Air Compressor Works. He has written several magazine articles on compressed air, and his connection with the Clayton Company has given him a wide experience

FIG. 107.—WHITFIELD P. PRESSINGER.

in pneumatics. It has been mainly through Mr. Pressinger's active management that the Clayton Compressor is so widely known. At present he is associated with the Chicago Pneumatic Tool Co.

Mr. Frank Richards stands at the top among pneumatic engineers. A voluminous writer on the subject, clear and interesting in his style and combining the theoretical with the practical. Mr. Richards is a trained mechanic, having

FIG. 108.—FRANK RICHARDS.

been at one time the superintendent of the shops of the Ingersoll-Sergeant Drill Co. He is at present associate editor of the *American Machinist*. His book on "Compressed Air" has had a large circulation, and contains more information on this subject than any other American publication. Personally Mr. Richards is of an extremely modest nature, popular with all his associates and a safe consulting engineer.

Mr. Edward A. Rix is better known on the Pacific coast than in the east. He has been intimately connected with compressed air during most of his business life. Mr. Rix is versatile and clever. As an inventor he has produced the Rix Drill and Air Compressor; his best work, perhaps, being the air plant

FIG. 109.—EDWARD A. RIX.

designed by him for the North Star Mining Company, Grass Valley, California. Mr. Rix has made some interesting and useful contributions to compressed air literature, among them "Rix Engineering Pocket Book," and several magazine articles.

Mr. Henry C. Sergeant is well known in connection with The Ingersoll-Sergeant Drill Co. Among his inventions are the Ingersoll Eclipse and the

FIG. 110.—HENRY C. SERGEANT.

Sergeant Drills, the Sergeant Coal Cutter and the Ingersoll-Sergeant Air Compressors. He first attracted attention in 1861, when by Act of Congress the United States Government gave him $10,000 for a marine engine regulator. He was at that time twenty-six years of age. All his inventions have been in the line of steam, gas and air machinery. The Patent office records bear evidences of Mr. Sergeant's fertility as an inventor. His work always bears the mark of practical simplicity, combined with economy of construction and operation.

Mr. J. W. Thomas, Jr., is assistant general manager of the Nashville, Chattanooga & St. Louis Railway. He designed and has successfully applied an orig-

FIG. 111.—J. W. THOMAS, JR.

inal pneumatic system of handling switches and signals, described in Vol. II., No. 8, Compressed Air, and elsewhere in this book.

Mr. Charles E. Tripler has recently attracted much attention in connection with liquid air. He has been engaged in researches in high pressures for the

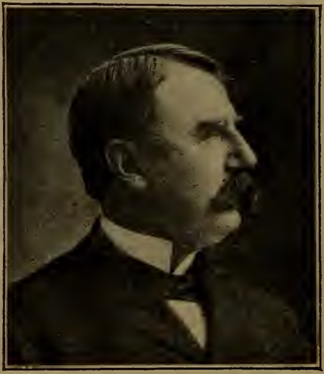


FIG. 112.—CHAS. E. TRIPLER.

liquefying of gases for a number of years, having devoted all his time and a great deal of money to this work. During his researches he devised a simple and economical apparatus for the liquefaction of gases, his investigations on this subject having developed many important results.

SOME OF THE USES AND ADVANTAGES OF COMPRESSED AIR.*

Previous to 1890, compressed air was used around railroad shops to a very limited extent. On roads having freight cars equipped with air brakes some of the freight repair yards were fitted with lines of pipe for testing the brakes on cars. For some time air had been used to force couplings into air brake hose and a few shops had air jacks for raising freight and passenger cars. The air pressure was supplied by locomotive air pumps and the limited amount of air furnished by each pump prevented a very general use of compressed air appliances, as it often required from six to eight air pumps to maintain the supply; more fuel was required in shops of ordinary size to furnish steam to run the pumps

FIG. 113.—AIR-DRIVEN BREAST-DRILL.

than was used to drive all the machinery in the shops. In machine shop practice the use of compressed air was confined to small pneumatic hoists.

In 1891 its first application to car work was for cleaning the dust from window sashes and blinds in coaches and such parts of the inside as could not be reached with a feather duster, a round nozzle with a 3-32 inch opening being used. This led to the application of a flat nozzle for cleaning cushions and seat backs, and afterwards for cleaning carpets, bedding and blankets in Pullman cars. The Pullman Palace Car Company recognized its superiority over any other method of cleaning, and where it could be done, contracts were made paying twenty-five cents for the air furnished to clean each sleeper.

Air pumps not being able to meet the demand, an air compressor was added giving an increased supply, and a new field was opened for air power. Air lifts began to replace the chain blocks or different pulleys at all the heavy machines; the driving wheel lathe being supplied with an attachment to work in a horizontal

* Read by J. H. McConnell before Western R. R. Club.

as well as a perpendicular direction to draw the wheels in or push them out from the centers.

As it required a large number of these lifts in an ordinary railroad shop it was necessary to devise some economical way of making them. By taking ordinary lap welded iron pipe cut to the required length and forcing a wrought iron die through, the pipe was made perfectly round and smooth inside and a leather packing on the bottom side of the piston made a tight piston when the air was applied, and allowed the piston to descend quickly when the air was released. A cast iron head was provided on each end and these were held in place with half inch or five-eights inch rods. A 1¼ or a 1½ inch piston rod was used with a hook and swivel on the end and an eye bolt screwed into the top cylinder head. These parts, together with an inlet and discharge valve, completed the lift. Those which have been in service five years have been very satisfactory and it has not been found necessary to make any change from this method in its lifts raising ten thousand pounds.

The introduction of air into shop practice has brought out, in the last three or four years, a number of valuable and useful tools such as pneumatic drills,

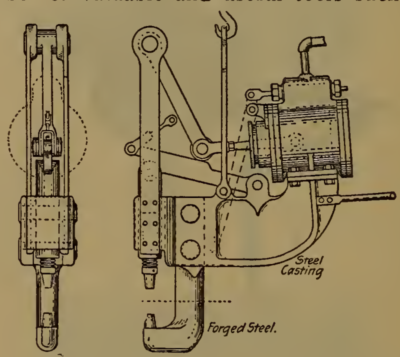


FIG. 114.—PORTABLE PNEUMATIC RIVET DRIVER.

pneumatic hammers, riveting machines for fire box, boiler and tank work, stay bolt cutters and stay bolt breakers. The pneumatic drill performs a very important part in building a new boiler or putting a new fire box in an old boiler. Two men with two drills can tap out the holes and screw in seven hundred stay bolts in a fire box in fourteen hours. By the use of a simple tool attached to the end of the shaft of the drill, stay bolts are screwed into the fire box without a square shank being provided on the end of the bolt, thus avoiding the necessity of forging a square head by which to screw it in. This drill has entirely supplanted the flexible shaft in work about locomotives, and in some shops a rachet is rarely seen in drilling holes about a locomotive boiler or frame. An air motor is considered an indispensable tool for flue work, and the past three years have not seen a flue fastened in a locomotive boiler except by use of one of these tools. Applied to a cylinder boring bar it will run a good size cut through a cylinder; attached to a valve seat facing machine it does its work quickly and very satisfactorily. It affords a quick and convenient way of grinding steam pipe rings. The pneumatic hammer has also come to stay. For chipping castings, caulking boilers, beading flues and driving rivets, it is one of the most valuable pneumatic tools in service. The application of air to portable riveting machines has done away with a great deal of hand riveting. With the exception of one end of the connection sheet between the cylindrical part of the boiler and the fire box, a boiler can be entirely riveted by air machines.

In car shop work air plays an important part. Jacks for passenger and freight car work are indispensable and any shop can have them if they can buy the castings. They are easily and cheaply made and can be built in any shop having a boring mill or a thirty-inch engine lathe. A small jack for raising draw heads, another for pulling down old draft timbers, do not cost much and they save time and labor in doing the work. Sand papering the surface of a passenger coach by an air machine makes better and is cheaper work than can be done by hand. On roads using gas in coaches an application of a jet of air and gas through a Bunsen burner removes the paint in a very quick and clean manner with no danger from fire. Attach a half-inch hose to the gas pipe in the car and another hose on the air supply, connect them both to the burner and see how cleanly and quickly you can burn off a coach. If you mix any paint, make a galvanized iron tank to hold fifty gallons—or make two if necessary—bend a piece of half-inch gas pipe in a circle two inches smaller than the inside of the tank, drill about fifteen holes on the top side of the pipe, plug up one end, put an elbow on the other, screw in a piece of half-inch pipe about four feet long, put on a globe valve, couple on the air, fill the tank with lead and oil or paste and oil, turn on a small quantity of air and see how quickly it will mix it. The material becomes agitated as if it was boiling. It is superior to any other way of mixing paint and it runs itself.

The use of air for painting buildings and freight cars has been successfully carried on for the past three years. Applied to a machine for white-washing it will cover a great amount of space; a twenty stall round house can be white-washed in twenty hours. I have seen a machine shop 150x200 feet with a trussed roof white-washed, over the walls, the roof and the trusses, in ten hours. For crossings, fences and bridges, it is the cheapest and quickest way; it makes a smooth surface and drives the white-wash into places which a brush will not reach.

In our machine shops air is now as important as steam. It is performing many things better than steam did, as there are many tools about a shop run by air that could not be run by steam. A three cylinder brotherhood engine operated by air is one of the most important tools in the shop. It is mounted on a small iron truck and can be readily moved. All complete it does not weigh over two hundred pounds. It will run an 18 inch slotter, a 42x42 inch planer; it will run a small driving wheel lathe and turn tires up to 56 inches in diameter; it will run a lathe for turning steel tired car wheels; it will run a drill press, a bolt cutter or any single machine, and frequently it will save running the whole shop when it is necessary to run one machine only. A press for rod work, driving box brasses, or other work that does not require over 15,000 pounds on the piston is a great improvement over the old screw press and much quicker.

An emery wheel driven by air on the principle of the Pelton water wheel makes a very handy tool for light grinding, two six-inch emery wheels on one shaft can be run from a quarter-inch pipe. A transfer table of one hundred feet travel can be successfully run by air by using a small engine.

Among the many uses of air in our shops that of blowing out steam passages in cylinders commends itself at once. To do this, fill the boiler with air at 100 pounds pressure, blow out the ports, put in the pistons, fill the boiler again with air and run the engine out of the shop into the round house. You have burned no wood, nobody has waited for the engine to get hot, and you have saved several hours in time in finishing the engine. In testing stay bolts with 100 pounds of air pressure on the boiler, a broken stay bolt is immediately detected when sounded with a hammer, when it might not be discovered if sounded when the boiler was empty or full of water.

At the scrap pile a cheap and effective shear for cutting off bolts to length can be made by using two short pieces of sixteen inch "I" beam and a passenger car brake cylinder which can be made to work automatically or by hand. A freight brake cylinder set in an upright wooden frame with an anvil below and a steel head on the end of the piston rod makes a good automatic hammer for straightening bolts and rods. The valve motion to the hammer consists of an ordinary three-way cock with a lever attached to the plug and a half-inch rod

FIG. 115.—PNEUMATIC TRACK-SANDER.

connection to the end of the piston rod. The supply of air regulates the stroke. It can be regulated as closely as a steel hammer and will strike two hundred blows a minute if desired. These tools can be located anywhere about a yard.

A sixteen inch cylinder makes a press for the tin shop, and with the proper dies and stamps the largest part of your tinware can be cut out, stamped and flanged ready to be put together. Galvanized iron water pails, dope and other buckets, are made in this way in pieces. The sides are cut out in sections, two sections forming the pail. The bottom is cut out and flanged at one blow. The tops and bottoms of tin or galvanized oil cans are made this way; also engine oilers, oil cans, spouts, tallow pots, water glass lamps, and a great variety of tinware can be made more cheaply and quickly than by hand.

Attach a small air cylinder to the splitting shears in the sheet iron shop and you have a very effective shear for splitting sheets from three-sixteenths of an inch in thickness down.

A portable forge for rivet heating and light blacksmith work is made by using a three inch iron tube below the fire plate. Extend this down below the bottom of the forge, connect a quarter inch gas pipe, use an elbow on the pipe, screw in a brass nipple with a 1-32 inch hole for the discharge, place the top of the nipple there ⅜-inch above the bottom and in the center of the tube and use a quarter-inch globe valve to regulate the supply of air. With this forge rivets can be heated faster than two gangs can drive them, and a welding heat can be made on a bar of two and one-half inch round iron.

In the office attach an eight inch cylinder to the letter press for copying letters; you will like it so well that you will not want any more screw letter presses.

The application of air in a sand house as a means of elevating sand to a tower where it can be discharged through a spout into the sand box of the locomotive has been adopted on a number of railroads. A passenger car auxiliary reservoir with the necessary air connections makes a convenient and economical machine for kindling fires in locomotives with oil. In a blacksmith shop a blast for all fires can be supplied by compressed air and the fan blast dispensed with, experiments in this direction having demonstrated the success of this plan.

New applications of air are constantly being made about railroad shops, each new application suggests another, and no shop is complete at the present

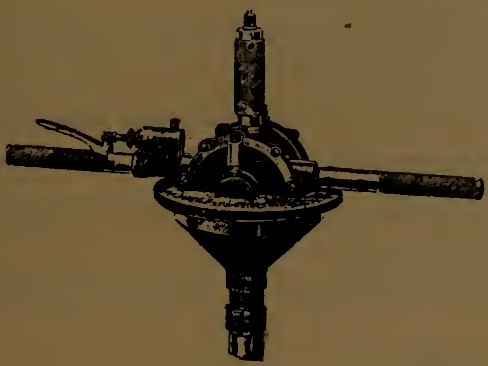


FIG. 116.—AIR DRILL AND REAMER.

time without an air compressor. Even small shops can afford to dispense with locomotive air pumps and buy a compressor, because one that will furnish as much air as six pumps can be purchased for about $800.

The economies effected by the use of air will, in a short time, pay for a complete air plant. A large reservoir supply is a great advantage, the larger you have it the more economically can the system be operated. A machine shop to-day can be fitted up to a better advantage and for less money than ever before. No main line shafting extending the entire length of the shop is necessary. A short line shaft may be used for heavy machinery and all the light machinery may be driven by air.

The last five years have produced many useful compressed air tools and the future will bring out others. Manufacturing establishments are investigating the advantages of air, and all railroad shops are more or less engaged in bringing out new appliances so that we are looking to the future and wondering what will be the next application of compressed air in shop practice.

ECONOMIES EFFECTED BY COMPRESSED AIR.

In an article by C. W. Shields, published in the *Railway Age*, Mr. J. H. McConnell, Sup't, M. P. Union Pacific R. R., is credited with furnishing the following summary of time and expense saving in various shop practices when done by compressed air:

	Saving per day.
Putting wheels in wheel lathe, three lathes in the shop an average of one change a day, save one man in handling this work	$1 60
Hoisting steel-tired wheels and axles in lathe, average of six changes a day, save one hour in time, $1.60; and one man less to handle the work, .20	1 80
Hoisting axles into cut-off lathe, an average of ten changes a day, save one hour per day in time	.25
One large boring mill averages two changes a day, $1.60; saving of time of 30 minutes and the use of one helper, .15	1 85
Handling cylinders in large boring mill and planer, save the labor of one man and one-half hour each change	1 60
Three men working on pistons, etc., in raising them from the floor to the bench, serving three machinists, save one helper five hours a day	.80
Raising chucks, face plates, and other heavy work, air hoists in the machine shop save one helper one day	1 50
Lifting driving wheels and other heavy work on the large slotting machine, save the time of one man and 20 minutes	1 50
In applying cylinders on boilers, save one machinist and helper's time of 10 hours	2 40
Facing valves, save helper's time of four hours	.60
Pressing on driving wheels and axles, etc., three less helpers one hour each.	.45
Boring out cylinders, three helpers' time four hours	1 80
Applying driving brakes to old engines, drilling holes, reaming, etc., saving 15 hours of time of machinist and helper	6 70

Pneumatic tin and galvanized iron press, in getting out stock for 20 dozen water buckets, get it out in eight hours where it previously took 40 hours.

In making brake shoes stamping a loup to have a casting run on, previously one man would do 200 in a day where he now does 600. All work on this machine saves in the neighborhood of from 50 to 60 per cent.

Running foundry elevator with the air hoist saves 25 per cent. of one man's time.

Save 75 per cent. time putting in stay bolts in a fire box by using air motor for tapping out holes and screwing in bolts.

Save in the neighborhood of 50 per cent. in using pneumatic hammer for caulking both flues and boilers.

Take engines in and out of roundhouse when necessary to change them, saves the work of six men pinching possibly 45 minutes, not counting the delay of the men waiting to go back to work on the engine.

Blowing out engines with air, save a cord of wood, besides the inconvenience and delay, as the men cannot work around a hot engine to advantage.

Handle all engines on the transfer table now run by air, previously run by crank. One man does now what six did before; where six men move a foot in a minute, air motor under like conditions will move twelve feet. As this is moved several times a day, this in itself is a great saving.

Pneumatic hoist for unloading scrap at the foundry, the old method took six men 10 hours; under the same conditions with the hoist, two men will do it in 4 hours.

Unloading a car of wheels, it takes six men half an hour; now three men will do it in 15 minutes.

Sandpapering off a 50-foot baggage car by hand took in the neighborhood of 60 hours; now it takes 14 hours with the sandpapering machine.

Air jacks for raising and lowering freight cars now take one man three minutes where previously it took two men ten minutes.

Truck jacks to remove three pairs of wheels takes 1½ hours; the old method takes 6 hours.

Cleaning a car save about 10 per cent. in time and 90 per cent. thoroughness.

Air whitewashing machine, where it took ten men five days it now takes four men one day, and a 75 per cent. better job.

DON'TS! FOR USERS OF COMPRESSED AIR.

The following hints have been drawn up in a somewhat breezy American style:

Don't install a compressor just about equal in capacity to your present requirements, for when once you have compressed air available, its number of uses becomes legion. Good practice is to provide a compressor at least fifty per cent. greater in capacity than your immediate necessities demand. Duplex compressors are made devisable, permitting the installation and operation of one-half at first and the other half later, when the additional capacity is needed.

Don't accept the theoretical capacity of an air compressor, stated in the list of the maker, as the equivalent of the actual volume of air needed for your service. Remembering the difference btween theory and practice, allow a small deduction for friction, heat, clearance, etc., being unavoidable losses in air compression, before calculating what your actual delivery in compressed air will be.

Don't buy an air compressor because it is cheap. It will prove the most expensive proposition of its size that you have ever encountered. If a water pump fails in its work, you will know it at once; if a steam engine is deficient, its shortcomings are self-evident; but if an air compressor is poorly designed or badly constructed, it may continue in the evil of its ways until the scrap heap claims it for its own, unless, as is more than likely, an absolute breakdown calls attention to its deficiencies, and you learn all too late that the hole it has made in your coal pile, added to the loss of keeping it in repair, would have paid a handsome interest on the additional first cost of a properly designed and properly constructed compressor.

Don't buy a second-hand compressor unless you know it has given satisfaction in work similar to your own, and that its working parts retain their full measure of usefulness without deterioration. An air compressor with valves, pistons, etc., worn out or in bad repair can waste more good power than anything of its size known.

Don't buy a compressor that your neighbor used for operating oil burners because you intend putting in pneumatic tools. For, even if all compressors look alike to you, experience teaches that oil burners operate under 12 pounds pressure, whilst pneumatic tools require 100 pounds, and the oil-burner compressor, with unevenly proportioned cylinders, devoid of water jackets, will equal your service as well as a low-pressure boiler for heating will run a high-speed engine.

Don't use air-break pumps or direct-acting compressors. Statistics show that their steam consumption is about five times that of a crank and fly-wheel compressor for the same volume and pressure of air delivered.

Don't install a steam-driven compressor if your steam supply is short and plenty of belt-power available.

Don't put in a belt-driven compressor if you have plenty of steam and are short of belt power.

Don't purchase a compressor of out-of-date design because you have heard of it for many years. Noah set the fashion in arks, and is known throughout civilization, but modern house-boats have evidenced the progress of the times by departing materially from Noah's standard.

Don't draw your intake air to the compressor from a hot engine-room, or from any point where dust is abundant. The volume of air delivered by the compressor increases proportionately as the temperature of the intake air is lowered, and dust or grit entering the compressor clogs the valves, cuts the cylinders, and generally impairs the efficiency.

Don't use any old thing for an air receiver. Compressed air under 100 lbs. pressure will leak a horse-power through a 1-16 diameter hole in five minutes, and a well-made, strong and tight air receiver is the second essentially important factor if you would realize to the utmost all the advantages which compressed air provides.

Don't connect your air admission and discharge pipes improperly at the receiver. To secure the best results and eliminate moisture from the compressed air, connect your pipe leading from the compressor at the top of the receiver and lead your air pipe to points of consumption from the bottom of the receiver.

Don't have leaky air pipes. Test your piping when it is installed and at regular intervals thereafter, allowing the full pressure to remain an adequate length of time, and if the gauge indicates leakage, locate and remedy it.

Don't install your piping without properly providing for drainage of condensed moisture at regular intervals in the system. The simplest method is to slightly incline the branches leading from the main line and insert drain cocks just before the hose connection is reached.—*New Zealand Mining and Engineering Journal.*

PROGRESS IN COMPRESSED AIR.

Mr. Walter H. Knight, consulting engineer of the American Air Power Co., the International Power Co. and the New York Auto-Truck Co., in discussing the advance to a practical point of compressed air for use as a motive power, says:

"The recent advances made in structural material has enabled us to handle pressures with absolute safety that were not heretofore possible. These air pressures mean a greater mileage of vehicles, so that, where one of the old time vehicles, such, for instance, as the compressed air cars used in Paris, can make but two or three miles from one charge, we are now able to run from 25 to 50 miles without recharging. We can build air cars to-day that will run half a day on one charge, having thus to be charged only at night and at noon.

"The air flasks that hold the compressed air under several thousand pounds pressure have been rapidly evolved during the last few years, so that now we can produce in this country, without going abroad, nickel steel flasks, not only twice the strength of those formerly used, but which are absolutely incapable of rupturing under the pressure used.

"There is absolutely no more danger in connection with the pressures used than there was, for instance, with electric motors, where the centrifugal force engenders a pressure of over 5,000 pounds per square inch in the armatures and commutators. This is evidenced sometimes by commutators distributing their commutator work on the roof of the car. In fact, the flasks are much safer, because the pressure is always definite, and not dependent upon some variable factor like centrifugal force, speed, or as in the case of a steam engine, low water, hot fire sheets, etc. The air pressure is a cold pressure and can never exceed that which is given it by the compressor, which itself can go no higher than a certain point and is just as fixed and absolute as is the strain upon the cables of the Brooklyn Bridge. It is always in this, as in other cases, a question and factor of safety. The Brooklyn Bridge would be a very dangerous structure if the cables were not strong enough. If they are, it is safe.

"Quite as important as the question of air reservoirs in bringing the air motor out of the impracticable into the practicable field was the question of heating, which has now been improved to such a point by the use of hot water in connection with the air, that more than double the effect is obtained from the same amount of heat as was done two years ago. This, together with the simplification of the motors to a point where they are scarcely more complicated than an air brake, enables us to produce an air vehicle that fulfills every requirement of an automobile. These vehicles may be charged instantaneously instead of requiring six hours, as in the case of a storage battery; their reservoirs are of unlimited durability instead of being susceptible to the rapid depreciation that affects the storage battery. They have only one-half the weight of a storage battery and, in common with the latter, possess an entire freedom from any æsthetic objection, such as exhaust, odor or noise.

"Analysis shows that only the stored powers are suitable for automobile work in cities. All prime powers have some one or more radical objections from an æsthetic or practical standpoint. Thus the gasoline or gas motors, when you come to have vehicles of any size, have a very objectionable odor. Even the smaller ones are disagreeable enough. Moreover, vehicles of this type lie down and die when they come to grades, even worse than do the storage battery ones, whereas air motors can be used on grades as steep as 20 per cent.

"There is no danger of injuring the reservoir by a sudden draught upon its power, nor is there any injury accompanying the total exhaustion of the reservoir. For street cars, it does away with all appliances along the line, such as trolley wires, underground connections, cables, etc., and requires only a good roadbed. For long distance work, such as now handled by steam locomotives, it offers on the one hand a stored power not limited by fire box or heating surface, and not requiring dangerous, inconvenient and expensive third rails or trolleys. It further offers an economy much superior to that of the steam locomotives, on account of drawing its power from a stationary engine, which, as is well known, produces power for about one-sixth the cost of that produced by a steam locomotive.

"We are in the air business at the birth of a gigantic industry (as we were fifteen years ago in the electric business), that will reach out into every field of power and bring about economies and simplifications that the much-vaunted electricity is incapable of realizing.

"For truck work, where tremendous power is required, with minimum weight and absolute reliability, there is no other force that I can see that comes anywhere near it. Our tracks for carrying 20,000 pounds weigh only 8.000 pounds. They are made of steel only and are as durable pieces of mechanism as any that I know of. They can run at an expense not exceeding ½c. a mile for power, and with instantaneous charging at numerous substations can cover any desired distance. Even with one charge, they can make an ordinary trip in the Metropolitan district with a maximum load."—*Railway Era.*

COMPRESSED AIR SUBSTITUTED FOR STEAM.

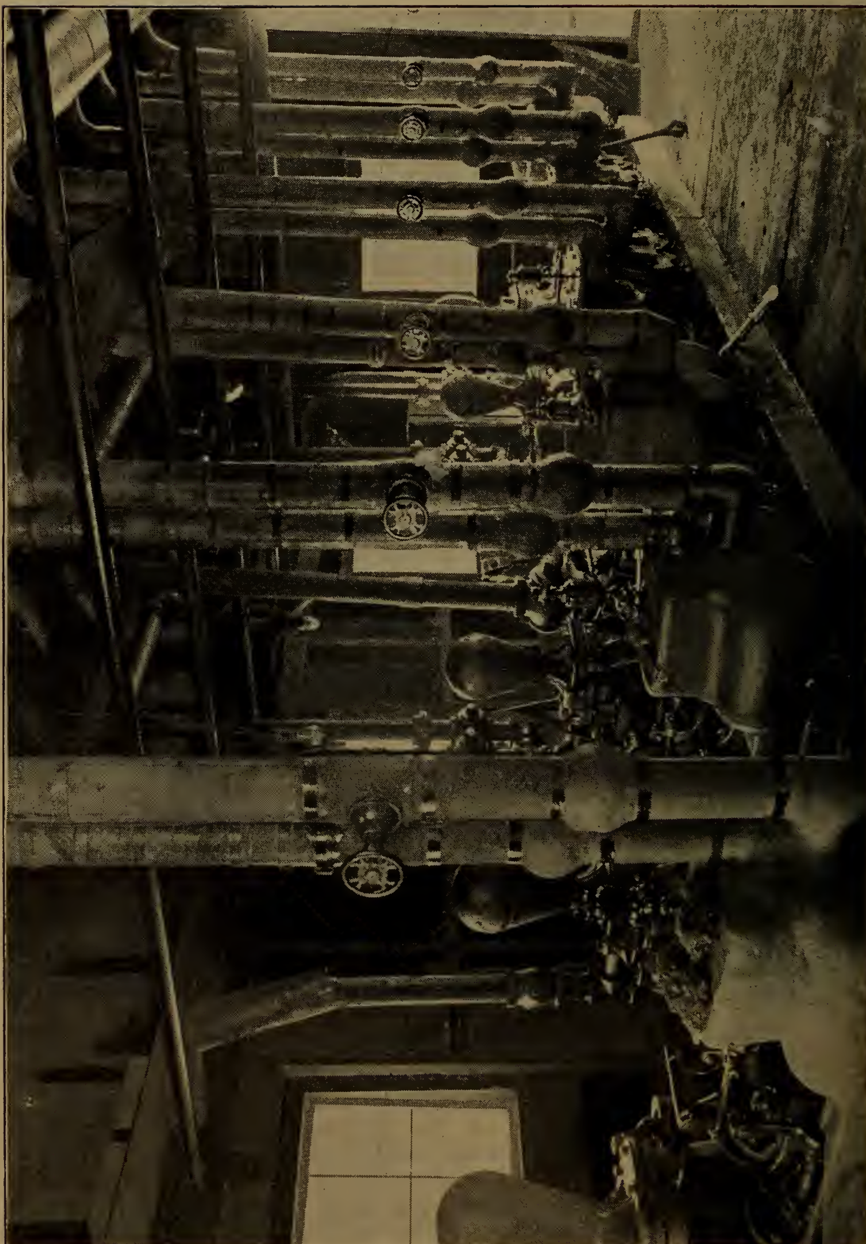
A recent instance of the economy resulting in certain cases, from the substitution of compressed air for steam is found in the Paraffine and Lubricating Department of the extensive refining plant of the Tide Water Oil Company at

Bayonne, New Jersey. In this plant the air from the compressor goes to a suitable tank or reservoir, thence to a series of direct acting steam pumps first reheated as shown in Fig. 117—thence through second reheater to second series of pumps, which were formerly actuated by steam, the exhaust air being finally utilized in the bleachers. The equipment not only performs the essential work formerly done by steam, but the compressed air system also does away with the use of several small compressors which supplied air to two pressing plants, the wax refinery and

FIG. 117.—REHEATING AT PUMPS.

also to the acid works. The machinery was furnished by the Ingersoll-Sergeant Drill Company, of 26 Cortlandt Street, New York, and Mr. P. R. Gray, Superintendent, of the oil works designed and put in the system.

From the compressor the air is conducted into an old steam drum which was formerly attached to the No. 2 battery of boilers, and from this drum, which serves as an air storage tank, the main line leads to the several oil agitators, with branches at several intermediate points for supplying the pumps with



air, where steam was used heretofore. Heaters for reheating the air for power were arranged in connection with the pumps, and the piping was so placed that the air after being twice used as power was finally used, as stated, for clearing the oil in the bleachers. The large pipe and fittings formerly employed for blowing the agitators were all replaced by smaller sizes in more simple arrangement. The larger portion of the air is used in blowing the agitators for which purpose three large steam blowing engines were used before. One portion of the pumping plant is illustrated in Fig. 118. These pumps are of the Smith Vaile duplex type, and are

FIG. 119.—STORAGE TANK.

arranged in two groups in the same compartment. The total number of pumps is 14, 12 of which are placed in the building shown in Fig. 117. Six of these have steam cylinders 7 inches in diameter, pump cylinders 6 inches in diameter by a stroke of 9 inches; one pump having steam cylinder 12 inches, pump cylinder 6 inches by a stroke of 11 inches; four pumps, steam cylinder 5 inches, pump cylinder 4 inches, and a stroke of 8 inches; and one pump steam cylinder 6 inches, pump cylinder 6 inches by 6-inch stroke. Air for the first series of pumps is first reheated in the reheater shown in Fig. 117, the air being used at a pressure of 60 pounds, and exhausted against a back pressure of 30 pounds. The exhaust is again reheated and passed to the second series of pumps which are designed for lighter service where it is exhausted against a pressure of 7 pounds into a storage drum, Fig. 119, from which it passes to the bleachers. This third use of the air was not included in the scheme as at first mapped out. The system is so adjusted that if the work being done at any time by the light service pumps does not use all the exhaust air from the high pressure pumps the surplus may be passed to the agitators for blowing.

In a statement made by Mr. Gray to the directors, we find the following: "This plant has displaced three steam blowers which used, when running in ag-

FIG. 120.—REHEATING FOR ACID WORKS AND PRESSING PLANTS.

gregate, at the rate of 239 horse power of steam, average time run eight hours in 24, or net average, 79 boiler horse power. Also two air compressors, 34 horse power; also steam displaced in 14 pumps which before used every 24 hours 90 boiler horse power, making total boiler horse power of steam displaced by air at the agitators, 203. Add three smaller compressors at the pressing plant and wax refinery, using an aggregate 30 horse power, makes a total of 233 horse power. Deduct from this the average of 55 horse power used by the Payne engine to drive the compressor makes a saving of 178 boiler horse power or $4,450 per year."

The plant was started in January 28, 1897, and with a few exceptions has been in use ever since, has run without a hitch or drawback, and does all that was expected of it by the company.

COMPRESSED AIR AS USED FOR POWER PURPOSES.

DELIVERED BEFORE THE ENGINEERING SOCIETY OF COLUMBIA COLLEGE, ON APRIL 22D, 1896, BY FREDERICK C. WEBER, M. E.

Professor Hutton and members of the Engineering Society: The subject outlined for the lecture to-day is "Compressed Air for Power Purposes."

The use of compressed air as a motive power presents many an interesting problem to the engineer, and especially at the present time when almost daily some new use is discovered for compressed air, so that the list of uses to which it is successfully applied is getting so large that it is difficult to keep track of them all.

A slight acquaintance with this power soon convinces one that it is now rapidly asserting its claim to being the *one power* that can be *most generally* applied. Only a few years ago it was restricted to the mine, the tunnel, and for work in confined spaces, and since it was the *only* power that met the essential requirements of these places, the question of economical production and use did not enter very largely into consideration, so that the early compressors were machines of very low efficiency compared with the best compressors of to-day.

As soon as uses were found for compressed air, that made economical production an important factor, the compressor began to improve; the improvement has been slow, however, and this subject still offers a big field for investigation. The indicator, which has done so much for the development of the steam engine, seems to have been applied very little at the air compressor, and it is only recently that manufacturers began to take cards from their own compressors.

To understand this subject of air compression in all of its details, some acquaintance with the science of Thermodynamics is necessary, and it seems that an air compressor would not be out of place in a laboratory of an Engineering College, where the heating and cooling effects of the air can be studied; also the question of the jacket and intercooler. The exact size of the latter has not been determined as yet; also the transfer of heat units from air to water through different media. Intelligent investigation would still reveal much to the manufacturer that is unknown to him, and would help to bring the air compressor and air motor upon the same high plane of the steam engine. This has reference especially to compound compressors, the economy of which over the simple compressor is not doubted and about which much remains that is unknown.

LITERATURE.

Literature upon this subject is not very extensive; it involves the science of Thermodynamics, and is also intensely practical, so that in order to advance in it a knowledge of the practical and theoretical is necessary.

Professors Wood and Peabody, in their works on Thermodynamics, give considerable space to air compression, the air compressor, and air motor. A. von

Ihering, in "Die Geblaese," published in Berlin by Julius Springer, 1893, treats the subject very exhaustively, and his work is really the highest authority to-day on air compression.

Quite a number of articles on compressed air and air machinery in general have appeared from time to time in the various technical journals, chief among them the *American Machinist* and *Scientific American*. Within the past month a paper called "COMPRESSED AIR" has made its appearance; it is devoted principally to the subject of air compression, and contains both theoretical and practical considerations on this subject.

PRINCIPAL USES.

Chief among the uses to which compressed air is applied, may be mentioned:

Driving rock drills.
Operating air hoists.
  moulding machines.
  sand blast.
  chipping castings.
  air brakes.
For cleaning car seats.
  switch and signal service.
  the Pohle air lift pump.
  sinking caissons.
  caulking.
Operating motors.
  street cars.

A complete list of uses up to date will be found in a work on compressed air by Frank Richards, published by John Wiley & Sons, 1895.

Its use in the mine and tunnel is probably as yet the most general, owing to the peculiarity and confined nature of this work, and other considerations, both mechanical and economical, which exclude steam, water and electricity.

Soon, however, some of the many other uses to which it is applied will equal in importance its use in the mine.

RAILWAY.

The railway companies all over the country recognize its importance in the safe handling of trains under very high speeds, and its position in the railroad shop and foundry will be hard to replace with any other power.

POHLE PUMP.

The Pohle pump is a valveless pump; the air under pressure is liberated at the bottom of a well, and by virtue of its expansive force, it raises a column of water from a depth at which the ordinary piston pump fails.

Sometimes a piston pump is placed so far from the steam-boiler that condensation losses in the pipes and heat generated when the pump is working in a confined space, give compressed air the advantage in operating this style of pump.

TRAMWAY.

Another important use is its use on the tramway, or in operating street car motors. I propose to deal somewhat at length upon this particular use; and since its application here involves high pressures, the compound compressor will receive a greater share of attention at the end of this article, and I will restrict myself to the use of high pressures as applied in the Hardie motor, having with others made an exhaustive test on this motor in May, 1895.

PRODUCTION.

Physical Properties of Air:

Air is considered a perfect gas, and is therefore subject to the natural laws affecting perfect gases.

WEIGHT.

The weight of one cubic foot of dry air at temperature of melting ice and at barometric pressure of sea level (29.92 inches mercury), is .080728 lbs. (M. Regnault.)

VOLUME.

The volume varies inversely as the density; or,

$$V=\frac{1}{W}=12.387 \text{ cubic feet per lb. (at sea level and at temp. of melting ice).}$$

PRESSURE AND TEMPERATURE.

Under constant pressure its volume varies directly as the absolute temperature.

For constant volume the pressure is proportional directly to an increase in temperature, when expressed algebraically—

$$\left.\begin{array}{l}(V_A)_P \propto T \\ (P_A)_V \propto T\end{array}\right\} \qquad \text{I.}$$

or by combining Boyle's law with that of Gay Lussac—

$$\frac{P_0 V_0}{T_0} = \frac{P_1 V_1}{T_1} = C \qquad \text{II.}$$

P_0=Atmospheric pressure at sea level.
T_0=Temperature (absolute) of melting ice.
V_0=Volume of one pound at that temperature (T_0) and pressure (P_0), and is a function of the density.
P_1 V_1 T_1 are specific values
$C=53.21$ for air.

SPECIFIC HEAT.

Air has two specific heats, one at constant pressure .... .2375
the other at constant volume .... .1689

$$\text{The ratio of } \frac{C_P}{C_V} = n = \frac{.2375}{.1689} = 1.4061$$

GENERAL PRINCIPLES OF COMPRESSING.

Work of Compression:

(Simple compressor.)

$$W = P_1 V_1 \log_E \frac{P_2}{P_1} \text{ foot pounds (isothermal)} \ldots\ldots\ldots\ldots\ldots\ldots \text{III.}$$

$$W_1 = P_1 V_1 \frac{n}{n-1} \left[\left\{ \frac{P_2}{P_1} \right\}^{\frac{n-1}{n-1}} \right] \text{ foot pounds (adiabatic)} \ldots \text{IV.}$$

when V_1 = volume of one pound of air at the pressure P_1 and compressed from P_1 to P_2.

COMPOUND COMPRESSORS.

$$W_2 = P_1 V_1 \frac{n}{n-1} \left[\left\{ \frac{P_2}{P_1} \right\}^{\frac{n-1}{n}} + \left\{ \frac{P_3}{P_2} \right\}^{\frac{n-1}{n}} - 2 \right] \ldots\ldots\ldots\ldots \text{V}$$

when compression is done in two stages and cooled to atmospheric temperature between stages.

P_2 = Intermediate pressure, and work done is a minimum when

$P = \sqrt{P_1 \, P_3}$.

COMPRESSION.

The first law of Thermodynamics tells us that heat and mechanical energy are mutually convertible; therefore, when the piston of the compressor is made to do work, heat is produced in exact proportion to the amount of work done (in the ratio of one B. T. U.) for every 778 ft. pounds expended.

Since, however, the usual conditions under which compressed air is employed place the motor at some distance from the compressor, this heat of compression is soon dissipated to the surrounding media, and this loss of heat then represents lost work, so that it is very desirable to be able to compress the air with as little increase in temperature as possible.

If the temperature could be kept constant throughout the compression, this process would be called an isothermal or equal temperature process, and if no heat passed to or from the air during compression it would be termed an adiabatic process.

The loss due to the heat of compression is the greatest loss in the production of compressed air, and to prevent this loss a cooling medium is supplied that will abstract the heat during compression. Water is usually employed, and it has been used in various ways, calling into existence two distinct classes of compressors—

1) Wet compressors.

2) Dry compressors.

In the first class water is introduced directly into the cylinder during the compression process, and in the second class *no* water is admitted to the air during compression.

Wet compressors are subdivided into two classes—

a) Compressors in which water is sprayed into the cylinder during compression, and

b) Those which use a water piston for compressing.

The first class of wet compressors has shown the highest degree of efficiency for one stage (or simple) compressors, because the water is thoroughly mixed with the heated air and takes up the heat readily (due to the difference in the specific heats of water and air). The injected water must not be excessive, or damage will result to the compressor. An increased capacity also results from using water in the cylinder to fill the clearance spaces.

Although the spray injection compressor will show a higher thermodynamic efficiency than the dry or jacketed compressor, its commercial efficiency is not so high, for water in the cylinder prevents proper lubrication; impurities in the water also attack the walls of the cylinder, and the moisture in the air causes

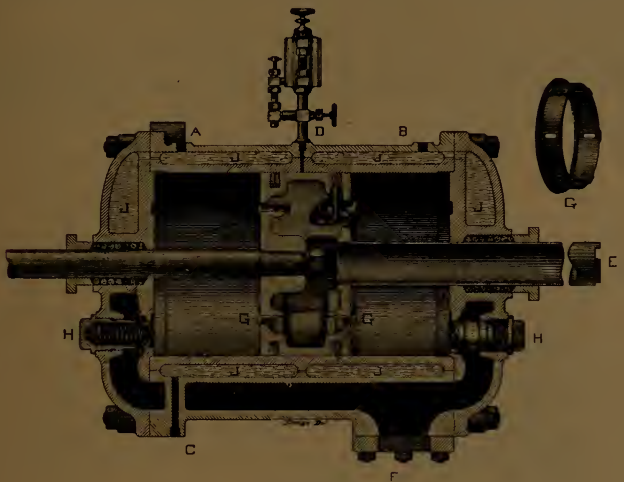


FIG. 121.

freezing of the delivery pipe in cold weather, also choking of exhaust in motor due to freezing, resulting from low temperatures of expansion.

The hydraulic piston or plunger compressor has a very low efficiency, and is now obsolete.

In the Dry Compressor the external walls of the cylinder are flooded with water, the cooling effect is not as great as in the spray injection compressor but it overcomes all of the disadvantages of the Wet Compressor—it is very popular in this country while the spray injection compressor seems to be the popular compressor abroad.

Fig. 121 shows the jacket (J) applied both on head and sides of a cylinder of the Ingersoll-Sergeant Compressor.

The air enters the cylinder through the hollow tail-rod (E) the inlet valves (G) being placed inside the piston. At the beginning of the stroke both inlet valves remain stationary, due to their own inertia and the piston moves towards the valve on the compressing side and away from the intake valve, about ¼″ is allowed between valve and seat, this is sufficient to admit a free inflow of air; there is no loss in vacuum due to late opening. On the compression side the pressure line begins to rise very close to the beginning of the stroke and increases until slightly in excess of the receiver pressure when the discharge valve (H) opens and the air is now forced into the receiver until the end of the stroke. The crank is now passing the center and for an instant the piston comes to a stop before it goes on its return stroke, during this operation the spring in the discharge valve combined with its weight forces the valve to its seat, cutting off all communication between receiver and cylinder—the air that remains in the clearance spaces expands back to atmospheric pressure and then admission for the return stroke begins and the same cycle is completed as described above.

SOURCE OF LOSS.

The Efficiency of an Air Compressor is often stated in terms of the mechanical efficiency and the efficiency of compression, this is the truth but not the whole truth, for in every Compressor there are two losses which effect the capacity or the amount of air delivered—the *first* of these losses is that due to the

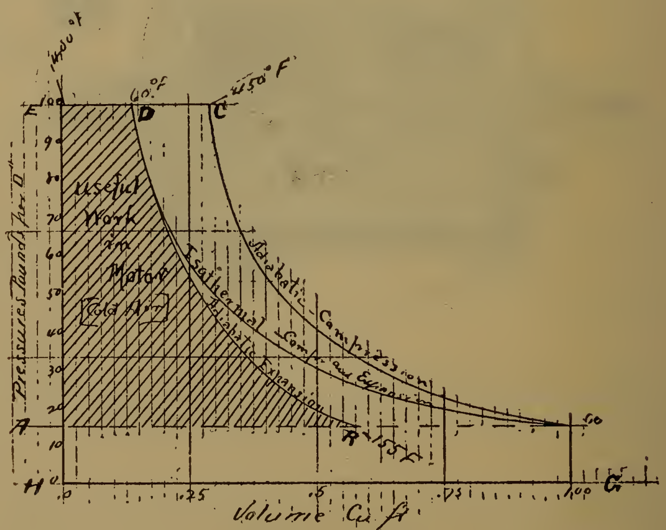


FIG. 122.

heat of the inlet valves by the friction of the air in passing into the cylinder—the ingoing air coming in contact with these hot valves expands and consequently a less weight of air is admitted per stroke.

The *second* loss is that due to clearance; the air in the clearance spaces in expanding back to atmospheric pressure prevents admission at the beginning of the stroke. The efficiency of the "intake volume" can be taken into account when a compressor is designed for a given quantity of air delivered, by increasing the diameter a fraction of an inch.

The *third* loss involves friction of the mechanism, and has been reduced to less than 10 per cent. in the best compressors, and should not exceed 15 per cent.

The *fourth* loss is that due to the heat of compression, and is the most serious, and can be best shown by a diagram.

Fig. 122 shows a theoretical card (no clearance) from an air cylinder. The admission takes place at (A), follows along (A B); (A B G H) represents work of the atmosphere on piston in suction stroke. When the compression is isothermal, the compression line is represented by (B D) and by (B C) when compression is adiabatic. (C D E) represents receiver pressure. The temperature for adiabatic compression in this card is (450° F.) at the end of compression; and from C to E it is lowered, due to the cooling action of the jacket water to about 400° F. From this diagram it is apparent that the benefit resulting from the jacket is greatest up to the point of communication between the receiver and cylinder (C); for after the terminal pressure has been reached there is no

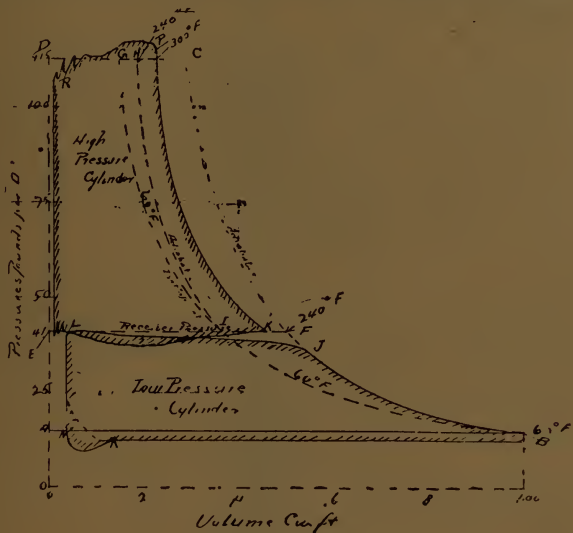


FIG. 123.

further need for cooling unless it be that the cooling for this part of the stroke (C E) helps to keep the cylinder cool for the next charge. If it were possible to obtain isothermal compression, the temperature throughout the process would be 60° F., and the area B C D would represent work saved.

In an actual diagram taken from a dry compressor, the line of compression lies very close to the adiabatic, because only a small part of the charge comes in direct contact with the cold walls; and since air has a very low specific heat and low conductivity, the cold does not penetrate the main body. When cards taken from a dry compressor show a compression line close to the isothermal, the chances of leakage by the piston or valves are very great.

From the fundamental equation of a perfect gas we are able to deduce the following:

$$\frac{P_1}{P_2} = \frac{T_1}{T_2} \text{ (when volume remains constant)} \ldots\ldots\ldots\ldots\ldots \text{VI.}$$

Any increase in the ratio of pressures means a corresponding increase in temperature; and from what has just been said about heat losses, it is very evident that any increase in pressure will be followed by a decreased efficiency of the compressor unless some means are provided for abstracting the heat during compression, for the jacket water of the simple compressor has been shown to abstract very little heat, the actual compression curve lying closer to the adiabatic than the isothermal.

This being the case, it clearly shows that the simple compressor is out of the question for high pressures when economy is looked for. The compound or stage compressor offers the best solution of this problem.

Fig. 123 represents a theoretical card taken from a compound compressor. The pressures are usually so proportioned that the total work is divided equally

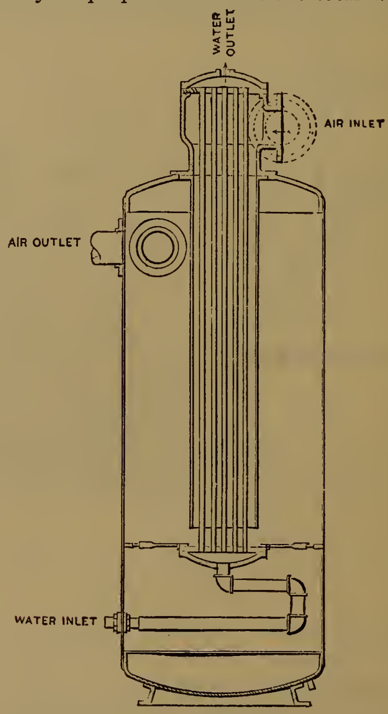


FIG. 124.

between the cylinders. Since any increase in temperature depends upon the ratio of pressures, the advantage of the compound compressors is apparent. The temperature now at the end of compression in each cylinder is 240° F. The pressure in the first cylinder is carried to 41 pounds (absolute,) and in the second cylinder the pressure reaches 115 pounds (absolute).

The line (L I F) represents the receiver pressure or the intercooler. The air in passing from low pressure to the high pressure cylinder, passes through an intercooler and is cooled down from 240° to 60° before it is compressed a second time, or the shrinkage in volume is represented by I F. Compression in the high pressure cylinder begins at I, and for adiabatic compression follows along the line I H. Assuming, now, that the cylinder jackets are inefficient, or that the compression process has been adiabatic in both cylinders, the saving due to the intercooler will be represented by the area F I H C.

INTERCOOLER.

The air in passing from the low pressure cylinder to the high pressure cylinder is conducted through an intercooler, which acts at the same time as a receiver.

This intercooler (Fig. 124) is filled with a number of small tubes made of material of high conductive capacity, through which water passes quite freely, and these tubes are so arranged that the air in entering the intercooler is made to flow over the tubes in fine layers, thus bringing as much of the whole body of air in contact with this cool surface as possible.

It is quite necessary that the intercooler should be of sufficient size to prevent fall in pressure when communication is established between it and the high pressure cylinder. Another advantage of size will be the greater chance of perfect cooling, shown on the card by a decrease in volume at the end of compression in the first cylinder and the beginning of compression in the second.

ACTUAL CARDS.

A set of cards taken from a compressor will show many defects, some of which have been shown in the diagram of Fig. 123. For instance, if the admission is not free, the compressor will be working against a partial vacuum, following along M O instead of N B. Then, if the jacket is inefficient, the compression line will almost coincide with the adiabatic. Next, if the intercooler fails to cool the air to atmospheric pressure, the compression will begin at (K) instead of (I) in the highest pressure cylinder.

The next loss is usually due to insufficient port opening at the discharge, or a loss in raising the delivery valve (P). If this valve is worked through a mechanical device from some other part of the compressor, a loss is often the result, due to late opening, the pressure in the cylinder being in excess of the receiver pressure, causing the air to expand from high pressure in cylinder to pressure in receiver, and no benefit is derived for the extra work done. Defective closing of discharge valves also cause a loss, as will be seen at (R). Clearance losses have been shown to affect capacity only; however, in the compound compressor this loss is reduced to a minimum, for the air in the low pressure cylinder is at a lower tension, and consequently its expansion is not so great. The effect of clearance in the high pressure cylinder is to throw only a slight amount of extra work upon the low pressure cylinder.

If the intake valve does not open at the proper moment, a partial vacuum results, causing another loss, due to negative work, as seen at N M.

Fig. 125 shows a cross-section of a double compound Norwalk compressor, with intercooler. There are 4 cylinders—2 air and 2 steam, arranged tandem—both pairs compounded. The cooling water is admitted first to the high pressure cylinder, then to the low pressure cylinder jacket, and lastly to the intercooler.

The air is admitted to the cylinder by valves of the Corliss type, and have a positive movement from the main shaft.

THREE AND FOUR STAGES.

The advantage of the compound compressor is very evident from Fig. 123, showing clearly how near we approach the isothermal line. Theoretically we can achieve isothermal compression only if we had an infinite number of stages to compress to. However, the friction of the mechanism will soon put a limit upon the number of stages.

TABLE SHOWING PER CENT. OF WORK LOST.

I have prepared a table (Table 39) showing the per cent. of work lost due to heat of compression, based upon Formula III., IV. and V. It is assumed that the temperature is brought back to atmospheric temperature between each stage, and no account is taken of the jacket cooling.

These figures speak for themselves, and show the advantage of compounding very clearly. For instance, at 2,000 pounds pressure, the loss in one

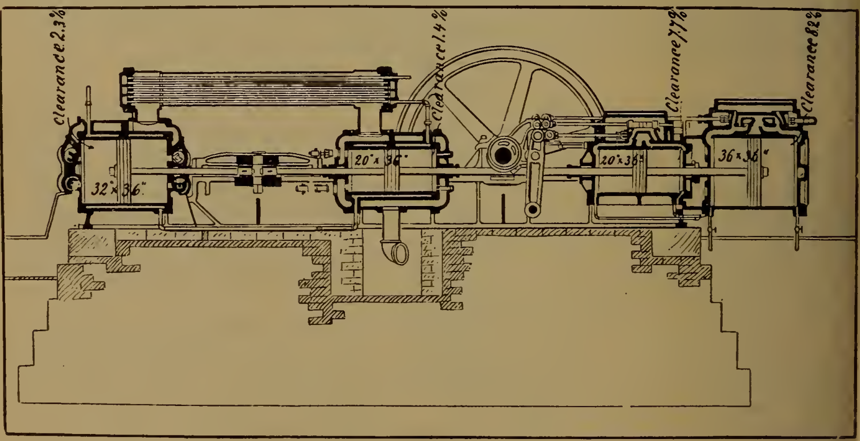


FIG. 125.

stage compressor is 54.8 per cent.; in a two stage, 30.8 per cent.; and in a four stage compressor only 16.65 per cent.

COST OF COMPRESSING.

The cost of compression will be in direct proportion to the amount of work done—i. e., pressure and volume swept through—and will depend upon the style of compressor. If a slide valve compressor is used to do the work, 30 or 40 pounds of steam may be counted upon to furnish a horse power; but if the compressor is a Corliss Compound Condensing Compressor, a horse power will be developed upon 15 to 18 pounds of steam, showing that for a permanent plant first cost is not the most important consideration.

TABLE 39.—PER CENT. OF WORK LOST DUE TO HEAT OF COMPRESSION.

Gauge Pressure.	ISOTHERMAL COMPRESSION AS BASE LINE.			
	One Stage.	Two Stage.	Three Stage.	Four Stage.
	No account taken of Jacket Cooling.			
	n = 1.408	Air assumed to be cooled to atmos temperature between stages.		
	Per cent.	Per cent.		Per cent.
60	23	11.8		4.45
80	25.26	13.12		4.80
100	27.58	14.62		7.41
200	34.40	18.88		8.27
400	40.75	22.90		11.04
600	44.6	24.60		13 10
800	47.4	26.33		14.32
1,000	49.2	28.10		14.45
1,200	51.6	28.60		14.85
1,400	52.0	29.4		15.00
1,600	53.3	30.0		15.54
1,800	54.0	30.6		16.05
2,000	54.8	30.8		16.65

COST OF HIGH PRESSURES.

The power cost of compressing to high pressures is not proportional to the pressure. It costs less proportionately to compress from 1,000 to 2,000 pounds than it does to compress from atmospheric pressure to 1,000 pounds. This can be shown by placing proper values in Equations IV. and V. Theoretically a point can be reached in the compression curve where a slight increase of power will result in an infinite pressure.

RAND FOUR STAGE COMPRESSOR.

The total compression is accomplished in four stages, and it is designed especially for marine service, to supply the torpedo boat with power for discharging torpedoes.

The problem for the designer was compactness consistent with strength and least weight.

INGERSOLL-SERGEANT FOUR STAGE COMPRESSOR.

Fig. 127 represents a four stage compressor (with intercooler) attached to a Corliss engine. The cylinders are single acting, and are fitted with plunger pistons. A compressor of this type will compress one cubic foot of free air per minute, from 15 pounds to 2,000 pounds per sq. in., at a power cost of .4-10 horse power and 1.3 lbs. coal per 100 cubic feet of free air. There are three intercoolers, each of sufficient size to reduce the temperature of the air at the end of compression to normal temperature.

USE.

Having thus shown how the air is compressed and by virtue of which energy is stored, our attention is next turned to the utilization of this stored energy.

The air cylinders are all enclosed and surrounded by water. Three gauges are shown which record the pressures of the different cylinders.

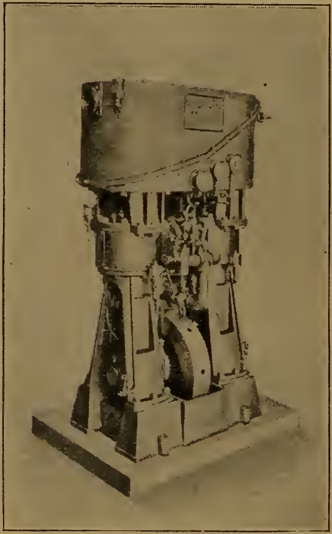


FIG. 126.—RAND HIGH PRESSURE COMPRESSOR.

The intrinsic energy of one pound of air at atmospheric pressure and temperature of melting ice, may be shown to be by the following formula:

$$C_v T_o = \frac{p_o v_o}{n - 1} = 64,735 \text{ foot pounds} \quad \text{VIII.}$$

C_v = Specific heat at constant volume.

T_o = Absolute temperature of melting ice.

p_o = Mean pressure of atmosphere in pounds per sq. ft.

V_o = Volume of 1′ at p_o and T_o.

n = Ratio of specific heats = 1,406.

Since the heat of compression due to the mechanical energy expended upon the air by the piston is usually dissipated to the surrounding objects before the air reaches the motor, and for which we therefore get no mechanical equivalent, we are obliged to draw upon the *intrinsic energy stored* in the air if we wish to get any useful return for the work expended.

WEIGHT OF AIR USED.

The number of cubic feet of free air used per minute for a given amount of work may be determined as follows:

$$C=\frac{W}{w}=\frac{33{,}000\ N}{U\ w} \qquad \text{VIII.}$$

W = Weight of air per minute to deliver N horse powers per minute.
w = Weight per cubic foot at atmospheric temperature.
U = Work in foot pounds per pound of air.

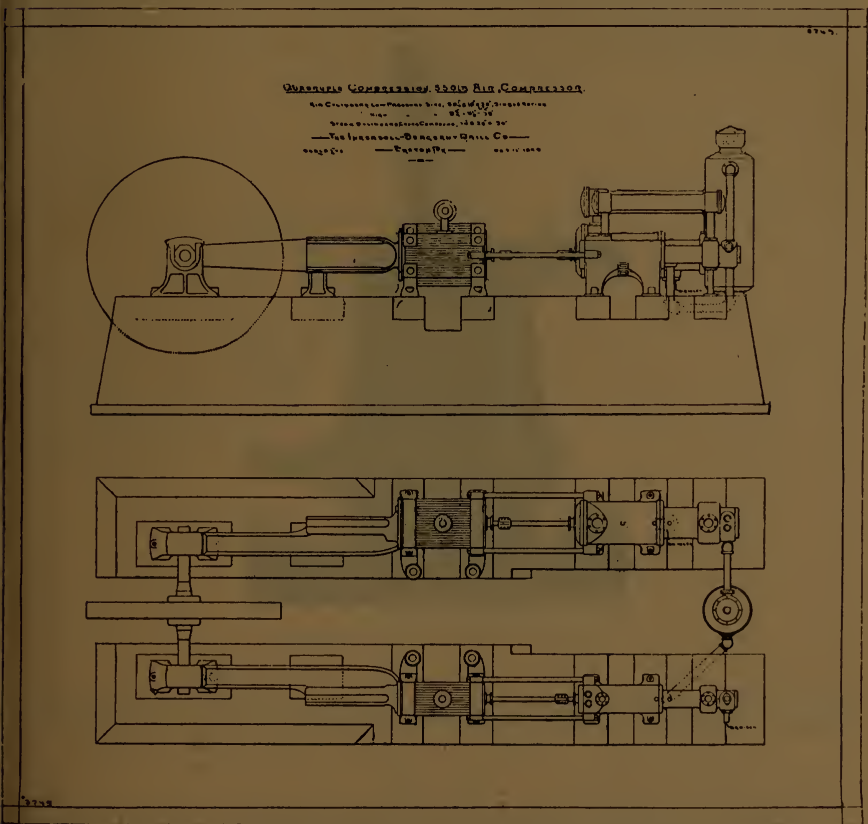


FIG. 127.—INGERSOLL-SERGEANT FOUR STAGE COMPRESSOR.

The value of U will depend upon complete or incomplete expansion, or upon full pressure working:

$$U=P_2 V_2 \frac{n}{n-1}\left[1-\left(\frac{P_A}{P_2}\right)^{\frac{n-1}{n}}\right]\left(\frac{T_3}{T_2}\right) \qquad \text{IX.}$$

P_2 = Initial pressure.
V_2 = Corresponding volume.
P_A = Exhaust pressure.
(No allowance for clearance, leakage and valve resistance.)

INGERSOLL-SERGEANT FOUR STAGE COMPRESSOR.

From experiments made with reheating air at a point very close to its application, it has been found that U may be increased in proportion to the heat imparted, or in the ratio of—

$\frac{T_3}{T_2}$ (absolute temperature.)

Since any increase in the valve of U will effect a corresponding decrease in C (number of cubic feet used per minute), the aim of the practical engineer

FIG. 128.—SERGEANT AIR REHEATER.

should be directed towards reheating and expansive working. The cost of reheating is about one-eighth of a pound of coal per horse power per hour.

AIR MOTOR.

Most air motors in use at the present time have been designed after the steam engine; in fact, the steam engine is often converted into an air engine with very good results. Considering, however, the difference in the properties of both fluids, there is no doubt that higher efficiencies can be attained when the motor is especially designed for the use of air.

Fig. 122 represents also a theoretical card taken from an air engine, and shows the volume of air taken in at the compressor to be contracted from C to D, due to falling temperature, and when it reaches the motor it is about 60° F. If it is used expansively, then the expansion line will be (D R); great cold will result, and the theoretical temperature at R will be about -155° F., and if moisture is contained in the air it will cause freezing of the exhaust ports unless provision is made for abstracting it.

If heat could be supplied during expansion, we would be able to trace the isothermal D B, and there would be no loss at all. This is impossible, of course, and the efficiency is, as here shown, about 50 per cent. Now, if the air is heated before it is admitted to the motor, the volume would increase from D to C, and if expansion took place along C B (adiabatic), we would get back all the work that was put into the air in the compressor, taking out, of course, valve resistance and other losses incident to transmission. Continuing this argument, if it were possible to use the air in the motor-cylinder at temperature above 350° to 400° F.,

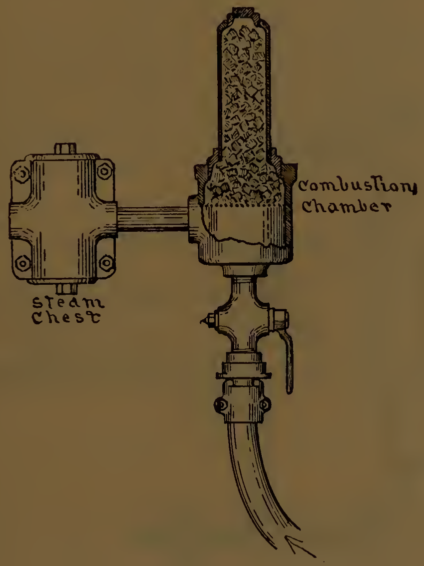


FIG. 129.

we would be able to obtain more work from the air than was originally expended upon it, at a very small additional cost for reheating.

We have just seen that by reheating the air we increase its energy in proportion to the heat applied, or—

$W = C_p (T_1 - T_2)$ foot pounds of energy supplied to every pound (at constant pressure.)

Aside from this thermo-dynamic gain, we also overcome the danger of freezing at the exhaust port in the motor, for the temperature of exhaust is raised above that of the freezing point.

REHEATERS.

There are various practical methods of reheating. The most prominent are:

I) Applying heat through metal surfaces.

II) Internal reheating.

SERGEANT REHEATER.

One of the first class is shown in Fig. 128, and is known as the Sergeant Reheater. This reheater consists of two cast iron shells, which are bolted together. Air enters the annular space at the top and passes in thin layers over the walls of the heater into the annular space at the bottom, which forms the outlet. In appearance it resembles a truncated cone. The advantage of this form is to keep the velocity of the air constant. The air being hot, it has greater volume,

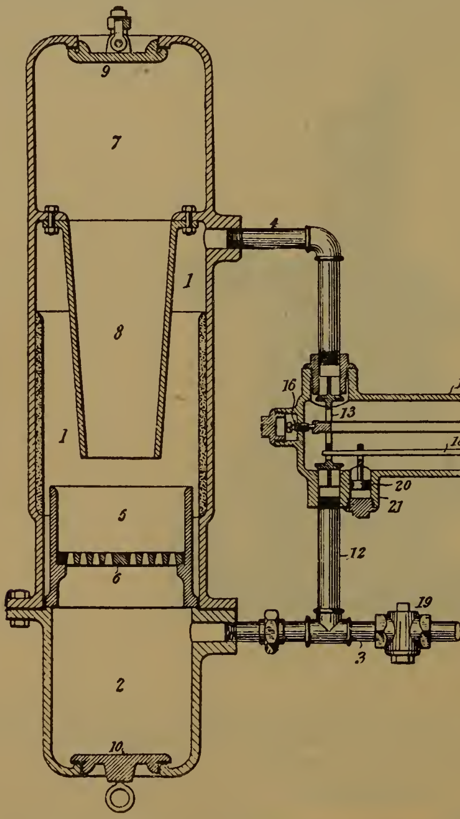


FIG. 130.—PARKE REHEATER.

and would consequently increase the friction if there was no room for expansion. The fuel may be either gas, oil or coal, or coke; when made for coal or coke, it will be supplied at the top, and the ash will be drawn from the bottom.

Tests have been made with this heater, and the results show that 340 cubic feet of free air per minute, at 40 pounds pressure, can be reheated to 360° F. This is equivalent to a gain of 35 per cent. imparted to the energy of a pound of air. The capacity of this reheater is given as 400 cubic ft. of free air per minute.

SAUNDERS' INTERNAL REHEATING.

Fig. 129 represents a reheater of the second class, known as an internal reheater—i. e., where the air comes in direct contact with the fire. This illustration represents the reheater actually applied to a rock drill. It is placed between the throttle valve and steam chest, and represents an enlarged pipe fitting, with a wire gauze to keep the coal or coke, which is in an incandescent state, from blowing into the steam-chest. Coke or charcoal is supplied through an opening at the top, which is then securely fastened. This method of reheating ought to be very economical and effective. The air supplies the oxygen which promotes combustion, and the resulting heat is transmitted direct into the motor cylinder.

PARKE REHEATER.

In the Parke Reheater, shown in Fig. 130, fuel is admitted at 9; 8 is a hopper, and 5 the grate; 2 the ash pit, and 10 an opening to blow out ashes. The air is supplied through the pipe 3, and it passes over hot coals and out through pipe 4, then into a thermostat; 15 is a bar made of metal, with a high coefficient of expansion; 13 is a double valve, and 14 is the outlet; 16 is a regulating screw. When the temperature is too high, the bar 15 expands, and, working through

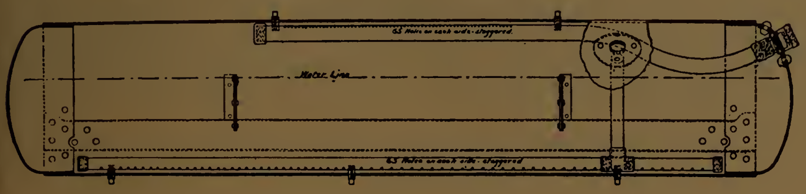


FIG. 131.—HARDIE REHEATER.

levers, 17 and 18 helps to shut off the supply of hot air and at the same time admits cold air through 12, thus reducing the temperature and keeping it uniform. The adjustment can be made so that the temperature will not vary 5 degrees. There is necessarily a limit to the temperature of the air at which it may be admitted to the motor, and this is about 300° to 350° F. The pipe for transmitting the air will have to be well covered to keep the air heated at this high temperature, as air parts with its heat as easily as it takes it up.

Another method of reheating, and one which has met with a very high degree of success, both in this country and abroad, is a system of passing the air through hot water under pressure on its way into the motor cylinder (Fig. 131). This system is in vogue in the Hardie motor, and has given good results, some of which are given in the table (Table 40).

The water in this tank is heated by blowing a jet of live steam into it, and the air passes through fine openings into the water at the bottom of the tank. In passing through the water the air takes with it some of this water in the form of vapor, passing through the perforations in the pipe in the top of the tank and then out into the cylinder. The advantage of this steam in the cylinder is twofold—(a) lubrication of cylinder and preventing leakage past piston; (b) the air in expanding draws upon the latent heat of the steam, and therefore brings the expansion nearer to the isothermal.

TABLE FOR REHEATING.

Table 40 shows the comparative values of different methods of reheating, as determined by experiment at Frabrick Street, Fargeau. The hot air and water injection method seems to have given by far the best results, the efficiency of the fluid being almost double that of the cold air.

SEPARATOR.

Sometimes it is not practical to reheat the air, especially when the motor is being moved from place to place; and then if the motor works air expansively, the danger due to freezing can be successfully overcome by means of a separator placed in the pipe near the motor.

An experiment was made at Cornell University, with which I am familiar, to operate a small slide valve engine with air at an initial temperature of 40° F. A separator was made out of a 6-inch pipe, with caps on both ends. The air was drawn from this separator at right angles to the supply; the moisture in the air was thrown against the sides of the separator and ran to the bottom, where it was drawn off from time to time by a small drip-cock. This experiment was successful, and the engine did not stall when we reached as low a temperature as 3° F. (A lower temperature might have been reached but for the fact that the engine was cutting off at ¾ stroke.)

TABLE 40—COMPARATIVE TESTS OF COMPRESSED AIR MOTORS AT FABRIK ST., FARGEAU, USING COLD AIR, HOT AIR, AND HOT AIR WITH WATER INJECTION.

Description.	Cold Air.	Hot Air.	Hot Air and Water Injection.
Weight of air used per 1 H. P. per hour in cylinder ..	63.65 lbs.	45.526 lbs.	33.59 lbs.
Volume " " " " " measured at exhaust........................	822.7 cu. ft.	586.14 cu. ft.	432.55 cu. ft.
Volume of air used per 1 H. P. per minute...........	13.7 "	9.76 "	7.2 "
Temp. of compressed air (inlet).......................	62° F.	392° F.	392° F.
" " (exhaust)....	—67° F.	32° F.	122° F.
Total efficiency of fluid	46.2 p. c.	64 8 p. c.	86.9 p. c.

(Abstract from paper of Jos. Francais in "Seraing Belgien," 1888.)

The consumption of free air per minute, when reheated, has been stated for the Paris air motors, by a writer of authority, to be from 11 to 15 cubic feet per 1 H. P. per minute, and when using air cold, 15 to 25 cubic feet per 1 H. P. per minute.

HARDIE MOTOR.

In the Hardie Motor tested by W. K. Lanman and myself in May, 1895, we found the consumption of free air per minute to be from 6 to 6.7 cubic feet per 1 H. P.

In this test our object was to determine the most economical working pressure, and also to determine the efficiency of the reheater. We made 7 runs with initial pressures ranging from 55 pounds to 140 pounds per square inch. Every other condition was kept as nearly constant as possible. The air was passed through the hot water in the reheater, but as the heat stored in the water was gradually becoming less, the efficiency diminished from beginning to end of run. This can be shown by a set of curves if desired.

Table 41 shows some results of tests of the Hardie Motor.

TABLE 41.—ABSTRACT FROM TEST OF HARDIE MOTOR, AT ROME, N. Y., MAY, 1895.

Number of Run.	I.	II.	III.	IV.	V.	VI.	VII.
Average working pressure lbs., sq. in......	54.6	69.6	91.9	100.2	116.8	141.	133.
Distance run in miles......................	1.14	2.49	2.96	3.27	3.25	3.58	1.57
—Reheater—							
Temp. of air entering heater	78° F.	70.8°	67.6	61.5	63.	65.2	71.
Temp. of air leaving heater................	210°	248	197.5	247.5	197.	240.3	196.7
Temp. of air at exhaust....................	127°	148.6	108.	146.7	104.4	130.7	99.
Degrees taken up by air in passing through heater	132°	177.	129.9	186.	134	175.1	125.7
Difference in temp. in heater, begin. and end run	18°	21	30	47	28	49	16
Indicated horse power	3	7.1	9.79	11.9	10.86	12.45	11.19
Pounds of water used during run...........	15 08	25.7	30.35	27.6	12.1	29.37	10.05
Air used per 1 H. P. per minute, cu. ft.....	7.7	6.4	6.1	6.1	6.6	6	6.7
Per cent. of power obtained from heater...	41.4	46.5	32.5	47.	36.	43.2	34.6
		I.	II.	I.	II.	I.	II.

There were two runs made with one charge of hot water, and the second run in each case necessarily shows a lower efficiency, due principally to loss of heat from the reheater. If the reheater could be supplied with heat during the entire run, there is no doubt that the above figure of 6 cubic feet per minute can be still further reduced. The power obtained from the reheater was about 45 per cent. of the total power developed. We made one run without hot water in the reheater, but as the temperature of the tank was still above 100° F. when we started our run, the consumption of free air per minute was 8.8 cubic feet. Other experiments made since, show that when the tank is at atmospheric temperature the consumption is about 12 cubic feet, so that when this motor is working with cold air it is as economical as the foreign motors, of which we have given figures above, working hot air.

In the Hardie Motor the air is compressed to a pressure of 2,000 pounds per square inch. It is stored in Mannesmann seamless tubes, which are shaped like a bottle with a round bottom. At the neck copper tubes are screwed in securely, and there are 16 tubes, and each 7½ inches diameter, but of different length, so as to utilize all dead spaces under the car body. These tubes are tested to 4,000 pounds pressure, and are all connected so as to form one receiver. The capacity in cubic feet is about 45, which means that the free air capacity is about 6,000 cubic feet. The car will be able to travel about 15 miles on one charge.

The power to compress 6,000 cubic feet per minute in a four stage compressor will be about 3,000 H. P., if done in one minute, and in 5 minutes it will take a 600 H. P. compressor.

Since it is not practical to use air at such high pressures in the cylinder, on account of losses due to clearance, this pressure is reduced by means of a reducing valve, and air is admitted to the reheater and then to the cylinder at about 140 pounds per square inch. This great loss, due to wire drawing, is compensated for in the storage, for with such a supply (6,000 cubic feet) there need be no delay and inconvenience due to recharging until the power house is reached.

If it could be arranged to keep the water heated throughout the run, there is no doubt that the efficiency of this motor would be very much increased.

Chairman—If any of the members desire to ask Mr. Weber any questions, I think he will take pleasure in answering.

Student—I should like to ask Mr. Weber how these air motors compare in efficiency with other forms of motors?

Mr. Weber—The efficiency is high. The compressed air motor is usually as high as that of the steam engine; and, as I said, if special designs were made for air, they would be still higher. There is a report published of tests made in Paris by Prof. Unwin, on small rotating air motors, and I think it showed from 80 to 85 per cent. I don't know the exact figures.

Student—In that reheater you spoke of, invented by Mr. Saunders, where the air comes in direct contact with the heated coals, I should think there would be trouble from ashes being carried into the cylinder.

Mr. Weber—Mr. Parke overcomes all that. I think his reheater is an improvement over Mr. Saunders' reheater, for he furnishes a constant supply at constant temperature, which is very important at times; but Mr. Saunders' idea is a good one for such rough work as with drills.

Student—I should think some sort of electrical reheater could be used.

Mr. Weber—I can refer you to an article by Mr. Wm. L. Saunders in "Cassier's Magazine," 1892, a reprint of his lecture on compressed air before the Franklin Institute of Philadelphia he speaks of some electrical devices.

ECONOMIES IN THE USE OF COMPRESSED AIR.

An Inlet Cooler which Saved Five Per Cent.—Suggestions Regarding the Suction Valve Chamber—Staging and Intercooling, and How the Latter Might Be Improved.

Advantages of Compressed Air Over Other Sources of Power in Deep Mining—Great Developments Predicted.

BY R. P. WHITELAW.*

It seems strange that although compressed air has been used chiefly in mines for hoisting, pumping, coal cutting and various devices for the last 50 years, little or nothing has been done towards making it an economical method—

*Paper read before the Mechanical Engineer's Association of South Africa.

whether on account of the difficulties which have presented themselves in the form of heat or cold, or a general indifference to its use, I am not in a position to say—but I am inclined to think it is the latter, as our greatest engineers and experimenters have lived during that period; and had they devoted the same attention to this subject as they have given to steam and electricity, compressed air would stand on a much higher level than it does to-day, and there would be but little use for electricity.

In about the year 1849 an air compressor plant was installed in Glasgow for driving an underground air hoist; the compressor, I might say, was a fast running one, and but little attention was giving to cooling devices, and the result was that it had not run many hours before the cylinders and pipes close to the compressor were red hot; in fact, the engineer thought they would melt, and then the report came up from below that the engine had frozen up; this was thought to be a great phenomenon, and was talked about all over the country. The freezing was caused by over-expansion, and yet the difficulty was got over without changing the ratio—by injecting a spray of water into the compressor cylinder the temperature was reduced to such an extent that there was no difficulty in running the compressor. The moisture thus injected was then carried over to the hoist and prevented the freezing up of the exhaust ports. Had the air been dry in the first instance (I might say there is no such thing as dry air) freezing up could not have taken place, and yet it was prevented by still adding more water to it. This may seem strange, yet it was so; for air with a high percentage of water has a much higher specific heat value than dry air, so that in the first place it is more difficult to heat, and in the second it is more difficult to cool. In round numbers, dry air at 140 deg. F. initial temperature, with a ratio expansion of 2, is reduced to 32 deg. F., whilst moist air with the same initial temperature is only reduced to 32 deg. F. after four expansions. The same applies to the compression of air. Atmospheric air at 68 deg. F. initial temperature, when compressed to 100 lbs. pressure, rises, if dry, without cooling to 490 deg. F., and if sufficiently moist to 194 deg. F. only.

The practice of injecting water into the compressor cylinder is being carried out to the present day in some of the Scotch collieries, and so long as it will run their engines they are satisfied, and the difficulty for them is ended; a few tons of coal per week is of no importance in their calculations; thus compressed air is, by Scotch coal owners and by many other users, left to work out its own salvation. It is wasteful even to the extent of 50 to 60 per cent., and we only use it where we cannot use steam; that is how compressed air is abused, and I really think there are more abusers than users of it.

When the air is compressed all the work which is done in the compression is converted into heat, and from this it would seem that as soon as all the heat has been got rid of the work done on the air is virtually thrown away, and the air will have not more energy than it had before compression if the temperature is not increased. It is quite true that it has no more energy than it had before compression, but the advantage lies in bringing it into a more available form. The heat of compression increases the volume, and it is, therefore, necessary to have a much larger compressor than if no heat was generated. The first cause of loss of work then is theoretically unavoidable, but then theory and practice are very different things, more especially in air compression—for instance, theory says that time plays no part in the heating of air during compression, whilst practice says the faster you run your compressor the higher the temperature will rise. That is quite true, but in the first instance the heat is lost by radiation, whilst in the second case, we cannot lose it as it has not time to get away, and this is the task we have to set ourselves to—viz., to get rid of the heat during the compression, or, if possible, before compression.

All makers of compressors in giving instructions how to use these machines advise taking the air from the cool or shaded side of the engine-room, so that the air will enter the compressor as cool as possible, and, therefore, it will occupy a smaller space and be so much cooler when compressed. You must bear in mind that every 5 deg. F. you reduce it in this way means 1 per cent. saving. Now the question arises, can this cooling before entering the compressor be extended beyond taking the air from the cool side of the house? It can, and the following method I tried at the Pearl Central with a new Riedler air compressor that had the advantage of two inlets to the suction valve chambers, one opening to the engine-room and the other could be led under the floor. The latter was carried down about 10 ft., and then a drive was cut from there to a distance of about 40 ft., then a shaft was driven down to meet this. An old chimney was put down the shaft and on top of the chimney there was fixed a large spray about 3 ft. in diameter—very little water was used to keep a decent shower going all the time, and the water not only cooled the air, but washed away all the dust. The results got from this were more than I expected, as the air was cooled 15 deg. F., showing a saving of about 3 per cent., and the engine-room temperature was 10 deg. F. higher than the outside air, so that I have a right to claim 25 deg. F. of cooling, or effecting a saving of 5 per cent. over taking the air from the warm room. The result was excellent, as the cost of installing the cooler was very small. The inlet cooler could be still further improved upon by having a fan blast to blow along the tunnel, and if compressed air was used anywhere close by for driving a pump or a hammer it could also be exhausted into the tunnel; so you will see that it is possible to effect a further cooling of about 10 deg. F. to 12 deg. F.

Another point that ought to be attended to is the suction valve chamber. With some compressors nothing can be done, but in the present Reidler the arrangement is simply splendid for having a trickling cooler keeping the chamber cool, as working at present the suction chamber is nearly as hot as any part of the machine, and the result is that the air in passing takes up a considerable amount of the heat from the walls, and is expanded just on the point of entering the cylinder. The degree the air is heated at this point cannot be arrived at, but it is just possible that it is something like 20 deg. F. If it were only possible to prevent 10 deg. F. of this amount it would mean that another 2 per cent. added to the 5 per cent. we arrived at previously would make in all a saving of 7 per cent., which is a large item where 500 or 600 horse-power is being developed for making compressed air on a plant such as I have made mention of, or, in other words, on a 45-drill plant it would mean a saving in round numbers of £46 per month.

Having done all we can for a single stage compressor, little else can be accomplished unless by injecting a spray of water into the air while it is being compressed. To do this properly it would require an arrangement of tappet valves so as to give it the spray at the right moment. If this arrangement was well carried out, I believe most excellent results would be obtained. The entrained water would be liberated as soon as the temperature dropped sufficiently and could be then trapped with an ordinary steam trap.

Jacket-cooling is practically of no service except in assisting lubrication of the cylinder, so that little can be gained by jacketing the cylinder and heads and piston, as only a thin layer of the air that comes in contact with the metal surfaces is cooled.

We now come to the staging of the air. This has been the means of already reducing the cost of compressed air by about 20 per cent. Now, what does staging do after all? Well, it simply draws away the heat from the air whilst it is being compressed, and this we have already decided is the great difficulty we have to overcome. Suppose, for instance, air is compressed by an indefinite number of stages, and that each time the air is cooled to free air temperature, what do we attain? Very nearly isothermal compression, and this is what we want to attain so that no loss will take place after the air has left the compressor. The gain is two-fold: first, less power is developed; and, secondly, the air is delivered cold, and will, therefore, have no loss due to reduction in volume, which is the bugbear of compressed air as used at present.

Air expands and contracts as its absolute temperature. For instance, we have two compressors, one a single stage and the other a double stage. The other is delivering air at 500 deg. F., and the latter 200 deg. F., or say 961 deg. and 661 deg. F. absolute. The relative efficiencies are as 961 deg. is to 661 deg., or the latter has an advantage over the former of 24 per cent. So that I hope you will agree with me that staging and efficient intercooling are what is required to elevate compressed air to a first place for the transmission of power.

Inter-cooling between stages, as carried out at present in many cases, is far from perfect. Inter-coolers are made after the same form as feedwater heaters or condensers with a great number of tubes which are very liable to leakage. The tubes get coated with lime and other matters, which considerably reduce their efficiency. The best result that I know of is a reduction of temperature of from 200 deg. F. to 140 deg. F., while the air, to give full value, should be reduced to at least 72 deg. F., or free air temperature. I think a method could be adopted whereby the air could be reduced to free air temperature, and a really simple method, too. I find that air delivered from a single stage air compressor at a temperature of 470 deg. F. has been reduced to free air temperature before it has traveled 250 feet through the delivery pipe. This is one of the great drawbacks to the use of compressed air; it is a decided disadvantage, but it might be taken advantage of for inter-cooling. What could be more simple for an inter-cooler than 200 ft. of pipes, even if it were 20 or 30 per cent. larger than is actually required? It would be much cheaper in the first place than the ordinary inter-cooler, if it was well laid down in the first instance—there is no reason why it should be looked at again, it would require no circulating water, if it was made large enough there would be no loss due to friction—it is a natural process, whilst the other is artificial. Any one of you can have a practical demonstration of it by fixing a thermometer to the air main. The pipe should not be buried into the ground, as earth is a good non-conductor of heat, and would give back heat to the air. It should be exposed to the atmosphere, and placed where it would get a free current of air, and should not be exposed to the sun. The present inter-cooler, as I have already mentioned, reduces the temperature to 140 deg. F., which I think is one of the best results that can be obtained, whilst the inter-cooler, already suggested, would reduce the temperature to say, at the very least, 70 deg. F., or a saving of 14 per cent. over the present system of inter-cooling. The figures I have just given refer to second stage compression, where the air is first compressed to 25 lbs. pressure and from 25 lbs. direct to 80 lbs. with a temperature of about 280 deg. F., from which temperature it is generally reduced to 70 deg. F., a drop of 210, showing a loss of exactly 28 per cent. from the time it leaves the compressor till the time it reaches the drills. The above figures work out as follows:—280 gives 741 absolute, 70 gives 531, and 741 : 531 : : 100 : 71.6, showing a difference on the wrong side of 28.6 per cent.—which is the actual percentage of loss. This is where better inter-cooling would give the advantage if the air was delivered at 70 deg. F. less, or 210 deg. F., the actual loss would only be 20 per cent. The remedies for this are three stage compression and reheating.

First, let us take three stages, and say the second stage raises the pressure from 25 lbs. to 60 lbs., and the temperature to 120 deg. F., and is again cooled down to free air temperature. It is well known that the temperature rises more rapidly in the early stages of compression than it does in the latter stages. For instance, from atmospheric temperature to 25 lbs. gauge it is raised from 80 to 290 deg., or an increase of 212 deg. F., whilst from 25 to 80 lbs. it is raised from 135 to 276 deg., an increase of 141 deg. In the first case, the pressure is only increased 25 lbs., and in the second case, the pressure is increased 55 lbs. This, I should say, speaks well for three stage air compression. The initial cost of such a compressor would certainly be much greater, but that would soon be made up in the increased economy. The temperature, as I have already pointed out, by compressing from 25 to 60 deg. would be 120 deg. F. The air is then cooled to free air temperature and is sent on its last journey to 80 lbs.; the temperature would then be increased to about 110 deg. F., and this would be its final temperature. It has then only a drop of 40 deg. F. until it reaches free air temperature. The loss sustained by this fall in the temperature would then only represent 7 per cent. with a two stage air compressor, showing a gain of 21 per cent. in favor of three stage air compression over two stages.

The cost of such a machine would be much greater than a two stage compressor; so is a triple expansion engine a great deal more expensive than a compound, but still they are being extensively used, and why? Because the economy in running soon makes up for any extra initial cost. The same argument applies to three stage air compression.

I think it would be unfair of me to conclude my paper without touching on reheating, which is a very important factor in the use of compressed air. It is argued by many prominent engineers that the reheating of air for use in rock drills is a very difficult matter. More difficult problems than this have presented themselves to the engineering world and have been mastered, so also will the reheating of air for use in rock drills. Air at a low temperature has very little cooling effect upon water or other bodies it comes in contact with. The application of this, inversely applied, is of great advantage in the use of compressed air for the transmission of power, or, in other words, it requires but very little heat to raise the temperature rapidly; in fact, there is no other source of energy to which heat can be applied with the same economical results.

It is well known that after the transmission of compressed air to the point where it is to be employed a considerable saving of cost can be effected by reheating immediately before using. It can be easily shown that where air has been compressed to a certain pressure, and has by transmission to any reasonable distance been reduced to its normal temperature, if the air is reheated and expanded, the extra volume resulting from the expansion is produced by an expenditure of heat much less than the original volume was produced for. Let us assume, then, for the sake of easy computation, that air is being compressed to 75 lbs. by steam at the same pressure, and that 2 cubic feet of steam are required for the production of 1 cubic foot of air, the weight of 1 cubic foot of steam at 75 lbs. is .208 lbs., and the total units of heat in 1 lb. of steam at 75 lbs. are 1151, therefore, the total units of heat in 1 cubic foot of steam are, in round numbers, 239. To produce 1 cubic foot of air at 75 lbs., will be required 239x2 B. T. U., or 478 B. T. U. As air at constant pressure expands or contracts at its absolute temperature, it is easy to show the quantity of heat required to double the volume of air at any temperature. We will again assume that we have got 1 cubic foot of air at 75 lbs. pressure and at 60 deg. F., or an absolute temperature of 521 deg. To double the volume we require to double the absolute temperature or, 521x 21042, deducting from this 461, would leave the temperature by thermometric measurement to be 581, showing an increase of temperature of 581—60, or 521 deg. F. The specific heat of air at a constant pressure is .237, or nearly a quarter of the specific heat of water. The weight of 1 cubic foot of air at 75 lbs. pressure is .456 lbs., the actual heat expended, then, in doubling the original cubic foot of air at 60 deg. F., is 521, the temperature x.237, the specific heat x.457, the weight in lbs.—or 56.3 B. T. U., or as nearly as possible, 12 per cent. of what it took in heat units to produce it in the first instance. Of course, we cannot expect to get a reheater that will give the full heat value of the coal, but it is quite reasonable to expect at least 70 per cent. efficiency from the coal, which can be easily got from a good steam boiler with suitable coal. This would work out at 20 per cent. of the original cost of the air to exactly double the volume—such a result as this could not be got at in actual practice. The temperature—viz., 581 deg. F., is too high, and, again, it is not possible to produce air at 600 deg. F. without such a series of staging and inter-cooling that it would make the process of air compression too difficult. Anyhow, with two stage air compression air can be produced at 280 deg. F. Suppose it is then reduced to 60 deg. F. by transmission and storage, the loss incurred is 30 per cent., due to contraction in volume. We would, therefore, require 50 per cent. of the original heat units to double the volume of the air. I do not mean to say that even such a good result as that could be obtained, but I do say this, that it is the duty of all engineers to do their utmost to endeavor to get as near to it as possible and raise to its proper level the most natural source of energy that exists in nature.

The reheating of air also makes it possible to use it expansively without fear of freezing up the exhaust ports; in fact, the temperature could be regulated to suit any reasonable cut-off, so that the temperature would not fall below 32 deg. F. without reheating. With dry air two expansions are all that can be got, whilst with reheated air it is possible to get five and six expansions, more so if the air is well saturated. Reheating with steam has been used with very good results, and, where found convenient, steam should be always used with air. Suppose a steam reheater was used for a pump within a reasonable distance from where a rock drill was being used, and the condensed steam was trapped, the trapped water would be led into a launder lying nearly level, so that the water would fill the launder. The air pipe leading to the drills is then immersed in the water, which would have a temperature of probably 140 deg. F. The air would have the same temperature as the water. Suppose it was only 100 deg. F. when delivered at the drills, it would always give a little help towards economy.

In the matter of economy, in generating and in distributing compressed air, if proper care is exercised so that the machine is as nearly perfect as can be, the receivers and the pipe main perfectly free from leakage, with only one safety valve, no matter how many receivers there are on the distributing main, and that one safety valve fitted with a good strong siren that will make the attendant wish he had been more careful every time it blows off, the transmission of power by compressed air should be at the very least equal to any other method. Whilst compressed air has many disadvantages, it has also many advantages that other sources of energy have not got. For instance, in deep mining such as we will have in the Rand presently, when depths of 2,000 and 3,000 ft. will be quite common, and temperature of between 90 deg. and 100 deg. F. compressed air will gain where electricity would lose. First, the weight of air in the column will add to the pressure, not to a great extent, but probably quite enough to make up for what has been lost in friction; at a depth of 2,000 ft. with air at 80 lbs. pressure on the surface, there would be a pressure of something like 87½ lbs. in the mine. Then, again, supposing the temperature of the atmosphere was 60 deg.,and the temperature of the mine was 96 deg., at 3,000 ft. the air would be reheated 36 deg. F., showing a gain of about 4 per cent., the mine itself acting as a reheater. Thus, it will be seen that for deep mining, where high temperature may be expected, compressed air will increase in economy, whilst, as I have already endeavored to point out, other sources of energy would keep on losing and regain nothing. Although not yet in economy, yet in many other ways does compressed air appeal to the mechanical engineer; it is perfectly safe, accidents caused by compressed air are so very rare that they are practically unknown. Should an air pipe burst, no harm is done except the loss that is caused by leakage. As a proof of its growing popularity, we have only to take up the advertisement columns of an engineering paper, and we find that the different appliances that are operated by compressed air are simply innumerable. We read about pneumatic painters, pneumatic cranes, and pneumatic so many different things, that I could stand here for another hour doing nothing else but reading over a list of the different appliances that are operated by compressed air. In fact, it would seem that it is just beginning to dawn upon the engineering world that the greatest force in nature is the air we breathe when put into the proper form. And now that the first blush of electricity has worn off, and scientific men are looking for new fields of thought, I think I am safe in predicting that compressed air will come in for a considerable amount of attention, and great developments may be looked for during the next few years.

THE EFFICIENCY OF COMPRESSED AIR ENGINES.

The increasing use which is being made of compressed air engines for mine and underground work stimulates the inquiry regarding their efficiency. By this is meant the percentage of power given out by the air engine bears to the power required to compress it.

The situation is apparently very simple. An engine drives an air compressor or compressing cylinder which forces air into a reservoir. The air under pressure is let through pipes to the various air engines, and is there used in the same manner as steam.

The resulting power is frequently a small portion of the power expended. In a large number of cases the fault is due to poor designing, and is not due to the fault of the system.

The losses are chargeable in a great many cases to fault of the compressor. This ordinarily is 15 per cent., but has been as low as 6 per cent., the average being about 12 per cent. in the common type of compressors; some of the high grade Corliss engines running air compressor will work on an average of less than 10 per cent. After the compressor we have the loss occasioned by pumping the air from the engine room, which would naturally be warm; therefore being lighter and less dense, this loss varies from 3 to 10 per cent.

Next the losses arising in the air cylinders. In sufficient supply, difficult discharge, defective cooling and a host of other things which perplex the designer and robs the owner of power. Next comes the loss in the pipes. This has, therefore, received by no means the consideration it should. The loss varies with every condition, and is somewhat perplexing. The next loss is due to fall of temperature in the cylinders of an engine, and often gives serious trouble. Losses often arise from leakage in pipes, and are too evident to call for much debate. No leak can be too small not to require prompt attention. The parties who are entrusted with the use of compressed air often permit loss which no engineering skill can prevent. We can only realize 100 per cent. efficiency in an air engine, leaving friction out of the question, when the changes of temperature are exactly the reverse in the air engine to those in air cylinder of the compressor, but these conditions can hardly be realized.

The air during compression becomes heated, and during expansion becomes cold. If the air immediately after compression and before losing any heat, could be expanded back to atmospheric pressure, it would on being exhausted have the same temperature as before, and consequently would exert as much power as it took to compress it (less friction).

But the loss of heat after compression and before being used again cannot be prevented.

We can by reheating with a very small amount of fuel expand the air and bring it up to nearly 100 per cent. efficiency. Consideration must be had for the friction of compressor and air engine.

We find for ordinary pressures, say 60 lbs., that the decrease in resistance to compression which is secured by the cooling attachment or improved circulating device, is equal to the friction of the compressor. Hence, it is safe in calculating the efficiency of the air engine, to consider the compressor as working without cooling attachment and working without friction.

The result of such calculation would be too high for low pressures, and too low for high pressures. This, of course, is due to the fact that air at low pressure contains less heat than at high pressures.

Following is a table which gives nearly the correct efficiency of air under various pressures:

Gauge	pressure—	2.9	lbs.	94.85	per	cent.	efficiency.
"	"	14.7	"	81.5	"		"
"	"	29.4	"	72.75	"		"
"	"	44.1	"	67.00	"		"
"	"	58.8	"	63.00	"		"
"	"	73.5	"	56.75	"		"
"	"	88.2	"	56.75	"		"

We observe the efficiencies of the lower pressure are much higher than that of the high pressure, and would be supposed to be most economical, but such is not the case, as air under a low pressure requires a much larger engine to do the work, and will therefore consume more air per H. P. than a smaller engine with higher pressure.

The matter of determining the efficiency of an air compressor varies so widely that it is impossible to lay down a rule to meet all conditions; hence, we have to test every case separately, but ordinarily the efficiency of an air compressor can be taken at about 50 per cent.; under certain conditions it might be taken at 60 per cent. A. W. TUBBS.

METERING COMPRESSED AIR.

As the installation of compressed air Central Plants for distributing power is gaining daily in importance, the problem of measuring the amount of compressed air at certain pressures used by any consumer confronts not only the Central Plant owners but also the consumer. The consumer should know how much air he uses in order to know that he is charged reasonably for it, and the Central Plant owners must also know how much every consumer uses in order to avoid abuse and to ascertain whether the plant is operated on a paying basis.

Thus the Central Plant owners having a main supply pipe which may be branched off for distributing to mines or manufacturing establishments will find the necessity of installing meters and other apparatus which cannot be tampered with, and which at the end of each month will be able to give, not only themselves, but also the consumer proper data, from which the bills for the month can be figured.

The only way to properly determine the amount of compressed air used by any single consumer is to determine the amount of free air, which, if multiplied by the mean average pressure, will give the total amount of energy furnished.

The Equitable Meter Co. of Pittsburg has studied the problem of metering compressed air for a number of years and are now manufacturing meters which we understand are giving very good satisfaction; as tests which have been made show that the readings vary but a very small percentage from the actual. Their standard size meters for compressed air, which we illustrate herewith, will carry a working pressure of 100 lbs. They have, however, made some high pressure meters for measuring compressed natural gas up to 500 lbs. pressure. The meters are made in five sizes, as follows: 10,000, 20,000, 30,000, 40,000 and 50,000 cubic ft. maximum capacity per hour. The reader will, of course, understand that the amount of air passing through a meter during a certain time means the amount of air in cubic feet at the pressure at which it passes through the meter, no matter if the air pressure is 1 lb. or 100 lbs. to the square inch, and then to find the total

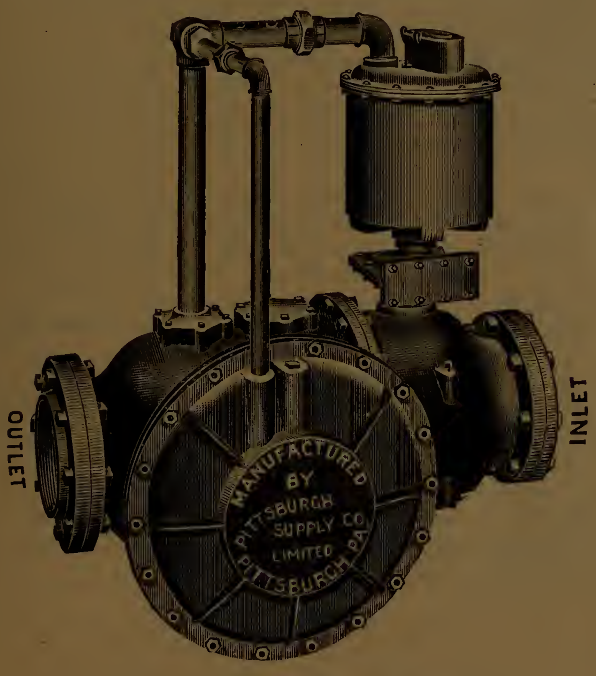


FIG. 132.—COMPRESSED AIR METER.

volume of free air passed, the volume of compressed air will have to be reduced into a volume of free air.

We are also informed that there is very little pressure absorbed by the meter while the air passes through it, the pressure absorption being only about 1 oz., no matter what the air pressure is. These air meters are provided with a special back pressure relief valve, preventing the wrecking of the meter in case high pressure air would be let into the meter or taken out of it too suddenly.

The next question of importance to be considered is for both producer and consumer to know that the air pressure is as steady as possible, and sufficient to run the apparatus to be operated by compressed air, as there would be no use for a consumer to pay for a larger volume of compressed air at 50 lbs. pressure should he require 80 lbs. pressure, as a large quantity of air at a low pressure would not do his work; thus it would be necessary to install a compressed air Pressure Recording Gauge in connection with each meter, and at the end of the month the mean average pressure could be figured and this multiplied by the number of cubic feet of free air, the product representing the energy furnished, would enable both producer and consumer to settle upon the amount to be paid.

The problem has been explained clearly enough, but it may be added, however, that it would always be advisable to install a small receiver next to the meter and that the pressure recording gauge should be connected with this receiver; this, not only to avoid the vibration of recording finger, but also to prevent any shock to the meter.

It should be noted also that a consumer situated far away from the Central Power Plant should pay more per unit of energy than one near by, for the reason that the friction in long pipes amounts to a certain percentage of power, and that a long pipe line is more subject to leaks and requires more attention than a short one.

The reader will, of course, also understand that it is impossible to give an idea of the charge which should be made per unit of power, as the cost of producing compressed air varies considerably, according to localities, size of plant, whether plant is operated by steam or water power, whether, if operated by steam the engines are economical or not; but there is one thing certain, which is that if a Central Power Plant even be operated by steam and this plant would be of 1,000 horse power, equipped with compound Corliss Engines, and would supply compressed air to, say five consumers, it should prove a great financial success, as it would save each consumer the installation of a small 200 horse power plant. These five 200-horse power plants costing much more by at least 30 per cent. and not being as economical by at least 60 per cent. as a first-class 1,000-horse power plant.

In addition each consumer would require a fireman and engineer, while the Central Plant could be operated practically at the same expense for labor as a single 200-horse power plant.

VOLUMES OF AIR USED IN ENGINES.

The present increasing demand for the use of compressed air as a motive power necessarily involves the use of intricate mathematical formulæ for estimating relative sizes of Compressors and Air Engines, etc.

Quite a number of these formulæ have been worked out to cover average practical conditions and are daily serving a very useful purpose in the form of tables.

A very intricate formula is the one based upon the use of free air per minute per Indicated Horse Power in an Air Engine, and as a problem is often stated in terms of the I. H. P. of the motor—*to find the quantity of free air per minute required;*—the following table which has not been published up to the present time, will facilitate computations of this kind and is in such shape that it will not require any extended knowledge of mathematics.

As will be seen from the table, the only data required is the guage pressure and point of cut-off; having those two items given, we find from the table the free air required per I. H. P., and it will only be necessary to multiply this amount by the total I. H. P. of the motor to determine the total quantity of free air required and consequently the size of an Air Compressor to furnish the air.

These figures do not take account of clearance, but it will be an easy matter to add the *per cent.* of clearance after having determined the total amount of free air required.

It will also be noticed that the free air consumption is based upon the use of cold air, *i. e.,* Initial temperature of air at 60° F. In case reheating is resorted to there will be a corresponding decrease in the amount used depending upon the temperature of air at admission to motor, and will be proportional to the ratio of $\frac{T_2}{T_3}$ where T_2 460+60=520° F. absolute temperature and T_3=460 + temperature of air at admission to motor.

Thus if the air is reheated to 300° F., the quantity in the table will have to be multiplied by $\frac{460+60}{460+300} = \frac{520.}{760.} = .684$

TABLE 42.—AIR USED [CU. FT. FREE AIR PER MIN.] PER I. H. P. IN MOTOR [WITHOUT RE-HEATING.]

POINT OF CUT-OFF	GAUGE PRESSURES. 15	30	40	50	60	70	80	90	100	110	125	150
1	31.2	23.3	21.3	20.2	19.4	18.8	18.42	18.10	17.8	17.62	17.40	17.05
¾	25.6	18.7	17.1	16.1	15.47	15.0	14.6	14.35	14.15	13.98	13.78	13.50
⅔	21.8	17.85	16 2	15.2	14.50	14.2	13.75	13.47	13.28	13.08	12.90	12.60
½	25.8	16.4	14.5	13.5	12.8	12.3	11.93	11.7	11.48	11.30	11.10	10.85
⅓	37.0	17.5	15.2	12.9	11.85	11.26	10.8	10.5	10.21	10.02	9.78	9.50
¼	167.	20.6	15.6	13.4	13.3	11.40	10.72	10 31	10.0	9.75	9.42	9.10

A further use of this table is to find the most economical point of cut-off for gauge pressures from 15 lbs. to 150 lbs. per square inch. This fact is apparent from a study of each vertical column; thus at 60 lbs. pressure, the lowest consumption of free air per I. H. P., is at 1-3 cut-off, while a 40 lbs. pressure will work most economically at ½ cut-off. F. C. WEBER.

THE AIR MOTOR.

A TRIAL TRIP ON THE ELEVATED RAILROAD, NEW YORK.

The Hardie Air Motor, which was built by the American Air Power Co., to demonstrate the possibility of using it to draw trains on the Manhattan Elevated Railroad, New York City, was put into service on Thursday evening, Aug. 19, and a public test of it was made by taking a train loaded with 192 persons over the Sixth Avenue road from Rector street to Fifty-eighth street and back to Cortlandt street.

The motor, with five cars attached, started a little after nine o'clock. Robert Hardie, the inventor, was in charge of the engine, having a regular engineer as pilot.

The train followed a regular train and made the run in 19 minutes, this being 3 minutes faster than the scheduled time. The time on the return trip, making all stops, was 26 minutes.

Among the passengers were a large number of representative railroad men and men interested in compressed air matters. Every one admitted that the trial was most successful and all that could be desired.

The Hardie Compressed Air Locomotive in its main features of construction is substantially identical with that of the steam locomotives in use by the Manhattan Railway. Its length is the same, its driving wheels the same, but its maximum weight when manned and ready for service is less than that of the steam locomotive. The wheel base of the driving wheels being six feet instead of five feet, as on the steam locomotive, makes it permissable to place a greater weight on the drivers than is allowable on the steam locomotives, without increasing the strain on the structure, thus giving it increased tractive power and enabling it to take the sharp curves on the line easier. The cylinders are 13 inches in diameter by 20 inches stroke, and the valves are specially designed. The variable cut-off is controlled by a hand wheel in place of the notched quadrant used on the steam locomotives. Two independent ways are provided for applying the air brakes, and in addition the locomotive has a compressed air-driving wheel-brake of novel design, thus affording additional security against accident. In place of the boiler and firebox of the steam locomotive, there is a bundle or nest of seamless steel flasks, 9 inches in diameter and about 15 feet long, having a total capacity of about 150 cu. ft., in which the air compressed to 2,400 lbs. pressure per sq. inch, is stored. In operation, the compressed air passes from these flasks through a regulating valve and is delivered at a uniform pressure into a low pressure receiver, where the air is re-heated by passing through hot water and is then applied to the cylinders at a uniform working pressure of 150 lbs. per square inch. The method of storing the air reducing the pressure, re-heating and controlling, as well as the application to the cylinder, is the result of many years of study and experimental work by Mr. Hardie, whose efforts have been unequalled.

The air to charge this locomotive is compressed at 100 Greenwich street by an Ingersoll-Sergeant four-stage compressor, and conveyed by pipe line through Greenwich street to Rector street, and thence up Rector street to the Sixth Avenue Elevated structure, to the point where the steam locomotives take their water. It does not take any more time to charge this locomotive with air sufficient for a run to Fifty-eighth street and back, than it does to take water on an ordinary steam locomotive. The Mannesmann tubes furnished by Chas. G. Eckstein & Co., 45 Vesey street, New York, are in use both on the motor and in the power house.

THE USEFULNESS OF COMPRESSED AIR UNDER DIFFICULTIES.

Another example of the usefulness of compressed air as a means of solving difficult engineering problems is afforded by the sinking of a caisson for the purpose of building a lighthouse at the mouth of the Potomac River, Chesapeake Bay.

A few years ago this lighthouse was built at what was known as Smith Point, a dangerous location where opposing tides and currents have built up shoals of sand which extend eight or ten miles out into the Bay. Severe wrecks had occurred on this shoal until it was determined to put a light just at the edge of the channel about eight miles from the shore and about one hundred and twenty miles south of Baltimore. The work was begun in 1896 and completed in about one year. The sinking of the caisson was the most difficult part of it and this was almost impossible except through that valuable auxiliary—compressed air. The caisson was such as is usally employed and an air compressor, boiler and other appurtenances were placed on the top and somewhat exposed to the waves during the storms. This work was successfully accomplished, the air being used to give life to the men beneath the surface who dug within the great iron cylinder until it rested upon a secure foundation. So long as the air compressor was kept working on the surface all was peace below, where the storms were not felt.

This is only a type which emphasizes the importance of compressed air in this valuable field of foundation building. Foundations for bridges are built in the same way and it would be difficult to find a means by which the huge difficulties encountered in this kind of work would be overcome without the aid of compressed air.

SAFETY IN AIR.

Compressed air is the safest of all powers. No other power or means of transmitting power compares with it in safety. This quality is one of great importance and is, we think, underestimated by those who advocate the use of compressed air. We have been carrying on for some months a series of editorials in this paper reciting cases where explosions have occurred in compressed air passages, and have been in a general way discussing the subject. It may have surprised some of our readers to hear so much about explosions in compressed air, and in fact we have been asked the question why we dwell so much upon a subject which only furnishes ammunition to electrical engineers. Our only answer is that compressed air can stand this sort of thing. Its freedom from explosions and its extreme safety in use, are so well known and so far beyond dispute when comparing air with electric or any other power, that we are encouraged at all times to search out cases where air has been shown to be unsafe, running them down by getting at all the facts, and pointing out where the fault lies so that such things may be stopped. Nothing of any great importance in industrial use is absolutely safe: Railway trains meet with accidents, bridges sometimes fall, buildings collapse, boilers explode, and yet no one thinks of abandoning the use of these things because they are unsafe. Compared with the number of buildings that fall, accidents of this kind are rare, and taking into consideration the number of boilers which are in use explosions are not serious, and when we consider the large number of compressed air installations using air, varying in pressure from 1 lb. to 3,000 lbs. to the square inch, an explosion is a rare occurrence. Every passenger train and a good many freight trains on every railroad of magnitude in the world is equipped with air compressors and storage tanks containing compressed air at considerable pressures, yet who ever heard of an air explosion on a railroad train? Most of the railroad shops and most of the machine shops in America have air plants. Nearly every mine of magnitude, where the ore is hard and where mining operations are carried on on a large scale, is equipped with a compressed air plant, and yet how many of us have heard of explosions there? A large number of compressed air installations are in use as permanent plants lifting water from driven wells: Caissons are commonly used for excavations under water: Tunnels through hard and soft ground invariably use compressed air: Street cars have been in use more than ten years in France, and during recent years in New York, with air as a motive power: Foundries are now equipped with air compressing plants, which are considered just as essential to their existence as the foundry crane: Coal mining machines, though in some cases propelled by electricity, chiefly use air; Quarries are equipped with air plants: Ships are provided with air compressors for refrigerating purpeses: Air is used to some extent for lifting sewage, and yet how seldom do we hear of explosions or accidents due to the use of compressed air. The reason for this is very plain. Air is a harmless elastic fluid, non-combustible, healthy, and it is the most widely distributed of all substances. We simply compress it and hold it in a condition of confinement, and must provide a vessel strong enough to overcome its elasticity. Unlike steam, air has no reserved force when in confinement. The destructive effect of a boiler explosion is mainly due to the sudden conversion into steam of large volumes of superheated water, held in a condition of water by the pressure of steam on top of it. Here we have a reserve force. With air when once a vent occurs the pressure falls very rapidly and the strain is soon relieved. This rapid fall of pressure is due to two things, expansion of the air from a smaller space into a larger one, and a rapid reduction in the volume of this air, due to shrinkage in expansion by cooling. Liquid air is produced by expanding compressed air down to atmospheric pressure, the intense cold being utilized to liquefy volumes of compressed air. This cooling effect takes place when air is expanded, and the rapid shrinkage of volume follows.

Now, as a matter of fact, no accidents occur in the use of compressed air that may not be traced to explosions through the ignition of oil or inflammable substances which are used with the air. If we throw kerosene oil into the inlet valve of a compressor, we are likely to have an explosion because this oil may meet with a temperature which is higher than its flashing point, and so with certain low grades of lubricating oils; but the air itself is perfectly safe, it being merely necessary to confine it in a receiver or pipe which is strong enough to hold it. This is not a serious problem, and in the case of air the factor of safety is not nearly so great as where steam, water, gas or other substances are similarly confined, because air does not corrode the vessel, its temperature is not changed, nor is there any liability of internal destructive action taking place, hence, it will be generally admitted that air, except through the course of compression, is as near the point of absolute safety as anything of this class can be. The elements of danger are therefore confined to the compressor, or, more properly speaking, to the compressing plant, and it is to this subject that we have been devoting our attention. Should some one discover a lubricant for air compressor cylinders which is not composed of a carbon, there would be no further occasion for discussion on this subject. It is simply because of the elements of uncertainty attending the use of oil that explosions in compressed air are made possible, and it is also because of ignorance as to the causes of these explosions and the carelessness on the part of the engineers that we hear anything about the subject.

Engineers get in the habit of feeding oil to the air cylinders as they would to steam cylinders, and compressed air generating plants are sometimes run so carelessly that proper attention to the causes producing explosions is not given. As the use of compressed air grows it becomes better understood, and the more we understand it the more we are convinced of its great safety and cleanness. Men are not afraid of a machine run by compressed air. There is no dread in their mind to upset their nerves. We are told that this feeling of dread exists among men handling electric machines, especially in mines. The electric current is a mysterious thing. It gives a shock, and it is not an uncommon thing for persons to read that electric shocks have produced death. It is known that in two States in America electric execution has replaced hanging, and all these things combine to add to the terrors of this great and mysterious form of nature's energy. Fires are becoming more frequent in large cities. Insurance statistics point to the serious effect which electricity has had in producing fires. Electrolysis is a destructive agent, directly traceable to the large use of electric power in cities, and all these things combine to make more plain the absolute simplicity and safety of pneumatic power.

A WAR-SHIP RUN BY AIR.

Machinery which May Revolutionize Naval Methods.

Of all the vessels of the new United States Navy, the monitor Terror is perhaps the most interesting. She is not by any means, the original "cheese-box on a raft," for her two turrets, smokestack, armored ventilator, etc., form a varied superstructure, very different from the single, low, round turret of Ericsson's Monitor. Quite a number of years back Congress appropriated money to build five of these vessels—the Puritan, Amphitrite, Miantonomah, Monadnock and Terror—but the appropriation was only sufficient to complete the hulls, and they lay unfinished until about six years ago. Then further appropriations were secured, and the vessels have been gradually completed. The Puritan is not yet entirely fitted up, and the Terror has but lately gone into commission, having recently been on a trial cruise of two weeks.

The Terror differs from her sisters in that the Navy Department contracted with the Pneumatic Gun and Power Company to install pneumatic machinery upon the Terror only, for turning the turrets, working the guns, steering the ship, etc. The other monitors have hydraulic machinery for their turrets and guns, and are steered by steam. The Terror, indeed, is the only vessel, in all the navies of the world, in which pneumatic power is thus applied, and is therefore a practical experiment whose success may lead to far wider use of the pneumatic principle.

The use of compressed air has several advantages over steam or hydraulic power. All pipes are liable to leak; and a leak in a steam or water pipe, in a turret crowded with guns and machinery in action, is inconvenient, if not dangerous, and requires both time and patience to repair it, when neither is likely to be available. In an air tube, on the contrary, a leak causes no inconvenience—since the waft of air from it would be rather agreeable to the men at the guns than otherwise—and, with a surplus of supply air, requires no immediate repair. Again, steam and water systems require exhaust pipes, whereas in the pneumatic system the exhaust is turned either into the turret or the open air, as desired.

The Terror has two engines for compressing the air, one situated in the hold near the forward turret, and the other on the berth deck near the after turret. Either of these, singly, can supply sufficient air, at a pressure of 125 feet per square inch to operate both turrets, including the guns—a total weight of nearly 500 tons. The compressor takes its supply of air from the chamber in which the engine stands, and compresses it in two cylinders, sending it also through two condensing cylinders, where it is cooled by circulating seawater. It is then carried by pipes and two engines, of two cylinders each, situated on each turret floor, precisely like steam-engines, about fourteen-inch stroke and eight inches diameter of cylinder. These develop about forty horse-power each, and are controlled by a lever in the sighting hood of the turret, over and between the guns, where are also situated the elevating levers. The movement of both turret and guns is thus controlled by the officer who sights and fires the latter.

Beneath the turret-chamber proper, where the guns are mounted, is the loading-chamber, with the magazine on its starboard, and the shell-room on its port side. The shell, which weighs 500 pounds, and a cartridge, in two parts, containing 240 pounds of powder, are run out into the loading room by a single overhead trolley, and dropped into a lift, which is swung around until the shell is opposite a loading car, into the lower compartment of which it is slid, partly by its own weight, while the cartridge is placed in the upper division. The car is then hoisted to the breech of the gun, by means of another pneumatic cylinder, placed upright between the guns. The car stops, automatically, when the shell is opposite the breech-chamber, and the rammer (telescopic in form, and also operated by compressed air) pushes the shell to its seat, and the cartridges follow. Usually, in these heavy guns, a loading-tray is placed in the breech to facilitate the entrance of shell and cartridges; but in the Terror the loading-car, as it ascends, throws the tray automatically into position, and when the loading is finished the tray is thrown out again, and the breech-block thrust into place by the pneumatic rammer, thus leaving the gun in complete readiness to be fired. So thorough and perfect are all these automatic adjustments, that the guns in either turret can be loaded independently, and in any position of train or elevation. All parts of the gun-carriage and turret move together, except one—that being the fixed central column through which the air pipes and communication pipes pass into the turret and up to the sighting-hood.

To elevate and depress the guns, there is on either side the turret a cylinder, containing glycerine and water, which is forced by compressed air into the elevating ram under the breech of the gun. This is regulated by double valves, and is controlled, also, by the officer who sights the guns. The guns are fired, either independently or together, by means of an electric push-button. The crew for the two guns of a turret comprises ten men. This is somewhat of a change from the time of the civil war, when twenty-five men were required to work a single heavy gun.

The recoil of the guns is controlled by two pneumatic cylinders, forty inches in length and fourteen in diameter. Before firing, these cylinders have a pressure, on the recoil side of the piston, of about 500 pounds per square inch, which is drawn from a special plunger attached to the compressing engine. The recoil cylinders are secured to the gun carriage, and the pistons to the gun. When the gun is fired, the pressure upon the recoil side of the piston is rapidly increased by compression. A tapered rod, passing through the centre of the piston, permits the air to pass more and more freely to the counter side, thus equalizing the pressure at the end of the recoil. By this simple arrangement, the recoil of the guns is limited to about thirty-four inches. At the end of the recoil, the pressure upon the recoil side of the piston operates upon a greater area, and immediately returns the gun to its place. The recoil and counter-recoil are both without shock, the air cushion preventing any sudden stopping of either.

The ship is also steered by compressed air, the steering-room being abaft the cabin. The shaft which operates the pneumatic valve has three clutches upon it besides the steering-wheel, by means of which the control of the rudder may be transferred to either turret, or to the pilot-house. The Terror is also fitted with an electric motor of five horse-power, and with hand-wheels, so that she can be steered either by electricity or by hand, if necessary. In actual size, she is about one-half as large as the Indiana class of battleships, but in proportion is far more powerful. She has a displacement of 4,000 tons, and is 260 feet long and 56 feet beam. She draws 15 feet of water, and with 250 tons of ammunition on board and her bunkers full of coal, her freeboard is only 27 inches or so. In an ordinary sea, therefore, her deck is more or less awash, and this renders her a peculiarly elusive target to the enemy. Her speed is about 10 knots, which is ample for the purposes for which she is intended.

With the new smokeless powder, her four ten-inch guns will give each of their 500 pound projectiles an initial velocity of about 2,400 feet per second which gives an energy of about 20,000 foot-tons—a force which, applied properly, would be sufficient to lift the Terror herself bodily five feet at each shot; and as these guns can be fired at the rate one gun every thirty seconds (the turret revolving once a minute), some idea of her power may thus be gained. The guns carry seven or eight miles, and a fair shot can be made two miles away.—*Evening Post.*

PROPOSED EXTENSION OF THE USE OF COMPRESSED AIR ON MEN-OF-WAR.

BY F. W. BARTLETT; P. A. ENGR., U. S. N.

Compressed air is now used for certain purposes on men-of-war, as, for charging torpedoes; in combination with water for elevating guns and running them out; for turning turrets; for steering engines, and for ash hoists.

It seems possible and feasible to extend this use, and the object of this article is to suggest some other ways of using air and to state why air is better for many purposes than either steam or electricity.

Air of various degrees of compression may be used for nearly all purposes on board ship, except for the main engines and possibly the dynamos. It could be used for running the dynamos as well, and it is only a question with these whether the economic loss would be balanced by the gains in efficiency, comfort, etc.

It is to be borne well in mind that one of the most serious troubles to be contended with on board men-of-war of modern types is the suffering due to heat and lack of proper ventilation, the debilitation and discomforts in summer, being excessive in cool latitudes and over-powering in hot ones.

An attempt will be made to describe a theoretical arrangement showing the proposed changes, using air in place of steam where possible, economy being perhaps sacrificed for the sake of making life bearable in hot weather on men-of-war, and in order to have the officers and crew in condition to put forth their best efforts when called upon in emergencies.

THEORETICAL ARRANGEMENT FOR THE USE OF AIR MORE EXTENSIVELY.

As near the middle of the length of the ship as possible, preferably between sets of boilers, so that the most direct and shortest steam pipe may lead to the plant, no matter which boiler may be in use, there is an auxiliary plant room, where is located every auxiliary machine in the ship that can be placed there, so that a machinist and oiler on watch may be able to take care of them all, and not have six or eight men on watch in detached parts of the ship. Here are placed the two auxiliary condensers, three evaporators and distillers, heating and ventilating machine, fire-room blowers, ice machine, dynamos, duplicate air compressors and reservoirs for the pressures required, as described later. These are all operated by steam for the sake of economy, as they all run with constancy when once started.

Besides the steam pipes for the main engines and this short auxiliary pipe for the central plant, the only steam pipes in the ship are those very small ones leading to the galley and pantries. This lessens materially the trouble due to heat, it being confined to a small portion of the length of the ship in port, and to only about a third at sea. The exhaust pipes are all in the central plant room and are short, the auxiliary condensers being close at hand. Thus the heat from this pipe is also in one compartment only. Another important gain here is in the fact that there is at all times a high vacuum in the condensers, all the leakages being in this one room and easily cared for, instead of there being many detached steam-using machines all over the ship, run by all sorts of persons, many of them not knowing enough to close exhaust valves and drains when through running a machine, and others not caring to take the trouble even if they know enough.

Aside from the traps for the main engines, there are only six traps in the ship—one from each evaporator, one for the auxiliary steam pipe, one from the galley pipe and one from the pantry pipe. All of these six traps are in the central plant room, and are accessible and readily kept in good order. The discharges from these traps all go into the auxiliary exhaust pipe, as the loss of heat is small, and not important, compared with keeping the ship bearable in hot weather. This prevents also the constant discharge of vapor from the escape pipe. The discharge pipes from the traps for the main engines are led into the main feed tanks in the engine rooms, and all the pipes lead to near the bottom of the tanks, so that as much of the vapor as possible may be condensed. It was not considered advisable to lead the drains from the main engine traps to the auxiliary exhaust pipe in the distant central plant room, as too much heat would be disseminated on the way.

The discharges from the auxiliary condensers lead to a tank in the same room, this tank being connected with the main feed tanks by a pipe, the water flowing by gravity, from the higher tank in the central plant room, a non-return valve preventing vapor from returning from the main tanks.

Thus the steam used in the ship, and the consequent heating, is only for the main engines and the central plant room, and the functions of the steam are reduced to a minimum, as far as the number of machines operated is concerned.

Of course the air compressors are of considerable power and the pressure accumulators large, to allow for emergencies. These latter, however, occupy the upper part of the room, and are as concentrated as possible. The room is kept cool by its special ventilation, so that the temperature of the air in the accumulators is never much over that of the water outside of the ship, which is used in cooling the air. The specially designed pressure regulators for the accumulators allow of a large surplus of air ready for any sudden call, so that the air compressors may fill all the chambers full when little air is being used.

Besides the special compressors for the high pressure needed for the torpedoes, of which there are two, as now provided on our large ships, there are duplicate compressors and reservoirs, or accumulators, that keep up a constant pressure of 60 pounds per square inch.

This pressure is kept constant by the action of the pressure regulators of the reservoirs acting on the throttle of the compressor, and the mechanism is found efficient for all emergencies, the pressure never dropping over 5 pounds at any time, and that only when a crane and anchor engine happen to be suddenly put in use at the same instant. At such times, however, warning is given, so that the steam stop valve outside the throttle of the air compressor engine may be opened wider, to allow for the sudden addition of such great quantities of work. Signals have previously been sent to the central plant room, to open air to the pipes for these machines, as explained below. In getting under way, and at drills when the turrets are likely to be used suddenly, both of the compressors are in operation to insure greater steadiness of pressure, but ordinarily one is amply sufficient for all needs.

In easy reach of the two attendants are valves plainly marked on the air pipes leading to each machine outside of the central plant room. Each of these machines has its own pipe, so that a large machine opening from a pipe may not throw out a smaller one, as happens with the steam pipes ordinarily in use. By this means absolute uniformity of air pressure is secured for each machine, the sizes of pipes to each being calculated for the work to be done. At a signal from any part of the ship, the air is turned on and the machine is ready for use at once. The throttle valve at the machine is the only valve that the attendant in the distant part of the ship needs to touch. Having no exhaust valve and no drains to attend to, the operator has a simple operation to perform, only oiling the machine. After use, closing the throttle valve secures the machine. No harm is done if a signal be not sent to the central plant room when finished with the machine, so that the valve may be closed there as a possible slight leak of air is the only trouble that can ensue. The pipe is left filled with air at the full pressure, and this air is always ready to do its work. No vacuum is destroyed by ignorance or carelessness. No return exhaust pipe is required, one small pipe carrying the power, the exhaust being into the atmosphere. The air to be used is drawn down from the ventilators, and passes around and among pipes filled with running water, so that a portion of the moisture in the air is condensed and tapped off. There are also separators where needed for removing the moisture from the air after it is compressed. The temperature of the air may be readily varied to any degree not below that of the sea water, by reducing or increasing the quantity of the circulating water, regulating the temperature of the discharge water and of the air compressed. By opening and closing the large exhaust ventilating doors at the top of the central plant room, the air in the accumulators may be kept at the temperature of the atmosphere, or as much higher as desired.

The engines in the different parts of the ship are all of the same type, but of three different sizes, thus making parts interchangeable and doing away with the carrying of many spare parts. The pipes to these machines are also of three sizes. Where a great power is required, as for turrets or anchor engine, two of the largest sizes of machines are attached to one shaft. The machines are small, three-cylinder, simple, long stroke, light and fast running, the air expanding just enough to prevent the formation of ice at the exhaust nozzles, the pressure at discharge being slightly above the atmospheric pressure. At the exhaust openings there are mufflers constructed of a non-resonant substance, thus preventing much noise. These engines are geared down for the work they have to do, thus enabling the three sizes of machines to handle all the various kinds and quantities of work to be done in the ship.

This system does away with the enormous prices paid for special machines all over the ship.

The following list shows the uses to which air is put on board:

To operate—Main engine auxiliaries; auxiliary, fire, bilge and water service dumps; steering engine; anchor engine; boat cranes; winches; turret-turning engines; hydraulic cylinders for working guns; ammunition hoists; ash hydro-pneumatic hoists; feed pumps; smoke hose for guns; whistle and siren.

Other uses: To send messages to clear a compartment of water when flooded; to ventilate; to heat and cool the ship.

Air is better than steam for auxiliary use on board ship, for the following reasons:

The ship is cooler in summer, and men are not debilitated by the heat; there are no hot bulkheads all over the ship; the auxiliary machinery and pipes last much longer; half the number of valves, pipes, etc., are needed; there are no ventilating blowers, the heater lines doing the work; there is great saving in cost of plants and in the cost of oil; no pipe coverings are needed; the machines are ready for use at once; there are fewer men on watch in port, and more for general work; the launch is ready at any moment, at sea or in port; there is no smoke, heat, etc., and only one man is required.

It is needless to say that all the machinery is in charge of the chief engineer of the ship.

It is certain that something must be done to relieve the officers and crew of our men-of-war of the suffering from the terrible heat on these ships in summer.—*American Machinist.*

COMPRESSED AIR IN EUROPE.

The delivery wagon shown in Fig. 133, constructed by Messrs. Molas, Lamielle and Tessier, was exhibited at the second Exposition des Tuileries, where it attracted considerable attention by reason of the relative simplicity of arrangement of its maneuvering devices and the limited amount of space occupied by the motive apparatus.

In this vehicle, the air-storage reservoirs employed consist of hammered steel tubes of 8-inch external diameter, the ratio of the weight of which to that of the air stored up is $\frac{178}{775} = \frac{1}{4.35}$. The heating is done directly by gasoline, instead of by steam from a boiler, as in the Mekarski system; the manufacturers being of the opinion that, since a direct heating of the air permits it to be raised to a temperature much higher than that which would be obtained by means of heating by steam, they obtain also a greater increase of volume and, consequently, of work that compensates for the heating during expansion obtained with the above-named system.

The stove, burners, and gasoline reservoir used for heating have here a feeble weight as compared with the arrangement in which a boiler is employed. The ratio of the weight of air stored up to that of the reservoirs and heating apparatus does not descend below $\frac{1}{4.85}$,

The air reservoirs are eleven in number and are distributed in two groups, one of six forming the "battery," and the other of five constituting the "reserve." The capacity of these groups is respectively, 11 and 7.5 cubic feet, or, altogether, 18.5 cubic feet.

With a charging pressure of 4,290 pounds to the square inch, the weight of air stored up, at a temperature of 13° C, is $1,100 \times 2.7 \times 638 = 392,370$ pounds.

Before its admission to the cylinders of the motor, the air passes into a steel worm of .28-inch internal diameter, of .14-inch thickness, and of a length of 19.7 feet, which raises its temperature to a figure that varies with the discharge of air and the intensity of the burners that heat the worm. The temperature may thus reach 150° C. The air afterward passes into an expander (maneuvered by the driver), which lowers its pressure by about from 11 to 44 pounds, according to the difficulties of the road, the load and the speed. This expansion of the air gives rise to a lowering of the temperature, in order to raise which, the air thus expanded is made to pass into a second worm concentric with the first and heated by the same burners. When the air makes its exit from this second worm, its temperature may be as high as 250°. It is claimed that this double heating is capable of more than doubling the volume, and, consequently, the work of the air stored up. This air is then admitted to the cylinders through an expansion distribution with a special change of speed. The admission takes place upon only one of the faces of each piston, and the motor is thus a single acting one. But the cylinders are four in number, and cast in pairs, and the connecting rods

FIG. 133.—COMPRESSED AIR DELIVERY WAGON USED IN PARIS.

(jointed directly to the pistons) actuate the same shaft, the cranks of which are set at an angle of 180° per group, and at 90° from one group to the other. The motor thus has the same power as a two-cylinder double-acting engine. The arrangement adopted offers numerous advantages, and permits especially of suppressing the shocks at the joints of the connecting rods that occur in double-acting engines at the time of the change of direction of the piston; of doing away with piston-rod stuffing-boxes, which it is often difficult to keep tight, and which absorb a certain amount of work in friction; of removing and putting in place a connecting rod and its piston without having to dismount a cylinder bottom.

The space available for a motor under the seat of a carriage is sufficient widthwise, but not lengthwise; and so the motor must occupy more space in the former than in the latter direction. Now, two double-acting cylinders of the same bore, placed either longitudinally or vertically, always take up more space than the single-acting four-cylinder arrangement adopted; and from this fact, it has been possible to have a greater available space for occupancy by the reservoirs of compressed air.

The distribution is affected by means of cams and valves. The opening of the latter takes place very rapidly. Their closing, on the contrary, occurs gradually, and is hastened or retarded through the shifting of the reversing lever, according to the admission that is desired. The minimum admission employed is 10 per cent., but this may be increased to 60 per cent. for starting. The exhaust and the compression are fixed, and have a duration of 20 per cent. of the stroke of the pistons.

There is no special cut-off of fluid between the expander and the cylinder admission valves. These latter open wide for all admissions between 10 and 60 per cent. of the forward and backward running of the engine.

The burners, which are three in number, are arranged beneath the worms in an iron plate-jacket 10.75 inches in diameter and 12 inches in height, surmounted by a chimney which leads the gases of combustion to the top of the roof of the vehicle. The burners are supplied by a gasoline reservoir of a capacity of about ten quarts in which an air pressure of from 45 to 70 pounds to the square inch is created. The pipe that leads the gasoline to the burners may be partially closed by a screw plug. Through such arrangements, it is possible for the driver of the wagon to proportion the intensity of the heating to the output of air, so as to obtain a temperature that is always sensibly the same.

The quantity of gasoline consumed by the burners is about 15 ounces per hour of running; but this might easily be increased if it were found that the operation of the motor became thereby more economical.

The motor rests upon the floor of the carriage, beneath the seat occupied by the driver, who can thus examine it while it is running. Its rotary velocity for a speed of five miles an hour made by the vehicle is 200 revolutions per minute. The transmission is effected by means of chains of the "Varietur" system, which connects two sprockets, keyed at the extremities of the driving-shaft, with two toothed wheels of six times larger diameter fixed through bolts to the spokes of the hind wheels. The power of the motor, upon the crank-shaft, is 20 horse at a velocity of 300 revolutions, and at a pressure of 285 pounds.

The differential consists of two friction-cones fixed near the extremities of the driving-shaft and actuated by the steering apparatus. The control of these cones is such that, in a turning about, the adhesion of the one that is situated at the side of the internal wheel diminishes in such a way as to permit of a certain amount of sliding of the cone in its socket, and, consequently, of a retardation in the revolution of the corresponding wheel; while the adhesion of the cone situated at the side of the wheel that is to traverse the wide radius increases, so that no sliding in its socket can occur, despite the greater resistance of the wheel that is moving ahead.

The pivoting can thus be effected upon a driving wheel that is rendered absolutely immovable, from the view-point of revolution, and, consequently, in a circle having as a radius the distance of such wheel from the opposite wheel of the front axle, and that, too, in running forward as well as backward.

The steering is done by means of a hand wheel keyed upon the axis of an endless screw, which gears from a toothed wheel keyed upon the shaft of the reversing gearing situated beneath the vehicle. An indicator placed before the eyes of the driver exactly reproduces the changes in direction of the axis of the vehicle's path, and thus permits him to keep in a straight line.

The intermediate screw lengthens the maneuvering, but renders it sure, stable and gentle. Such an arrangement, however, offers advantages only for heavy vehicles designed for running always at a low speed.

Finally, let us say that the accumulators are placed longitudinally under the floor of the vehicle in two superposed rows, and are connected by easily accessible couplings placed in the rear. Movable panels permit of an inspection and of a tightening of the joints and couplings.

The motor and vehicle as a whole are well elaborated and denote upon the part of the manufacturers the possession of real ingenuity and a complete knowledge of the question with which they had to deal.—*The Automobile Magazine.*

REHEATING COMPRESSED AIR.

The importance of reheating compressed air is as yet but little understood. Theoretically, reheating offers great economical advantages; practically, these advantages have not been attained, largely, we think, because of the lack of experience. There are, of course, limitations to reheating; it is not practical, for instance, to use dry, hot air in the cylinder of an engine at temperatures much above 350°, but even if the air is heated to 300° and used at that temperature the increase in volume which this effects under constant pressure is large and important. Under normal conditions, say at 60° temperature, air reheated to about 300° will be increased in volume nearly 50 per cent. It has been claimed by engineers who have tested reheaters applied to pneumatic motors, that a storage tank of given volume and pressure has been used to propel a car 3¼ miles with cold air, and at the same volume and pressure when used with heated air, the car was propelled 6½ miles.

We recall a personal experience last year during the tests of the Hardie motor on 125th street, New York: a car which had been making three trips with a single storage of air was unable to make but two trips, when it was discovered that the steam which was used at the terminal station to reheat the storage water on the car had so far run down in pressure that, notwithstanding the fact that the hose had been coupled to the tank as usual, yet the water received only a part of the accustomed temperature. This was not discovered because the motorman omitted to keep a record of the initial temperature at the charging station.

It has been shown by figures and is claimed by those of experience, that the cost in heat units of the increased volume of air produced by reheating is from one-sixth to one-eighth of the cost of an equal volume when produced by the process of compression.

In connection with this subject the following letters are interesting as pointing to a practical system of reheating first used, we think, by Mr. Rix on the Pacific Coast. The availability and simplicity of this system are apparent, though it can hardly be claimed that this is the most economical method of reheating compressed air. It is obvious that there must be the usual loss of heat units up the flue of the boiler, which should not take place in the same degree where reheaters are employed which are specially designed for the purpose. We will be glad to hear from our readers in criticism and comment on Mr. Rix's system of reheating. What is very much needed in this line is a record of practical experience.

CALIFORNIA EXPLORATION LIMITED.

San Andreas, Cal., June 8, 1898.

Editor Compressed Air:

I am just in receipt of the May-June number of your journal, and have read with much interest the article on Compressed Air Motors. I am particularly interested in what the writer says in regard to heating, since that is a matter of much importance with us, and I venture to ask if any facts were determined in these experiments which would bring into question the efficiency and desirability ofthe plan recently followed by E. A. Rix, at the Jupmper Mine, of passing the air through the steam dome, or *above* the water line, of an ordinary boiler. This plan seems to be satisfactory where a boiler is already installed. The consumption of fuel is low—about ½ cord wood per 24 hours, for 100 H. P., and there would seem to be no reason to fear any of the difficulties due to passing the air *through* the hot water. W. L. Honnold.

San Francisco, June 22, 1898.

Editor Compressed Air:

In any stationary boiler of a reasonable capacity there is no danger at all of the compressed air admitted to the boiler carrying water over into the engines, or in other words, priming the boiler.

I failed to see any difference in the actions of the hoisting engine at the Jumper Mine, whether I introduced the air into the boiler through the blow off and mud drum or whether I introduced it in a pipe through the steam drum down to within about six inches of the surface of the water, but the action on the boiler was very marked. When I introduced the compressed air through the mud drum and allowed it to bubble up through water into the steam space, it vibrated the boiler to such an extent that I feared the setting of the boiler would be injured. In fact, if I had continued to run the plant another day I would probably have cracked one of the boiler walls, so I introduced the steam through the steam drum, and brought it down so that it impinged upon the surface of the water, and I noticed no different results as far as economy was concerned.

The hoisting engine is a 75 H. P. hoist, having double 10x12 engines, hoisting from a depth of 700 feet, and handling sufficient ore, waste, men and timbers to operate a 20 stamp mill. The fuel used in reheating is eight cords per month of pine wood.

As far as economy of reheating is concerned, dry reheaters give a greater economy than the wet reheaters—that is, if you take into consideration the fuel which the heater absorbs, but I generally advocate wet reheating, that is to say, using a steam boiler, especially if there is a boiler already installed, for if excessive work should be thrown upon the compressor, or an accident should happen to it, steam is already on the boiler, and it is only necessary to throw in additional fuel and the plant can be operated with steam.

In general mining work I find that no matter how carefully a plant may be designed, there comes a time when it is necessary to shut it down, for a short period at least, to put in new brasses for the connecting rod to perhaps repair something which has been unavoidably broken, and it is at this time that the steam reheater pays for itself, and its perhaps inferior economy to dry reheating.

RIX ENGINEERING & SUPPLY CO.
Per E. A. RIX.

EDITOR COMPRESSED AIR: March 9, 1898.

In reading COMPRESSED AIR I have been much interested in the re-heating of air after it has been compressed to 80 lbs. or more; by different methods, par-

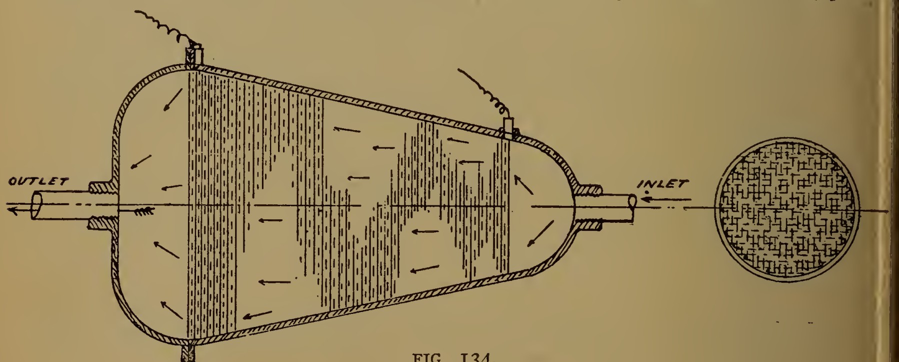


FIG. 134.

ticularly in the Sergeant Reheater, which seems to give such good results, the thought struck me that as electricity was used in connection with nearly every air compressing plant, and cars run by compressed air, for lighting, a reheater could be constructed by enclosing, in suitable form, coils of wire arranged to divide the incoming air into thin layers, and by the passage of electricity through the coils heating the air.

Referring to the figures above, Fig. 134 is a sectional view of a reheater, cone shape, the inlet being at the right, the air entering is thoroughly cut up, if I may use that expression, and becoming heated, expands and passes out at the left. The other figure is an end view showing coils as they are arranged to divide the air. WM. F. TOWEY.

21 Emery Street, Medford Hillside, Mass.

A NEW DEVICE FOR REHEATING COMPRESSED AIR FOR USE IN PUMPS.

Too much attention has been given of late to the economical production of compressed air to the detriment of the economical use of compressed air in motors. As applied at present to the ordinary direct acting steam pump there is utilized only a fraction of its intrinsic energy, and many are the complaints directed against the economy of compressed air, on account of the very small returns which are made by these pumping devices.

Of course the readiness with which an ordinary direct acting steam pump can be set up in a mine, and air turned into it, is the great reason for the numbers which are in use to-day. In other words, the problem is one of utility rather than economy. An ordinary direct acting pump does not use air expansively, therefore but little can be expected from it, about 20 per cent. of the useful effort of the air being all that is converted into water pumped.

In many places pumps of this character cause considerable annoyance from freezing, and for this reason compound direct acting pumps cannot be used with cold air. One can readily see that if the temperature of the exhaust of an ordi-

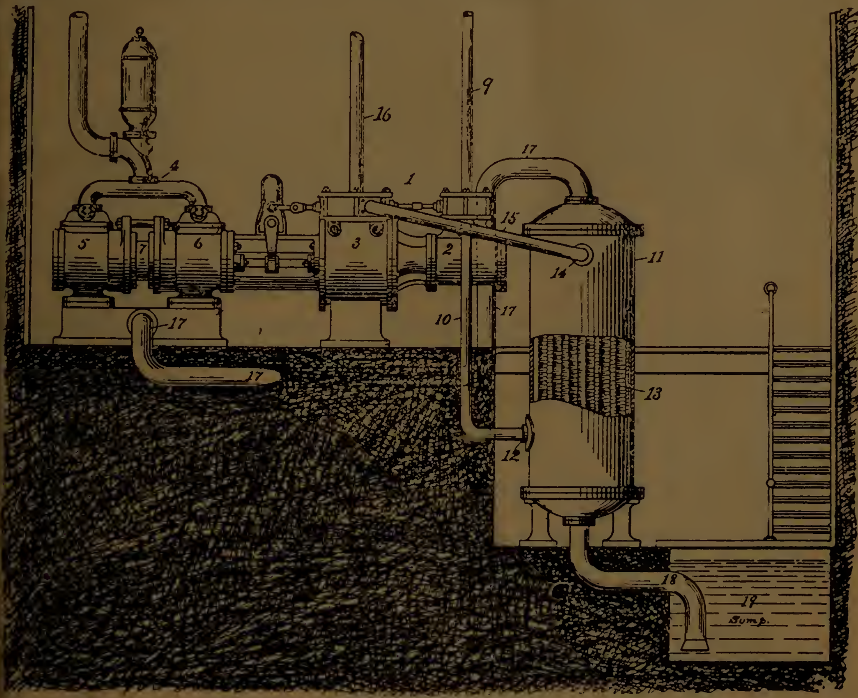


FIG. 135—PUMP REHEATING DEVICE TO INCREASE EFFICIENCY.

nary direct acting steam pump is from 20 to 30 degrees below zero, which frequently causes stoppage from freezing, that to exhaust this low temperature of air in a compound cylinder and further reduce its temperature to perhaps 100 would be an impossibility, because it could not work longer than the time which it took to reduce the temperature of its cylinder to the freezing point.

A compound direct acting pump, which is heated sufficiently to prevent its freezing, will pump twice as much water for the same amount of air as a single acting pump. If a single acting pump will not freeze in working under ordinary conditions, introducing the air into the cylinder, we will say at 60 degrees temperature, the compound pump will not freeze if the air entering the compound cylinder be brought up to this same temperature.

If the ventilation in a mine is such that a reheater can be established underground, of course there is no difficulty whatever in running compound pumps, and very economically at that. There are some mines that do not object to carrying a steam pipe into the lower levels for the purpose of furnishing heat for the low pressure cylinder, but such opportunities are infrequent, inasmuch as the temperature of the mine is raised to an undesirable point, and in carrying steam a long distance it becomes an expensive operation.

A problem which occurred to the writer was to attempt to run plain compound pumps without any extraneous source of heat by utilizing simply the heat stored in the water being pumped at ordinary temperatures. The result was an installation of a Worthington pump having a capacity of 200 gallons per minute at a lift of 600 feet in the Gwin Mine, Calaveras County, California.

The accompanying illustration, Fig. 135, shows approximately the manner in which the installation was made. A 300 horse-power Wainwright copper corrugated heater was placed in the suction pipe of the pump, the water being pumped passing through the corrugated copper tubes at a temperature of from 60 to 70 degrees. The air after being exhausted from the high pressure cylinder at a pressure of about 35 pounds, passes into the shell of this reheated and around the outside of the copper tubes. The extremely low temperature of the exhaust from the high pressure cylinder is thus neutralized by coming in contact with the water in the copper tubes, while the temperature of the air is raised to practically that of the water. It then passes to the compound cylinder, does its work and is exhausted without freezing.

Before installing this compound pump on the 600-foot level of this mine a Worthington sinking pump had been used to pump out the water. The compressor furnishing the air to this pump made 55 revolutions to actuate it and to supply power for a hoist and to overcome pipe leakage, the latter two items taking about 20 revolutions of the compressor, leaving 35 to be used for the pump. When the compound pump was put in place the revolutions of the compressor dropped down to 35, which showed a gain of 50 per cent. in favor of the compound proposition with its reheating.

The work being done at this mine was to pump out an old shaft 1,500 feet deep, which had remained idle for about twenty-five years. The water was therefore foul and inky in color and full of decomposed slates. This frequently coated the inside of the copper tubes and materially lessened their conductivity for the heat contained in the water, the result was that the pump froze up. After cleaning the tubes, however, the pump operated as freely as before, showing conclusively the advantage of the system.

A still further gain would have been accomplished had the pumps been specially constructed for this character of work and the high and low pressure cylinders been water jacketed, permitting either the suction or the discharge water passing around the jackets and thus keeping them at an even temperature.

This apparatus can be installed in the discharge pipe or in the tank adjacent to the pump where the water accumulates in the mine and can overflow it freely. Moreover, this is the proper manner of applying heat to air used in a compound pump. Many pumps have the air heated before it goes into the initial cylinder, which is economical as far as the initial cylinder is concerned, but by actual observations the writer has found that the clearances between the high and low pressure cylinder are such that the exhaust from the high pressure cylinder loses a considerable portion of its pressure before the stroke commences, and the drop in pressure causes such a drop in temperature of the air entrained between the two cylinders that the virtue of the reheating affects but slightly the compound cylinder where it is most needed. To be really an economical proposition the air should not only be heated before it goes into the high pressure cylinder, but in the receiver between the two cylinders and also in jackets around the two cylinders. There is no doubt that by doing this reheating properly in compound pumps where steam or highly reheated air is used, that the efficiency of this pump can still further be raised 25 per cent.

If compressed air engineers desire to hold their own against the installments of electrical pumps they must employ more economical processes for pumping water, and pump builders can assist materially in constructing pumps properly for such work, and the above device will be found extremely economical and useful where heat cannot be safely introduced underground.—E. A. Rix.

South Norwalk, Conn., Aug. 25, 1900.

"Compressed Air:"

Your July issue describes a Worthington pump with a re-heater device and refers to the apparatus as a novelty.

This device was patented by me 19 years ago—U. S. Patent No. 244,603.

The claims recite among other things:

"First, the method of expanding or increasing the effective force or power of the air in a pumping engine driven by compressed air by utilizing the heat of the water acted upon by the pump as hereinbefore set forth.

"Second, the combination of a compound air motor pumping engine and an interheater to be supplied with water from the pump as and for the purposes hereinbefore set forth."

The device is good, but as you see from the above, not new.

E. Hill, Gen. Manager,
Norwalk Iron Works.

Editor Compressed Air:

I have a case where it is desired to reheat compressed air, to be used in a stationary automatic cut-off engine, consuming, perhaps, 300 to 450 cubic feet of free air per minute. We propose using oil burners of a small size and would like to know whether we can use a small-sized air re-heater, as the expense of a large size is rather too much. Can you give us any idea as to the number of heat units which will be necessary to raise the temperature of the air from 80 degs. to 375 or 400 degs., so that, knowing the heat units in the crude oil, we can get a pretty good idea as to the amount of oil which will be consumed. Of course, in a common open re-heater all of the heat would not be effective. About what per cent. would you figure as effective?

I would greatly appreciate your views at length on this matter.

Wheeling, W. Va. PRACTICAL.

A large heater is required for this work. If you expect to heat the air to 400 degs., you might use two reheaters or a series of reheaters, though, except in stationary plants, we do not advise reheaters of large sizes.

Four hundred and fifty (450) cubic ft. free air per minute, to be raised from 80 degs. to 400 degs. F.,

$$\frac{450 \text{ c.}}{13} = 34\tfrac{3}{4} \text{ lbs.} \times .2377 = 8.26$$

heat units per degree rise in temperature; 400—80=320 degs. required; 320 x 3.26 =2643 heat units per minute using oil=to 20,000 heat units per pound, say, deducting waste heat=14,000 heat units are available $\frac{2643}{14{,}000}$ =.188 of a pound of oil required per minute, 11.28 pounds per hour, or 112.8 pounds per day of 10 hours, or about 16 gallons crude oil per day, at 3c., would be 48c. price to reheat 450 cu. ft. of free air per minute from 80 degs. to 400 degs.

The compressed air has slightly greater specific heat than free air, which may add a few cents to the cost while the efficiency will be increased by reheating 44 per cent.

REHEATING COMPRESSED AIR WITH STEAM.

In the operation of motors by compressed air it is possible to bring about a considerable saving in the amount of air required in a given case by heating the air.

This heating, or reheating as it is generally termed, may be accomplished in a variety of ways, generally by some form of furnace or combustion heater.

In certain classes of work it becomes convenient to reheat the air with steam by either of the following methods:

First.—A pipe from the boiler discharges steam into the air main and the mixture is carried into the cylinder of the motor.

Second.—Air is passed through the boiler, either up through the water or simply through the steam space over the surface of the water, and becomes mixed with and heated to the temperature of the steam.

The accompanying tables show the results obtained with these two forms of reheating and will prove of value to those interested in the important problem of efficient reheating of compressed air.

In calculating these tables one pound of air was assumed as the unit. The weight of steam to heat the air to any given temperature, and the final temperature after adiabatic expansion of the mixture to atmospheric pressure was determined. Then from the initial and final conditions of the mixture, and the properties of the adiabatic, the work of expansion and other desired relations were calculated.

Dalton's law states that the pressures exerted by a mixture of gases or vapors is equal to the sum of the pressures exerted by the individual gases or vapors. Thus at 212° F. steam exerts a pressure of 14.7 lbs. per square inch absolute. A pound of air at 212° F., occupying 10 cubic feet, exerts a pressure of 24.8 lbs. sq. in. absolute.

If this cubic foot tank is also saturated with steam at 212° F. the total pressure exerted will be the sum or

$$14.7 + 24.8 = 49.5 \text{ lbs. sq. in.}$$

In the present problem steam is saturated and its pressure is found from its temperature in steam tables.

The air pressure is found from the equation $PV = RT$, and the total pressure is the sum of the two, thus determined.

The following notation will be used:

n = pounds of steam mixed with one pound of air.
Ps = pressure per sq. in. absolute, corresponding to temperature of steam.
$t, q, \rho, x, \gamma, s, p$, etc., the corresponding steam quantities as found in Peabody's "Tables of Properties of Saturated Steam."
Pa = the "air pressure" lbs. sq. in. absolute in mixture, according to Dalton's Law.
V = specific volume of air.
R = gas constant.
P_0 = initial air pressure in main.
t_0 = initial air temperature in main.
C_v = specific heat at constant volume.
C_p = specific heat at constant pressure.
$P = Pa + Ps$ = total pressure lbs. sq. in. *absolute.*

Denote conditions after heating by subscript 1, and after expansion by subscript 2.

STEAM DISCHARGED INTO AIR MAIN.

Assume boiler and receiver pressures equal and neglect kinetic energy of motion. Suppose (n) pounds of steam separated by a circular diaphragm in the air main, from one pound of air, both air and steam being separated from the rest of the air by two sliding pistons.

The volume occupied by the steam is ns; volume occupied by air is v_0; volume occupied by both air and steam is $-ns+v_0$. Remove the diaphragm, allowing steam and air to mix intimately, assuring finally a common temperature t_1; the pistons moving out under constant pressure p_0, finally enclose a total volume $.v_1$. The steam, of course, cools to a temperature t_1, causing some condensation. The final weight present, as steam, is nx_1.

From the energy relations the loss of heat by mixture equals the work of expansion against pressure in air main. Hence,

$$n\,(q+\rho-q_1-x_1\rho_1)-C_v\,(t_1-t_0)=Ap\,(v_1-v_0-ns);\ \text{A} = \frac{1}{779};$$

$$\text{but, } v=\frac{RT}{144\ P_0};\ v_1=\frac{RT_1}{144\ Pa_1};\quad ns_1x_1=\frac{nx_1}{\gamma_1};\ \text{and, } pa_1+ps_1=P_0.$$

Making these substitutions and solving for n

$$n=\frac{C_v\,(t_1-t_0)+144\ AR\,p_0\left\{\dfrac{T_1}{(p_0-ps_1)}-\dfrac{T_0}{p_0}\right\}+\dfrac{RT_1\,\rho_1\,\gamma_1}{144\,(p_0-ps_1)}}{q+\rho+144\ Ap_s-q_1}$$

With but a very small approximation, $\lambda - q_1$ may be substituted for the denominator, and substituting numerical values we have finally,

$$n = \frac{.1692\,(t_1 - t_0) + .0683\,p_0 \left\{ \frac{T_1}{p_0 - ps_1} - \frac{T_0}{p_0} \right\} + \frac{.3694\,T_1\,\rho_1\,\gamma_1}{p_9 - ps_1}}{\lambda - q_1}$$

ADIABATIC EXPANSION OF THE MIXTURE.

By adiabatic expansion is meant that no heat is given to or taken from the mixture although during expansion there may be a flow of heat between steam and air.

Since $$p = pa + ps,$$

$$p\,dv = pa\,dv + ps\,dv.$$

For an adiabatic $$dQ = o.$$

$$dQ = C_v\,dt + n\left\{ dq + d\,(x\rho) \right\} + Ap\,dv$$

$$= C_v\,dt + Apa\,dv + n\left\{ dq + d\,(x\rho) \right\}$$

$$+ Aps\,dv = o.$$

But $-n\left\{ dq + d\,(x\rho) \right\} + Aps\,dv$ may be reduced to, $n\left\{ dq + Td\left(\frac{xr}{T}\right)\right\}$

$$\therefore\; C_v\,dt + Apa\,dv + n\,dq + n\,d\left(\frac{xr}{T}\right) T = o$$

divide by T,

$$C_v\frac{dt}{T} + Apa\frac{dv}{T} + \frac{n\,dq}{T} + n\,d\frac{xr}{T} = o$$

Integrate,

$$C_v\,ln\,T + \int Apa\frac{dv}{T} + \frac{\int n\,dq}{T} + \frac{nxr}{T} = K$$

$$\frac{\int Apa\,dv}{T} = AR\,ln\,v - \frac{\int n\,dq}{T} = \frac{n\int dq}{T} = n\,\tau$$

Then,

$$C_v\,loge\,T + AR\,lu\,v + n\tau + \frac{nxr}{T} = \text{Con'st.}$$

$$\text{Also}-x = \frac{RT\gamma}{144\,(p - ps)}\;\frac{nxr}{T} = \frac{RPP}{144\,(p - ps)}$$

MAKING NUMERICAL SUBSTITUTIONS AND APPLYING LIMITS.

$$.5469\,log_{10}T_1 - .1573\,log_{10}\,(p_1 - ps_1) + \frac{.3694\,r_1\gamma_1}{p_1 - p_1s} + n\tau_1$$

$$= .5469\,log_{10}T_2 + .1573\,log_{10}\,(p_2 - ps_2) + \frac{.3694\,r_2\gamma_2}{p_2 - p_2s} + n\tau_2.$$

In this equation T_1, ρ_1, ps_1, r_1, γ_1, τ_1, p_2 are generally known.

T_2 is unknown, as are the other quantities, which are direct functions of T_2.

The equation can only be solved by the long and tedious method of trial and error and then only approximately.

WORK DONE BY ADIABATIC EXPANSION OF THE MIXTURE.

Proceeding by the usual thermodynamic method, draw an indicator diagram for an ideal engine expanding one pound of air and n pounds of steam to atmospheric pressure, and call this work W.

In Fig. 136 let W=area $abcf$.

W_1=area $bcde$;

W_2=area $oabe$=144 p_1v_1;

W_3=area $ofcd$=144 p_2v_2.

Then $W=W_1+W_2-W_3$.

TABLE 43—REHEATING COMPRESSED AIR WITH STEAM.

Results for Adiabatic Expansion of Mixture from 60 lbs. Gauge.

Initial Temperature of Mixture.	Pounds of Steam per Pound of Air.	Volume of Steam before Mixture.	Volume of Mixture.	Ratio:—Volume of Mixture / Volume of Air.	Per cent. of Steam condensed by Mixture.	Final Temperature of Expansion.	Final Volume.	Total Work in ft. lbs. done by Mixture, with Adiabatic Mixture.	Number of Expansions.	Final per cent. of Condensed Steam.	Per cent. increase of work due to Steam.	Rate of increase in lbs. of Steam per I. H. P. hour.	Lbs. of Steam per B. H. P. hour with 25 per cent. loss.
150	.0515	.365	3.178	1.23	32.4	32.°	12.5	50,500.	3.9	92.	34.	7.96	10.6
170	.0778	.552	3.390	1.32	29.5	71.8	13.7	52,500.	4.05	78.	39.	10.4	13.9
190	.1175	.801	3.677	1.43	23.2	101.	15.1	58,000.	4.1	63.	54.	11.5	15.3
210	.1798	1.275	4.090	1.59	17.5	124.6	17.	64,400.	4.15†	48.	71.	13.4	17.8
230	.2818	2.000	4.733	1.84	12.5	145.3	19.6	74,600.	4.15†	36.	98.	15.	20.1
250	.4684	3.326	5.855	2.27	8.4	164.	24.3	93,300.	4.15†	27.	147.	16.8	22.4
270	.8741	6.203	8.242	3.2	5.	181.5	34.2	122,800.	4.14	18.	226.	20.4	27.2

In the above it is assumed that Steam is fed to the air main by a separate pipe-boiler pressure and air pressure being 60 lbs. gauge.

Condensed Steam is supposed to be carried into the cylinder by the mixture.

By Adiabatic Expansion is meant that no heat is given to or taken from the mixture.

1 lb. air at 60° F., 60 lbs. gd. occupies 2.575 cu. ft. and gives 37,700 ft. lbs. with adiabatic expansion.

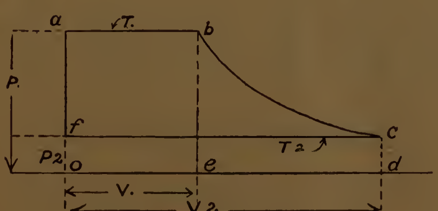


FIG. 136.

Since the curve bc is an adiabatic, W_1 is equivalent to the loss of heat from b to c.

The heat present at b_1—heat present at a_1 equals W_1.

$$\therefore W_1 = 779 \left\{ (q_1 + x_1 \rho_1) - (q_2 + x_2 \rho_2) + cv\,(t_1 - t_2) \right\}.$$

As shown above, $x = \dfrac{RT\gamma}{144\, n(p-ps)}$; also, $v = \dfrac{RT}{144\,(p-ps)}$. Making these substitutions,

$$W_1 = 779 \left\{ n\,(q_1 - q_2) + \frac{RT_1 \gamma_1 \rho_1}{144\,(p_1 - ps_1)} + cv\,(t_1 - t_2) - \frac{RT_2 \gamma_2 \rho_2}{144\,(p_2 - ps_2)} \right\}$$

$$W_2 = \frac{144\, p_1\, RT_1}{144\,(p_1 - ps_1)} = \frac{RT_1 P_1}{(p_1 - ps_1)};\ \text{also,}$$

$$W_3 = \frac{RT_2 P_2}{(p_2 - ps_2)}.$$

Table 43 gives the approximate results of calculation from the above formulas, when both the boiler and air pressure are 60 lbs. gauge. Various initial temperatures are assumed to which the mixture is reheated, corresponding to which the weight of steam and other quantities are calculated.

The increase of work due to reheating is the gain over the work of adiabatic expansion from 60° F. The rate of increase of work is given in pounds of steam per indicated horse power per hour; also the steam per brake horse power per hour assuming 25 per cent. loss.

TABLE 44—REHEATING COMPRESSED AIR WITH STEAM.

Air is passed through a Steam Boiler and the Mixture works with Adiabatic Expansion.

Initial Temperature of Mixture.	Pounds of Steam per pound of Air.	Final Temperature after Expansion to Atmosphere.	Final Volnme Cubic Feet.	Ratio of Final to Initial Volume of Mixture.	Per cent. of Steam Condensed by Expansion.	Work done by Mixture—ft. lbs.	Per cent. Increase of Work by Steam.	Total B. T. U. supplied by Boiler per lb. of Air.—Feed at 60° F.	Thermodynamic Efficiency of Reheating
RECEIVER PRESSURE 60 LBS. GAUGE.									
150°	.03276	32.°	12.46	3.92	88.78	47,480.	25.9	57.4	21.9
190°	.09027	99.75	15.04	4.09	53.28	57,740.	53.2	131.3	19.5
230°	.24648	144.8	19.55	4.13	27.69	74,440.	97.4	319.3	14.8
270°	.83078	181.4	33.74	4.09	16.35	130,670.	246.1	997.4	12.0
RECEIVER PRESSURE 100 LBS. GAUGE.									
150°	.02095	Final Temperature below 32° F.							
190°	.05601	53.83	13.11	5.74	84.59	66,740.	55.4	93.2	32.8
230°	.14130	116.4	16.18	5.96	49.14	80,630.	87.8	200.7	24.2
270°	.37395	157.4	22.24	5.97	25.74	106,460.	147.9	478.4	17.1

REHEATING BY PASSING AIR THROUGH A STEAM BOILER.

In this case, the pressure in the boiler is also the receiver pressure and a pound of air is assumed to leave the boiler with n pounds of dry steam, both having the temperature of water in the boiler.

The heat supplied by the boiler is in addition to that of the steam, the amount necessary to raise the temperature of and expand the air.

Suppose air and water supplied to the boiler at the temperature t_0, while the boiler is maintained at the temperature t_1. The initial volume of one pound of air and n pounds of water is v_0+n_0 cu. ft. The final volume at temperature t_1 becomes $v_1=ns_1$. Hence, the heat equivalent of external work becomes $144\ Ap_0$ $(v_1-v_0-n_0.)$

Heat added to air $= cv\ (t_1-t_0)$.

Heat added to steam $= n\ (q_1+p_1-q_0)$.

Then the total heat supplied by boiler becomes,

$$(B_1 T_1 U_1 \text{ per lb. of air}) = cv\ (t_1-t_0)+n\ (q_1+p_1-q_2)+144\ Ap_0\ (v_1-v_0-n_0.)$$

Substitute,

$$p_0=pa_1+ps_1\ ;\ s-o=w.$$

$$144\ Apv=ART;\ \text{and neglecting } p_0no,$$

$$B_1 T_1 U_1=Q+cv\ (t_1-t_0)+n\ (\lambda-q_0)-$$
$$+AR\,(T_1-T_0)+144\ Aps_1v_0.$$

Since, $Cv+AR=Cp$, specific heat at constant pressure,—BTU becomes,

$$B_1 T_1 U_1=cp\ (t_1-t_0)+n\ (\lambda_1-q_0)+144\ ps_1Av_0 \text{ and when } t_0=60^\circ \text{ F.},$$

$$B_1 T_1 U_1=.2375\ (t_1-60)+n\ (\lambda_1-28.1)+.4662\ ps_1.$$

The weight of steam per pound of air is calculated from the formulæ:

$$ns_1=v_1\ ;\ \text{or } n=\frac{RT_1\gamma_1}{144\ (p_1-ps_1)}$$

TABLE 45.

T	A	B	C
150°	27.8	21.9	
170°	21.3		
190°	19.2	19.5	32.8
210°	16.5		
230°	14.7	14.8	24.2
250°	13.2		
270°	10.8	12.0	17.1

T.—Initial Temperature of Mixture.
A.—Thermodynamic Efficiency of Reheating Steam fed in pipe near motor.
B.—When passed through boiler at 60 lbs. gauge.
C.—When passed through boiler at 100 lbs. gauge.

The final temperature and work of expansion are calculated by the general formula given above.

The thermodynamic efficiency of reheating is the ratio of the heat equivalent of increased work to the heat added.

Table 44 gives the approximate results of calculation for this method of reheating.

Air and water are both assumed to have a temperature of 60° F. before heating.

Table 45 shows the relative merits of the two systems, both being on the basis of 60° temperature of feed, air and water.

It is interesting to note that the efficiency of dry reheating is 38% at 60 lbs. gauge, and 45% at 100 lbs., gauge, with adiabatic expansion.

CLARENCE R. WEYMOUTH.

ELECTRIC AIR HEATING.

It is perfectly practicable to heat compressed air before it passes into the motor cylinders, by means of electric currents, and that without the slightest danger. It may be done either by forming a resistance coil in the usual way, in the path of the air, or by wrapping the pipe with a conductor through which a current of electricity is allowed to pass. The conductor must in each case be allowed to attain a fairly high temperature, but it need not be exposed, nor need the temperature be such as to be dangerous, in case of the presence of an explosive gaseous mixture.

EXPERIMENTS ON THE REHEATING OF COMPRESSED AIR.*

By WILLIAM GEORGE WALKER, A. M. I. C. E., M. I. M. E.

Mr. Patrick Y. Alexander, of Experimental Works, Bath, and the author, have during the past few months, at Chiswick and elsewhere, carried out some experiments on the reheating of compressed air. Considerable economy can be obtained by reheating compressed air before admitting it to the engine. Reheating is accomplished by two methods:—(1) By passing the air through hot pipes heated by a furnace fire. (2) By passing the compressed air through water in a boiler at a temperature depending on the pressure in the boiler. The former is called the dry method and the latter the wet or moist method of heating. It has long been the custom in Paris to use a small stove, through which the compressed air is passed before being used in the motor. Prof. Unwin, F. R. S., states that "Prof. Riedler tried an old 80 horse-power steam engine in Paris which had been adapted to work as an air motor, and which was actually giving 72 indicated horse-power with compressed air at 5½ atmospheres. It was using about 31,000 cubic feet—reckoned at atmospheric pressure—or about

* British Association, Bradford, Section G.

2,376 lbs. of air per hour. This air was heated to a temperature of about 300 deg. Fah. by the expenditure of only 15 lbs. of coke per hour. On a favorable assumption a steam engine working to the same power would have required ten times this consumption of fuel at least." Prof. Unwin also says that reheating has the practical advantage of raising the temperature of exhaust of the motor, and for the amount of heat supplied the economy in the weight of air used is surprising. "The reason of this is that the heat supplied to the air is used nearly five times as efficiently as an equal amount of heat employed in generating steam." The author and Mr. Patrick Y. Alexander have, during the past few months, carried out a number of experiments on the reheating of compressed air by the wet method, i. e., by forcing compressed air into a boiler containing water, when very economical results were obtained.

Last year Prof. J. T. Nicolson, D. Sc., M. I. C. E., carried out some very valuable experiments in Canada under the auspices of the Taylor Hydraulic Air Compressing Company. Prof. Nicolson experimented with five different methods of using compressed air in an ordinary steam engine of the Corliss type of about 27 indicated horse-power. (1) The air was supplied to the engine cold. (2) Steam was injected into the air in the main pipe before supplying it to the engine. (3) The air was injected amongst the water in the steam boiler and heated by mixing with the water and steam of the boiler before being supplied to the engine. (4) The air was blown upon the surface of the water in a steam boiler and heated by mixing with steam in the same, before being used to drive the engine. (5) The air was passed through a tubular heating vessel and heated by a coke fire, afterwards being used to work the engine. The compressed air was drawn at a pressure of 53 lbs. from the 6-in. main air pipe of the Taylor air compressor. The author gave an account of this compressor at the Bristol meeting of the British Association, 1898. The wet heating was carried out in a Lancashire boiler 7 ft. diameter by 30 ft. long.

Experiments were first made without reheating, when about 850 cubic feet of free air were used per indicated horse-power per hour. The air was then heated to 287 deg. Fah., by passing the compressed air through pipes heated by coke, under which condition 640 cubic feet of free air was used per indicated horse-power per hour, being a reduction of 210 cubic feet of free air per indicated horse-power per hour, due to reheating. Thus a saving of 25 per cent. is effected in the quantity of air used. This saving was effected by the burning of 348 lbs. per horse-power hour. The results may be stated as follows:—100 horse power in cold compressed air was raised to 153 horse-power when reheated to a temperature of 287 deg. Feh. by an expenditure of 47 lbs. of coke per hour, or at the rate of 1.42 lbs. of coke per horse-power per hour additional. This is equivalent to an additional horse-power for every pound of coal burnt in the heater, which is far more economical than the most efficient steam engine and boiler. By mixing from 10 to 15 lbs. of steam per horse-power with the air, the quantity of air required was reduced from 850 cubic feet to 300 to 500 cubic feet per indicated horse-power per hour. The results showed that the extra horse-power due to heating by the wet method was obtained at an expenditure of 1.3 lbs. of coal per additional indicated horse-power per hour.

The author's own investigations are most conclusive as to the efficiency of reheating, either by the dry or wet method. Generally speaking, the results show that an additional horse-power can be obtained with an expenditure of 1 lb. of coal. Better results even than this have been obtained, which is far more economical than the most efficient engine and boiler using steam ever produced. And the experiments seem to show that in many cases it would prove advantageous to use compressed air in conjunction with steam in an ordinary engine.—*The Engineer,* London.

THE AIR BRAKE.

As early as 1852 a patent was granted in this country for an alleged invention of a railway brake operated by steam, and a few years later patents were issued in England for alleged air-brakes, but the first practical air-brake was not produced until about 1869, when George Westinghouse, Jr., of this country, invented what was then known as the "plain-brake." This consisted of a pump operated by steam from the locomotive boiler, which compressed air into a reservoir located under the locomotive cab. This was under the control of the engineer by a valve in a pipe leading from the reservoir. From this valve a pipe extended under the tender and was connected by flexible hose sections to a similar pipe under the entire length of each car. Branch pipes led to "brake-cylinders," and the stems of the pistons in the latter were connected with the brake-levers on the cars. Upon opening the engineer's valve, air pressure passed to these cylinders, pushing the pistons backward, operating the brake-levers and forcing the brake-shoes against the wheels. It was found that the operation of this apparatus was too slow, and was attended by danger of collision in case one part of the train became detached.

About 1872 or '73 Westinghouse produced an "automatic brake" which embodied the addition of an auxiliary reservoir and a triple-valve device to each car. Each reservoir was of sufficient capacity for at least one full application of the brakes, thus providing for automatic action in the event of accident. The operation of this brake was radically different from that of the "plain-brake." In the former the compressed air was stored in the main reservoir until required for the application of brakes; in the latter the main and auxiliary reservoirs and trainpipe were always charged with compressed air at working pressure, to prevent the application of the brakes. The former system was operated by pressure from the main reservoir, while the latter system was operated by reduction of pressure in the train pipe. The result was automatic in action in case of accident, such as the bursting of hose or the train breaking in two. But this "automatic brake" was not capable of successful operation on long trains of freight cars. It was publicly tested in 1886, near Burlington, Iowa.

In 1885 the Railway Master Car-Builders' Association arranged for a series of experiments. Several companies entered into the competition, but none succeeded in stopping long trains of freight cars without violent and disastrous shocks. The trials were renewed in 1887, with five competing companies. The report of the committee was against all the competing devices, the committee concluding that air-brakes actuated by electricity were the only ones likely to be capable of successful operation on long trains of freight cars.

After these trials Mr. Westinghouse set himself to work to obviate the difficulties that had not yet been overcome, namely, to provide for uniformity in the application of the brakes and preventing shocks to the cars.

In the latter part of 1887 he succeeded in constructing a quick-action automatic brake, capable of being successfully applied to a train of 50 cars, and operative under all conditions of practical railway service. The requirements with which he then for the first time successfully complied were: (1) The regulation of the force to be applied to the brake-shoes so as to secure all necessary graduations, from the mere slackening of speed to the service-stop, and from the service-stop to the emergency-stop. (2) The automatic operation of the brakes in case of accident. (3) The practical simultaneous operation of the brakes on each car, so that, in long trains of freight cars, shocks might be avoided. (4) The control of all these operations by the engineer; and (5) Certainty of operation under all conditions.

This has been judicially determined to be "the first system which practically solved the problem of immediate stoppage of a long freight train in time of danger, in connection with and supplemental to "train-brake graduations."

Less than ten years ago this matter was still problematical. To-day nearly every railroad in the United States and Europe is equipped with brakes operated by compressed air.

AIR BRAKE SERVICE.

The air brake is one of the applications of compressed air that has made a permanent place in its own field, and its development brings out some interesting facts in connection with train service.

During the three years that the high-speed brake has been in service on the Empire State Express not a single case of slid flat wheels has been reported. From 1886 to 1896 the distance required to bring a passenger train to a stop has been reduced one-half. This is due to the use of the high-speed brake instead of the plain automatic brake. The distance in which a train can be stopped from a speed of 40 miles is nearly twice as great as that from which it can be stopped from a speed of 30 miles an hour. To stop a train going at the rate of 50 miles an hour, the stopping distance is three times as great as that required at 40 miles an hour. At 60 miles an hour the distance required for stopping is about five times as great as that required for 30 miles an hour, and more than two and one-half times as great as that required at 40 miles per hour.

THE AUTOMATIC AIR BRAKE.

The Automatic Air Brake has been in service for so many years, and has been so faithful and punctual in performing the offices required of it, that we have come to look upon its prompt and efficient action as a matter which is of course to be expected. A little reflection upon the conditions under which it operates, however, will bring the conclusion that the certainty and reliability with which the automatic brake performs its work is one of the most remarkable characteristics of the apparatus.

In the first place, the orderly performance of the different operations of the automatic brake is entirely dependent upon the operation of a piece of mechanism called the triple valve, which requires unusual nicety of construction, and which, in some respects, requires the most careful adjustment. This valve mechanism consists of a number of moving parts, which must operate every time the brakes are applied, and every time that the brakes are released. The delicacy of the adjustments would appear to require careful watchfulness, considerate attention and reasonable protection. Yet this apparatus is secured beneath the floor of a railroad car which goes jolting over the road, is subject to constant vibration and concussion, and is subjected to the influence of a constant whirl of cinders, sand and dirt. These conditions are of themselves such as would seem to prohibit the successful use of a delicate piece of mechanism to be operated by small differences of air pressure. More than this, the neglect to clean and lubricate the frequently moving parts of this delicate mechanism has in many instances extended over years at a time, so that it would most naturally be expected that it would become so disordered as to entirely refuse to operate. Yet it has gone on, year after year, under these most trying conditions, performing the service required of it with promptness and efficiency to an extent that seemed to indicate to some that it really was unnecessary to give the apparatus any attention at all.

The continued reliability of the apparatus must be attributed, first of all, to unusual care in the selection of material, and to methods of special accuracy and refinement in manufacture. The prompt release of the brake depends, to a large extent, upon such a high character of material and workmanship, because the operation of the triple valves to release the brakes depends upon a small excess of air pressure upon one side of a small piston, which excess can be obtained but gradually, and would be impossible to obtain at all if any material leakage past the small piston occurs.

But the complete reliability of the apparatus for the application of the brakes is a feature of design and invention. The brakes are applied by dissipating the air pressure in the main air pipe which extends throughout the train, and, however much difficulty there might be in charging an efficient pressure into the pipe, there can never be any doubt of the ability to promptly discharge the air pressure, as it merely requires an opening from the pipe to the atmosphere at any point. In this way a powerful pressure upon one face of the small piston of the triple valve may always be promptly rendered available for moving the piston into a position to apply the brakes.

Any uncertainties, therefore, as to the operation of the automatic air brake, which may arise from neglect and disorder, apply only to the release of the brakes, whereby the train may be enabled to proceed; but, once that the brakes are released and charged with air pressure, the prompt response of the apparatus to apply the brakes, at any time that they may be required, is assured and inevitable, as the only requirement then is that the train pipe shall be given an opening to the atmosphere.

QUICK-ACTION AUTOMATIC BRAKE.

The April issue of COMPRESSED AIR contained a brief resume of the history of the air-brake down to the completion of the present quick-action automatic brake, which has successfully stood the test of time and use and demonstrated beyond peradventure its superiority over all other brakes known and tried.

In the quick-action automatic brake the application of the brakes to the wheels is effected by reducing or cutting off the air pressure in the main train pipe leading from the main air reservoir. This reservoir is carried beneath the engine and is charged with air from a pump also on the engine, the pump being operated by steam from the boiler. The "engineer's brake and equalizing discharge valve" is located in the cab of the engine and is connected to a pipe leading from the main reservoir and a second pipe communicating with the train-pipe. This valve regulates the flow of air from the main reservoir into the train pipe for releasing the brakes, and from the main train or brake pipe to the atmosphere for applying the brakes. The main train pipe leads beneath all the cars of a train, being connected between the cars by flexible hose coupled to the pipe sections. By means of an anglecock at each end of the pipe of each car, such pipe is closed before separating the couplings, thus preventing the escape of air and the application of the brakes when the cars are uncoupled.

Beneath each car is an auxiliary reservoir which takes a supply of air from the main reservoir, through the train pipe, and stores it for use on its own car. The brake cylinder is connected to this auxiliary reservoir, and its piston rod is attached to the brake levers in such a manner that, when the piston is forced out by the air pressure, the brakes are applied. The quick-action automatic triple valve is connected to the main train pipe, auxiliary reservoir and brake cylinder, and is operated by the variation of pressure in the pipe—first, so as to admit air from the auxiliary reservoir to the brake cylinder, which applies the brakes, at the same time cutting off communication from the brake pipe to the auxiliary reservoir, or, second, to restore the supply from the train pipe to the auxiliary reservoir, at the same time letting the air in the brake cylinder escape, which releases the brakes. A pump-governor regulates the supply of steam to the pump, stopping it when the maximum air pressure desired has been accumulated in the train pipe and reservoir.

In practice, a moderate reduction of air pressure in the train pipe causes the greater pressure remaining stored in the auxiliary reservoir of each car to force the piston of the triple-valve and its slide-valve to a position which will allow the air in the auxiliary reservoir to pass directly into the brake cylinder and apply the brakes. In the event of emergency or accident, a sudden reduction will be had in the train-pipe, producing the same effect, and in addition to this, causes supplemental valves in the triple-valve to be opened, permitting the pressure in the train pipe to also enter the brake cylinders, increasing the pressure from the auxiliary reservoir about 20 per cent., resulting in instantaneous action of the brakes to their highest efficiency throughout the entire train. Hence, in case of accident, real or threatened, a train can be brought to an immediate stop. When the pressure in the train pipe is again restored to an amount in excess of that remaining in the auxiliary reservoir, the piston and slide valve are forced in the opposite direction, opening communication from the train pipe to the auxiliary reservoir, and permitting the air in the brake cylinder to escape to the atmosphere, thus releasing the brakes. When the engineer wishes to apply the brakes he operates the "engineer's brake valve," so as to close one port, retaining the pressure in the main reservoir, and then permits a portion of the air in the train pipe to escape, reducing the pressure therein and allowing the greater pressure in the auxiliary reservoirs to be brought into action on the brakes through the agency of the triple valve. To release the brakes he so turns the valve as to allow the air in the main reservoir to flow freely into the train pipe, restoring the pressure therein to a degree greater than that in the auxiliary reservoirs.

A valve in each car, called the "conductor's valve," is capable of operation by any of the train men in the event of emergency. By pulling on the cord of this valve the latter will be opened and allow the air in the train pipe to escape. Should any of the cars of a train become accidentally disconnected, the air in the train pipe escapes and the brakes are instantaneously applied in each section of the train. They are likewise applied in the event of a pipe bursting. Hence, the underlying principle is that any reduction of pressure in the train pipe applies the brakes to the wheels.

AUTOMATIC OR DIRECT AIR-BRAKES FOR STREET RAILWAYS.

With the advent of heavy cars of the double truck type, air brakes are coming into very general favor, but on roads operating with trail cars they have for a long time past been very successfully used. In this latter case, particularly where the cars run over grades of any moment, some engineers contend that the so-called automatic system, such as is in very general use on steam railroads, should be applied to street railways, even where but one trail car is used. As in this system the breaking away of the trail car automatically applies the brake, it is quite natural that engineers should advocate its use, but a close study of the question will show that the conditions of service on street and steam railways are very different, and what is an excellent device on the latter has many serious drawbacks when used on the former in trains of two or three cars.

In the direct air system the pressure stored in the main reservoir is admitted directly to the brake cylinder pipe, the application of the brakes on a two or three car train being practically instantaneous when we open wide the valve on the motor car connecting this pipe to the reservoir. Now if we also run a pipe from the main reservoir, on the motor car, through to a reservoir on the trailer, and on the latter put a cock between the reservoir and train pipes, the conductor by opening it can apply the brakes, in case of necessity, as well as it is done in the automatic system. Again, if the couplings between the cars are provided with check valves which are pressed open when the two halves are connected, and close instantly when pulled apart, should a trailer break away from its motor car, it will have a supply of air at main reservoir pressure in its own reservoir, and the conductor, upon feeling his car take a retrograde movement, can open his valve and apply the brakes. This valve may be operated by a cord running the length of the car; so he has only to raise his hand to put on the full power of the brake, and this device is all that would be necessary on 99 roads in a hundred. If, however, an automatic device is insisted upon, as it might be in the one hundredth case, another cock, placed at the end of the trail car, with its handle connected by a chain to the motor car, would be opened upon the breaking off of the trailer, and apply the brakes as quickly as the "automatic air" system.

Therefore, it should be a simple matter for a street railway manager to decide whether or not he will equip his cars with a device which takes the direct control of his power brake out of the motorman's hands, and thereby jeopardizes every one of about a million stops, for the sake of moving by air a valve that will automatically apply the brakes in case of the trailer breaking away, when equally safe results may be obtained by a valve operated by the conductor or mechanically, but which leaves the operation of the brake directly in the hands of the motorman, thereby making it absolutely certain to act when he moves his hand, to say nothing of the smoother and better service thereby obtained.

Furthermore, the improved automatic couplers and heavy safety chains used to-day reduce to a minimum the liability of a trailer breaking away from its train, and thus, for this class of service, rob the automatic system of its peculiar charm. In view of the magnificent service performed by the automatic system on steam railroads, no one could deny its value in this field, but on street railways it is a "white elephant," pretty in theory, but bad in practice.

E. H. Dewson

TESTS OF STREET CAR BRAKES BY THE NEW YORK RAILROAD COMMISSION.

The most important and exhaustive series of tests of street car brakes ever undertaken was made last year by the New York Railroad Commission; and their results have just been made public in a pamphlet of 60 pages, accompanied by plates showing the autographic records taken during the tests. Copies of this pamphlet can be obtained, we presume, by addressing the office of the New York Railroad Commission at Albany. In the present article we shall attempt to summarize the main results reached by these tests, and the most important lessons to be drawn from them.

These tests, which were briefly described in this journal while they were made on the Lenox avenue line of the Metropolitan Street Ry. Co. in New York City. The track chosen for the test has a very slight grade (8.8 ft. per mile), and is laid with 90-lb. girder rails with 2-in. head. The line is a double track line, operated by the electric underground conduit system. The cars used were the Metropolitan company's standard 8-wheel cars, weighing 20,816 lbs., equipped with Brill "maximum traction" trucks, with 30-in. and 20-in. wheels, and a total wheel-base of 17 ft. 6 ins. Brake shoes were applied to all wheels.

There were 26 applications by brake manufacturers and inventors to take part in the tests; and 16 companies actually equipped cars and had their apparatus

..ed. Of these, 4 were air brakes, 4 electric, 3 hand-power, 2 friction, and 2 were combined track and wheel brakes. The different brakes are described as follows in the official report:

AIR BRAKES.

The reliability of the air brake has been thoroughly established by its use on steam roads. A large number of them are now used on electric cars, and with proper inspection and care, the air brake, as applied to electric cars, is a reliable, powerful, quick and easily controlled means of applying the braking power to a car wheel. Four systems of air brakes were submitted and tested. All were similar, so far as relates to the use of air under compression in a cylinder to operate a piston from which, through levers, the power was transmitted to the brake shoes. They differed in the method of compressing the air and applying it to the piston.

The G. P. Magann Air Brake Co. presented what is known as a storage air system, in which there is an air compressor and reservoir located at the power-house or some central point on the street car system. This reservoir is charged with air usually compressed to 300 lbs. pressure. The car is equipped with two storage reservoirs, which are charged in a few seconds from the stationary reservoir at 300 lbs. pressure. By means of a reducing valve this pressure is reduced to 50 lbs., at which pressure the air enters an auxiliary reservoir from which it is controlled, to the brake cylinder by means of the engineer's valve, in the usual manner. There are some special features in the construction and operation of this valve. The storage equipment of cars is calculated for 300 stops, which is sufficient for ordinary car operation; when necessary the capacity can be increased.

The Christensen Engineering Co. presented what is known as the straight air system, which consists of a reservoir, an electric motor compressor, an automatic regulator which governs the operation of the motor compressor; an engineer's valve and the usual brake cylinder. In this system, as its name implies the compressed air passes direct from the reservoir to the brake cylinder, there being no auxiliary reservoirs or reducing valves between the pressure reservoir and the brake cylinder. All of this apparatus, with the exception of the controller, is placed under the car. There are a number of special features in the construction and operation of the system as presented by this company.

The Standard Air Brake Co. presented an automatic air brake system, consisting of an electric motor-driven compressor, a storage-pressure reservoir, motor controller, brake cylinder and engineer's valve. This system is similar to the one described above, except that there are a number of special features construction and operation in which the two systems differ; the general princip of compressing and applying the air is, however, the same.

John E. Reyburn presented an air brake system similar to the two lt described, except that the compressor was operated mechanically instead of by an electric motor. This compressor was worked by the motion of the car ax, which was transferred to the compressor by means of friction discs, or whee, one of which revolved with the axle, the other being fast on the compressor sha These were placed in such position that they made a firm frictional conta These friction discs are thrown into contact and released by compressed a the reservoir. After the air has been compressed in the cylinder, the opera- is the same as usual in air brake systems.—*Engineering News.*

INDEPENDENT MOTOR TO UTILIZE THE BRAKE ENERGY.

In a lecture before the Board of Trade of the City of Worcester, Mass., Mr. ll E. Clark, who has invented various ingenious machines, introduced and bed a system of independent motor and a means of utilizing the brake y in connection with street railway and other traction.

He described it as a self-contained, independent motor; one where it was necessary to return to a storage station at short intervals, as is necessary with

FIG. 137—EXPERIMENTAL AIR MOTOR.

igh pressure systems. In this system the air is compressed to the working ure only.

"In connection with this independent system is another source of economy, ect gift, if so it may be called. This source is from the compressor brake, rangement whereby air compressors are operatively connected with the axles e truck, in such a manner that when the car is retarded or stopped, the y ordinarily lost in the application of a brake is used to operate the air com- or and the air stored for subsequent use. As it requires about three times the r to start than it does in the general run, the immediate use of the air just d by simply moving a lever is very desirable. Thus we have at our disposal for useful work the entire momentum of car or train less the friction, wher we wish to reduce its speed.

The majority of motor vehicles are propelled from the axle. Why not them from the same point?

That energy due to the moving car or train, is not only available. but v able, is illustrated by an estimate made at the Polytechnic Institute, April 2 1896, in which it was shown that the work required to stop a train weighing 424,000 pounds, in twice its length, say 800 feet, from a speed of one mile a min was 4,665 H. P. applied constantly during a period of 20 seconds, or 1,555 H. for one minute. Illustrations of this problem can be seen daily. The eleva roads in New York and Chicago are good illustrations, where the trains run abo one-third of the time on the brake, drawing from the boiler or electric supply

FIG. 138—MOTOR OPERATING BAND SAW.

apply them. Suppose these conditions were reversed and energy stored during the same time. The cost of operating would be materially reducd.

In the introduction of the combination air compressor, the brake compressor finds its largest development, whatever heat is lacking, due to intermittent operation of the brake, is supplied from the exhaust of the impulse cylinder

In the ordinary oil or gas engine quite an amount of heat escapes through the exhaust, but in the compressor system the largest proportion of heat is utilized. The heat from the impact cylinder supplying the motor requirements, and the cold produced by the motors, is turned back to do service at the combustion cylinders. Thus the exhaust is both utilized and muffled. As an illustration of this, it is shown that the exhaust from air motors in Paris, is used for refrigerating purposes and the exhaust from gas engines in Pittsburg is used for heating purposes.

To harness an external combustion engine direct to the axle of a car or locomotive offers difficulties at once, an impact sufficient to start from a point of would wreck the machinery. We can secure the energy, but the natural ... of the pistons would be many times faster than the speed of the crank pin ... the Empire State express engine running at its best.

The combustion compressor here advocated is so constructed that a very uniform pressure is maintained between the combustion and air cylinders, the result of which secures to this system, not only the highest attainment of the ... engine, but reduces impact to pressure, in the most efficient form. For when the predetermined working air pressure is reached, the supply of fuel is cut off, and the machine stops, not simply runs idle, which occasions waste to a con-

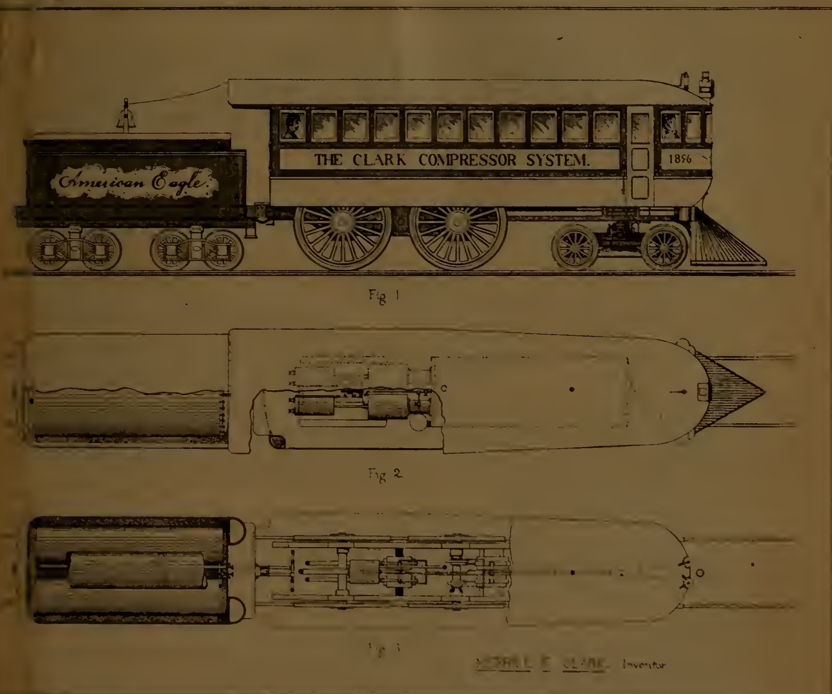


FIG. 139—THE INDEPENDENT MOTOR SYSTEM.

siderable extent and when the pressure falls below the desired point, the compressor automatically starts, restores and maintains the said working pressure.

In this way all waste from the safety valves with its attendant disagreeable noise is avoided.

It will be noticed that in this system the fire-box, flue system, cinder chamber and smoke stack are dispensed with and locomotives in use at the present time can be readily equipped with this system, at comparatively small expense.

What is here said of the locomotive is applicable to the steamship, where this system can be used with great efficiency and economy.

When we consider the force developed in the internal combustion cylinder at small expense, and know that this power can be greatly increased, when the mechanism is favorable to transmit it with safety, that compressed air possesses the advantage of steam, from maximum pressure, to multiplied expansion, with a balance in its favor. We look to see in the near future the perfected motors not only on our streets but making the longer journeys on land and sea. Not only with the speed of the wind, but with the annoying smoke and cinders eliminated.

At this writing, we are not prepared to publish the details of construction of the motor and other apparatus, owing to the preliminary work.

We will say, however, that this motor consists of a plurality of internal combustion and air cylinders with their axis in alignment for the purpose of reducing friction to the minimum point.

These several cylinders are arranged to develop the highest power in the combustion cylinder to correspond to the highest performance of the air cylinder, thus creating a practically perfect and uniform power during a whole revolution.

This point is certainly worthy of consideration in street railway practice where shocks or vibrations are to be avoided."

AIR CARS.

The late Franklin Leonard Pope, a distinguished electrician, said that if but a fractional part of the money and brains that have been spent upon the development of electricity as a motive power for street railroads had been spent upon compressed air, we would now be riding on pneumatic tramways. This is a statement worthy of serious consideration. Prof. Hutton of Columbia College, recently repeated it, quoting Mr. Pope's words, and expressing his own belief that compressed air offers much encouragement to experimenters in this line. The extensive development of the trolley is the result of brains, energy and money, which in all things is sure to win in the end. Nobody now doubts that electricity is well adapted for tramway work, nor does any unbiased person question the fact that the trolley, under certain conditions, is the best means of street car propulsion. But there are some places, and certain conditions, where the trolley either should not be used because of objectionable features, or, when used, it does not accomplish the result in the most economical manner. This is the field for the compressed air motor.

It is well known among engineers that it is not economical to distribute power electrically unless that power is consumed as fast as it is produced. In other words, a dynamo developing, say, 50 H. P. and distributing it for power purposes, is not economical unless the motors consume the maximum available power at all times. If we have a short line of street cars, say one mile in length, as for instance a means of transporting passengers between a railway station and some other point, and desire to equip this line with a motive power other than horses, it is not likely that it would pay to equip with the trolley, because with one or two cars on the line running at infrequent intervals, there would be times when no part of the power generated at the central station would be required at the car, because there would be no car in motion; hence it would become necessary to either stop the engine which runs the dynamo, or to provide some other means of utilizing the electric current. Such a road as this calls for a storage system, and the best power for a storage system is compressed air.

There can scarcely be any doubt about the fact that there is a field for the storage system of street car propulsion, because so much time and money has been spent in efforts to perfect the storage battery. It is equally as clear that the electric storage battery system is a failure up to date. Whatever other reasons there may be for this, the principal difficulty is in the battery itself. This being the case, is it not surprising that some of this time and money is not spent upon some power other than electricity as a storage power? Compressed air is particularly well suited for this purpose. Nor is it a matter which involves much doubt as to the practicability of compressed air as a power for propelling cars by the storage system. It is almost entirely a question of availability for specific purposes, of adaptability for tramway service; and in order to reach this point, experiments involving time, invention and money are of course necessary. The pneumatic locomotive, which has been built, and which is now used largely in mines and elsewhere, is an evidence of the practicability of compressed air as a tractive power. Some of the locomotives are of large size, others are small, and many of them have about the same power capacity as that required for street car propulsion. These locomotives store air at pressures varying from 400 to 2,000 pounds pressure per square inch. Many of them do not reheat the air at all before use, and yet we venture to say that it would be a serious matter if those now using them should be called upon to stop, as we doubt that any power would be as useful, or in most cases as economical.

To store compressed air and use it as a power is a very simple matter. There are many erroneous ideas on the subject, and much ignorance. In order to store compressed air, we must first have a receiver or tank sufficiently strong to withstand the pressure; then it is simply a question of an air compressor and plenty of free air. The popular idea is that there is an enormous amount of heat developed which in some mysterious way has a bad effect during compression and storage; that this heat all disappears, and that it is impossible to use this air without freezing, resulting in stoppage of ports and passages and serious hindrance to the machinery. The heat of compression is no longer a bugbear in air compression. It is now under control to such an extent that by compound compression, or by compressing in stages with inter-coolers between each stage, the heat produced by the compression of air is not only reduced in degree, but the objections to it on the ground of economy no longer obtain. By the modern compound, condensing Corliss Air Compressor provided with quadruple compression cylinders and inter-coolers, compressed air may be delivered into the receiver at 2,000 pounds pressure, and at a temperature nearly equal to that at which it was taken into the compressor; that is, the temperature of the engine room or of the atmosphere surrounding it. The heat loss—that is, the loss of power due to the heat of compression, which a few years ago ran as high as 50 per cent.,—may now be brought down to 17 per cent. This large saving is due mainly to compound compression and inter-cooling, and it represents a marked advance in compressed air science. This fact alone should at least give compressed air engineers a hearing when pressing their claims for a better storage system of street car propulsion than has been or can be produced by electricity. After compression the air is stored in tubes, which are made of solid ingots of mild steel, free from joints and welds, capable of standing pressures from 2,000 to 4,000 pounds per square inch, and which do not explode. Even if an explosion should occur, or a weakness develop in the reservoir, there is not likely to be any serious result, because the rent which would quickly be made in the pipe would soon discharge its stored air. Were the material brittle the pieces might fly in all directions and do considerable damage, but the metal used for this purpose is soft and pliable, and would tear or stretch instead of break. A discharge or explosion from compressed air will not scald like steam, though it is likely to produce quite as much noise.

Having compressed air stored in suitable receivers, it is simply a question of keeping them tight, and of providing a sufficient volume to run a car, locomotive or any other traction engine. Almost any design of engine which runs by steam will run equally as well by compressed air, but an air motor designed for use with air is better and more economical. Pneumatic engineers have already developed reheaters by means of which the stored compressed air before use in the engine is very much increased in temperature; hence its volume is increased and less air is required to do a certain work than when used cold. Reheaters will, of course, overcome all liability to freezing, but the main purpose of a reheater is to save power. That it does this at an expense in fuel which is but insignificant in proportion to the gain, is a matter which cannot be disputed in view of recent facts of experience. Mr. Robert Hardie has practically demonstrated the fact that the cost of reheating air is about one-eighth the cost of compression. That is, it will only cost one-eighth as much to add a horse power to a compressed air volume as it originally costs to produce one horse power by the process of compression.

AIR CARS.

The air cars illustrated on the cover of this issue are those which have been operating for some time past on North Clark Street, Chicago, Ill. The motors are the Hardie type and their service has been very satisfactory. In ordinary weather these cars simply do all that could be expected of them, but in time of storm, when snow and ice cover the tracks, they have proved to be able to cope with the emergency and the system appears to be adapted to all kinds of weather. The Compressed Air Company, 621 Broadway, New York, has issued a pamphlet showing the actual service given by the air cars, and the numbers of passengers carried during very stormy weather.

Mr. H. D. Cooke, president of the Compressed Air Company, has submitted the following statement showing the cost of operating compressed air motors for street car service. For the week ending December 2d, 1899, only 409 cubic feet of free air per mile was used by the air motor cars while carrying passengers, and not including an allowance for occasional trail cars.

"Taking above as a basis of air consumption, and the statement of the cost of compressing air in large volumes as stated by the Ingersoll-Sergeant Compressor Company as being $0.0285 per 1,000 cubic feet compressed to 2,000 lbs.

pressure, the cost per car mile (for large installations) 409-1,000 of $0.0285 = $0.0117 or in round figures, 1 2-10 cents per car mile.

These figures cover cost of superintendence, labor, coal, waste, oil, interest on cost of power plant and a charge for annual depreciation. Price of coal is charged at $2.90 per ton.

On this basis, and adding charges of wages, conductors and motormen, and labor of charging and repairing motors, the cost of operating per car mile in units of not less than 100 cars would be $0.0756 per car mile.

This does not include general expenses, such as interest on, or repairs and maintenance of track and roadbed, or salaries of general officers, damage suits, etc.

The noiseless air brakes, and the starting and stopping of the car with the small lever in the same movement (Hardie system) must reduce chances of accidents and consequent charges to damage account. These figures are based on the results of the present service in Chicago, covering a period of seven months, and also one year's experience on 125th street, New York. They were gone over, item by item, by practical street railroad men, and are based on actual facts, as stated."

AIR CARS.

The beginning of the new century seems to be a peculiarly fitting time for us to tell of the status of the compressed air motor in street car service, and it happens that just at the present time we have also at hand data of sufficient interest and authority to warrant us in setting it forth. The readers of Compressed Air have been informed from time to time of the various installations of compressed air for operating street cars. Much of the record has not been of a character to encourage either the participants or the onlookers, and some who were interested and hopeful have dropped out of sight in connection with it. Compressed air seems, when first thought of, so simple in its operation, so easily understood, controlled and manipulated, that it has not received the proper study of its conditions, and in consequence many crude experiments have ended unsatisfactorily. Those who have stuck to it are to be praised for their perseverance, and to be congratulated for the present promise of gratifying and enduring success.

The most interesting installation probably ever yet made of motor cars operated by compressed air is that of the 28th and 29th street crosstown line of the Metropolitan Street Railway Company of New York. It is interesting, especially in the fact that it is a complete installation, no other cars being operated upon the line either night or day but the compressed air cars. In this plant, as elsewhere in compressed air trials, it would seem that the best conditions were not at the first insisted upon. Indeed some mistakes were evidently made. The tracks of this line were cheaply and hastily laid some ten years ago for the light horse cars of that time, with no thought of any heavier traffic, and the track had not been maintained in proper condition, and upon this track the air cars were started. The tracks have since been relaid, and are now in fair condition for the service. We cannot but think also that it was a rash and risky thing to do to start a permanent service of this responsible character with a single unit of supply at the power house. However perfect and adequate the apparatus, there are too many possibilities of accident or derangement for the risk to be taken. The compressor in use is also of much larger capacity than the present service requires, it having been designed in contemplation of partially supplying a much more extensive service, which it was hoped would be and is now confidently expected, will be developed. The compressor is easily capable of supplying three times the number of cars now in service, or three times each day the business of that which it at present supplies. The compressor is now run at 27 revolutions per minute, when it might be run at 75 revolutions. No larger force of men, of course, would be required for the increased speed, although a few more men would be required in the car shed.

The following is an official statement of the running of the present cars since they have been in steady operation. It will be noticed in connection with this statement that the number of cars in operation at the beginning of the period was considerably less than at the last of it. On the day of the Sound Money Parade the running of the cars was stopped entirely by the obstruction of the streets for eight or ten hours.

RECORD OF AIR CARS BEING OPERATED ON 28TH AND 29TH STREETS, NEW YORK CITY.—ROUND TRIP 5.5 MILES.

Date. 1901.	No. of Cars in Opr.	Round Trips.	Total Mlge.	Total Pass. Carried.	
September ...26	13	186	1023	13,271	
27	13	215	1182	13,724	
28	13	218	1190	13,710	
29	13	222	1221	15,544	
30	13	234	1287	11,840	Sunday.
October 1	13	222	1221	14,474	
2	15	219	1204.5	14,476	
3	15	252	1386	16,253	
4	16	256	1408	16,231	
5	16	270	1485	16,968	
6	16	269	1479.5	17,670	
7	15	239	1314.5	13,240	Sunday.
8	16	269	1479.5	19,069	
9	17	302	1661	18,690	
10	17	302	1661	18,078	
11	17	340	1870	18,599	
12	17	320	1760	18,455	
13	17	332	1826	22,081	
14	18	245	1347.5	12,197	Sunday.
15	18	330	1815	19,520	
16	18	346	1903	21,142	
17	18	340	1870	18,862	
18	18	328	1804	18,692	
19	18	341	1875.5	18,618	
20	18	334	1837	19,672	

Date. 1900.	No. of Cars in Opr.	Round Trips.	Total Mlge.	Total Pass. Carried.	
21	18	245	1347.5	14,409	Sunday.
22	19	330	1815	19,890	
23	19	324	1782	20,052	
24	19	343	1886.5	20,972	
25	19	354	1947	19,074	
26	19	349	1919.5	19,857	
27	19	356	1958	22,173	
28	18	245	1347.5	12,324	Sunday.
29	19	331	1820.5	19,421	
30	19	335	1842.5	19,341	
31	19	327	1798.5	19,062	
November 1	20	340	1870	19,274	
2	19	345	1897.5	19,978	
3	19	197	1083.5	12,730	Sound Money Parade.
4	16	245	1347.5	13,470	Sunday.
5	20	351	1930.5	19,846	
6	17	256	1408	15,440	Election Day.
7	18	352	1936	21,317	
8	19	334	1837	20,274	
9	19	339	1864.5	19,194	
10	19	341	1875.5	20,035	
11	16	244	1342	12,860	Sunday.
12	20	338	1859	19,525	
13	20	353	1941.5	19,738	
14	20	354	1947	20,056	
15	20	352	1936	19,506	
16	20	352	1936	19,228	
17	20	353	1941.5	22,231	
18	15	245	1347.5	13,454	Sunday.
19	20	348	1914	20,557	
20	20	338	1859	20,390	
21	20	350	1925	20,785	

Total round trips	17,197
Total mileage	94,583.5
Total passengers carried	1,017,269
Average number passengers per trip	59.15
Average number cars running	17.5
Average number daily trips per car	17.2
Average number miles per day per car	94.6

The following is the computed total cost of operating 20 compressed air cars on the 28th and 29th streets (New York) line under present conditions:

REPAIRS.	Cents per car mile.
Including material, supervision, and 9 men, adjusting valves, piping, brakes, rods, brasses, labor, etc., $35.00 per day	2.

CHARGING STATION.	
Including oil, waste, foreman, charging gang (2 shifts), oilers, cleaners, etc., $28.00 per day	1.60
POWER HOUSE.	
Including engineers, coal passers, pipe fitter, machinist, oilers, etc., and 16 tons coal per day, oil, waste, etc., $82.50 per day	4.71
Cents per car mile	8.31
Conductors and motormen, inspectors, roadbed, ties and timber, removing snow, salaries of officers, switches, material, etc	9.11
Cents per car mile	17.42

The above computation is made on a basis of 1,750 miles per day, and although every charge is made for the present operating of only 20 cars, yet from 60 to 80 cars could be operated by the charging and power plant without any material increase in cost, so that for a more extensive installation the cost of operating would be materially reduced.

As a reminder to our readers it will be well for us here to recapitulate the principal features of the above installation. The air compressing plant and the shops are at 12th avenue and 24th street. The compressor comprises a 1,000 h.-p. Reynolds-Corliss, vertical, cross-compound, condensing engine with cylinders 32" and 68" in. diameter and 60" stroke, running with present load at 27 revolutions per minute under a boiler pressure of 150 pounds, the piston rods of the steam cylinders being extended below into the air cylinders of a four-stage Ingersoll-Sergeant air compressor. The successive diameters of the air cylinders are 46", 19", 13.75" and 6"' with the common stroke of 60". Effective intercoolers are of course provided between the successive stages and after the final compression. The compressor is designed to compress 3,750 cubic feet of free air per minute to a pressure of 2,500 pounds to the sq. in. Four Babcock & Wilcox boilers of 250 h.-p. each supply all the steam for the compressor and also for the shops and for the hot water service of the motors, which latter is a future essential to their economical operation.

The storage capacity at the station for the compressed air is now 1,050 cubic feet, which can easily be enlarged at will by successive addition of "bottles." Two cars may be charged at once with air and with the hot water for reheating, the entire operation for each car requiring about two minutes. The cars can make two round trips for each charge. They have Pintsch gas lights, the most effective air brakes ever employed and means for heating the cars during the cold season. The cars have each a storage capacity of 55 cubic feet of air at the maximum pressure. Nothing about the car in any way interferes with the passengers any more than in any other car. The operating devices on each platform consist of a reversing lever, throttle lever, air brake lever and a valve for shutting off the air storage. There is a pressure gauge visible, and a hand brake is retained for emergencies.

The cars are 32 feet long over all, the body being 22 feet, and seating 30 persons. The weight of the motor truck is 11,000 pounds and the total weight of the car in running order is 19,000 pounds. The car body is carried on elliptic springs that rest directly on the truck frame and are pivoted by special fulcrum to the car body. The driving wheel axles are journaled in regular locomotive style, and have the usual driving box spring suspension. The cars run steadily and smoothly and there is no jerking in stopping or starting.

The first passage of the air from the storage system of the car is controlled by a valve on the platform. It first passes the reducing valve, beyond which the uniform pressure of 150 pounds is maintained. Before entering the cylinders for work it goes through the hot water tank or reheater. It enters at the bottom by small perforations in a long pipe lying along the top, and thence to the throttle valve. The use of the reheater has been experimentally proved to almost exactly double the efficiency of the air used. The Hardie improved cut-off valve gear secures high economy in the expansive use of the air in the motor cylinders under the wide and sudden variations of load.

The report of the Metropolitan Street Railway Company for the year ending June 30, 1900, gives the relative and actual costs of operating cable, electric and horse railroads. For horse cars the average was 18.98 cents per car mile, the cars being much smaller than those of the other systems; for cable cars, 17.76 cents, and for electric cars, 13.16 cents. The figures were made to include all expenses of operation and maintenance. The estimate given may be assumed to show very nearly the best attainable results by either of the systems at present. The figures given in the computations relating to the air cars evidently do not give the best results, as the conditions are far from being the best that can be secured with our present knowledge. The compressor, as was stated, is very much too large for the present service and works at a constant loss. The plant has all the disadvantages of a new plant in the inexperience and lack of trained judgment of the men employed. It is to be noted that the expenses for repairs, two cents per car mile, are even now remarkably low for any system except the horse-car. On a recent visit to the shops we asked the superintendent what the repairs chiefly consisted in, and he said that there were really no repairs required, what went under that term was the occasional taking up of the brasses and the usual readjustments of the working parts, as with a first-class locomotive. Of the 20 cars, which is the total number on the line, there is seldom more than one at a time undergoing these "repairs." The estimate of the Compressed Air Company that the running expenses can be reduced to 13.57 cents per car mile, when the conditions are all correctly adapted to the work, does not seem to be unreasonable. With this figure crowding so closely the operating expenses of the electric cars it is to be remembered that the air cars have not in addition the enormous fixed charges for the construction of the roadbed which the electric cars labor under, so that with this load added to the electric service the balance is greatly in favor of the air cars.

The most important practical evidence of the favorable light in which the compressed air cars are at present regarded is in the fact that the installation of which we have been speaking was formally taken possession of by the Metropolitan Street Railway Company on Dec. 13th last. This does not necessarily mean that this system is at once to be adopted in place of the large number of horse cars still running upon the various crosstown and other lines of the city, but that it has at least so far demonstrated its desirability as to make it worth while for the greatest street railway system of the world to undertake for itself to get at the bottom facts in the case. The full service is to be maintained upon the line where it is now in operation, and trials of the Hardie cars are soon to be made upon other lines. Not only the general principles of the system and its general efficiency is to be completely determined, but it is also necessary to know the size of car and the motor and storage capacity best adapted to all conditions. Another car is nearly completed which embodies in every detail of it every improvement which experience has suggested. This car is to have a considerably increased storage capacity, so that it will be capable of running 25 miles upon a single charge of air, and this car will be tried upon any line that may be suggested. The absolute independence of these cars when charged leads to many suggestions of combination routes for them to run on, as with an omnibus system, for the accommodation of the public by quick transit and the avoidance of transfers. Other things being equal, the independence of all connection with the power house and the easy manipulation of the car as long as its charge holds out give the air cars a great advantage, to which is to be added their speed and safety and smoothness of running.

At present it must be said that the compressed air car in New York is commanding respectful consideration. Too much can scarcely be said of the engineering ability and farsightedness of Mr. Robert Hardie, who so long ago so completely designed the present system of operation and of the perseverance both of himself and of Mr. H. D. Cooke, who is still pushing as resolutely and as earnestly as ever.

AIR CARS.

The illustration shown, Fig. 140, is a view of the new Hardie Compressed-Air Motor Car. In view of recent events on the 28th and 29.h streets lines in New York City, this car is interesting in that it has recently been decided to substitute an improved form of the Hardie car for the experimental cars that have been removed from the 28th and 29th street lines. These Hardie cars are admitted to be the best in the line of pneumatic storage cars. They are built on the basis of a large experience in which Mr. Robert Hardie has been personally the active mechanical engineer, watching results and changing and simplifying the motor on lines of experience. This in itself should inspire confidence, but in addition we have the facts before us that the Hardie motor was in operation in New York for one year on 125th street, during which time a complete record was kept and this rcord is open for inspection. The work done was satisfactory to the officers of the Railroad Company, and to the thousands of patrons of the road who used them daily. It is a matter of note that, unlike the cars recently removed from the 28th and 29th streets lines, these cars on 125th street were so easy of movement that the general public were unconscious of the fact that they were being drawn by air as distinguished from any other form of motor. These motors were afterwards taken to Chicago, where they have been in daily operation for about fifteen months, and recently they have been purchased by the Chicago Company, the purchase comprising the entire plant, two cars and the air compressor. They are used in Chicago as "Owl cars," running at night on cable roads. During the severe snow storms of the past winter they ran satisfactorily. The work in operation now on the 28th and 29th streets line is to prepare the road bed for these cars. The old light rails that were used are being replaced by others sufficiently heavy to carry the air

FIG. 140—THE NEW HARDIE AIR MOTOR ON THE METROPOLITAN STREET RAILWAY CARS, NEW YORK.

cars. It is but natural that an air car, or, in fact, any form of motor car, should be heavier than a horse car, but the Hardie air cars are lighter than the electric storage cars and compare favorably in weight with any other system of power traction. The Metropolitan Street Railway Company, of New York, has ordered twenty-eight of these cars for service on the streets and have placed with the Compressed Air Company, an additional order for one hundred air cars to be taken after the twenty-eight have been put into operation as per agreement.

These facts are important to railroad men and engineers in that they indicate the practicability of using independent motors which are always appreciated because they are complete in themselves, carrying their own power, and can be readily removed from the track and taken to the shop, in this way avoiding interruption to the general traffic of the road.

AIR POWER CARS IN CHICAGO.

The first trip in Chicago of a car operated by compressed air was made the evening of May 12 over the tracks of the North Chicago street railroad company between the limits barns and Washington street. The run was made in place of the first "owl" car. The experiment was so successful the company will supply at once all its north side lines with similar cars in place of the horse cars which now make the night trips.

People who caught the compressed air car were surprised to find themselves at the limits barns in twenty-five minutes, including a stop of five minutes at the Elm street power house. The car proved capable of any speed desired, ran without noise, and was under perfect control.

Robert Hardie, inventor of the car, was the engineer, and Otto Berthold collected the few fares. The passengers were mostly officials and others interested in the test. Henry D. Cook and A. C. Soper, officers of the Compressed Air Motor Company, were among them. The actual running time from the Elm street power house to Washington street and return to the limits barns was twenty-eight minutes.

THE NEW TRAMWAY.

Horse cars are the ruin of street railways, therefore all cities are at present trying to substitute some means of mechanical traction, such as electricity or compressed air.

The electric traction known as "The Trolley," with its overhead system of wires and return by rail, has been somewhat developed in France through lack of anything better, but it carries with it many disadvantages. From a purely æsthetical point of view it disfigures our cities with its many posts and the network of wires of which it is composed. Looked at from a point of safety, its many victims in Bordeaux, Lyons, Marseilles, Brussels, Gênes, etc., testify against it, to say nothing of the great havoc it has played with telegraph and telephone lines, water and gas pipes, etc. In the United States, from whence we received this system, New York, Washington and other large cities have prohibited its adoption.

In Paris, the "Compagnie des Omnibus," noting all these disadvantages, has used compressed air as one of its means of traction, though the methods employed up to date have been much more costly than had electricity been adopted. It has been necessary to use very high pressures in order to supply a sufficient amount of compressed air to last for the entire trip of the tramway. That necessitated having numerous engines, caused a considerable loss of time, and forced the building of heavy cars with large receivers, which materially added to the dead weight of the tramway. It became imperative to find a better and more economical method of utilizing compressed air, and that is what MM. Popp and Conti have done. They have presented to the members of the General Council of the Seine, to the Municipal Council of Paris, as well as to the chief engineers employed by the government, a tramway which seems to give absolute satisfaction. Though of light weight and graceful form, it is sufficiently strong to draw several other cars and also to accommodate forty passengers, who suffer no inconvenience from heat, unpleasant odors or disagreeable noises. It moves easily and rapidly, stopping quietly or suddenly at the will of the motorman, if by chance a horse or carriage crosses its path. It is even able to back on the track without disturbing either the passengers who are in the tramway or those who are on the two large platforms outside. At starting, the tramway is charged with a sufficient quantity of compressed air to enable it to run for four kilometres, after which distance it becomes self-charging, and by the following ingenious device.

Before each waiting station the rails are provided with a pipe which is set in the hollow over which the wheels pass. That causes a smaller pipe to spring from the ground and enter a hydraulic joint placed under the tramway, by which means the receivers installed there are connected with the undrground conduit. The amount of compressed air received in a few seconds is sufficient to propel the tramway for a further distance of four kilometres. This done, the little pipe re-enters the ground and is automatically covered by an iron plate, over which men and horses alike may pass with perfect safety.

The Presidents of the General and Municipal Councils, as well as the members and the eminent engineers, MM. Huet, Boreux, Humblot, Petsch, Monmerquè, &c., who were present at the tests, warmly congratulated M. Victor Popp upon his success.

In conclusion, we trust Paris will follow in the footsteps of Saint-Quentin, Angouleme and Lyons, who have already adopted this system, and not wait for the Exposition of 1900 before giving the public a means of transportation which will be so greatly to its advantage.

CHARLES CHINCHOLLE.

Translated from *The Figaro,*

AIR POWER REFLECTIONS.

Compressed air is speaking daily for itself, through the various machines in which it is used. The physical part of man is itself only a machine which uses air. Sir John Lubbock says, "Men, like trees, live in great part on air;" and Oliver Wendell Holmes says, "Laughter and tears are meant to turn the wheels of the same sensibility, one is wind-power and the other is water-power."

Man's motive power is air. He breathes 40 times a minute. Hardie's motor takes a breath every 13 or 17 miles of travel, using air at a constant of a little over 100 lbs. p. essure and stores it for convenience at 2,000 lbs. pressure.

Air has never, to my knowledge, been tried and found wanting. It has been used from the earliest days more prominently to propel ships and work wind-mills, and for other purposes, but its first general application, which brought it prominently to the public notice as a mechanical force, was its adoption in the Westinghouse and other air brakes. It was strange that this did not suggest the thought that what was good to stop the train was equally good to start it. And it is a curious fact that even at this late date the electric trains upon the elevated roads in Chicago, which are propelled by electricity, use the current from the rail at the moments of rest to work an air pump to store air to stop the train. The only reason air is used to stop these trains is because mechanical experience has proven that there is nothing better than air for that purpose, and in my opinion, the only reason why air is not used to start the trains is because it has never yet been tried. Wherever air has been used it gives satisfaction. There is no more economical power distribution than by compressed air, for the reason that this power once made it can be saved in storage pipes and reheated at time of using, which gives an advantage over electricity. In storing

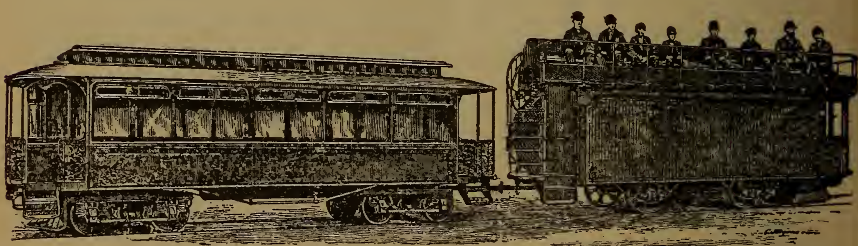


FIG. 141—JUDSON AIR CAR AND TRAILER.

air in pipes and reservoirs, there is little waste and scarcely any depreciation in material. The fact that air is good for small machines is equally true of large machines, and its uses are being extended from day to day, until there are many who believe that in the near future air will be commonly supplied throughout cities in the same manner as water and gas.

The fact that electricity has been taken up so prematurely by street railways has given it undue prominence as a power distributor, and has crowded out of notice its less pretentious ally—compressed air—which has been gradually introduced into service upon the steam railroads, in shops, mines and general mechanical work, until it is a question whether there is not fully as much power conveyed to-day by compressed air as by electricity, though the air is used in out-of-the-way places where its growth has not been remarked.

My attention was first directed to compressed air in 1888 at the Minneapolis Exposition, where I saw a small car 22 in. long and 8 in. wide, which was operated by levers placed in a trench between a small circular track laid out on a table. Movement was imparted to the car by a lever which seized a triangular cam, and in making half a revolution passed the car on 16 feet. This cam was attached to an apparatus, which was connected to the car through the slot, and when one lever let go another lever took hold, and so on. What surprised me was that the air power which operated the cylinders that moved the cam levers was conveyed in a lead pipe not larger than a lead pencil, and the hole conveying the air was no larger in diameter than the lead of an ordinary pencil.

On this car I saw a man who weighed 229 lbs., and who was carried around this track at speed. To hold on to the car it was necessary for him to kneel down with his feet hanging over one end of the car. This exhibition suggested thoughts of the power of air, which I had only considered in a general way up to that date.

In 1891, principally through the efforts of a party of friends in Chicago, a geared motor car was built at Pullman and a charging device constructed by

FIG. 142—HARDIE CAR NO. I.

which the car was automatically charged while passing over a specially constructed pit. Air in this motor was only used at 190 lbs. pressure, and the motor travelled 4½ miles with one charge of air. These patents are now all owned by the American Air Power Co., but Robert Hardie's experience has proved that air at high pressure is easily and safely handled, and possesses many commercial advantages which recommend it above the use of low pressure.

During the construction of the World's Fair Buildings at Chicago, a proposition was made by the parties interested with me at that time to construct the intermural railroad in the fair grounds, and operate it with compressed air. The proposition was to charge only 5 cts. fare, and divide the profits after the structure was paid for. The electric people, however, controlled the situation and made a contract to charge 10 cts. fare and give the World's Fair people half from the start, which was more to their liking, and therefore compressed air was turned down, or it would have made its advent as a motive power in this country at an earlier date than it has. Subsequently I had the good fortune to form the acquaintance of Mr. Robert Hardie, whose knowledge and practical experience in the use of compressed air at high pressures, and whose ability as a mechanical engineer impress all who come in contact with him, and are borne out by the great merit of his devices, I was much impressed by Mr. Hardie's plans, and was one of the humble instruments in bringing together the combination which joined in putting Mr. Hardie's inventions before the notice of the public.

The merits of Hardie's inventions class him in the foremost rank of the inventors of this century. All of his promises have been more than fulfilled, and his knowledge and experience were the one thing necessary to perfect the

FIG. 143—HARDIE MOTOR, 1879.

motor up to the severe requirements of the street railroads of the present day. Motors constructed under his supervision have been practically tested by the combination represented by the American Air Power Co. for the last three years, and latterly two of them have performed daily schedule on 125th Street since August 3d, last. In every respect they have fulfilled the most sanguine expectations, indeed surpassed them, and two of them have travelled about 24,000 miles and carried about 140,000 passengers without serious delay or accident.

Compressed air in this field proves itself equal to any and all emergencies. It is nature's prominent force, which she uses to stir the heavy waters of the ocean and prevent their stagnation, or to perform lighter service, such as to carry seeds. It is the natural ally of steam to distribute its force. It is not as wasteful as electricity nor as destructive. It is one of nature's vehicles of motion. What can man do better than to imitate nature? HENRY D. COOKE.

PNEUMATIC TRACTION.

We present the case of Pneumatic Traction as it stands up to date. Special attention is called to the facts and figures given by Mr. Pettee in the paper entitled, "Cost of Operating Air Cars in New York City." That the Hardie air motor represents an advance in street car propulsion by compressed air, will, we think, be generally admitted. One of these cars has been in continuous operation in New York since last August, carrying passengers, and to all outward appearances, differing but little from the regular cable and electric cars. This is the first time that a compressed air car has done regular and successful commercial service in America for any length of time. All previous attempts may be classed as experimental and it is a fact worthy of notice that these experiments have usually failed to produce permanent results, not because of mechanical failures, but owing to lack of funds. To develop a new system of power for tramways is an undertaking which involves a large expenditure of money. Those who are familiar with the early experiments with the trolley know how expensive it was to get started, and what an enormous amount of money was consumed in experiments before commercial success was reached. The late Mr. Franklin Leonard Pope said that compressed air traction would now be successful, had there been spent upon it even a fractional part of the money and brains that have been used in the development of electricity as a motive power for street railroads. Electricity has always been popular as an investment. Its marvelous success in the telegraph, telephone and elsewhere led capitalists to contribute largely toward its use for street cars, and its final success was the result of the strong combination of capital and brains, which combined steadily and faithfully through so many years.

It is only during recent years that the storage system of compressed air traction has been made practicable. A successful storage system involves an air compressor capable of economically producing air power at a pressure of about 2,000 lbs. per square inch. In order to do this economically, compound compression becomes necessary. The modern high duty compound compressor consists of four cylinders compressing in four stages, with intercoolers between each stage. A Corliss engine furnishes the power and the air is delivered at 2,500 lbs. per square inch, and at a temperature about equal to that in the initial stage. The heat loss, that is the loss of power due to the heat of compression, which at these high pressures with single stage compressors was as high as 50%, is now brought down to 17%. In addition to this, the Corliss mechanism produces a H. P. with an evaporation of less than 16 lbs. of water, consuming less than 2 lbs. of coal. After compression the air is stored in tubes which are made of solid ingots of mild steel free from welds and capable of standing pressures as high as 4,000 lbs. per square inch. It is only during recent years that these storage reservoirs have been brought to the point of absolute safety. Thus we see that air power may be produced and stored safely and economically, and as compressed air is capable of driving an engine designed for steam power, the problem resolves itself to a common reciprocating engine as a motor to drive the car. For the sake of economy the air motor is of special construction, using hot air and cutting off early in the stroke, expanding and exhausting at atmospheric pressure.

PNEUMATIC TRACTION IN NEW YORK.

The installation of a large compressed air plant on West 23d Street, New York, for the purpose of supplying power to street cars on the 28th and 29th Street lines, is an important event in compressed air history. It is also a hopeful indication that pneumatic traction may become of useful commercial interest.

Certain facts may be asserted with confidence. The American Air Power Company has arranged with the Metropolitan Traction Company to install an air compressor of 1,000 h. p. capacity for street car purposes. The Air Power Company has also contracted with certain well known manufacturers of machinery to build this plant. Looking into the details of the case we find that this installation is to be unlike any that has heretofore been brought to public notice in America. In the first place the business is in the hands of the Traction people, who have the experience and the money to develop this new system for street car propulsion. In the second place, this case appears to have been wisely considered by business men, and an order given for a plant of machinery which represents the best that modern mechanical science can devise. The makers are not restricted to anything on lines of economy or on the plea of temporary use, but are asked to build the best machinery that can be devised for this purpose, and in a unit so large that it is reasonable to expect a condition of economy in the production of compressed air which has not heretofore been reached.

This appears, in a measure, to be a development of pneumatic traction experiments which have been carried on at infrequent intervals and in a rather erratic manner since 1879. Efforts twice made by the Hardie motor to find a place on the Elevated Railroad should not be belittled in the light of present knowledge, because, while ill-advised from a business standpoint, they were important mechanically in that it was demonstrated that a train of cars could be handled with reasonable economy by an air motor.

Pneumatic experiments on the elevated road cannot be called mechanical failures; hence the results do not reflect discredit either upon compressed air or upon the engineers engaged in them. Their chief weakness was in attempting to develop an important pneumatic application by beginning at the top. The Judson system which was installed at Washington, D. C., attracted attention to pneumatic traction, and suggested, perhaps, some of its possibilities. The experiments with the Mekarski system had a like influence, but this system did more than the other in that it confirmed the confidence of engineers in the storage system for pneumatic traction. The work of Jarvis, Parke, Hoadley and Knight was in the nature of an advance, developing new ideas and profiting by earlier experiences of others. One of the difficulties against which pneumatic traction has had to contend, is that there was too much speculation in it. Time and money were spent in selling rights, in developing patents and in the organization of companies, which might have been spent to better advantage in the equipment of a small street railroad. The common error has been made in supposing that compressed air was the coming power for street railroads, and that it would replace all others. Compressed air is only one among other useful means by which street cars may be driven. It has its place alongside of electricity, and perhaps closely associated with it, but it is not at all likely to drive electricity out of the field.

The American Air Power Company is a consolidation of all American pneumatic traction interests. This company controls most of the patents on this subject. On its staff are the engineers who have had the experience, and on its Board of Directors are men who know the street car business. Mr. H. H. Vreeland, President of the Metropolitan Traction Company, has a hand in this matter in no uncertain way. Mr. Vreeland has never been known to be windy on this or any other subject. He thinks, perhaps, that there may be a field for compressed air on cross-town service, where the runs are shorter, and where the independent motor will be useful in traveling on different tracks, and where its use will not involve a large expense in construction, which is necessary when the overhead trolley cannot be used.

It is perhaps true that the officers of the Traction Company are not yet confident believers in the success of pneumatic traction, but those who have greater confidence than this should be well pleased at the opportunity which will here be afforded to prove this case under the eyes and supervision of President Vreeland, supported by men who have at least thus far shown a willingness to pay for a demonstration which is not restricted for want of funds and which has at least been started in a way that indicates permanence.

PNEUMATIC TRACTION.

We have never been enthusiastic over pneumatic traction. Our readers will recall several publications in this paper containing descriptions of street car motor propelled by compressed air. We have also touched upon the subject editorially, and have always made an effort to watch the developments closely following all designs, both theoretically and practically, believing as we always have that ultimately a street car propelled by compressed air would be developed and put into constant practical service.

The June number of this paper contained an original description with illustrations of the pneumatic system which has recently been put into operation in New York City. This cannot be called a new system. It is simply a development based on large experience. Heretofore running street cars by compressed air has been experimental only; that is, one or more cars have been built and run experimental from time to time with a view of attracting attention, interesting capital, with the purpose in mind to equip a road. The most important step toward the solution of this problem was made by the American Air Power Co. when it ran a car steadily for one year on the 125th street line, New York. This was a Hardie car and the results obtained were quite satisfactory. The length of service enabled the engineers of the company to figure closely as to the cost of operation, volume of air consumed, repairs, percentage of grades, etc. In this experiment the total average daily mileage was 125.16 miles, and the total distance covered, 23,000 miles; the total number of passengers carried, 137,386. At that point the car traveled on a grade of 7 7-10 per cent. for a short distance. The expense of operating including coal and water items, and all labor, including night-watchman, record-keeper and switchman, for a portion of the time figure about $.26 per car mile. When based on two-car service during the latter period of the experiment the cost was brought down to a little over $.20 per car mile. Mr. Pettee, the engineer in charge, states that if the proportion of labor actually utilized in this service is considered, the expense would only amount to about $.18 per car mile. These figures are all based on the services of one or two cars with an air compressing plant to average economy, and should not be reckoned in comparing with the cost of operating the entire system of street cars of any other power. In fact, it is safe to assume that based on this experience, a large equipment of cars might be run at an expense of about $.12 per car mile. The Hardie car in this work showed an average consumption of a little over 400 cubic feet of free air per car mile, though at times the consumption was less than 400, and it is not difficult to understand wherein improvements might be made which will reduce this consumption considerably. In fact, it is claimed by persons connected with the Air Power Company that the cars of the 28th and 29th street lines will consume only about 350 cubic feet of free air per car mile.

The system of reheating employed on the Hardie and the Hoadley-Knight cars is from steam and hot water; this adds largely to the economy of air consumption, but it cannot compare in efficiency with the dry system of reheating which is likely to be the system adopted for the future. The cost of compressing air up to 2,500 lbs. pressure per square inch is about $.05 per thousand cubic feet of free air when based on plants of average capacity. It is likely that this cost can be reduced and it will be interesting to note the results of a test made on the large air compressor which was described in our June number, and which is now installed at West 24th street, New York, for the purpose of compressing large volumes of air up to 2,500 lbs. pressure. As the cost of motive power is merely but a fraction in the cost of operation in street car services, perhaps from $.02½ to $.03 per car mile would represent the cost of motive power when based on the experience of 125th street, the balance is chargeable to repairs, administrations, etc. The item of repairs is an important one and will be watched with great interest in the 28th and 29th street lines.

Several cars are in regular operation for carrying passengers crosstown in New York, and as they are similar in every respect to the original electric cars, they attract little or no attention. The cars are noiseless, free from all odor, and perfectly safe, each car being an automobile, running with its own power and entirely independent of a central connection. This feature is important in cars at service as it admits of running on different tracks, and practically makes an independent automobile 'bus out of the street car.

The plant now running in New York is, we think, without question, the highest type of pneumatic equipment for this purpose which has been brought to our attention. Improvements have been made throughout the system in the air compressor, and in the motors which promises well. There is really nothing very experimental about this plant, as it follows closely well established railway practice. The cars are the standard of The Metropolitan Street Railway Company. They are built on the standard Brill truck, air motors being simply substituted for electric motors; the weight of the motor being partially on the car axle, all other parts are mounted on the car body. It looks very much to us as though this plant had been installed to stay. The entire system is so thoroughly modern and the installation so large and at so great an expense that it has the air of permanency, and, in fact, we look for its development from this starting point to other lines.

Paris, May 14, 1899.

Editor Compressed Air:

I have been just now reading in your Vol. IV. No. 2 of April, 1899, an interview of Mr. Abdank, which was taken by an *Evening Post* reporter.

Before discussing this subject, I must remark that Mr. Abdank, who is in the "Societé Francaise de Procidis Electriques Thomson-Houston" in Paris, has never had anything to do with the mechanical traction applied to tramcars and overall to pneumatic traction. Therefore, it must be admitted that his authority on the subject is discreditable and his assertion that in France the problem is definitely solved by the adoption of the trolley electric system and pneumatic tramway practically discarded, is the best proof that he is not very well acquainted with the subject he is treating, and the best proof is the Paris Compagnie des Omnibus, the most important of the French companies, who has given a fair trial to all kinds, has pneumatic cars on different lines, and is now building a new station of 5,000 horse power with air compressors, and has enlarged the number of its pneumatic cars from 100 to 250.

As may be therefore easily understood, Mr. Abdank takes his dreams as facts.

Reviewing the technical part of this interview, we must again remark that he is making another mistake when saying: "The compressed air system involves a larger number of transformations of energy than the electric system." Although Mr. Abdank is described as an eminent consulting engineer, we must confess that after having read this part of his interview, we would not care to consult him on the subject; the reason is: Compare both systems and you will find that they require for the initial transformation:

Steam boiler and dynamo for electricity; steam boiler and compressor for compressed air. No difference, no more complication in one case than in the other.

The net loss practical of energy in the compressor is of less than 10-15%, the loss of the dynamo is wholly equal. Again no difference.

I may claim that, having built and established in Paris, 1st, 8,000 H. P. of compressed air works; 2d, 10,000 H. P. of electric works, for distribution of light and energy throughout the city, I know and perhaps am the only one who knows that the loss in initial transformation is about equal in both systems. Proofs at disposal.

The distribution is afterwards obtained 1st, by condensation for compressed air; 2d, by cable for electricity. There the advantage remains entirely for different reasons with the compressed air.

Cost of canalisation is smaller (50%) loss of energy, lessened smaller resistance.

The trolley system necessitates as many miles and yards of cables as there are of lines.

Compressed air does not necessitate any canalisation if the line is of less than four or five miles, or if longer, it does not necessitate more than one-half the line or even less.

The compressed air motor car line has another advantage, viz.: Each car carries its own power with itself, and therefore the service is not liable to be totally interrupted all at once, as has often been the case when one serious accident happened on the line or to the cable of the trolley. The proof is: The works I have erected in Paris in 1880 have at present a canalisation of 180 miles, distributing energy to 2,000 H. P. lifts, etc., in 2,000 houses and winding 7,000 public and private clocks, and since 1880 there has never been an interruption of this public service which was worth mentioning; nor has there ever any serious or even light accident occurred in the works or on the streets, or in private houses, and the compagnie have never paid damages to any one for that reason. Proofs at disposal.

Can Mr. Abdank say the same of the trolley, cable and electric works?

About the complication of the motor, I may say that the 50 moving parts of which Mr. Abdank speaks do not exist anywhere else than in his imagination, and I wish to add that in my works in Paris I have compressed air motors which for 15 years have never been out of order for more than a few hours, necessitated by minor repairs.

The fact that the cost of repairs is not larger, and in fact much smaller on compressed air cars is that, as before explained, the Paris General Omnibus Co. has ordered 150 new pneumatic cars for running our lines. Although this company uses all kinds of systems used in Europe.

To sum up: Against the interview of the prominent consulting engineer, Mr. Abdank, there is the official report of Mr. Hetier, Chief Engineer of Paris and Seine department, whose authority on the subject cannot be discussed.

Extract of report of March 19, 1896, on compressed air tram cars.

"Their auto cars can easily draw one or more carriages attached to them, and therefore carry 100 to 150 passengers at a time, and this even on difficult lines. Their employ in the very centre of Paris on the "Coeurs de Vincennes-St. Augustine" line, where the circulation is extremely intense overall in the Rue de Lafayette and around the St. Lazare railway terminus, has not brought to light any serious inconvenience.

These cars are clean, noiseless and do not emit any steam, smoke or odorous gas.

They run over the difficult parts of their track at great speed and with the greatest ease, owing to their reserve of compressed air, which allows them at any moment to give an exceptionally large effort.

To sum up, experience proves that this system of traction is a good solution of the mechanical traction of cars in towns and suburbs.

(Signed) Hetier,

Engineer in Chief du Department de la Seine.

Mr. Abdank, in his substantial interview, insists upon explosions which he has seen. "Of course, he does not speak about the number" of deaths brought by the trolley, high tension on the trolley wire. But, then, he makes another mistake. Mr. Abdank has never seen any explosion arising from compressed air, but he may have seen explosions of the steam boiler employed on the Mekarski trams for the purpose of heating the compressed air (what in my mind is a mistake) and which do not exist on my cars or on any of the motors I have built and patented. He cannot have seen any compressed air explosion in France, because there never was one, owing to the fact that the air tanks are subjected to trials (every 10 years) with 33 per cent. suppression and that (contrary to steam boilers) their contents do not alter their intra structure to any extent.

I am willing to prove to this Mr. Abdank with my own tramcars on any line in Paris he might choose that: First, the mile car cost will not be larger than the overhead trolley; second, that it will be much cheaper than the underground trolley and ammutator cars; third, that the cost of the engines and works is very much cheaper; fourth, that the compressed air is after all very much less dangerous than electricity.

Because they have had lately the greatest financial success (owing to the fact that American money was behind them) the electricians believe and try to make others believe that they are alone in this world, and that they surpassed by far all others. It is going a little far in a wrong way.

There is room in the field of industry for all of us.

We shall have our turn and then let me tell you that the day we shall be on equal financial terms with you, the battle will certainly be short and decisive, although, perhaps, not with the result you would like. VICTOR POPP,

Engineer founder of the Cie Rue de la "Air Comprime System Popp."
Commissionaire of the Ville de Paris for Distribution of Energy and Light.

COL. PROUT ON PNEUMATIC TRACTION.

A very interesting and timely article appeared in the *New York Times* of Sunday, July 24th, discussing "The Motive Power of the City Railroads of New York," contributed by the editor of the *Railroad Gazette,* Mr. H. G. Prout. In it he notes the progress being made in this city in street railroad work, and indicates the change from horses and cable to underground trolley and compressed air; we extract as follows:

"But the whole story is not yet told, and perhaps the present state of the art is to some extent only a temporary state. The interest cost and the labor charges of the fixed plant for the underground trolley are, roughly speaking, as much on a route where there is a car service every five minutes, as where cars must be run every forty seconds. There are routes of travel, however, especially on crosstown lines, where mechanical traction is desirable for the better public service and to stimulate travel, but where the underground trolley would perhaps not pay, or, at any rate, would not pay until there has been a considerable growth of passenger movement on such lines. This is still more true of a great many towns smaller than New York City. So it is desirable to have a set of independent, self-contained motor cars that can run on horse car tracks as they now exist, and save the cost of the underground trolley construction. Still further, such independent, self-contained motor cars could be diverted to any route, and interpolated between electric or cable cars, and so aid in the development of the logical routing of cars according to the demand of the hour.

"But for such service the steam motor is out of the question, for reasons which need not be developed here. The same is true in the present state of the art of the electric storage battery motor. The same is probably true of the hot-water motor. And so we are brought around to compressed air. There are reasons to suppose that a compressed air engine will do street railroad service with acceptable speed, reliability and economy. We cannot admit that this is demonstrated yet, but there are reasons to suppose that it is true. There is considerable accumulated experience in mines, on cotton wharves, and on experimental surface lines which justifies such a hope at least, and compressed air motors have been improved in design since that experience was begun. There has been no important experiment with the latest designs of such motors, and compressed air has never been put to the actual work of hauling city street cars in a large and responsible way. Such an experiment will soon begin in New York City. The Metropolitan Street Railway Company will, within a few months, have a line of compressed air motors in service between the ferry at West Twenty-third Street and that at East Thirty-fourth Street, by way of Twenty-eighth and Twenty-ninth Streets. It will also have a service by compressed air between the West Twenty-third Street ferry and the Grand Central Station. This will be a thoroughly modern and scientific equipment, and here an actual demonstration will be carried out on a large scale. This demonstration will show whether compressed air can fill the requirements of speed, power, reliability and economy, as well as electricity or steam can do in like situations. The social and financial results of that demonstration may be very important; to an intelligent public they may be deeply interesting, and so it is worth while to keep close watch of them."

PNEUMATIC PROPULSION.

The facilities which the atmosphere offers as a propelling agent, and the readiness with which it lends itself to the purposes of locomotion, have for many years past caused a considerable amount of attention to be given to the utilization of its mechanical properties for facilitating human intercourse. At no time, perhaps, was inventive talent more earnestly and more widely engaged in connection with pneumatic propulsion than in the early days of railways, when the advantages which the atmosphere theoretically offers in that connection were seriously pitted against those presented by steam. Prior to the advent of steam-worked railways in 1830, in which year the Liverpool and Manchester line was opened, inventors were hard at work in their endeavors to perfect the atmospheric system of railways, as it was then called, and a stimulus was given to their labors by the unfortunate death of Mr. Huskisson—the first railway victim—upon that occasion. One example of the prior application of the atmospheric principle to the propulsion of railway trains was that by Mr. John Vallance, of Brighton, in 1827, whose experiments were described in *The Engineer* of May 19th, under the heading of "A Singular Railway Experiment." It may prove interesting if we supplement that notice by a brief history of pneumatic propulsion, in which question such an amount of active interest was evinced during what is known as the railway mania, that a Select Committee of the House of Commons was appointed in 1845 to inquire into the matter. Let us, then, as Lord Jeffrey puts it, call back the departed life for a transitory glow.

It is now nearly two centuries and a half since Papin, in the year 1654, suggested the employment of atmospheric pressure against a vacuum as a motive power. The suggestion, however, does not appear to have been acted upon, nor the principle applied to any practical purpose until it was embodied in Newcomen's engine, which, of course, was not for purposes of locomotion. That application was left for later times to develop; and, according to the *British and Foreign Review* of April, 1844, the idea of applying atmospheric power for the propulsion of land carriages first occurred in a definite form in 1805 to Mr. Taylor, of Manchester, the inventor of the first power loom. Although that gentleman conceived the idea, he does not appear to have possessed sufficient ingenuity to carry it out in practice. He, however, submitted the notion to his friends, Messrs. Duckworth and Clegg, two engineers of the time, and although they were all three of opinion that the idea was capable of realization, they found that the accomplishment of their object was so beset with difficulties that they eventually allowed the matter to drop. Taylor's scheme only extended to the conveyance of letters and despatches. He suggested that a tube large enough to contain a parcel, should be laid down from one town to another, a stationary engine being employed at either end to exhaust the tube.

The subject was then taken up by Mr. George Medhurst, a London engineer, who, in 1810, published a pamphlet in which he described "A New Method of Conveying Goods and Letters by Air." Two years later he published his calculations and remarks on the practicability of his scheme. By the year 1827 Medhurst appears to have further developed his ideas, for in a pamphlet which he then published he describes a system in which he employed a tube through which he drove a carriage by air pressure in one direction and drew it by vacuum in the other. A further development of the system was the employment of a tube 24-in. in diameter, within which worked a piston with a piston-rod passing upward through a longitudinal channel and connected to a carriage running on rails. The piston was to be driven by air-pressure, and the channel was to have a water seal. His third suggestion was a combination of the two methods, goods being conveyed within the tube and passengers in a carriage outside it. Yet another method proposed by Medhurst was to have an iron air tube of square section, 4-ft. in area, fitted with a longitudinal flap valve on the top, through which the arm of the piston projected, and was attached to a carriage running upon the ordinary roadway without any rails. By this modification goods and passengers were to be conveyed "at the rate of a mile a minute, or sixty miles an hour, and without any obstruction, except at times contrary winds, which may retard its progress, and heavy snow, which may obstruct it." However wild Mr. Medhurst's system may appear, to him must be given the credit of originating the longitudinal valve on the tube, a principle which underlies the inventions of nearly all others who subsequently sought to solve the problem of pneumatic propulsion with external carriages.

Previously to the appearance of Medhurst's last pamphlet, Mr. Vallance had, in 1824, taken out a patent for his system of locomotion by atmospheric pressure. This system was described by us in the article already referred to, so that we need not here do more than observe that it was only a modification of Medhurst's first suggestion of a tube through which a carriage was to be propelled and drawn alternately by means of a plenum and a vacuum. The working model of this railway, 150 ft. in length and 8 ft. in diameter, appears to have been the extent of the application of the principle by Mr. Vallance. In 1834 Mr. Henry Pinkus appeared upon the scene with a patent for a pneumatic railway, which was on the same principle as Medhurst's fourth modification, with the exception that Pinkus proposed to use a circular instead of a square tube, and to employ a hemp-and-tallow rope for his continuous valve. The rope valve was to be opened by a small friction roller passing under it, and closed by another passing over it, both being attached to the carriage about it. In practice, however, it was found that on employing a vacuum the rope was forced into the tube by the external pressure of the atmosphere, the vacuum being thus destroyed.

The question now was to devise a valve which should neither be blown out under internal, nor be forced in under external pressure. And here Mr. Clegg took up the running, and in 1839 obtained a patent for a continuous valve having a leather hinge, and working in a trough containing a fatty composition which was solid at the ordinary temperature, but which was easily melted by the application of warmth. This, of course, involved the heating of the composition in order to seal the valve in the rear of the opener as the carriage passed onward, and this was to be effected by a tubular heater containing burning charcoal. Besides the modification of the valve, Mr. Clegg, in conjunction with Mr. Samuda, improved the armature, which, instead of proceeding vertically from the piston to the carriage as in Pinkus' patent, passed through the valve at a very low angle—nearly horizontally, in fact—which caused the valve to be only very slightly opened. The details of the piston were also materially modified by the same inventors, whose names stand out very prominently in the history of the atmospheric railway.

So far the respective inventors only availed themselves mainly of the mechanical properties of the atmosphere resulting from its action on a piston working in a tube and connected, through a continuous valve, with an external carriage. In 1844 Mr. James Pilbrow pointed out that the idea did not appear to have occurred to any one to connect a carriage outside the tube to a piston within it without the use of the continuous valve. He thereore patented a system which consisted of a circular tube having a longitudinal square chamber mounted on the top and opening into it. The piston, which traveled in the tube, was connected by an armature with a tail-piece which travelled in the square chamber above it. This tail-piece was a double rack, which, as it passed along, drove pinions fixed at intervals in pairs on either side of it. The spindles of these pinions were continued upward through stuffing-boxes, their upper ends carrying pinions gearing into racks attached to the underframing of the first carriage of the train. This system was designed for use either on common roads or on railways. Two other modificaticns of the continuous valve should have a passing notice. They are those of M. Hallette and Mr. Hay, the former of whom proposed to close the longitudinal aperture of the piston tube by means by one which was free at both edges—a mere strip, in fact, held at the two extremities and passing through a forked armature.

Such are the broad and general principles upon which the construction of the old atmospheric railways were based. These principles were applied in practice to a limited extent only, although, in some instances, with considerable promise of success. In 1840, Messrs. Clegg and Samuda's system was laid down experimentally on a portion of the West London Railway, at Wormwood Scrubbs. So favorable were the results, that the atmospheric system was adopted on the Dalkey extension of the Dublin and Kingstown Railway, and this—the first atmospheric railway—was in full operation at the commencement of 1844. Its satisfactory working is alluded to in the report of the House of Commons Select Committee, to which we have already referred. This success led to the London and Croydon Railway Company, in 1844, laying down a line of atmospheric railway alongside its locomotive line, and, further, to the adoption of this method of working by the South Devon Railway Company on a portion of its line. On the latter lines, however, the principle was soon given up as unsatisfactory. It was likewise ultimately abandoned on the Kingstown and Dalkey line after a trial of several years, when the railway was extended to Wicklow. The results of working in all cases clearly showed that the atmospheric system could not compete with the locomotive with any hope of success. The first cost was favorable, but the expense and extreme care necessary to keep the tube and its accessories in working order killed it. Thus, the history of atmospheric railways can only be considered as a chapter of failures.

Later times, however, have witnessed a return to the principle, but worked out under conditions differing widely from those under which it existed in the examples we have mentioned. In the pneumatic system, as it was now called in contradistinction to the old title of atmospheric, a tube of large diameter was employed, the carriage itself forming the piston, a useful vacuum being thus obtained. It was, in fact, Mr. Taylor's original proposition, which improved mechanical appliances enabled engineers to work out in practice. About thirty years since the pneumatic system was carried out in various ways. An experimental line of pneumatic despatch was laid down and worked at Battersea, whilst later on a shorter pneumatic passenger railway, embodying advances in detail, was constructed and worked for a time at the Crystal Palace. The outcome of the experimental working of these two lines was the construction of a pneumatic despatch tube by Mr. Ramell in the very heart of London. This tube extended from the General Postoffice, St. Martin's-le-Grand, to the London and Northwestern Railway terminus at Euston Square. There was a central station in Holborn, where was placed the machinery for effecting the transit of the trains of carriers. The air motor consisted of a 22-ft. fan, driven by a steam engine having a pair of 24-in. cylinders with a 20-in. stroke. The tube was of a flattened horseshoe section, 5 ft. wide and 4 ft. 6 in. high at the centre, and had a sectional area of 17 sq. ft. The tube between the General Postoffice and Holborn was 1,658 yds. in length, or nearly a mile, the length from Holborn to Euston being 3,080 yds., or a mile and three-quarters. The carriers which were

10 ft. 4 in. in length, were at the ends of the same sectional area as the tube, and weighed 22 cwt. each. The trains of carriers were drawn from the post-office and from Euston by exhaust, and were propelled to those points by pressure. Although the system worked very successfully, and was proved to be well adapted for the safe and rapid transit of mail bags and parcels, neither the postoffice authorities nor the general public availed themselves of its services, and this revival of the atmospheric principle proved a commercial failure, and the pneumatic despatch fell into desuetude. It was also proposed to work vehicles in the tunnel under the Thames between Smithfield and the south side by the pneumatic system, but nothing was done in this direction. So far as we are aware, the only form in which the principle has survived is that employed in connection with the telegraphic department of the General Postoffice.

It now only remains to refer briefly to the Select Committee of the House of Commons, which was appointed in 1845 to inquire into the merits of the atmospheric system, with a view to its general adoption. The committee consisted of the following members: Mr. Shaw, Mr. Bingham Baring, Lord Harry Vane, Sir George Clerk, Mr. Baring, Viscount Mahon, Sir Charles Lemon, Mr. Hawes, Viscount Hawick, Mr. Hodgson Hinde, Mr. Morrison, Mr. Pakington, Mr. Gibson Craig, Mr. Lascelles and Mr. Wyse. The committee took ample scientific evidence, but it was of a very conflicting character. Among the witnesses in favor of the atmospheric system were some of the leading engineers of the day, including Brunel, Vignoles, Bidder, Samuda and Cubitt. On the other hand, there were the opinions of equally eminent engineers against it, including Stephenson, Locke and Nicholson, all of whom strenuously advocated the use of steam. The committee reported strongly in favor of the general merits of the atmospheric principle, but wisely recommended that it should be left to experience to determine under what conditions of traffic or of country the preference to either system should be given. Experience was not long in determining in favor of steam locomotion, the disciples of which system rapidly increased and multiplied exceedingly.—*The Engineer.*

TRIAL OF A NEW AIR POWER CAR.

The first of the air-power cars for the Twenty-eighth and Twenty-ninth street line of the Metropolitan road made an experimental run over the Twenty-third street line April 16th last. Among the officials who made the trip were H. H. Vreeland, president of the Metropolitan; A. A. McLeod, president of the American Air Power Company, which supplies the air motors; Fred Pierson, chief engineer of the Metropolitan; W. H. Knight, chief engineer of the American Air Power Company; M. G. Starritt, assistant engineer of the Metropolitan, and H. D. Macdonald, of the Metropolitan.

The air for these cars will be compressed by the 400 h. p. compressor which has been in operation at the power house near the foot of West Twenty-third street for some time. The 1,500 h. p. compressor is not completely installed. It is expected that it will be in operation within a few weeks, and then the twenty new cars for the Twenty-eighth and Twenty-ninth street line will be started. The roadbed will not be changed now. New rails will probably be laid after the air-power cars begin their trips.

The new cars have the same general appearance as the standard electric cars used by the Metropolitan road. Some of the experimental cars were run on uptown lines among the electric cars and passengers never noticed the difference. The compressed air bottles are carried under the seats, three on a side. These bottles are made in Germany of a specially prepared nickel steel after a process similar to that used by Krupp in making armor plate for battleships. The first bottles were made to withstand a pressure of 4,000 lbs. to the square inch. This left a margin of safety of only 1,500 lbs. The new bottles can withstand a pressure of 13,000 lbs. to the square inch. The maximum working pressure will be 2,500 lbs., and the normal pressure will be 2,200 lbs.

In the new power house at Eleventh avenue and Twenty-fourth street is the 1,500-h. p. air-compressor, which has much the appearance of a marine engine. This vertical compressor is a great improvement over the horizontal compressor now in use and will do its work much more economically. The compressor is about 60 ft. high and has a fly wheel 22 ft. in diameter. It is a four-stage compressor. The air is taken in at the rate of 64 cu. ft. to a stroke. In the first compressing cylinder it is under a pressure of 50 lbs. to the square inch. In the second compressor the pressure is raised to 172 lbs. and the original bulk is reduced to 18 cu. ft. In the third compressor the pressure is 589 lbs. and the bulk is reduced to 5 cu. ft. Finally, in the last compressor, the pressure is raised to 2,000 pounds and the bulk reduced to 1½ cu. ft. This is all done in four seconds. Compressing air so rapidly heats it to a high degree of temperature, and so after each compression, the air is cooled by passing over cold-water pipes.

The capacity of the new compressor, if the cars were charged directly from it, would be eighty cars. By establishing a reservoir of compressed-air bottles the capacity will be increased indefinitely. From the compressor bottles the car bottles can be charged in two minutes.

A car will run sixteen miles on a single charge, and the cars, as built, will have a speed capacity of from ten to twelve miles an hour. They will be run at from five to six miles an hour and will be charged after every other trip.

The mechanism of the new air motors is very simple. Unlike the first air-power cars, in which there was a great number of moving parts, the engines now to be used have very few moving parts. The running gear moves in a bath of oil.

The motors are controlled by the motormen just as the motormen control the electric motors now. The platform controllers are only slightly different in appearance from those used on the electric cars.

The new cars run very smoothly. They are started with very little of a jerk. The aim of the Metropolitan's engineers has been, in fact, to produce a car which should be as much like the standard electric car as possible, so that the running of them would not confuse the employees. The car which made the experimental run yesterday was hailed several times by persons who thought it was one of the crosstown electric cars. Over in Paris the air-power cars are built on locomotive designs.

The new cars for the crosstown line will be the first cars to be regularly run on a street railroad in this country.

COMPRESSED AIR STREET CARS.

In considering the practicability of propelling street cars by pneumatic power, we must not lose sight of the fact that for upwards of ten years the Mekarski system, which is strictly compressed air system, has been in use at Nantes, France, and that this system has also been adopted at Berne, Switzerland, and at Vincennes, France. The Popp system, which has recently been installed at Vincennes, is an improvement on the Mekarski system, and is likely to replace it there. There are in this country two systems—the Hardie and the Hoadley-Knight. The American Air Power Company, of New York, owns all the American rights for these two systems, by virtue of a consolidation of the respective interests, except for the States of Illinois and Wisconsin, where the Hardie patents are owned by a company, of which Mr. H. D. Cooke is president. The European rights under the Hardie system are controlled by the American Air Power Company, but in the consolidation, the so-called Hoadley-Knight patents for Europe, were not included. The Mekarski and the Popp system are known as low pressure systems, the air being stored on the cars at pressures of from 400 to 700 pounds per square inch. The American systems are high pressure systems, the air being stored at from 2,000 to 2,500 pounds per square inch. The Mekarski system has demonstrated clearly, that it is not impracticable or extravagant to use compressed air as a power for tram cars. Mr. Popp in his system has gone further than Mekarski; reducing the weight of the car, and simplifying the machinery. It is plain that the Popp system is in advance of any other French system, and it does not differ very materially from the best American systems.

There is little or no radical difference between the Hardie and the Hoadley-Knight systems; the difference being largely matters of mechanical arrangement, as for instance an English locomotive differs from an American locomotive —the cylinders of one are in a certain place and apply the power of the drivers in a certain way; but both are machines built according to our recognized ideas of steam engineering practice, and both "go" successfully. We might carry this demonstration of the locomotives further, because it really gives a better idea of the points of difference between the two American systems. Hardie applies his power at the wheel of the car, by means of an engine of long stroke, while the Hoadley-Knight system is like the English locomotive, in that the engines are between the wheels, the power being applied through a crank shaft. Compound engines are used in one case, to compensate for the long stroke and early cut-off in the other. The Hoadley-Knight system is more like the best practice with electric motors for tram cars, in that the weight of the motors is partially placed on the car axle.

If we admit, that a practical street car can be, and has been designed, using compressed air as a motive power, the question arises, why is it not generally used for that purpose. The answer to this is, that outside of France, the pneumatic tram car has not, until recently, been favored with that combination of mechanical ability and money, which is essential to the success of any mechanical enterprise. Mr. Franklin Leonard Pope, a distinguished American electrical engineer, now dead, said that compressed air traction would be a success, if there had been spent upon it, even a fractional part of the money and brains, that have been used in the development of electricity, as a motive power for street railroads.

Electricity has always been popular as an investment. Its success in the telephone, electric lighting, etc., led capitalists to contribute largely toward its use for street cars, and it was only after many years of work and expense that the difficulties were overcome. Another obstacle, which has up to this time prevented the more general introduction of compressed air traction, is that it is only recently that we have been able to make a safe, simple and light bottle for storing the air. The storage system has always been aimed at, both in compressed air and electricity, and in order to store sufficient power on the car, it is necessary to provide bottles or reservoirs, which cannot occupy much space, which must be light in weight, and absolutely safe. This has been accomplished in Germany by what is known as the Mannesmann steel tube, which has been adopted generally for this purpose.

The condition of things up to date, is this: Two cars built under Hardie's directions are now running in Chicago, on the North Clark street cable road. These cars are similar to two cars built by Mr. Hardie, and operated for twelve months at 125th street, New York, Third avenue railroad line. Over twenty cars of the Hoadley-Knight pattern have been in operation between three and four months on the Twenty-eighth and Twenty-ninth street cross-town line, in New York city. This plant was installed by the American Air Power Company, but it is under the supervision and has the co-operation of the Metropolitan Street Railway Company, New York. Compressed air for street cars has lately been adopted in Rome, N. Y., the home of the new Hardie motor. These three cases are the only ones, and we cannot safely say, that in either case, the installation has passed entirely beyond the experimental stage. It cannot, however, be said, that compressed air traction is in the experimental stage, in the sense that one would class automobiles. The difference is this: In street car work the improvements are likely to be in details, matters of construction, saving of expense of repairs, and such like; while with the automobile we may see radical changes in general design, as well as in matters of detail. Compressed air traction is now in a condition where it should appeal to commercial interests, where men, who are in a position to supply the means and get opportunities to place the cars on established roads might make money, provided of course, they employ proper mechanical aid and start in at the point which compressed air traction has reached to-day. The question of comparative efficiency naturally arises. Electricity admittedly is the most successful power for propelling tram cars. It is used extensively for that purpose, and has passed beyond the experimental stages; but it has certain limitations, and this is where compressed air comes in. There are places where it is not permissible to place overhead wires and poles in the street, and this is the present field for the pneumatic tram. In comparing electricity and compressed air for mechanical traction, we must not forget that the successful electric system is not a storage system. Power is generated at a central station and distributed along the line.

Unfortunately a great deal of time and money has been spent upon the development of an air system on these lines; that is, the lines where electricity is supreme. Engineers now, however, are convinced that the best air system is a storage system, and in this air is superior to electricity. Electric storage for street cars has repeatedly failed because of expense of maintenance, weight of apparatus, time required to charge, and other obstacles, while it must be admitted even by partisans of electricity, that air is easily stored, and that if we are to propel tram cars by the storage system, we may turn to air, as the most practical power for that purpose. Now this introduces between the storage system and the central plant system, which we will not go into here, any further than to say, that it is generally admitted that a good storage system will have a large field. Each car is independent in itself and is its own locomotive. If it is out of order it is taken off and other cars are not interfered with. It does not require expensive track construction. It calls for an inexpensive plant, and there are other conditions, many of which seem to have a strong element that should appeal to the popular idea of successful transportation. We have become accustomed to such things as wires, poles, and slots in the street, while in Europe and in England in particular, the Bus idea seems to be popular. People prefer individual carriages to long trains. The laws restricting placing obstruction in the streets are more rigid, and a compressed air storage system, which calls for nothing more than two rails in the street, should have a better chance than any other.

Three systems of mechanical propulsion are to be considered: 1. The electric overhead trolley. 2. The electric underground trolley. 3. Compressed air. The cost of equipping a line, that is the cost of the plant in overhead trolley and compressed air are practically the same, and it may safely be said, that the cost of operation in both cases is about the same, but that the underground trolley is very much higher in first cost, and the figures of cost of maintenance, including interest account, etc., will favor compressed air; so that in one case the champions of air may meet the overhead trolley system under equal conditions of cost, and without the obstructions in the street, and when competing with the underground trolley, compressed air has the advantage of lower cost. In connection with this important matter of expense the only undetermined point, so far as the compressed air system is concerned is the question of durability of apparatus, but as all the machinery is built according to common steam engine practice, and as in the score of cars installed on the 28th and 29th street lines, in New York, the car engines are encased free from dust, and running in oil, the question of durability does not appear to be a serious one. Even in this it has to compete with the electric engine and attachments, which are mostly of copper, while the air engine is all steel and iron. In the Hardie car service on 125th street, New York, the average cost per car mile with a two car service running 156 miles per day, was about 20 cents. Of this item coal and water represented about one-quarter, the principal cost being for power plant labor, conductor and motorman, 20 cents per car mile is not high for a two car service, and might be reduced one-half in a large installation.

COMPRESSED AIR STREET CARS.

No reference to the subject of Pneumatic Traction is complete without mention of the plant which was installed by the American Air Power Company, on the Twenty-eighth and Twenty-ninth Street Crosstown lines, New York City, page 463. This is the largest pneumatic traction installation that has ever been attempted and its importance must be recognized. Nineteen cars of the Hoadley-Knight pattern have been running for some months, and it is now proposed to place some of the Hardie cars on the same line for the purpose of comparison. This illustrates the broad view of the subject taken by the American Air Power Company, and their determination to test pneumatic traction thoroughly and to adopt that system which is best. Fortunately, there is at the head of this company a practical street railroad man, who appreciates the situation, and who is reasonably sure to accomplish good results in the present case. It is, however, a matter of surprise that a duplicate generating plant has not been installed. Electric light installations, electric traction plants and such like are almost invariably equipped in duplicate. Pumping plants, and in fact wherever the centralized system is used, it has been considered wise not to depend on one machine or one set of machines, yet in this case there is one large air compressor of 1,500 H. P. capacity, upon which the whole system depends. That the cars should be kept in motion so constantly, notwithstanding the mechanical difficulties which are sure to arise in the development of any new system, is a point in favor of pneumatic traction, and that the cars may at any time be taken off and horses substituted is an illustration of the fact that a pneumatic equipment on the automobile plan may be applied to standard horse car roads, and that the installation itself is simple and inexpensive. We are heartily with the American Air Power Company in this work. We admire the pluck that they have exhibited in spending money to try experiments on a broad scale, and we have no doubt that this same spirit will follow them until the road has passed experimental conditions, and is an accepted success—a credit to the company and to those who have always believed that a good system of running street cars by compressed air would some day be brought to the front.

THE MEKARSKI SYSTEM AT BERNE, SWITZERLAND.

The main line of the compressed air tramway of Berne, Switzerland, traverses the town from east to west, and measures 3 kilometres or 2 miles, within which, being a single line, it has eight passing places about 66 yards in length each. The extensions shown in above map practically cover the city, and reaching all the principal points of interest or of commercial importance. At certain points there are rising and falling gradients of 5 to 6 per cent., and this precluded horse traction. Cable traction would have been too costly and the same objection applied to underground electric traction, and the local authorities positively declined to allow overhead trolleys. Traction by electric accumulators was by general consent recognized as a failure. Under these circumstances, concessions were granted to a company using the Mekarski system in 1889 and put in operation.

Tables of cost show that the cost of operating does not exceed 8.9d. per car mile. The number of single journeys made per day of 14 working hours, is 160, equal to about 300 car miles, and the number of passengers in the year 1891 being 3,140 per day, or 20 per car journey. Seven motors are required; six

FIG. 144—PLAN OF BERNE AND SUBURBS.

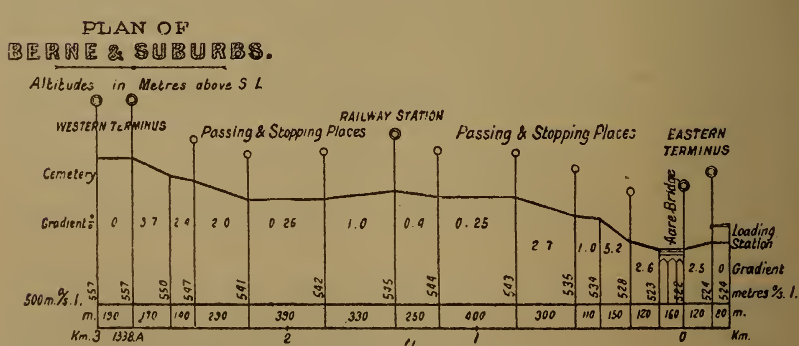


FIG. 145—PROFILE OF ROAD.

are constantly on the line, and two cars are kept in reserve. Their carrying capacity is about 28 passengers.

THE MEKARSKI CAR AT TOLEDO, OHIO.

In 1892, the Consolidated Company at Toledo, installed a plant of the Mekarski system. The trial trips were made from the power house along the principal business street of Toledo, and on tracks used jointly by the horse and

FIG. 146—THE MEKARSKI SYSTEM AT TOLEDO, OHIO.

electric cars, where the traffic was heavy. The car rode smoothly and offered no objectionable features to the public.

The car would run between eight and nine miles without recharging, and was handled with ease and promptness, and all motions were under perfect control.

COMPRESSED AIR MOTORS.

The compressed air system has been adopted for the 28th and 29th street cross-town lines of New York, by the Metropolitan Street Railway Co. During the past three years strong efforts have been made to secure for this system a permanent franchise for its establishment.

Extended experiments in connection with the Hoadley-Knight system have been conducted by the Metropolitan Railway Company, of which Mr. H. H. Vreeland is President. Over eight years ago it was seen that of necessity, some efficient and economical method of operating street railways in New York would have to be adopted, and gas engines, ammonia motors, compressed air, electric storage batteries and electricity as a constant current as used in the overhead trolley system, were all considered. New York has stoutly refused to have the overhead system, and it was necessary for his company to go ahead and find some other system. Eminent engineers were sent abroad and the inquiries brought forth some 2,600 replies offering many schemes. Some had merit, but after giving them consideration the company was, so to speak, in on the air; and as Mr. Vreeland himself says: "We are latter day saints in the compressed air proposition."

No such exhaustive research has ever been made in the history of traction. It was not conducted solely in the interest of compressed air, but in the interests of capital invested in plants, rapid transit for the traveling public, and the comfort and safety of patrons. The experiments and tests of steel tubes alone being of a most exacting nature. Large numbers of the best tubes were purchased and tested to destruction. This system did not dawn on the Metropolitan Street Railway Company like a sunburst. It grew and developed, and finally became what it is, and its adoption leaves no doubt in the mind of the company as to the success of the system both in regard to its efficiency and economy and other advantages commonly conceded to compressed air. At the same time the Hoadley-Knight system was being tried on the Lenox Avenue line, New York, and on the Eckington & Soldiers' Home Railway at Washington, D. C., but the results desired from the experiments were so exacting that the chance for their adoption seemed for a time hopeless.

THE HOADLEY-KNIGHT SYSTEM.

The compressed air motor cars for this system were designed by Mr. J. H. Hoadley and Mr. Walter H. Knight. In general construction the motor resembles an electric motor—iron clad, and resting with one end upon the axle, to which its crank shaft is geared.

The unsatisfactory results attending the use of side rods and exposed machinery, in connection with the electric motor, were, of course, well known, and it was realized at once that in any form of air motor it was essential that the moving parts should be enclosed in a case where they could run in oil, free from dust, and where they would lubricate themselves continuously without the attention of the operator. It also seemed extremely desirable to continue the use of standard street car wheels, axles, trucks and car bodies, as these have all reached a standardized form which is known to insure the least expense of maintenance.

Owing, also, to the limited intelligence of the motorman, and the necessity of more prompt control than is had with steam locomotives, it was considered necessary to develop a controller, which could be operated by a single handle to perform all the various functions of the controller in their proper sequence, without requiring thought on the part of the motormen. These three features of iron clad motors, running in oil, standard street railway rolling stock and single handle controller, were therefore made the distinctive features of the Hoadley-Knight system, which may be described more in detail as follows:

MOTOR CYLINDERS AND MECHANISM.

On each axle is mounted an iron clad motor, having two cylinders and cranks at right angles. One motor has two high pressure cylinders, 3½ ins.

diameter and 6 ins. stroke, and the other motor has two low pressure cylinders, 7 ins. diameter and 6 ins. stroke. Upon the crank shaft is a pinion, about 9 ins. in diameter, meshing into a 23 in. gear wheel mounted on the middle of the axle; the axle is straight, as used for electric motors, and the wheels are ordinary street car wheels. The motor consists essentially of a cast iron case or basin, to which the two cylinders are bolted and in which all the moving parts, the piston rods, crossheads, connecting rods, cranks, gears, valve rods, eccentrics and reversing mechanism are located. The basin is covered with a lid which can be quickly removed, thereby exposing all the machinery for complete inspection. A

FIG. 147—COMPRESSED AIR MOTOR CAR.

sufficient quantity of oil is introduced into the basin to keep the moving parts continuously drenched with the lubricant, thus insuring for them the longest possible life, and reducing to a corresponding degree the maintenance account.

AIR RESERVOIRS AND HEATER.

The air reservoirs, in the shape of seamless steel bottles, are under the seats of the car, and a pipe leads from them to a combined reducing and throttle valve, which reduces the storage pressure to the working pressure. The pipe before reaching the reducing valve passes around the heater, so that the air can receive sufficient heat to prevent freezing any moisture that may be in it.

The heater consists of a seamless flask charged with hot water under a pressure of from 150 lbs. to 250 lbs.

WHAT THE AIR DOES.

The air on leaving the reducing valve passes through a coil kept hot by the heater to a temperature corresponding to the steam pressure of the hot water, and is then introduced into the high pressure cylinders, both of which are in one motor on one axle. During its passage between the reducing valve and the high pressure cylinder, means are provided for injecting a certain amount of moisture into the air, this having been found to give certain advantages, as will be described later. In exhausting from the high pressure motor, the air is again heated and passes through the low pressure motor on the other axle, from which it escapes through a muffler into the atmosphere. By having one motor high pressure and the other motor low pressure, undue slipping of the wheels is prevented,

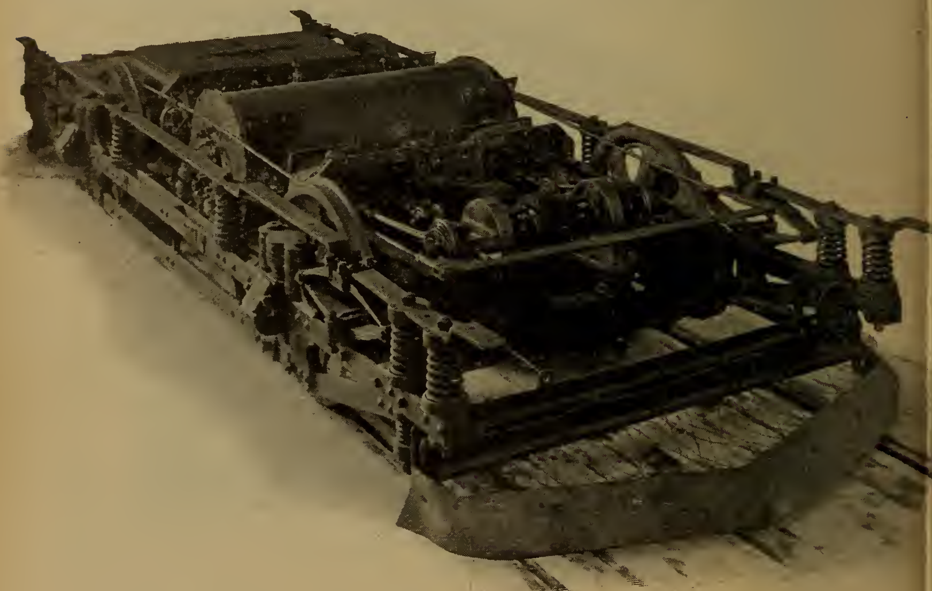


FIG. 148—HOADLEY-KNIGHT COMPRESSED AIR MOTOR TRUCK.

as when the high pressure wheels slip the low pressure motor gets more air and more pressure, and the back pressure from the receiver tends to stop the slipping. When the low pressure motor slips its wheels, it draws down the receiver pressure and thereby weakens itself, correspondingly increasing the strength of the non-slipping motor. The direction of the flow of the air is shown in Fig. 3 where *R R* are the air reservoirs, *V* the reducing valve, *H* the heater, *M M* the motors.

DURABILITY.

Twelve months' operation has demonstrated that these motors are highly efficient and exceedingly durable, all of the original parts being still in use. The manufacturers estimate that, making a liberal allowance for the wear and tear that must occur, which, in the case of the more rapidly wearing parts, has been measured, the maintenance per car mile can be figured at not more than one cent, which compares favorably with that of the electric motor.

WEIGHT OF CARS.

The weight of the standard Hoadley-Knight air car is tabulated as follows:

Car body	6,000	lbs.
Trucks	4,500	"
Air reservoirs	3,000	"
Heater	500	"
Motors (each 1,500 lbs.)	3,000	"
Controlling apparatus	400	"
Piping	150	"
Total	17,550	"

TRACTION AND CONSUMPTION OF AIR.

The motors are capable of slipping the wheels on a dry rail under a weight of 30,000 lbs., and are therefore as powerful as the heaviest electric motor equip-

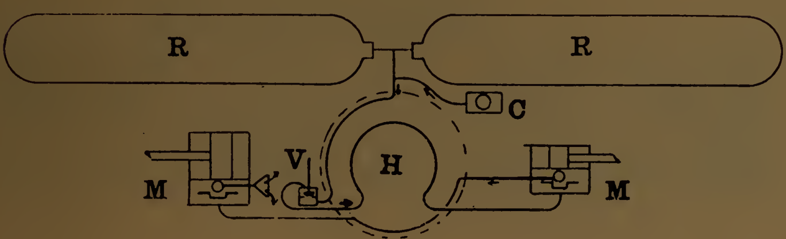


FIG. 149—DIAGRAM SHOWING FLOW OF AIR.

ment. The total weight is little, if any, more than that of an equally powerful electric equipment, and the rigid weight on the axle, to which maintenance of track is mostly charged, is considerably less.

The air consumption of these cars varies from 30 lbs. to 40 lbs. per car mile, for a 34 ft. car of the Broadway type. About 11 lbs. of air can be compressed to 2,000 lbs. per square inch per horse power hour. The cars require therefore, on an average a little over 3 h. p. hours per car mile, which in a modern compressor, running on a steady load and pumping into a reservoir of ample capacity, can be produced, it is claimed, for one-half cent per horse power hour, including all power house charges. To this must be added the cost of the hot water for reheating, which is given by the engineers of the system as one mill per car mile. The motive power expenses per car mile on this basis are therefore estimated as follows:

COST PER CAR MILE OF MOTIVE POWER.

3½ h. p. hours at ½ cent	$.0175
Hot water for reheating	.001
Maintenance of motor equipment	.01
Total	$.0285

This compares favorably with the best that has been done with electric motors. The storage capacity for a run of 17 miles would be 45 cu. ft.

CONTROLLING THE CAR.

The Hoadley-Knight motors are controlled by varying the cut-off as well as by the throttle, the two being operated simultaneously. This method of controlling is adopted because it not only gives the highest efficiency, but also gives the greatest range of power. A car can be started with a promptness only limited by the friction of the wheels on the rails, or may be started with almost imperceptible acceleration. In common with other air cars, the start is easy and free from jerks.

A forward movement of the single controller handle starts the car and the propelling force is proportional to the distance that the handle is moved from its starting point, so that any degree of acceleration can be obtained. A backward movement to the starting position brings the valve to a minimum cut-off and closes the throttle. A still further backward movement reverses the motors and opens the throttle to back the car. The inventor claims that anything less simple than this is not feasible, or indeed safe, for street car work, and they point out as sustaining this view, that the only successful electric controllers have been substantially as simple. Of course, with an electric motor the reversing handle has been kept separate, as it is undesirable to reverse an electric motor, but with an air motor there is no objection to reversing, and there is therefore no need of more than one handle on this account.

HEATING.

The inventors have made a large and exhaustive series of experiments on the subject of the heater. They have tried all the known forms. Their first experiment with the Mékarski heater, which is the one generally in use on air cars and in which the air is made to pass up through hot water, proved to them that such a method is liable to bring excessive quantities of water over into the motors, when heavy demands are made upon the air. They also found what had not been generally recognized until they announced it, that such a heater, when the contained water is under a pressure exceeding that of the air, runs the motor, practically as a steam engine, with too much visible exhaust and too little air, and that after the pressure of the water in the heater falls below that of the air, practically no steam is generated and the air enters the motor practically dry. Their experiments with dry heaters showed them that the same economy could be obtained with dry heat as with wet, but the heater itself proved objectionable and difficult to regulate. This brought about a return to the hot water heater, but with certain precautions against admitting the air to the water, which proved highly satisfactory.

STORAGE RESERVOIRS.

Their experiments with air reservoirs have been probably the most extensive ever made. They have tried large numbers of each of the five different prominent manufacturers and have experimentally blown up all kinds repeatedly, both with air and water, and find that they are all very much alike, both as regards strength and character of rupture. They are now using the Ehrhardt flasks. It seems to be generally admitted that the air motor would have reached a practical state of perfection much earlier, had it not been for the slow development of the art of making high pressure flasks, which until the last few years were not

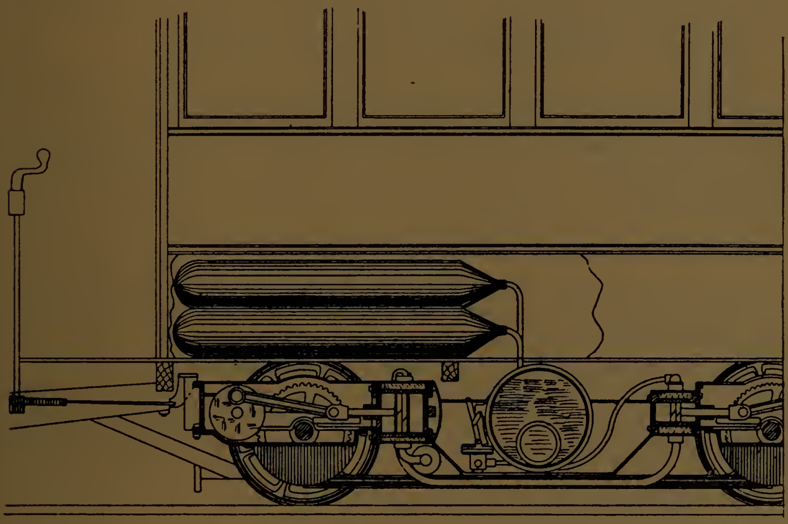


FIG. 150—SECTIONAL VIEW OF MOTOR CAR.

obtainable of sufficient strength to give the desired capacity within a reasonable space.

One of these cars will run 15 miles on a good track on a charge that is restricted to a space under the seats, and this could be even increased to 20 miles by crowding in all the flasks that the space could allow.

As the air pressure in the reservoirs is always limited to that which the compressor can give, and as the reservoirs themselves are capable of withstanding nearly three times this pressure, it will be readily seen that the element of danger is practically eliminated. There is no possible way in which the air pressure can be increased to the bursting pressure of the flasks. Furthermore, they are protected by a safety pop set up to open at a pressure slightly above that given by the compressor. There is no deteriorating influence incidental to their use. There has never been an explosion with any of these flasks by air, except when premeditated, and only then with the greatest difficulty and with apparatus especially constructed at great expense to bring the required force into play. Every flask is tested to 2½ times its working pressure before being used. Steam boilers are only tested 1½ times the working pressure.

COMFORT AND APPEARANCE.

The placing of the motor in the middle of the axle and the driving of the axle in the middle, by means of the gear, does away with all lateral oscillation, so common in side rod motors.

The car presents an appearance like that of an electric car without the trolley accessories, and it is claimed to accelerate as quickly, to run as fast, to be as free from vibration, start with greater ease, stop with greater promptness (owing to lack of momentum of armatures) and to possess in general all the advantages of the electric car, without any of its disadvantages.

It is true that every two hours the cars must be charged, but this is done in two minutes and at the end of the line, where it does not inconvenience the passengers, and therefore, so far as the traveling public is concerned, is attended with no disadvantages. To the street railway man it means practically almost no additional expense, as in general a wait of at least two minutes is made at the end of the line.

COMMON ADVANTAGES.

As compared with the storage battery car, which in its absence from dependence upon a distributing system the air motor resembles, the latter is claimed to possess the following advantages:

1. Its storage cells cost very little, comparatively.
2. They are a permanent investment, requiring practically no repairing.
3. The reservoirs can be charged in two minutes instead of six hours.
4. An exhaustion of the battery does not injure it (as with the sulphating of the electric battery).
5. The weight is about one-half.
6. There is no odor.
7. There is no corrosive liquid to slop over, or injure operatives' hands.
8. In case of necessity it can be charged along the line without leaving the line.

Barring fuel burning motors, which seem to be by common consent ruled out of the sphere of street service, compressed air stands alone as the only available stored force, which suffers no loss or deterioration while stored, which is instantly available, which requires no skill to utilize it and which is absolutely free from any offensive products. It is due to these practical features that compressed air has been so successful as a transmitter of force in mining work and air brakes, and the same advantages, it is believed by its promoters, will bring about its very general adoption for propelling vehicles.

The expense of installing this system does not differ materially from that of the electric trolley system. The compressed air power plant can be installed for the same amount as an electric power plant, and the cars, while costing somewhat more than the trolley cars, are more than offset, it is claimed, by the expense of the trolley line itself. As compared with the underground trolley, there is, of course, a saving of the interest and maintenance of the conduit, a sum which would in itself exceed in many cases the whole motive power expense of the compressed air car.

AIR COMPRESSORS.

Orders have been given for air compressors with four stage single acting air cylinders and intercoolers. They are to be driven by a vertical cross compound condensing Reynolds' Corliss engine, built by the E. P. Allis Co. The compressing cylinders are to be set underneath the engine and are to be built by the Ingersoll-Sergeant Drill Co. The initial cylinder is to be 46″ diam. by 60″ stroke.

TRACTION AND AUTO-MOBILE.

Air Plant of the Metropolitan Street Railway Co. in New York.

A compressed air plant, unusual in almost all of its features, and embodying characteristics in design and construction far in advance of ordinary practice, has just been completed by the Ingersoll-Sergeant Drill Co. of 26 Cortlandt street, New York. The installation was made for supplying the air motors on the cars of the Metropolitan Street Railway Company of New York. The station is located at Twenty-third street and North River.

The plant is uncommon mainly for two reasons, its great efficiency in producing compressed air and the high pressure obtained. High pressures with small machines are common, but pressures of 2,500 pounds to the square inch in 1,000 horse power machines are new. In general the machine consists of a duplex vertical cross compound engine built by the E. P. Allis Company of Milwaukee, which has cylinders 32 in. by 68 in. and 60 in. stroke, provided with Reynolds Corliss valve gear. With steam pressure of 150 pounds, furnished by Babcock & Wilcox boilers and 40 revolutions per minute the horse power is 1,000. The shaft is of hammered iron 22 inches in diameter outside of the journals, 20 inches diameter in the bearings, which are 36 inches long. The fly wheel placed between the cylinders, as shown, is 22 feet in diameter and weighs 60 tons. The engine is mounted upon brick piers, and directly underneath it is placed

THE AIR COMPRESSOR.

This machine is of the four cylinder type, the low pressure cylinder being 46 inches, the first intermediate 24 inches, the second intermediate 14 inches, and the high pressure cylinder 6 inches in diameter, the stroke being common with the engine, 60 inches. All of these are single acting. The free air capacity per revolution is 56.735 cubic feet; capacity at 40 revolutions 2269.4 cubic feet, and the free air capacity at 60 revolutions is 3404.1 cubic feet. The approximate pressure in the first cooler is 40 pounds, in the second 180 pounds, and in the third 850 pounds, the final approximate pressure in the after cooler being 2,300 pounds.

The compressor pistons are arranged in pairs vertically in line beneath the steam cylinders, as is shown in Fig. 1, the initial and first intermediate air cylinder being below the low pressure steam cylinder, while the second intermediate and high pressure air cylinders are below the high pressure steam cylinder. Motion

FIG. 151—THE VERTICAL FOUR STAGE HIGH PRESSURE AIR COMPRESSOR USED FOR SUPPLYING POWER FOR STREET CAR SERVICE ON THE 28TH AND 29TH STREET LINES, NEW YORK.

is transmitted from the steam engine cross heads through distance rods for each cross head to a cross head attached to the air cylinder piston rods.

The inlet and discharge valves of the initial air cylinder are of the "Mechanical" type and of a special design. These valves are shown at K Fig. 1. Air is admitted to the top of this cylinder through the supply pipe *a*, and leaves the cylinder through the pipe *a'* by which it is conducted to the first inter cooler E. From the cooler E the air flows through the pipe *b'* to the lower end of the first intermediate air cylinder B from which it passes through the pipe *b* to the second

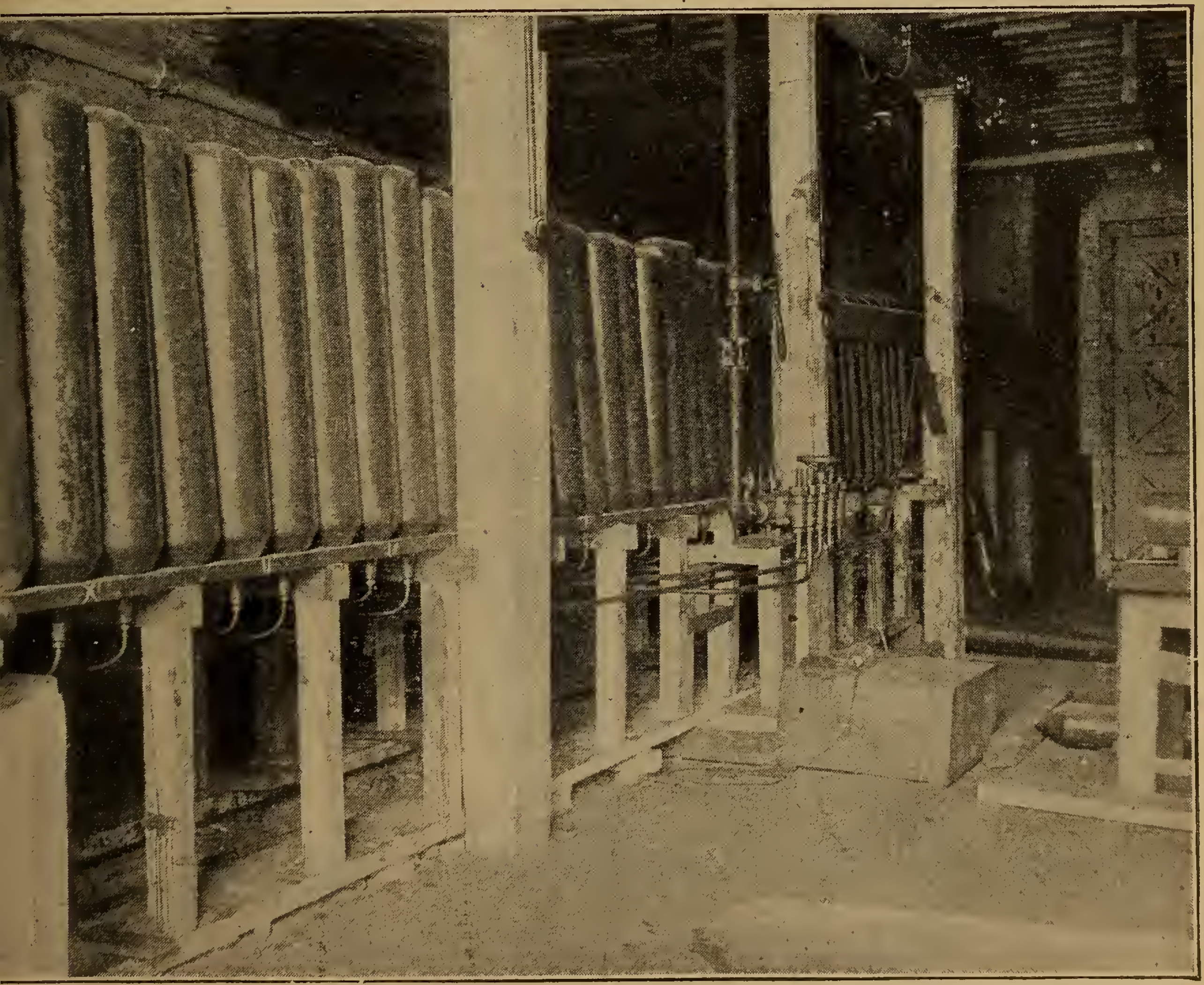


FIG. 152—BATTERY OF STORAGE TUBES, IN WHICH AIR IS KEPT AT 2,500 POUNDS PRESSURE, AND FROM WHICH THE CARS ARE CHARGED.

intercooler F. From here it passes to the pipe *c* to the upper end of the cylinder C from which it passes to the third cooler G and from here through the pipe *c'* to the lower end of the cylinder D and from this through the pipe *e* to the final after cooler H, from which it is led through the outlet *f* to the storage bottles. From this it will be seen that the air passes through the upper end of the cylinder A, lower end of cylinder B, upper end of cylinder C and lower end of cylinder D and in its passage between each passing through one or the other of the coolers.

The intercoolers employed are of two different designs, the two coolers for the lower pressures consist of a shell enclosing a nest of vertically arranged cooling pipes through which the air passes going from one cylinder to the other, the coolers for the higher pressures consist of a shell enclosing a pipe coil, the air passing through the coil from one cylinder to the other. In providing a cooler for the lower pressures where great cooling surface is required on account of the large volume of air to be cooled, it was considered proper to provide tubes, but in dealing with the cooler for the higher pressures, coils were substituted so as to dispense with as many joints as possible. The coolers are arranged so that in case a leakage of air from the cooling pipes into the shell or casing that this air rises with the circulating water up to the operating floor of the engine room and is discharged through a sight discharge pipe under the immediate care of the engineer. All the piping from the first air cylinder and through the entire compressing plant is made of copper.

What may be called an auxiliary governor controlled by air pressure is provided to act upon the governor of the steam engine. This consists of a weighted lever which is operated upon by a small piston which in turn is actuated by the air pressure. If for any reason the pressure should become excessive the lever is lifted, when it opens a valve admitting air to a device on the governor so designed as to reduce the steam supply and to all practical purposes throttles the engine.

Some idea of the massiveness of the machine may be obtained from the bare statement that it is 60 feet in height. It will be employed exclusively for supplying air to the air motor on the street railway cars. It may be stated that since their first trial several months ago the air motors of the Hoadley-Knight type introduced on the street railroad line have given good results.

Compressed air for the purpose of traction by this system is generated and collected in a manner similar to the manner of generating and collecting gas, and the necessary means for the storing of compressed air at high pressure consist in the collection of numerous bottles connected together in series or manifolds whereby the different sections of storage can be cut out from one another. In the storage system erected at the Twenty-fourth street compressor station there are about 600 bottles. These bottles are all tested to a pressure of 4,000 pounds per square inch, and are used to store air at a pressure of 2,500 pounds per square inch. There is no wear and tear on these storage bottles other than can be made good by painting from time to time. The storage bottles are connected together with proper pipes and valves and communicate with several charging stands in the car house. The cars can be charged with compressed air at 2,500 lbs. pressure in about two or three minutes' time. The method of connecting the compressed air pipe to the car is similar to the way in which the breach is locked to a gun.

The charging nozzle is introduced in the charging orifice and a partial turn given to the charging nozzle locks the charging nozzle in the charging orifice, then the main valve is opened admitting air to the car. The reheater is charged with steam in a similar manner.

The charging nozzle of the reheater is provided with a vent hole through the centre whereby the coupling of the charging nozzle to the charging orifice makes communication for the steam to enter the reheater and for the vent to go out from the reheater with the one charging nozzle. In the recharging of the

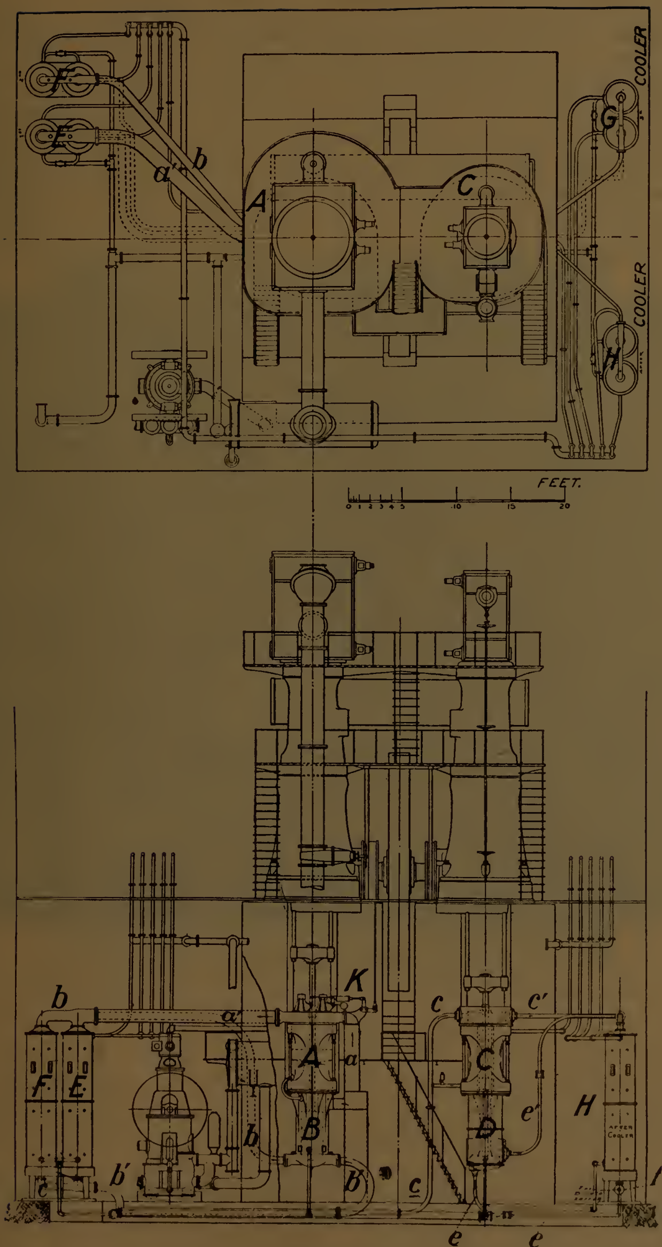

COOLER
G
F
E
a'
b
A
C
COOLER
H
FEET.
0 1 2 3 4 5 10 15 20
K
b
a'
c
c'
F
E
A
a
C
B
D
H
e'
b
b'
b'
c
c
e
e
AFTER COOLER

FIG. 153.

compressed air cars the first operation is to connect the steam charging nozzle to the reheater and then to connect the compressed air charging nozzle to the charging orifice. This operation takes from three to four minutes. These compressed air cars are equipped with six Mannesmann tubes, three on either side of the car under the seats and making a storage capacity of about 45 cubic feet. This storage capacity will enable the car to travel distances of about fifteen miles. The reheater is hung to the car body and lies between the two motors. It is a seamless welded tube and holds about six cubic feet of hot water. The air from the storage reservoir passes by a reducing valve and is reduced from a varying high pressure to a constant normal pressure. A throttle valve is on the

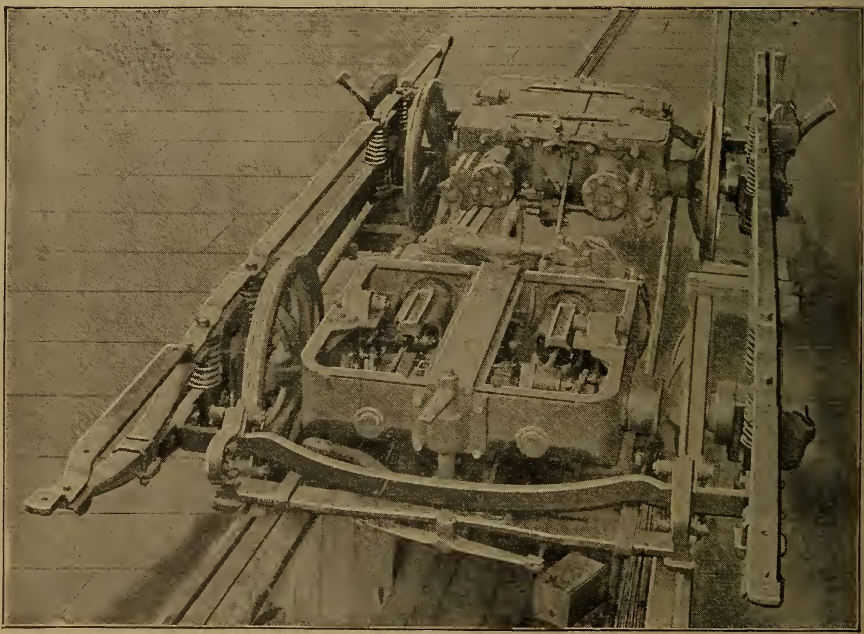


FIG. 154—BIRDSEYE VIEW OF THE MOTOR AND TRUCK OF THE AMERICAN AIR POWER COMPANY'S SYSTEM OF STREET CAR PROPULSION.

other side of the reducing valve controlling the admission of the air to the heater and thence to the motor. When the throttle is opened the air passes through a coil in the reheater and before it enters the reheater a spray of water is introduced into the air and passes through the coil in the reheater on to the motor.

The motors are of the compound type, high and low pressure, the air entering the high pressure and doing work expansively and then passing over to the low pressure motors and doing more work, and then being exhausted to the atmosphere through a muffler to prevent noise. The motors are of the enclosed type, similar to street railway electric motors, and are applied directly to the car axle. They consist of the two high pressure motors four in. in diameter by six in. stroke, and two low pressure motors eight in. in diameter and six in. stroke. Mounted on the crank shaft in the motor is a pinion which engages in a spur gear fixed to the car axle, the reduction is about 2¼ to 1. The motor cylinders are equipped with piston valves which are controlled by a movable eccentric of the wedge type. These eccentrics are connected directly to the crank pins of the motor and the wedges for operating them connect it to a common lever extending

FIG. 155—CHARGING APPARATUS FOR AIR AND STEAM. THE STEAM BEING USED FOR RE-HEATING PURPOSES.

across the motor casing, and by means of this wedge eccentric the motor is adapted to run in the forward or backward motion and any degree of cut off for the control of the motor can be obtained. This valve mechanism is connected directly with the throttle valve and is so arranged that the motor man in managing his car has but one lever to control. The motor casings are partially filled with oil, so that when the motor is in operation the oil is thoroughly broken up in small particles, thereby properly lubricating all moving parts. These cars are the standard of the Metropolitan Street Railway Co. They are built on the standard Brill truck of eight feet wheel base.

The application of these compressed air motors to street cars is similar to the application of electric motors, that is to say the weight of the motor is partially on the car axle. All the other parts of the system, as the storage bottles and the reheater, are mounted to the car body and all under the effect of the car springs.

The Mannesmann bottles are all tested to a pressure of 4,500 lbs. per square inch, and as they are filled with air at a pressure of 2,500 lbs. per square inch, there is a factor of safety of about 2. The question is frequently put as to the liability for these tubes to explode. When the tubes are filled with the air at 2500 lbs. per square inch there is no practicable way whereby the pressure can be increased, in fact, the only thing that can happen is for the pressure to decrease. This condition is greatly different from any other engineering problem. A bridge is built over a stream or anything else to carry the public and designed to carry a certain load. Bridges so made do very well but it sometimes happens that they get overloaded and break down. This cannot happen with the compressed air bottle. Should a car collide with another car or something similar the worst that could happen to the bottle would be to squeeze it together a little bit and then it would relax to its normal condition. Possibly one of the small pipe joints might start to break, but no serious explosion or destruction is likely to be caused by a collision.

New York, Sept. 13, 1899.

Editor Compressed Air:

One of the New York daily papers has commented quite severely on the Compressed Air Street Railway System now being operated on 28th and 29th streets, New York City. The main objection offered is the dropping of oil along

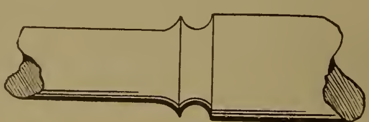


FIG. 156.

the track. This is unquestionably a fair objection and one which must be removed before the system will give complete satisfaction. It is, however, a trouble which appeared in the earlier experiments with electric motors and caused a great deal of annoyance and expense and some criticism. In the case of electric motors the trouble was remedied by adopting an enclosed motor and gear case and adopting a form of bearing which prevented the oil used in the gear cases from leaking out of the bearings. It is, of course, apparent that oil will, from capillary action, work through the bearings of the oil-filled case to the outside, and unless some means is arranged to catch this oil, it will be thrown off and collect under the car body and along the track. In the case of the air motor as used on the 28th and 29th street line, the reduction gears run in oil to reduce friction and prevent noise. As far as I am able to determine, no precautions have been taken to prevent this oil working through the bearings as described, and it would seem advisable for the railroad company to adopt the

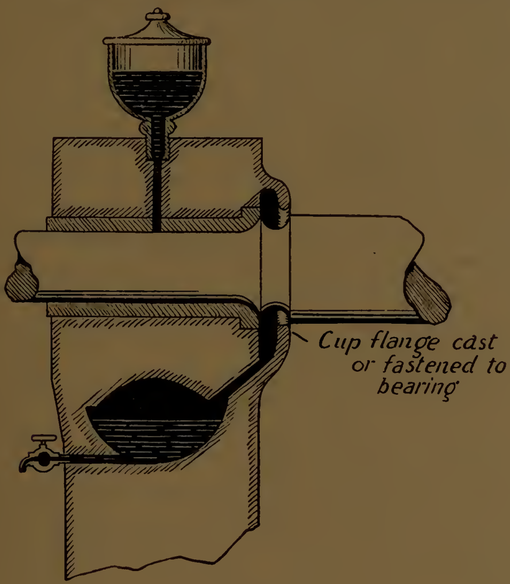


FIG. 157.

simple method used by the manufacturers of electric motors, a sketch of which is sent herewith.

THE POPP SYSTEM.

The several papers which have been published serially in this paper, written by Mr. Victor Popp, of Paris, are worthy of serious study by those interested in the practical application of compressed air. Mr. Popp writes from a practical, as well as a theoretical standpoint. His large experience and the success of his work entitle him to the position which he holds as a recognized authority on this subject, and we doubt that there has been published anywhere so important a series of papers giving such practical information as those written by Mr. Popp. We have been accustomed to read highly technical matter on this subject, and engineers are prone to deal in formulas and calculations, which are interesting enough to theorists, but which really bring no practical results. Mr. Popp, without neglecting theory, treats of the subject in so practical a manner that his theoretical deductions are easily understood, and they add to the value and reliability of the practical information which he gives.

Professor Riedler has said that Mr. Popp was the first to successfully use the reheating system with good results. We think it quite true that the first practical reheater was used in Mr. Popp's system, in Paris. A great many desultory experiments were made, and reheaters of many kinds were put in use in America; but Mr. Popp's heater was the first one to give practical results, and to be applied in continuous service. Mr. Popp is also the author of a very interesting system of Pneumatic Traction, which has recently been introduced into France. Two trams of the Popp system are running at Vincennes, in competition with the Mekarski cars. It is generally known that the Mekarski cars have been running in France for more than ten years, and that they have been giving good practical results. The Popp cars appear to be superior to the Mekarski in many ways, they are lighter in weight, more simple in construction, and under easier control by the motorman. Besides these advantages, the Popp car is reversible, it being simply necessary to transfer the brake-wheel and certain light parts from one end of the car to the other, and start the car in the opposite direction. An important point of difference is in the system of reheating. The Mekarski car using the "wet" system of reheating, while Mr. Popp applies the "dry" system. In the wet system it is well known that water heated by the introduction of steam, is used for warming the air, and that the air passing through this hot water, carries with it a certain amount of moisture. Apart from the expense involved in producing heat through steam, the wet system has other disadvantages, viz.: the tanks occupy space, time is required to heat the water at the end of the line, and in a long run the temperature is considerably lowered. Another disadvantage, and one which is seldom touched upon, is that wet air, like wet steam, helps to destroy the cylinders, pistons, and other moving parts. Though the air is hot when it enters the cylinder, it is soon cooled below the dew point by expansion, and deposits its moisture; so that what at first appears to be an advantage in vapor from water mixed with air, is only an advantage while the air is hot, and is a distinct disadvantage when condensed and left in the cylinder. Water in cylinders wipes away the oil, and is a source of destruction howsoever clean the water may be. It is a mistake to suppose that water is a lubricant; on the contrary, it interferes with lubrication. Mr. Popp overcomes these difficulties by the introduction of a small dry heater, burning coal, charcoal, or coke, the draught for which is made by the exhaust from his motor. It is always easy to get coal and coke, and the quantity used in a tramway heater is so small that it does not materially affect the cost of operation; besides, it is difficult to overestimate the value of reheating.

On this subject, we would refer our readers to recent numbers of this little magazine, more especially to the October number, in which a description is given of Mr. Popp's heater, together with figures and data based on experience. Mr. Popp gives us the figures to show that, according to Professor Guttermuth's experiments, one kilogram of combustible will, under good circumstances, give up as much as 5,600 calories in an air heater. This result Mr. Popp goes on to say "being superior by at least 500 per cent. to the results obtained by the best triple expansion compound condensing engine," and again it is interesting to note the statement made by Mr. Popp that "the amount of coal required for reheating air for large motors being 0.2 of the pound per h.-p. hour." This, as engineers will see, is about six times more efficient than the best results obtained in producing compressed air through our best Corliss engine system.

In an article which follows that of Mr. Popp, in the October number, some interesting figures on this subject are given by Professor Nicolson, in a report on trials made at Magog, Quebec, to test the economy effected by re-heating compressed air. This article is also worthy of very serious consideration and study. It impresses us as practical, and as of value as a matter of reference. The system which Professor Nicolson refers to, is the well-known Taylor system of compressing air by the flow of water. This had been in successful operation at Magog, and as a water power installation on a large scale, it is a success of the highest scientific interest. Professor Nicolson gives us some figures showing comparisons between the wet and the dry systems of reheating, concluding by saying that wet heating is inferior to dry heating. He quotes Professors Riedler and Guttermuth as having obtained an additional power in air motors for every three-quarters pound of coal burnt to heat the air, and goes on to say that this is an economy "far surpassing that of any prime motor in existence." We think this latter statement will not be questioned by engineers, nor does any one doubt the correctness of the results obtained by Professors Reidler and Guttermuth; these results, as remarkable as they are, are capable of considerable improvement when a perfect reheater has been designed. Thus far, our best reheaters in practical service do not convert the maximum amount of fuel into expansiveness of the air, while it is quite within reason to expect almost a complete conversion of the theoretical efficiency of a pound of coal into expanded air by a thorough system by which all the heat produced by burning the coal is transferred into the air. Then again, we have further possibilities in reheating air because the science is likely to develop into compound engines using air at different pressures, and reheating between each stage.

So economical in results is the system of using reheated air, that it is quite possible to restore at very little expense in fuel all, or nearly all, the power expended at the generating station, and lost through the heat of compression, friction, leakages and other conditions that will always exist in a compressed air installation. The encouraging point about the use of compressed air, is that, notwithstanding these losses, there still remains boxed-up a cold elastic substance, which is capable of taking up heat in large quantities and expanding in proportion as the heat is applied. In no other power are there such opportunities, because we must all admit that in every other known form of power it is impossible to restore energy lost at the generating station or along the line, except at an expense that makes it prohibitive. It is often said that compressed air is only a means by which power is transmitted, and is not a power in itself. We now see that through reheating, compressed air is justly entitled to be called a source of power, and not merely a means of transmission.

REPORT ON THE NEW HARDIE AIR MOTOR CARS NOW IN USE ON THE 28TH AND 29TH STREET LINE, NEW YORK CITY.

September 18th, 1900.

Mr. Clark, No. 621 Broadway, New York City, N. Y.

My Dear Mr. Clark:—Agreeable to your wish, I have the honor to report to you that I have inspected the Hardie Air Motor, now in service on 28th and 29th Streets, New York City,

Motor: A four wheel Air Motor, about 20 horse power. Cylinders, 6½ inches by 12 inch stroke. Four driving wheels, 26 inches in diameter; steel tired.

Rigid wheel base, 8 feet.

Weight of iron frames, pedestal jaws, boxes, shoes, wedges and binders—all in good proportion, and same as the running gear of a steam locomotive.

Cylinders well secured to frames. Guides, Crossheads, Linkvalve motion and valve gear with independent cut-off. All parts easily to adjust and cared for. Wheels are connected by Crankpins, parallel rods and main rods to crossheads and pistons.

Frames: The frames are extended 6 feet and 9 inches from center of pedestals, making a total length of frame 21 feet and 6 inches.

Heater Tank: A heater tank, or "Cylinder" is placed between frames, as also are the air storage tanks and reducing pressure valve. All pipe connections are made in a good and workmanlike manner.

The storage tanks have a capacity of 55½ cubic feet of air, which is compressed to 2,500 pounds per square inch.

Car body, 22 feet outside, with platform at each end, 4 feet.

Total length over all, 32 feet.

Seating capacity, 30 persons.

Total weight of Motor Truck, 11,000 pounds.

Total weight of car, ready for service, 19,000 pounds.

The body of car is fastened to Motor framing by elliptic springs, and Motor Frame rests on saddles and springs, which give the car easy motion over rough and uneven tracks.

Under side seats in car are placed air storage tanks, which are connected by piping to air storage tanks on Motor Trucks.

Also Pintsch Gas Tanks, from which the cars are well lighted by night. This light, so well and favorably known, needs no further comment.

On each platform is placed the operating mechanism consisting of reversing lever, throttle lever, air brake lever hand brake, and valve for shutting off air storage. The simplicity of this operating mechanism makes it easy to control the movement of the car, and in appearance, that of electric motors.

The air brake is especially a new device, and commendable. It is easily operated, and very effective in braking power. It is noiseless and instantaneous, both in application and release—no noise or hissing of air, as in other air brakes. All other air brakes that I know of do not release until the brake cylinder is bled. It is a special feature of this brake that it releases first, and bleeds afterwards. The same air which applies the brake releases it without the aid of a spring, and without noise.

I will here state that the air brake valve performs other functions in addition to operating the brakes. One is to start the motor from a state of rest, and the other is to rapidly accelerate the speed of the motor from a state of rest to full speed.

It will be readily understood that, with an engine having two cylinders with cranks at right angles, if the cut-off is earlier than half stroke one crank may be on the dead centre and the other on the quarter, but cut off, the engine will not start. By moving the lever one position in the opposite direction from that required to apply the brake, air is admitted from the brake valve directly through the main valve, which starts the engine, instantaneously and positively. By moving the brake lever still another position, air is bled from one side of a piston attached to the valve stem of the reduction valve, so that pressure acting on the other side of this piston assists the valve spring to hold the valve open, requiring a higher pressure to close it against the combined action of the spring and piston. This high pressure is just what is wanted to enable the motor to accelerate rapidly from a state of rest. As soon as the motor has acquired the necessary speed the motorman moves the lever to the normal running position, restoring the pressure behind the piston so that it is a gain in equilibrium, and the motor again is operated under the normal pressure.

The whole mechanism is ingenious and novel, and may be characterized as admirable.

The hand brake is similar to the street car hand brake, and is only an alternative in case of the air brake failing—and only to be used to complete the balance of the trip.

The car is nicely painted on the exterior and interior, and resembles in appearance the electric car.

The motor trucks are not exposed, being shielded by a lattice screen below the car body.

The air compressing station is situated at the foot of West 24th street, New York City.

A 1,200 horse power engine, operating four stage Ingersoll-Sergeant air compressors, with a capacity of 56¾ cubic feet of free air per revolution compressed to 2,500 pounds per square inch. This air is stored in reservoirs in the car shed, from which the reservoirs on the cars are charged to the same pressure. The charging a car with air, and the hot water tanks, or "superheater" requires an average of two minutes. The car is then ready for a fifteen (15) mile run.

I find that there is very little noise when the motor is first started, and after starting, entirely noiseless, and that there is no jerking motion. The motor is clean, and free from dust and oil.

The motor and car herein described, I think, will prove in service to be practicable, and each car with its power is independent. The air storage is automatically reduced to a working pressure of 150 pounds per square inch. Having the storage at 2,500 pounds, the reduction valve governs this pressure through all stages until it is reduced to 150 pounds.

I think the Hardie Motor will prove economical in maintenance, as all its wearing parts are well constructed and easily accessible for adjustment and repairs.

I have looked over the reports made by experts, and have every reason to think they are correct—showing compressed air power to be cheaper than electricity or any other motive power.

Safety: The air storage tanks are all tested to a much higher pressure than the pressure they are stored with for service.

It is my opinion, judging from the construction of these storage tanks, and the tests they are put to before they are placed in service, that there is no possible danger of explosion, and they should prove to be practically indestructible.

I see no reason why the Hardie motor should fail to prove itself a success as to economy, safety and efficiency. Respectfully submitted,

W. L. Hoffecker.

THE JARVIS PNEUMATIC CAR.

At Detroit, Mich., in 1892, inventor Samuel E. Jarvis made experimental trips with a low pressure car on a mile of track. Air was compressed at one end of the line and was delivered to a 6-inch main which was laid just under

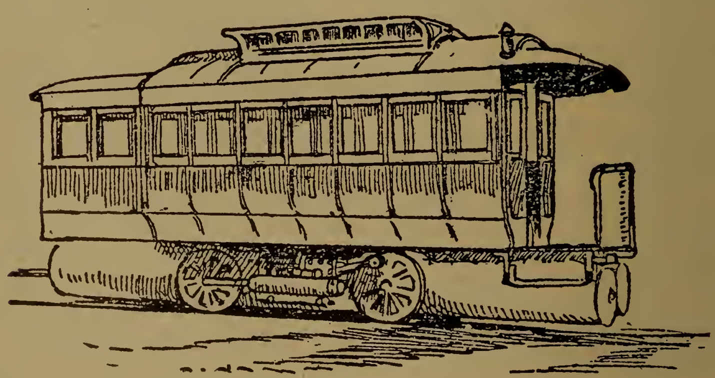


FIG. 158—THE JARVIS SYSTEM.

the pavement in the centre of the track for the full length of the road. The motor got its power from this pipe. The car carried four cylindrical tanks. It was able to run at the rate of fifteen miles an hour.

The tanks were charged at street crossings or other places where it was necessary to make stops.

THE VINCENNES-VILLE EVRARD COMPRESSED AIR TRAMWAY.

In 1888, a tramway was constructed from Vincennes to Ville Evrard, and the Mekarski compressed air cars put in operation. The system then employed consisted of a motive fluid, not cold and dry compressed air, but a mixture of air and steam. This was done because it was known that compressed air when expanding produced a strong depression of temperature, the steam in giving up its heat limits such depression, which is the cause of a great loss of power. Air was used under low pressure. A regulator was interposed between the com-

FIG. 159—PLAN SHOWING AN AIR PIPE LINE IN PARIS.

pressed air reservoirs and the engine; (1) a heater that serves for obtaining the motive fluid, and (2) a regulator or expander that serves for sending the gaseous mixture to the cylinders under a constant pressure, whatever be the pressure in the reservoirs. The results obtained show it to be a most economical process. An examination of the figures for several years showed that animal traction cost from 23 to 15 cents per mile, and steam propulsion cost 20 to 15 cents per mile, and compressed air propulsion at Nantes cost less than 12 cents per mile.

The line mentioned is 58 miles in length. It runs through the Bois de Vincennes, passes near Fontenay-Sous-Bois, goes to Nogent-Sur-Marne and

Perreux, touches Neuilly-Sur-Marne, and finally ends at the departmental asylum of Ville Evrard. It has gradients reaching half an inch to the foot. This same system has been in operation at Nantes for nine years previous, and satisfactory results had been obtained.

THE POPP-CONTI SYSTEM.

The Popp-Conti system which is in use in Saint-Quentin, Angoûleme and Lyons, France, is described as follows:

It is a low pressure system, and at starting the tramway is charged with a sufficient quantity of compressed air to enable it to run for four kilometres,

FIG. 160—THE POPP-CONTI SYSTEM.

after which distance it becomes self-charging, and by the following ingenious device:

Before each waiting station the rails are provided with a pipe which is set in the hollow over which the wheels pass. That causes a smaller pipe to spring from the ground and enter a hydraulic joint placed under the tramway, by which means the receivers installed there are connected with the underground conduit. The amount of compressed air received in a few seconds is sufficient to propel the tramway for a further distance of four kilometres. This done, the little pipe re-enters the ground and is automatically covered by an iron plate, over which men and horses alike may pass with perfect safety.

Such prominent engineers as MM. Huet, Boreux, Humblot, Petsch, Monmerqué, etc., who were present at several tests, congratulated M. Victor Popp upon the success of his system.

THE HUGHES AND LANCASTER CAR.

In 1890, Messrs. Hughes and Lancaster, of Chester, England, operated a tramcar by compressed air at a pressure of 155 lbs. to the square inch. The air was carried in vessels attached to the car, and the supply of air was renewed at intervals on the journey by an automatic valve on the car. A corresponding

FIG. 161—THE HUGHES AND LANCASTER SYSTEM.

valve is placed on an air main which is laid the whole length of the tramway where the road had heavy gradients, and where the traffic was exceptional they were placed at smaller intervals. Air could be taken whenever required. This mode of collecting energy en route has its own friends, and is said to be economical.

THE FIRST STREET RAILWAY.

The first ancestor of the street railway was the tramway. Tramways were first introduced in the coal mining districts of the North of England, between the years of 1602 and 1649. They consisted of parallel lines of wooden trams or beams, pinned down to the ground, with flanges on them, and not on the wheels as now. Coal wagons were drawn to and fro along these flanged trams from the coal pits to the shipping ports. The first use of iron on these tramways was in 1767, when cast iron plates were nailed down on timbers to protect them where they wore out the fastest. The plates or rails were cast in sections five feet long, four inches wide and an inch and a half thick. All iron rails were cast until rolled wrought-iron rails were introduced in 1820. The width of the tramways was about four feet, eight and one-half inches, because that happened to be the usual width of wagon tracks in that region. Horse railroads of a crude type were in use in England in 1805. We find in that year five were chartered by act of Parliament; sixteen were chartered in 1815, and thirty-two in 1825. After that it seems to have become a lost art in England, as the modern tramway was not employed until 1832, at which date, the first street car line for passengers was built on Fourth Avenue, New York. The system was not con-

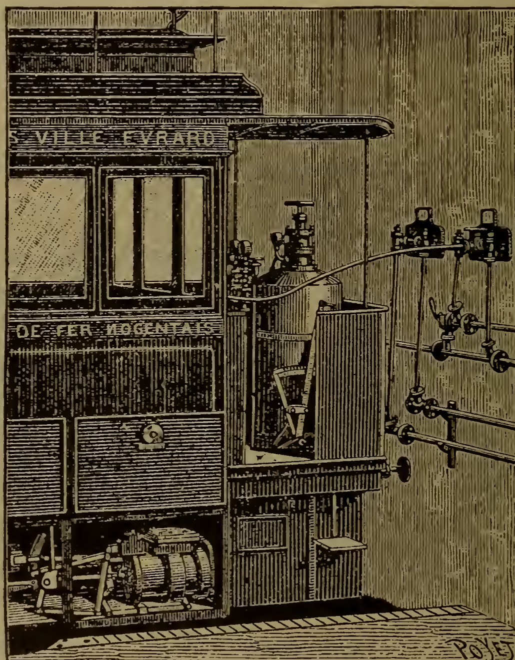


FIG. 162—THE MEKARSKI SYSTEM.

sidered a success, however, until twenty years after, or in 1852, when a second line was constructed, and from this date the system spread rapidly throughout the United States. In 1860, George Francis Train attempted to introduce the present type of street railway into England.

A line was laid on one of the roads of Birkenhead, and the following year a temporary footing was obtained within the suburbs of London. Owing to opposition created by prejudice, the system was extinguished for some years, and was not successfully revived till 1868, when by act of Parliament, permission was obtained for a system of horse railroads in Liverpool. Following this, there was a rapid development of horse street railroads on the continent and other parts of the civilized world.

RECENT EXPERIMENTS IN COMPRESSED AIR MOTORS.

In 1880, it was thought Col. Beaumont, R. E., of England, had effected a locomotive that had mastered the problem of compressed air for traction purposes. The construction of the engine was based upon the principle of utilizing the entire power stored up in compressed air, no matter how high the pressure should be. This was effected by admitting the air into successive cylinders, having different areas, commencing with the smallest, and in making provision by which, as the pressure fell in the reservoir, the consumption of air can be

FIG. 163—TRIAL OF THE BEAUMONT COMPRESSED AIR MOTOR AT WOOLWICH ARSENAL, ENGLAND.

increased. In appearance the engine differed from an ordinary locomotive, the absence of a funnel or other outlet for smoke or steam being a prominent departure.

Col. Beaumont was allowed by the British Government to experiment in the Royal Arsenal, Woolwich.

A difficulty met with in the Beaumont method, was the tendency to produce extreme cold, which became condensed and frozen on the working parts. Reports of tests, however, show that very good results were obtained.

COMPRESSED AIR FOR STREET RAILWAY OPERATION.*

"Compressed Air for Street Railway Operation" is the subject assigned to me for treatment in this paper, and I find it difficult to place all the facts for an intelligent consideration of this subject before this convention in the twelve minutes allotted to me.

The question of liquid air was also coupled with this subject, but I do not deem it necessary to touch on this question more than to say that nothing has been accomplished in the manufacture of liquid air which will warrant its consideration as a factor in the operation of street railroads at this time. The present method of its production is to start with compressed air at 2,000 pounds pressure, and by expanding many volumes of air at this pressure, thereby producing intense cold, to liquefy a small volume of air. The only advantage which liquid air has is the small form in which it can be stored, 800 feet being compressed into one; but, on the other hand, as in this form it is the ice of air, the additional cost of heat necessary to return it to ordinary air for use in cylinders adds unnecessary expense. In other words, you cannot get out of a thing more than you put in it, and the expense in this case is prohibitive.

The subject matter of our theme therefore will be confined to the latest and most improved compressed air cars now in actual service in three cities of the United States, which are started, kept running and stopped by compressed air. When it is considered that one of the earliest applications of air in railroad service was its use for air brakes as a stopper of trains, it is passing strange that its use as a starter and stopper of trains did not earlier occur to mechanical minds.

Space precludes any general review of the past history of air, except to state that it was one of the earliest known of what may be termed the secondary forces or powers. Authentic records of the application of air are found among the writings of the Alexandrians, 300 years before Christ, and, later, water was used in connection with steam but not much progress was made with either of these until the present century, during which such advances have been made in the manufacture of iron and steel, which have been used in the construction of engines, boilers, tubing, etc., as to make the use of steam the most important factor in modern life.

Although the application of compressed air to the propulsion of vehicles is of comparatively recent date, the fact that it is used in practically the same way as steam gives to it the benefit of all that has been done in the way of the perfection of the steam engine. In fact, there are many instances where steam boilers have been charged with compressed air and engines operated therefrom, and, in one instance, a locomotive was charged with compressed air and run about the railroad yards and used for switching, etc. For such purposes, however, specially designed machines are better.

Limited space precludes any but the most general review of this important subject, and certainly nothing is more important to street railroads than the question of a power which can be economically applied to all conditions of

* Paper read by Mr. H. D. Cooke, President of the Compressed Air Co., at the annual meeting of the New York State Railway Association, held at Buffalo, N. Y., Sept. 18 and 19, 1900.

service, and which is of so simple a character as to make its operation and maintenance equally economical. Recently, however, it has been given serious consideration and all the claims made for it have been fulfilled. It has proven itself reliable, unchanging, and where it has once performed a service it has always, under the same conditions, continued to perform that service. Unlike steam, compressed air does not have to be used as it is generated. It can be stored up and is ready for use when needed. Compressed to any required degree, it will always return to its normal atmospheric density.

Briefly described, the construction and operation of an air car are as follows, viz.:

The most approved form of motor now in use in this country, and of which a number have just been constructed for the Metropolitan Street Railway Company, of New York, for their crosstown lines, consists of two small reciprocating engines underneath the car body, each connected directly to one pair of the car wheels according to the most approved form of locomotive engineering practice. The pair of wheels so driven are connected by parallel connecting rods to the other pair of wheels, thus making all the wheels under the car drivers. The air, before passing into the cylinders of the engine, passes through a reheating tank of water heated to an initial temperature of 300 degrees. The reheating of the air before use returns to it all, or a very great portion of, the heat units which were taken from it during compression. To illustrate this, a test was made of a motor in Rome, N. Y. This motor, which carried thirty-five cubic feet of storage, was run with cold air, until all the air was exhausted, and covered only eight miles. Afterward the same motor was run, using the reheating apparatus, and fifteen miles were covered. The heating of the water in the tank is done by attaching a steam connection directly from the boilers which furnish steam to the compressors, to the reheating tank on the motor and passing the live steam into the water.

In order that the minimum amount of difficulty might be experienced by the average motorman, a controller was devised which, in appearance and operation, is very like an electric controller. An air brake is one of the features of these motors, and an ingenious contrivance in the way of a starter is also controlled by the brake handle. The valve motion is exceedingly simple, and gives a range of cut-off of from 1-10th to 5-8th of a stroke. There is no appreciable exhaust and the operation of the motors is practically noiseless. The air brake used on these motors is operated from air stored on the car, and is absolutely noiseless, both in its application and release. Being operated by the same handle which starts the car, there is no danger of the motorman leaving his brake on and trying to start the car at the same time.

Cars of this type are in their sixteenth month of operation on the North Clark Street Cable line in Chicago, doing the night or owl service on that line, and sometimes hauling two trail cars. During the severe winter weather and snow storms which prevailed in that city last winter, the compressed air cars were the only ones to perform their regular schedule. Compressed air cars have been in use in France for several years, and also in Switzerland, and in some places in those countries are used to haul two and three trail cars, but the American motors are pronounced by both our own engineers, and engineers from other countries, to be far superior to those of European manufacture.

The storage tubes under the car are of mild steel, capable of withstanding a pressure of 5,000 pounds to the square inch. Bottles of this character are used, both in the power house and on the car; the initial pressure in the power house being about 2,500 pounds and on the cars about 2,000 pounds, which pressure on the cars is, by means of a reducing valve, reduced to about 15 pounds to the square inch before going through the reheating tank and thence passing into the cylinders. It will be seen, therefore, that there is an ample factor of safety allowed by the storage tubes, and, while all precautions which can be, are provided, and it is apparent that the further the cars travel the greater the factor of safety becomes. The storage on the car is underneath the seats, or the car floor, and the cars, in appearance, resemble the standard Broadway, New York, cars, none of the storage or machinery being in sight, and no paying space is taken up by either.

We now come to the power house. Air compressors, driven by an economical stationary steam engine, or by water or other power, compress the air from atmospheric to 2,500 pounds pressure to the square inch, and as the air is compressed it is stored in a battery of steel bottles of the character of those above mentioned. During compression, however, great heat is developed and a system of water jacketing is used which reduces the temperature of the air to that of the surrounding atmosphere. By means of a special separator, all the moisture contained in the air is separated from the air as it passes from the compressor to the storage, thus securing perfectly dry air. It is well known that expanding gas or air develops an exceedingly low temperature, but the use of the separator, removing all water from the air before storage, obviates freezing upon expansion, and the passing of the air through the hot water before use in the working cylinders restores to the air the heat units which were taken from it during compression and also furnishes enough moisture in the form of steam to assist in lubricating the cylinders. The exhaust from the engine cylinders never falls below 70 degrees.

In order to recharge the storage on the car it is only necessary to connect the storage in the power house with that on the car and equalize the pressure between the two. This is usually done at the end of a run, and while the car is waiting and takes about two minutes. In Chicago, however, this is done on the street and while the car is en route, and has never caused any delay or stoppage of the service, even though done while the air cars were running between cable trains.

During the last four years experimental and actual demonstration of air cars in service have reasonably determined the following facts, viz.:

That the cars operated in Chicago during a period of six months consumed an average of 400 cubic feet of free air per car mile, and that the cost of maintenance of these motors is much less than that of the ordinary steam engine, as there is no boiler to be cared for.

We have been furnished figures by the most responsible builders of air compressors in this country, estimating on a volume of 6,800 cubic feet of free air per minute, which should be sufficient to operate 100 cars, which show that

2 8-10 cents will compress 1,000 cubic feet of free air to 2,000 pounds pressure. This estimate is approximate for local conditions, and coal is figured at $2.90 per ton for a twenty-four hours service, taking two pounds per hour for indicated horse-power. This includes attendance of engineers, helpers, firemen and laborers, and also for oil and waste, and allows for 10 per cent. per annum for depreciation.

The cost of equipping with air cars varies according to local conditions, but in the present state of the art is approximately the same as the overhead trolley. It is believed that the cost of operation and maintenance through a term of years will prove to be very much less, and that increased facilities of manufacture will greatly lessen the first cost.

It is believed that compressed air cars have a place in every large system already installed, whether cable or electricity, either for performing night service where it is not advisable or economical to run a large plant for the operation of a small number of cars, or where feeders or crosstown lines are necessary and the installation of the overhead or underground trolley would not be permitted.

In brief, the advantages of compressed air for the operation of street railways may be summed up as follows, viz.:

First—A system of independent motors, which, after receiving their charges, do not rely upon the power plant and which will always finish their run should anything happen to the power plant; which also do not need any special outdoor construction, either underground or overhead, with the attendant cost of maintenance.

Second—Slow moving machinery, both in the power house and on the car, which is easily maintained.

Third—Opportunity for charging cars, and storage in power house, during light hours, for use during rush hours.

Fourth—Spring supported motors and load, doing away with excessive jarring and pounding on track, and thus greatly prolonging the life of the road-bed, the life of the motors, and contributing to the easy riding of the cars.

Fifth—Low first cost of plant; low cost of maintenance, and opportunity for making repairs and adjustments without stopping the operation of the cars.

Sixth—Freedom from liability in transit from snow, ice or sleet.

HARDIE CARS RUNNING IN CHICAGO.

The compressed air motor cars on the North Clark street cable road in Chicago are making a good record for themselves, and much can be said of their reliability.

The first car made its initial trip May 30th; soon after the second car was put on, and a third car is held in reserve to provide for any emergency or accident.

No trouble has originated from lack of efficiency on the part of the inexperienced motormen. They were instructed originally by Robert Hardie and have been able to handle the cars perfectly ever since.

The cars still continue to make the first trip from air that was left over from the previous night service, and, on one occasion, one of the cars made an excursion trip in daylight for the benefit of those who were invited to be present, and still made its regular trip at night with what air was left from the preceding night.

From May 30, 1899, to June 20, 1899, inclusive, car No. 107 ran alone. On June 21st car 102 was put in service, and since then two cars have been running regularly and doing the complete "Owl Car" service.

In order to show the actual service performed by these cars a brief table is given:

	Car No. 107.	Car No. 105.	Car No. 102.	T'ls.
No. of miles covered......	1,232	189	616	2,037
No. of trips without trailer	148	21	84	253
No. of trips with one trailer	26	6	4	36
No. of trips with two trailers	2	..	..	2
Total No. of trips, each car	176	27	88	291
No. of passengers carried paid fares..................				24,294
No. of hours car service from June 21st to July 17th inclusive, for two cars..............................				142
No. of hours compressor ran from June 21st to July 17th, inclusive....................................				93h. 43m.

THE HARDIE NEW VALVE GEAR.

Mr. Robert Hardie has invented a new valve gear for his compressed air motors, and is having it put on a sixty-foot car now being built at Rome, N. Y., and later it will be applied to the street cars equipped with the Hardie air motors. The object sought in the invention was to obtain an arrangement whereby a cut-off valve could be worked in conjunction with the main valve by one lever. The new gear gives a cut-off (including clearance) at any desired point between 1-10 to nearly ½ stroke. In the position of earliest cut-off there is also the greatest amount of lead, as has been shown by a working model of the gear.

A regular Stephenson link with a fixed cut-off (from 1-10 to 1-5), worked by separate eccentrics, was formerly used on the Hardie cars. While a late cut-off results in a greater consumption of air than an early cut-off, the advantage comes in being able to adopt smaller cylinders. We defer illustrating the new gear until the foreign patents have been granted.

The figures in the accompanying table were calculated from valve and piston movements of the model. The indicator cards for each of the three positions of the reverse lever, as here shown, were drawn from calculations based on the figures obtained from the actual movements of the pistons and valves of the model. The expansion curve in each card is between the adiabatic and isothermal.

In the following table, are given the openings for every 30 degrees of the main and cut-off valves for three positions of the link, with 3-16 inch for both outside and inside lap of main valve, and 11-16 inch negative lap of cut-off valve.

These figures are for cylinders $6\frac{1}{2} \times 12$ inches, and admission port, $\frac{1}{2} \times \frac{5}{8}$ inches. The inside and outside lap being equal, the main valve compression and cut-off

TABLE 46—RESULTS OF DISTRIBUTION OBTAINED BY THE HARDIE VALVE GEAR.

Crank angle, deg.	First Position. Main valve (full) travel, 2 in.; cut-off valve travel, 2 in.					
	Cut-off valve opening, inches.		Main valve opening, inches.		Piston travel, inches.	
	Front.	Back.	Front.	Back.	Front.	Back.
0	$\frac{15}{16}$	$\frac{7}{8}$	$\frac{7}{32}$	$\frac{7}{32}$	.0	.0
30	0	0	$\frac{5}{8}$	$\frac{21}{32}$	.94	.67
60	$-\frac{11}{16}$	$-\frac{23}{32}$	$\frac{3}{4}$	$\frac{7}{8}$	3.39	2.62
90	$-1\frac{3}{32}$	$-1\frac{1}{8}$	$\frac{11}{16}$	$\frac{7}{8}$	6.53	5.48
120	$-\frac{15}{16}$	$-\frac{31}{32}$	$\frac{13}{32}$	$\frac{1}{2}$	9.39	8.62
150	$-\frac{13}{32}$	$-\frac{15}{32}$	$-\frac{1}{32}$	$-\frac{1}{32}$	11.33	11.06
180	$\frac{15}{32}$	$\frac{13}{32}$	$-\frac{9}{16}$	$-\frac{19}{32}$	12.00	12.00

Main cut-off and compression crank angle, 117°.
Lead angle of cranks: front, 18°; back, 18°.
Point of cut-off not including clearance $\frac{1}{2.42}$ of stroke.
Point of cut-off including clearance $\frac{1}{2.29}$ of stroke.
Greatest port opening, $\frac{9}{32}$ in.
Relative travel of main and cut-off valves, $1\frac{5}{8}$ in.

TABLE 47—RESULTS OF DISTRIBUTION OBTAINED BY THE HARDIE VALVE GEAR.

Crank angle, deg.	Second Position. Main valve travel, $1\frac{1}{4}$ in.; cut-off valve travel, $1\frac{11}{16}$ in.					
	Cut-off valve opening, inches.		Main valve opening, inches.		Piston travel, inches.	
	Front.	Back.	Front.	Back.	Front.	Back.
0	1	$1\frac{1}{16}$	$\frac{5}{32}$	$\frac{5}{32}$	.0	.0
30	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{7}{16}$	.94	.67
60	$-\frac{1}{4}$	$-\frac{1}{4}$	$\frac{9}{16}$	$\frac{19}{32}$	3.39	2.62
90	$-\frac{21}{32}$	$-\frac{5}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	6.53	5.48
120	$-\frac{19}{32}$	$-\frac{9}{16}$	$-\frac{1}{4}$	$\frac{9}{32}$	9.39	8.62
150	$-\frac{9}{32}$	$-\frac{5}{32}$	$-\frac{9}{64}$	$-\frac{5}{32}$	11.33	11.06
180	$\frac{5}{16}$	$\frac{3}{8}$	$-\frac{1}{2}$	$-\frac{17}{32}$	12.00	12.00

Main cut-off and compression crank angle, 138°.
Lead angle of crank : front, 13°; back, 13°.
Point of cut-off not including clearance $\frac{1}{6.29}$ of stroke.
Point of cut-off including clearance $\frac{1}{5.19}$ of stroke.
Greatest port opening, 3/8 in.
Relative travel of main and cut-off valves, $2\frac{11}{16}$ in.

TABLE 48—RESULTS OF DISTRIBUTION OBTAINED BY THE HARDIE VALVE GEAR.

Crank angle, deg.	Third Position. Main valve travel, 1 in.; cut-off valve travel, 1½ inch.					
	Cut-off valve opening, inches.		Main valve opening, inches.		Piston travel, inches.	
	Front.	Back.	Front.	Back.	Front.	Back.
0	$1\frac{1}{16}$	$1\frac{1}{8}$	$\frac{1}{8}$	$\frac{7}{64}$	.0	.0
30	$\frac{21}{32}$	$\frac{3}{4}$	$\frac{1}{4}$	$\frac{9}{32}$	.34	.67
60	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{1}{4}$	$\frac{5}{16}$	3.39	2.62
90	$-\frac{1}{16}$	$-\frac{1}{16}$	$\frac{5}{32}$	$\frac{9}{32}$	6.53	5 48
120	$-\frac{5}{32}$	$-\frac{3}{32}$	$-\frac{1}{16}$	$\frac{1}{32}$	9.39	8.62
150	0	$\frac{3}{32}$	$-\frac{9}{32}$	$-\frac{9}{32}$	11.33	11.06
180	$\frac{7}{32}$	$\frac{5}{16}$	$-\frac{15}{32}$	$-\frac{15}{32}$	12.00	12.00

Main cut-off and compression crank angle, 148°.
Lead angle of crank : front, 12°; back, 12°.
Point of cut-off not including clearance $\frac{1}{14.81}$ of stroke.
Point of cut-off including clearance $\frac{1}{9.54}$ of stroke.
Greatest port opening, $\frac{7}{16}$ in.
Relative travel of main and cut-off valves, 3⅝ in.

take place at the same point. The greatest port openings are taken at the point where cut-off and main valve openings are equal, the cut-off closing while the main valve is opening. There is always ample exhaust opening. The readings in the table were taken (for convenience) at equal crank angles, but the valves would be set to cut-off at equal piston movements from each end of the cylinder The clearance in the cylinder is 4 per cent. The cut-off, including clearance, as noted under each card means

$$\frac{\text{Piston travel at cut-off} + \text{clearance}}{\text{Stroke of piston} + \text{clearance.}}$$

THE HARDIE AIR-MOTOR CAR.

The first of the two Hardie air-motor street cars to be tried by the Third Avenue Railroad Co., arrived in this city July 22, 1896. It was shipped on a platform freight car on the New York Central Railroad from the works of the American Air Power Company at Rome, N. Y., where it was manufactured. The new car was taken from the freight car at 129th street and Hudson River, whence it was propelled by its own power about 1,000 feet to the station of the 42d street, Manhattanville and St. Nicholas Avenue Railroad, at 129th street, between Twelfth avenue and the Boulevard.

Its air tank was charged, just before the car was taken from the works, with compressed air to a pressure of 2,000 pounds to the square inch, and in the three days that elapsed from that time the loss of pressure was only twenty pounds, which is regarded as small.

The weight of the car complete is 18,000 pounds. Of this, 6,000 pounds may be charged to the car body, 500 pounds to hot water for heating the air, 500 pounds for the compressed air itself, and the rest to the truck and motive equipment and air cylinders. The controller, or throttle and reverse lever as Mr. Hardie prefers to call it, is situated on the front platform, and is strongly suggestive of the ordinary street car controller. A crank handle operates the throttle valve which admits air to the engine cylinders and controls the motions of the car. The reversing lever merely throws the Stephenson link, or regulates the grade of cut-off. A third lever controls the air-brake, and also by swinging over to another position can admit air to the ends of the cylinders for starting, after the cut-off valves have closed, and also make the air pressure momentarily much higher to start off rapidly. This Mr. Hardie calls the accellerator. The brake is released by equalizing the pressure on either side of the piston by a specially designed valve. This action takes place almost instantly. A fourth handle takes the place of the hood switch on the electric car and cuts off the air altogether. The motorman takes all these four handles with him and covers up the top of the controller with a brass cap, thus preventing intermeddling by passengers, and also preventing the soiling of clothing by oil or grease.

The car is 28 feet long, its body being 20 feet long, and the remaining 8 feet being occupied by the two platforms. It has a seating capacity for 28 passengers, and when its compressed air and hot water tanks are charged, it can run 16 miles without recharging, and is capable of attaining a speed of 15 miles an hour.

The motorman controls the machinery with a little lever only 6 inches long, while the rate of speed is graduated by the use of valves, by which the pressure of the motive power on the engine cylinder, usually 150 pounds to the square inch, is regulated.

A movement of the lever one inch to the right lets off the brake and starts the car, while a movement one inch to the left puts on the brake and stops the car, and a further movement to the left starts the car backward. These movements can be made so easily, and the car started, stopped or backed so quickly, that it is contended danger of accident is reduced to a minimum.

The wheels and the hot water and compressed air tanks, which are underneath the car, are concealed by a drop, or curtain, composed of slats of wood.

THE HARDIE AIR MOTOR.

Mr. Frank Richards, in a letter to the New York "Sun," speaking of the cars running on 125th street, New York, says: "Each car is independent of every other, and independent of the roadbed. The disablement of one car affects only itself. It is the safest system known. No passenger has ever discovered or suggested an objection. The officers of the Third Avenue Railroad Co., upon whose lines the cars have run, have entirely failed to discover any objection to the system, and state so officially."—Mr. Albert J. Elias, President of the Third Avenue R. R. Co., N. Y., in a letter to Mr. E. A. Willard, President of the American Air Power Co., dated March 31st last, writes:

"Your cars operated by compressed air have been steadily operated on the 125th street line of the Third Avenue Railroad Co. since the 3d of August last.

FIG. 164—ROBT. HARDIE AND HIS MOTOR.

They have been easily handled, started, stopped and reversed; the last named quality being a very desirable feature, reducing the liability to accidents. Of course, the advantage of a motor that operates independently of connection with any subterranean motive power is apparent. I have not been able accurately and definitely to determine the relative cost of this compared with other motors, but am quite sure that it is not greater, and am of the impression that it is less than animal and probably less than cable traction. The motors are capable of attaining high speed and overcoming considerable gradients."

The following from the "Railroad Gazette" shows that the Hardie system is attracting attention abroad:

"Sir A. B. Forwood, a large owner in the Liverpool, England, tramway system, before the city acquired the plant, has been for a considerable time making an investigation by direction of the Liverpool authorities for the purpose of report, of the working of the Hardie Air Motor on 125th street, New York. He employed as an expert, Mr. A. Thomson. The report which has been forwarded contains detailed description of the motors and plant now in use in New York, together with estimates of cost of their working. The report concludes as follows: 'Looking at this system from a mechanical point of view, there appears to be no doubt of its efficiency. The details connected with the service which we examined have been very carefully wrought out and constructed, and the machinery appeared to have sustained no wear and tear of any moment after continuous service of about eight months. The arrangement of the machinery in the car is that of a plain simple engine, the working parts are of good, strong section and design, and should last for a long time with a very little upkeep, and we have no hesitation in stating that a plant fitted upon this system, with the arrangements and details carried out properly to begin with, would work as great or greater efficiency and more economy than any other system which we are acquainted with.' "

COST OF OPERATING AIR CARS IN NEW YORK CITY.

It seems especially pertinent at this time to publish a statement of the actual operation and operating expenses of the American Air Power Company's cars that have performed a regular commercial service on the 125th St. line of the Third Ave. R. R. in New York City, since the 3d of August, 1896, with a success unparalled in the history of mechanical traction.

The period elapsed covers the extreme ranges of temperature experienced in this locality, and fortunately also two snow storms of more than ordinary severity, so that the seven months continuous duty on which the following statement is based will meet the conditions incident to any street railway service.

The 125th St. line of the Third Ave. R. R., extends across town from the North River to the Harlem River, the length of the tracks being 10,854 feet, making the round trip 4.11 miles, over which cable cars are operated at intervals of 2½ minutes. Air cars were substituted for two of these cable cars, the schedule calling for 19 round trips each, or 79.09 miles per car; for a daily service of 156.18 miles besides 1.14 miles of switching to and from the car house and street tracks, making the total distance covered daily, 157.32 miles. Each car runs from 12.50 to 16.67 miles on a single charge of air.

The switching referred to is unavoidable in operating this service owing to the arrangement of the car-house in relation to the street tracks, it being some distance from the terminal of the road.

During a portion of the time, only single service was performed, as at present, so that the total average mileage per day, from August 3d to March 3d. was 125.16 miles, and the total distance covered, 23,030.5 miles; and the total number of passengers carried, 137,386. The cars have operated every week-day, but are not run Sundays.

The accompanying profile of the 125th St. line shows that the grades to overcome fairly represent average conditions in New York. The grade from

Fort Lee Ferry east to the Boulevard being 1.96%, while at the New York Central R. R. tunnel crossing, the maximum grade is 7.7% for a short distance, which is just as difficult to start the car upon as a long grade of the same ascent.

In the following statement of operating expenses, the coal and water items include all that has been used at the compressing plant during this period, and the labor account includes in addition to the operating employees, a night watchman, record keeper, and also switchman for a portion of the time. It must also be borne in mind that the fires are kept under boilers for 24 hours, although the compressor only runs 7 hours daily.

Actual average cost per car mile for entire period—7 months—125.16 miles per day.

Coal	$0.0563
Water	.0103
Oil and Waste	.0013
Power Plant Labor	.1261
Conductor and Motorman	.0608
Repairs, Car Equipment	.0038
	$0.2586

Average present cost per car mile, while one car service performed—78.09 miles per day.

Coal	$0.0675
Water	.0113
Oil and Waste	.0017
Power Plant Labor	.0833
Conductor and Motorman	.0608
Repairs, Car Equipment	.0038
	$0.2284

Average present cost per car mile with two car service—156.18 miles per day.

Coal	$0.0433
Water	.0103
Oil and Waste	.0013
Power Plant Labor	.0833
Conductor and Motorman	.0608
Repairs	.0028
	$0.2018

If the proportion of labor actually utilized in this service is considered, the expense would only amount to $0.1791 per car mile at present.

Present number of employees, six, besides conductors and motormen.

The reason for the present cost of operation being lower than the average for entire period is that the number of employees has been reduced in addition to a less air consumption by the car. The number of employees at present is, however, sufficient to operate a fifteen car service, so that the proportion of labor charges per car mile is still very high.

At a recent conference of several engineers, who investigated the cost of operating the American Air Power Co.'s system in behalf of a street railway now operating a large number of cars at intervals of one minute, it was determined after careful examination, and agreed that for the items above enumerated, the cost per car mile would in no event exceed $0.085, and that with a large equipment of cars in service, like that performed on 125th St., the cost would only be $0.0756 for the same items now costing $0.2018, while operating the two car service. This would make the total operating expense of such a road about 12 cents per car mile.

For the benefit of any who may not be familiar with the operating cost of so small a number of cars by mechanical power, the following data is furnished:

In the recently published report of the operating expenses of 22 electric roads in Connecticut for 1896, the West Shore Street Railway Co., West Haven, is reported as operating precisely the same mileage, namely 4.11, with the same

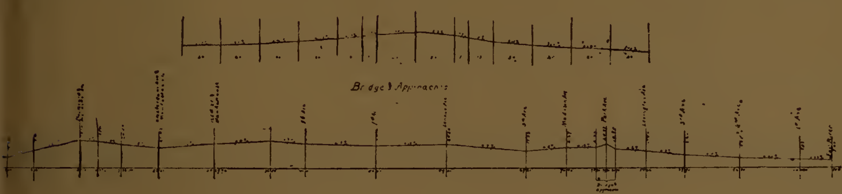


FIG. 165—PROFILE SHOWING GRADE ON 125TH ST., NEW YORK.

number of cars in service, having, however, only five employees, and the average cost of operation per car mile is shown as $0.2991.

In the published report referred to, the average cost of operation per car mile of the 22 roads given, is $0.1444; and in the 20 roads having the items of motive power, and line repairs given, the average cost appears as follows:

Motive Power, Average......................	$0.02816
Line " "	.00270
	$0.03086

The average consumption of free air per car mile for the seven months service of air cars on 125th St., has been 477.7 cubic feet. During the severe snow storm of December 16, 1896, the cars performed the schedule service with promptness and regularity, carrying 20 per cent. more passengers and using 22% more power than the day previous. In comparing results with an electric road in this vicinity, it appears that with 33% less service than the day previous, the load on the power-plant was about 80% greater.

During the last week, the average consumption of free air per car mile was only 414 cu. ft., and many of the trips were made on considerably less than 400 cu. ft.

The actual cost of compressing air to 2,500 pressure per square inch, and storing for use in a modern air compressing plant operating with condensing engines including coal at $2.75 per ton, water, at $1.00 per thousand cu. ft., oil and waste, the removal of ashes, labor, repairs and maintenance of power-plant, depreciation, and interest on cost of entire power-plant including buildings, for compressing plants of the following capacities, based on the consumption of 2½ lbs. of coal per hour, per horse power for 20 hours per day, will not exceed the following figures:

Cost per 1,000 cu. ft. of free air compressed to 2,500 lbs. pressure per sq. in.

Station Capacity.	
500 cu. ft. per minute	$0.0675
1,000 " "	.0571
2,000 " "	.0469
3,000 " "	.0419
4,000 " "	.0394
5,000 " "	.0375
6,000 " "	.0359
7,000 " "	.0342
8,000 " "	.0326
9,000 " "	.0312
10,000 " "	.0300

Responsible parties will guarantee that the cost will be less than stated, and the writer believes that the cost in highest grade plants can be reduced fully 25%.

Assuming the average consumption of air per car mile can be kept as low as at the present time, the average cost of motive power per car mile on the above basis, would range from $0.0124 to $0.027; or an average of $0.0197; and even if 477.7 cu. ft. the same as averaged for the past seven months in regular service, the cost per motive power per car mile, will range from $0.014 to $0.032, or an average of $0.023. Placing these figures against the cost of motive power as averaged in the Connecticut electric roads for 1896, the results seem to show considerably in favor of compressed air as a motive power.

This cost of motive power, based on 20 hours service, does not represent the lowest cost that is available for the different capacities in the best practice for this reason, that in a compressed air plant having station storage reservoirs for accumulating the air, the engines can be worked at a uniform load at the most economical point of cut-off, for say 16 hours after which the engines may be shut down and the power-plant charges stopped.

At the 125th St. compressing plant, the engine is operated only about 7 hours daily, while the cars perform a 12 hour service from a 7 hour station duty.

The process of operating the compressed air system on 125th St., is as follows:

The air is first compressed by a steam actuated air compressor, which is compounded in three stages from which the air passes through a cooler and dryer and is accumulated in a nest of Mannesmann steel flasks which are all connected in multiple by a series of headers or manifolds, in which stop valves are placed for controlling and confining the air to be stored at a maximum pressure of 2,500 lbs. per square inch. A pipe leads from this air storage to the car house charging stand placed alongside the track, which consists of a copper pipe in three sections, having a controlling valve and flexible joints and a charging nozzle at the end. All the joints and the nozzle are self-packing, so that no leakage has occurred in the seven months' service. After the car has been connected by inserting the nozzle in a pipe at the side of the car track, the charging valve is opened and contents of the station storage flasks admitted until the desired pressure—2,000 lbs. per square inch—is registered by the car storage gauge. When the charging valve is closed, and a small bleeding valve in the charging pipe opened, permitting the high pressure air in the short length of pipe to escape, at the same time a check valve in the car piping closes automatically preventing any escape of air, after which the nozzle is removed and the car ready for another 17 miles' service. The entire time occupied, including connecting and disconnecting in actual daily service, takes less than 2 minutes, and has been done in less than 1 minute in numerous trials.

At the same time the car is being charged with air, another nozzle is introduced to the heater connection, and live steam from the boilers is admitted, until the temperature registered is about 300 degrees Fahrenheit.

The air storage reservoirs on these cars have a capacity of 51 cu. ft., sufficient to run the car 18 to 20 miles continuously, or from 14 to 17 miles, making the stops incident to ordinary street railway service. A larger capacity could readily be installed on the car, giving it ample power to run 20 miles with a reserve. The reservoirs consists of seamless steel flasks capable of standing a pressure of double that used without reaching the elastic limit of the metal and with no possibility of leakage. They are 9 in. in diameter and of varying lengths adapted to their location under the seats and the car floor. Between the flasks and the motor is placed a small tank containing 6 cu. ft. of water which is heated as before described. The tank is jacketed with non-conducting material preventing external radiation. This provides not only against loss of heat, but also against any perceptible rise in the surrounding atmosphere. so that no discomfort can arise from it.

Numerous trials have proved that the application of heat as employed in this system enables the cars to run nearly double the distance that cold air will carry them.

In operation, the compressed air, after passing through a reducing valve and being lowered to 150 pounds to the square inch (the working pressure), circulates freely through the hot water, and a mixture of heated air and vaporized water passes to the motors, working expansively, the terminal pressure being so low as to cause no sound in exhausting the air.

The motor mechanism consists of two simple, link-motion, reciprocating engines having cylinders seven inches in diameter and fourteen inch stroke, with valves cutting off at from 1-10 to 1-6, and applying the power by connecting and parallel rods direct to the crank pins of the drive wheels which are four in number, twenty-six inches in diameter, running on a wheel base of seven and one-half feet. Upon this four-wheeled truck rests the entire weight of the car and mechanism, evenly distributed upon elliptic springs, enabling the car to pass much more smoothly over bad track and crossings, than an electric car (on which the motors are a dead weight upon the axles) besides being a great saving in wear on the rails at the joints, and on the rolling stock.

The mechanical features of the motors are substantially identical with those of a steam locomotive, minus fire box and boiler, which in point of perfection in mechanism as a moving power, is too well known to need any comments.

The manipulation of the car is simplicity itself, requiring no special skill or training to handle with perfect facility, and capable of being moved in either direction as little as two inches.

It is perfectly noiseless, odorless, and entirely free from any other offensive feature, sending neither smoke nor steam into the air. It responds to the start-

FIG. 166—THE HARDIE MOTOR CAR, 1897.

ing and stopping devices with remarkable promptness, operating without any jerks or jars.

This feature of easy and perfect control seems to me to be the most vital point in relation to the public; as in other respects (freedom from the element of danger to the public as a manifestation of power), its non-hazard superiority is easily demonstrated. The ease and infallibility of control excels that of any other system known to the writer for street railways, and can never fail so long as the car has ability to move.

The car is fitted with specially designed air-brakes of sufficient power, with the high-pressure air always at command, to set the wheels instantly if desired, by a single wrist movement of the motorman. Upon releasing the brakes there is an entire absence of noise of any kind from either the mechanism or escaping air, which is so noticeable and annoying with air-brakes generally.

The same lever that releases the brakes, operates, by a slight advancing movement on the quadrant to open a by-pass admission of the compressed air, directly into the cylinders of the motors, enabling them to start easily and positively, whatever the position of the cut-off valves may be, and preventing any possibility of being stopped on "dead centres," after which the throttle is opened. This ability to start so promptly and surely under all conditions, is a feature possessed by no other reciprocating motor, and the inability to overcome this difficulty has been one of the principal causes of failure in kindred types of motors heretofore exploited. The application of the principle of a by-pass admission of air into the cylinder, seems to be confined exclusively to the motors of the General Compressed Air Company, and is of the greatest importance, materially affecting the economic operation of the motors, aside from assuring their infallibility in starting.

The entire system embodying the mechanism and method of developing and applying the power, for the purposes under consideration, consists of simple, practical devices, operating on the most approved principles, from which all offensive and uneconomic features have been eliminated and better fulfilling the requirements of an ideal means of street car propulsion than any other within the writer's knowledge. EDWARD E. PETTEE.

March 15, 1897.

FACTS IN REGARD TO AIR POWER AND AUTO-TRUCK COMPANIES.

During the past two weeks a great deal of publicity has been given to the various companies which have been organized by persons directly interested in Hoadley-Knight Compressed Air appliances. Messrs. Hoadley-Knight have patented Motors for operating Street Cars, Carriages and Trucks.

In the early part of last year The American Air Power Company was formed by the combination of the Hoadley-Knight and Hardie Companies. Capital $7,000,000. Its president is Mr. A. A. McLeod, formerly president of the Reading Railway, and its directors are William L. Elkins, Thomas Dolan, Thomas Ryan, Joseph H. Hoadley and A. A. McLeod. Its relations with the Metropolitan Street Railway Company are very close.

Arrangements have been made by The American Air Power Co., with the Metropolitan Street Railway Company allowing the equipment of the 28th and 29th Sts. crosstown lines in New York with cars having improved air motors. The work of installing the plant at 24th St. and 13th Ave. for that purpose is now progressing rapidly. The Air Compressor and twenty cars are nearly completed.

Messrs. Hoadley-Knight are also interested in what is known as the Auto-Truck. Imbued with the idea that this truck answers all the requirements of automobile traction, another company has been formed for the purpose of developing the Auto-Truck. The Hoadley-Knight Truck was fully described in the December, 1898, number of COMPRESSED AIR, showing a truck as constructed, and used in the works of the Am. Wheelock Engine Co., Worcester, Mass.

The company known as the New York Auto-Truck Company was organized under the laws of New Jersey and capitalized at $10,000,000. Its incorporators are Richard Croker, Nathan Straus, Lewis Nixon, Robert I. McKinstry, Senator Arthur P. Gorman, Joseph H. Hoadley.

Still another company has been recently organized under the auspices of Messrs. Joseph H. Hoadley, William E. Knight, Harry E. Knight, Robert I. McKinstry and Edwin F. Glenn, known as the International Air Power Co., with capital stock $7,000,000. The purpose of this company is to operate in foreign countries under patents similar to those assigned to The American Air Power Company and the New York Auto-Truck Company, the Hoadley-Knight foreign patents on pneumatic traction not having been assigned to The American Air Power Co. The daily papers of New York and elsewhere have given wide circulation to the plans of the movers in these compressed air enterprises, and the impetus thus created has provoked numberless inquiries as to the feasibility of the published claims.

All that can be said at this writing is that the avidity of the newspapers is responsible for many of the assertions that lack the stability necessary to useful results; at the same time, the publicity has produced a healthy consideration of compressed air.

COMPRESSED AIR TRUCK.

Compressed air is the most compact, the lightest and the cheapest stored power outside of original fuels, and lends itself perhaps more readily to the horseless-vehicle than it has to the many other applications that has been made of it. Thus there might be some question as to compressed air cars having very decided advantages over the trolley or the cable car, they all run on a definite route and on a definite schedule, but for miscellaneous routes and miscellaneous traffic, freight or passenger, compressed air has as its only competitor the electric storage battery, over which it claims many advantages.

Air compressed to 2,500 and 3,000 per square inch can be stored in a reasonable space on a truck, or other vehicle, and will carry the same 20 miles. The air is handled in exactly the same manner to that used on the compressed air cars, that is, it is let out from the reservoirs by an automatic reducing valve to the motors at a pressure of about 200 lbs. per square inch, its introduction to the motor being controlled by the ordinary throttle valve. The motor that is used for this purpose is of the ordinary Hoadley-Knight type, that is to say, it is an iron-clad motor, having all of its working parts in a closed iron basin partly filled with oil, so that no attention for lubrication is required. A simple wedge movement enables its operator to reverse the motor or control the point of cut-off. This is done by the lower hand wheel, shown in the cut. The upper hand wheel is used for steering purposes, it being connected to a segmented gear, attached to a single steering wheel. The throttle is controlled by a lever which is opened by the operator pressing his knee against it, and is closed by the action of a spring. The motor drives both the rear wheels through a compensation bevel gear arrangement, thus allowing it to turn in any direction. The truck when working under ordinary conditions consumes about 75 cu. ft. of air per mile. This would involve a cost per mile for power of less than one cent.

The compressed air truck in our illustration shows very forcibly the substantial progress being made in the automobile field by the compressed air experts. Here is a truck which will handle ten tons of freight, and which occupies a space of 4 x 15 feet. It is guided and controlled with such ease that it is safe in the hands of the most ignorant operator. It is claimed that it will run about half a day on one charge of air, and will operate with a power cost not exceeding one cent a mile. The absence of all combustion of any kind insures the popularity of this form of stored power, and its great economy as compared with storage batteries places it in the lead of the possible powers for automobile work. For the race that must start in the near future for commercial supremacy in the automobile field, there are preparing in the mechanical world many radically different

FIG. 167—COMPRESSED AIR TRUCK.

forms of motor vehicles. The race cannot be said to be started until actual competitive manufacturing has begun. Doubtless there will be found special fields available for several of the more successful types. There is the long distance work for vehicles traveling out many miles from the center, which of necessity cannot well be supplied with power from a central station. There is the light vehicle competing with the single horse rig for which almost any form of motive power is suitable, but which can, perhaps, after all be best operated by the horse. There is, again, the omnibus field which, running as it does over limited and definite routes, can evidently be operated by a secondary charge from some central source of power, such as stored steam, compressed air or storage batteries. There is, further, the field of heavy trucking which amounts to many times more than all the rest of the work done by horses put together. This trucking being generally confined to the city streets, and to limited distances, and often to definite routes, is again a field open for secondary stored powers operating in conjunction with central stations, and it is an attempt to occupy this field that gave birth to the truck shown in our illustration. The attempt will be made to handle greater loads with more expedition and with the occupying of less space in the street than can be done with horses, and in these features the chief sources of economy are expected to be derived. Apart from the saving brought about by the substitution of mechanical power for animal power, the item of wages will be materially reduced. It is evident that with heavy loads moving at greater speeds the operator's time will be just so much economized.

The truck, as shown, is in daily use at the works of the American Wheelock Engine Co., Worcester, Mass., and fills a long-felt want in moving large castings and other bulky work from place to place without the need of cranes or hand trucks.

The air truck has been developed by the Pneumatic Carriage Co., and is being manufactured by the American Wheelock Engine Co., Worcester, Mass.

ANNUAL MEETING OF THE AMERICAN AIR POWER COMPANY.

The annual meeting of the stockholders of the American Air Power Company, which had twice been adjourned, was held recently, when A. A. McLeod, president of the company, tendered his resignation, he to continue, however, as a director. He will be succeeded by H. H. Vreeland, of the Metropolitan Street Railway Company, which is largely interested in the American Air Power Company. Directors were elected as follows: William L. Elkins, Thomas Dolan, T. H. Vreeland, J. H. Hoadley, A. A. McLeod. With the exception of Mr. Vreeland, who succeeded Gen. G. E. P. Howard, resigned, these had served on the previous board.

Following is a report read by the retiring president, Mr. McLeod.

"Mention was made in the last annual report of the contract your company made with the Metropolitan Street Railway Company for the establishment of a plant and the equipment of twenty cars to be put on the Twenty-eighth and Twenty-ninth street line.

"This line was put into operation in July last, and the cars have been in successful operation since that time. In August last, under the terms of the contract, the line was turned over to the Metropolitan Street Railway Company for the purpose of making an operating test, which is now being made.

"The cars are giving excellent service, the traffic on the line has increased very largely, and the result of the operation thus far is very gratifying, and may be considered a commercial success.

"It may be said that when the cars were first put into practical operation some few mechanical defects were discovered which could not be foreseen, as is likely to be the case with every new device, but the short experience already had has enabled your engineers to make such improvments as were necessary, and as a result the latest improved car which has been put on the line is giving great satisfaction.

"I am of the opinion that the method of propelling street cars by compressed air, the patents for which are exclusively owned by your company, is on the eve of such success as will prove very gratifying and valuable to your shareholders, and enables me to turn over to my successor in such a way as to secure for your shareholders the greatest possible advantage.

"As the Metropolitan Street Railway Company is the largest individual holder of your capital stock, and as it has a very large street car mileage in this city which is now operated by horse-power, naturally the first work of importance for your company will be the equipment of these lines, and as Mr. H. H. Vreeland, the president of that company, has kindly consented to take the presidency of your company, I believe it will be greatly to the interest of your shareholders to elect him president.

"I, therefore, decline a re-election, and while I regret that I feel it incumbent upon me to do so, owing to the pressure of other business, the affairs of your company are so well established and will be conducted in the future by so able and experienced a man as Mr. Vreeland, that I am sure your interests will not only not suffer, but be greatly enhanced. As a member of the board I shall continue my interest in the company."

Mr. Vreeland says that his election to the presidency of the American Air Power Company, which has been operating the cross-town cars on Twenty-eighth and Twenty-ninth streets by compressed air, would not affect the policy of the company materially. The American Air Power Company, he said, has always been in close touch with the Metropolitan, being practically under the control of that company since its formation. The present equipment, used only on the Twenty-eighth and Twenty-ninth street lines, will be increased as soon as possible, and air motor cars will be placed on Thirty-fourth street.

The problem of the downtown crosstown lines, he said, has not been taken up as yet. The success of the air power cars was assured, declared Mr. Vreeland, and the defects which at first appeared in the mechanical equipment had been remedied.

AN AIR WAGON.

The illustration (Fig. 168) on page 502 is an air wagon constructed by Chas. D. P. Gibson, and is the property of the Air Vehicle Company, of New York. The engine is of the usual 2-cylinder type, and weighs 36 pounds, and has several special features in its construction. It is adapted for the use of air or steam, as may be required. With the use of air it has a storage capacity of six cubic feet, which could be increased without material addition to the total weight of the wagon, which is with the present capacity 670 pounds.

With air as a power appliance for reheating the air is used. The air is stored at a pressure of 2,500 pounds per square inch, and reduced to an initial cylinder pressure of 150 pounds by an ingenious arrangement of reducing valves, which are under the control of the operator and allowing the working pressure to be regulated as required.

On a recent trial on a bad road this wagon was operated with a consumption of 60 cubic feet of free air per mile. The condition of the road was much below the average, and the trial was not one which would give the most economical results in the use of the power, yet under these conditions it would be seen that the storage has capacity to run the wagon 20 or 30 miles. And as it is estimated that air can be compressed for less than 4 cents per 1,000 cubic feet, it is believed that it will prove a desirable and economical power for propelling omnibusses and delivery wagons which have a definitely determined route to travel. Its freedom from odor or visable final exhaust makes it the ideal power to

FIG. 168—THIS AUTOMOBILE IS OPERATED BY COMPRESSED AIR, AND BUILT BY THE AMERICAN VEHICLE CO., NEW YORK.

use. The engines of this wagon operate equally well with steam, and buyers are to be supplied with steam wagons or air wagons as they may desire.

With steam the power is supplied by a small steam boiler, the fuel is gasoline, the supply of which is automatically controlled by the boiler pressure, and the water feed operated by the engine and under the control of the person operating the wagon.

The steam wagon has no radical departures in use of steam in engine or boiler, but special care and consideration has been given each detail that it will do its work with a minimum of attention and reliability in operation. Particular attention has been paid to simplicity of details, as well as to their durability, and with steam as a power, the range of the wagon's distance of operation, or the distance that it can be run, is unlimited.

We hope at an early day to give more fully the details of this company's wagons.

EDITOR COMPRESSED AIR:

It is proposed to run a horseless carriage by compressed air, and the arrangement is to construct a light vehicle on the bicycle principle with a good air motor, using air reheated from a steel bottle compressed to a high pressure of 1,000 to 2,000 lbs.; this apparatus to be used for conveying persons from one point to another within a few miles.

For the information of myself and other readers who favor air whenever it can be used, will you please answer the following:

A pair of single-acting cylinders, 2½″ diameter by 5″ stroke, at 100 lbs. air. What power will this develop when air is heated so as to use it by expansion, and how long will a steel bottle of 2 cubic feet at 2,000 lbs., run the engine, and what horse-power will it take to charge the bottle? Also, what revolution per minute would the engine run at its full horse-power? Could the air be used without heating, and would it freeze up the engine?

Leavenworth, Kan., July 16. W. J. E. CARR.

[Compressed air as a motive power has many economical and useful applications, but it has its limitations. Our hope in this direction seems to be confined to the possibilities that might result from the use of liquid air. At present there does not seem to be much encouragement in the use of compressed air for motor carriages. The limited space attainable and the weight of the apparatus seems prohibitive. A steel tube of one cubic foot capacity with air at 2,000 lbs. pressure (say 9″ diameter), will contain 268 cubic feet free air, and power required to compress this quantity per minute will be 268 x .43 = 115 H. P.; or if done in one hour's time, will be 2 H. P., and this calculation is based upon the very best type of 4 stage compressor with perfect intercoolers.

A pair of 2½″ x 5″ single-acting cylinders operating at 100 lbs. pressure, require each 32 cubic feet free air when running at best speed (say 400 revolutions per minute), so that out of a storage reservoir of 2 cubic feet, you will only get a run of about four minutes.

The weight of a Mannesmann steel tube 9″ diameter, per cubic foot storage, is 82.2 lbs., and weight of 1 cubic foot air at 2,000 lbs., is 10.2 lbs., making a total weight of 92.4 lbs. for every 2 minutes the carriage will run.—ED.]

AUTOMOBILE COMPRESSED AIR FIRE ENGINE.

The time is comparatively near at hand when every city will have its public supply of air power, and when such a time arrives the utilization of compressed air will enter into almost every nook and corner of industrial, municipal and domestic enterprise. Its usefulness is so comprehensive that a central compressed air power plant might in these days look for a large and prosperous patronage.

One of the most forcible arguments for introducing a public supply of compressed air will be the degree of economy and the vastly increased protection which would be afforded by compressed air in the matter of fires. It is entirely feasible to propel a fire engine to a fire without horses, and when it reaches the water supply to be operated by compressed air.

Protection against fires is one of the most important municipal questions, and the expense to the public of handling a modern fire department is one that

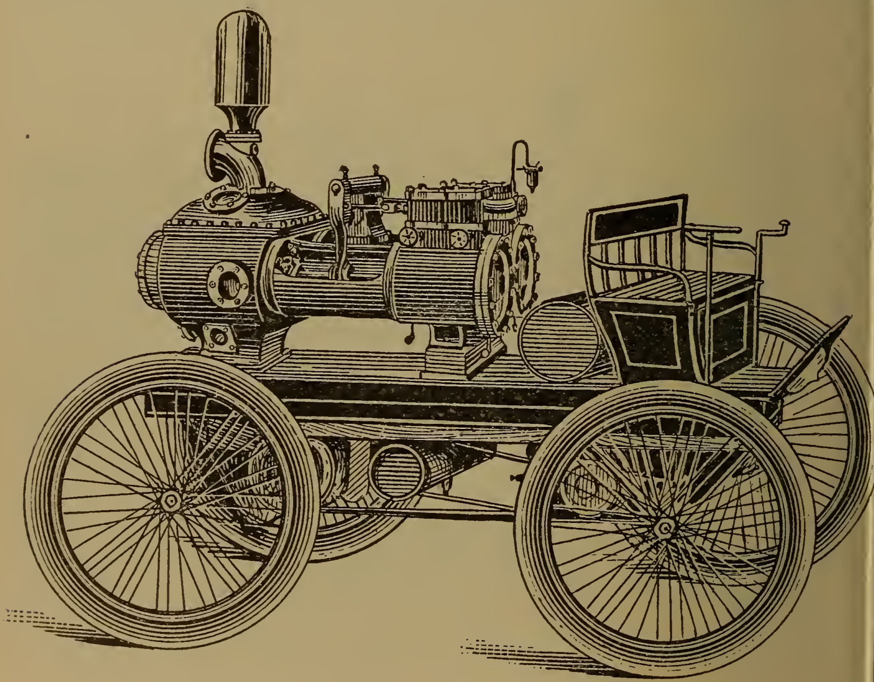


FIG. 169—AN AUTOMOBILE COMPRESSED AIR FIRE ENGINE.

requires skillful financial treatment to keep it within bounds, and at the same time, have an efficient department.

A public supply of compressed air would certainly reduce the expense of a fire department to within a reasonable figure, and the proposition to introduce automobile compressed air fire engines will in time bring forth potent reasons for the adoption of this system. The installation of a compressed air supply would not have to be borne by the fire department, because private enterprise will be glad to install central compressed air power plants, relying on the patronage of the general public in the matter of power, but when the advantage of such a system is well known, any proposition to lay pipes in the streets for this purpose will receive the moral support of every fire board and a majority of the citizens, all of whom are interested in fire protection.

The plan to be followed is similar to that followed by the installation of gas and water plants. Mains would be laid in all streets, and air hydrants would be close to the water hydrants.

An automobile carriage with a suitable fire pump would constitute a fire engine, to be propelled by compressed air, electricity, gasoline or other motive power. With such an apparatus, the time used in reaching a fire would be reduced to a minimum, and the operation of applying the air power for pumping the water would take but a few seconds.

The advantage of this system, which does away with cumbersome boilers and dangerous progress through crowded streets with wildly excited horses, will be apparent to every one. If necessary, a speed of 30 miles an hour may be obtained in going to a fire and without any undue commotion. The weight of the vehicle itself would be very much reduced. An ordinary engine to be drawn by horses weighs about 8,500 lbs. and an equally efficient automobile engine will not weigh more than 5,000 lbs. or possibly less.

As an illustration of possibly economy in a city, we will give the statistics of the fire department of Newark, N. J.

The manual force of this department is 202 men with the following apparatus: Fourteen steam fire engines, 4 hook and ladder trucks, 1 aerial truck, 1 chemical engine, 4 engineer's wagons, 2 wagons for superintendent of fire alarm telegraph. In reserve are two steam fire engines, one hook and ladder truck, one chemical engine and one engineer's wagon; and the cost of operating the department for one year is $251,000. Eighty-two horses are kept in this department, aggregating the value of upwards of $30,000, and the mortality among horses in fire departments is necessarily high; consequently there is a constant expense from this cause.

Automobile fire engines should not cost more than ordinary fire engines. The number of men employed for taking care of horses would be dispensed with. No coal or other fuel need be used.

The item of keeping the above number of horses would amount to $19,680 a year, counting the expense of keeping one horse at $20 per month. The total saving in a department of the size of Newark, N. J., would probably reach $30,000 a year, or about 7½ per cent. of the total cost of running the department.

In the foregoing estimate no account is taken of the cost to the department for the use of the compressed air for operating engines which would be used during fires, and the reason for omitting it is because any company putting in a compressed air plant would readily concede the free use of power for such purposes in part compensation for the franchise privileges. But even if it had to be paid for at regular rates, the cost would not amount to much.

The development of such a scheme is within practical limits and it only needs discussion and intelligent demonstration.

The automobile fire engine shown herewith is simply the combination of an automotor with an ordinary pump mounted on it. It admits of any modification from the position of the pump, which may be vertical instead of horizontal, and the construction of the carriage, which may be propelled by any reliable power, preferably compressed air.

A RIGHT WAY AND A WRONG WAY TO PLACE COMPRESSED AIR IN COMPETITION WITH ELECTRIC POWER FOR STREET RAILWAYS.

The indications being that compressed air will be experimentally used for practical street railway operation at an early day, it should be earnestly hoped by all friends of compressed air, and especially by those who are interested in its introduction as a motive agent, that it will be so experimentally introduced as to give a reasonably fair impression. The use of compressed air for street car propulsion has hitherto been regarded with distrust and prejudice, for several reasons. It may be reasonably hoped that a fair trial of compressed air for this purpose, under circumstances that will do it justice, will, to a large extent, remove this prejudice and draw attention to the advantages of such a motive power. A number of important requisites to the fullest success of a compressed air system for street railway operation might be profitably considered. These features vary somewhat in importance in different systems which have been proposed. There are, however, two considerations which apply with equal force to all compressed air systems, and it appears desirable to draw attention to their importance at this time. The two features referred to are, first, the pressure at which the compressed air is stored upon the cars, and second, the suitability of compressing apparatus for charging the cars. These two matters may properly be considered simultaneously.

The only apparent practical method of using compressed air for street car propulsion is that known as the storage system. In every case where air is stored in reservoirs upon the cars for this purpose, the air is admitted to the motor cylinders at a moderate pressure and is stored in the reservoirs at a considerably higher pressure, in order to enable the car to be run some distance without renewing the supply of air. There are two ways of increasing the mileage of a car with one stored charge of compressed air; one is to enlarge the reservoir volume for storage, and the other is to increase the pressure of the stored air. For practical reasons, the size and volume of storage reservoirs is limited and the temptation to store the compressed air at high pressures has consequently been great, in order to cover long distances with one supply of air. If the absolute pressure of the stored air be doubled, the available power, at the reduced pressure for the motor, is doubled; but in thus doubling the stored power, the cost of the compressed air supply has been very much more than doubled. After compressed air is stored in the reservoir, the temperature of that air becomes practically the same as that of the external atmosphere. Each cubic foot of air so stored, at an absolute pressure of p pounds per square inch, has required, in the process of compression and delivery into the reservoir, the expenditure of work, which, in a properly designed compressor, is represented by

$$W = 144\, p \, \frac{sn}{n-1} \left\{ \left[\frac{p}{14.7} \right]^{\frac{n-1}{sn}} - 1 \right\} \text{foot lbs.}$$

In this formula, s represents the number of stages during compression, with complete cooling of the air to atmospheric temperature between each two consecutive stages; and n is a number not exceeding 1.408, and is usually a trifle less.

If the air be subjected to no cooling influence whatever during compression in the air cylinder, the value of n is 1.408. For practical reasons, it is always customary, in compression plants of any considerable size, to water jacket the air cylinders, which exerts a cooling influence, in greater or less degree, upon the air during the period of compression. Where the compressing cylinders are very small, it is not improbable that the cooling effect, due to the water jacket, is a very material one; but it has been fully demonstrated that where large compressing cylinders are used, as would be the case in a compressing plant of suitable proportions to supply a street railway system with compressed air, the cooling influence of the water jacket upon the air during compression is quite small. In view of the fact that more or less loss occurs by leakage past the air piston and valves, it may, without any material error, be assumed that the cooling influence of the water jackets about offsets these losses, and the valve of n should therefore be regarded as 1.408.

The number of stages which should be employed for compression depends upon the final pressure and the quantity of air to be supplied. When a large quantity of compressed air is to be supplied at a high pressure, an economical performance of the compressor can only be obtained by compressing in several stages. For the purpose under consideration, the final pressure being 500 lbs. or more, the number of stages should not be less than three or four.

Assuming that the compression occurs in four stages, the following table shows the foot pounds of work expended upon the air for each cubic foot of compressed air stored at atmospheric temperature and different storage pressures, from 500 lbs. to 2,000 lbs. Indicating by w the foot pounds of work which

TABLE 49.

Storage Pressure by Gauge.	Work Expended. (W)		Work Restored by Motor.	Efficiency.
	Foot lbs.	Rel've.		
500 lbs.	300 600	1.	1.000 w	1.000 E
1,000 lbs.	724 100	2.409	1.971 w	.818 E
1,500 lbs.	1 201 300	3.997	2.943 w	.736 E
2,000 lbs.	1 714 800	5.705	3.914 w	.686 E

may be done in the motor by one cubic foot of air stored at 500 lbs. pressure, the table also shows the relative amounts of work that can be performed in the motor by one cubic foot of air stored at the various other pressures. Also, representing the efficiency of any system, when operating with a stored pressure of 500 lbs., by E, the table shows the relative efficiencies of the same system with greater pressures of storage.

It will be seen from this table that the efficiency of the system diminishes very rapidly as the pressure of the stored air is increased. Whatever the system itself may be, and regardless of what its actual efficiency may be under any stated conditions, the efficiency of that system will vary somewhat more than is indicated by the table. The reason for this is that the greater the pressure of storage, the more difficult will it be to prevent loss by leakage, and consequently the incidental losses due to leakage, etc., will be increased by the higher pressures, with the result that there will be a greater difference in the actual efficiencies, with different storage pressures, than is shown by the table.

To indicate the fact that the conditions are less favorable to economy for all storage pressures, but especially so for the higher storage pressures, when the air is compressed in a smaller number of stages, the following table has been prepared, for single stage compression:

TABLE 50.

Storage Pressure by Gauge.	Work Expended. (W)		Work Restored by Motor.	Efficiency.
	Foot lbs.	Rel've.		
500 lbs.	461 500	1.535	1 000 w	.651 E
1,000 lbs.	1 217 500	4.050	1.971 w	.487 E
1,500 lbs.	2 134 000	7.099	2.943 w	.415 E
2,000 lbs.	3 169 600	10.544	3.914 w	.371 E

It will be seen by a comparison of the two tables, that good commercial economy is absolutely out of the question without the use of suitable multiple stage compressing machinery. It will be equally evident that a system which might compare very favorably in point of efficiency with the electric trolley systems, when operating under a storage pressure of 500 lbs., would be hopelessly out of competition in this direction if operated with a storage pressure of 2,000 lbs.

Attention is called to these matters more especially on account of the evil influence of the wholly incorrect and misleading statements which have been made by those who desire to befriend the use of compressed air. It has been stated, by at least one writer, that the increased cost of supplying compressed air for storage at high pressures is insignificant in comparison with the advantage of the increased mileage due to a single air supply. In comparing the cost of compressed air power with that of horse power for street railways, such a statement may perhaps be excusable; but in comparing compressed air with electric power, such a statement is absolutely unfounded and is extremely dangerous, in that it may be influential in condemning the use of compressed air altogether in the event of the failure of a high pressure storage system.

It cannot reasonably be expected that the efficiency of the electric trolley system can be materially surpassed by that of a compressed air storage system operating under the most favorable conditions; and it is certain that it cannot be nearly approached by a compressed air system which stores air at such high pressures as have been recently proposed, or in which the compressed air is supplied by anything but a high grade compressing plant. It will be far better to store air at a moderate pressure and to attempt only a moderate car mileage between successive chargings. This will, in many cases, require additional charging points, which may be supplied either by additional compressing stations or by carrying the compressed air in pipes from a central compressing station to local charging stations; but there can hardly be any doubt that the cost of operation will, in the long run, be very much reduced by this plan.

Nothing is now said regarding any collateral advantages in the use of compressed air for street railway operation; it is simply desired to point out that there is a right way and a wrong way to place compressed air in competition with electric power. It is to be hoped that compressed air enthusiasts will not give the future of compressed air a black eye by adopting the wrong way.

R. A. PARKE.

POPP COMPRESSED AIR MOTORS FOR TRAMWAY TRACTION.

The installations transmitting power by means of compressed air from central stations to an aggregate of 8,000 horse-power for a great number of industries in operation in Paris, effect the transmission by means of canalisation, or miles of air mains laid in the streets, with branches leading into workshops and other places where required. The successful operation of this system, invented and carried out by M. Victor Popp, induced him also to extend it to the supply of compressed air for tramway traction.

It is impossible to better explain the position which compressed air as a motive power occupies than by quoting the report of Mr. Humblot, inspector-general of the Department of Bridges and Roads of France. In effect, he says:

"Compressed Air is not a source of power. It is, in reality, only a vehicle for the transmission of power in heat, which heat can retransform itself into power.

In order to obtain from air an economical return, it is necessary to supply it with caloric at the moment of its utilization, by re-heating, in order to compensate for the losses of every nature to which it has been subjected as as a consequence of cooling after compression in the tubes and reservoirs.

By employing compressed air in traction, all the many advantages are secured which this agent has been demonstrated to possess in the mechanical applications which have heretofore been made.

If there is anywhere a demand for an easily manageable motor, it is certainly for tramways.

With compressed air, variations of speed are obtained with the greatest ease and without shock, by the simple turning of a cock; stops are made almost instantaneously, as vehicles operated by this system naturally employ air brakes, the reliability of which is so well known.

Owing to the Popp system of feeding points along the line, a single power station can supply several lines at the same time, becoming therefore a veritable central station for the entire network of tramways of a city, and at the same time distribute in a whole city mechanical energy as done now in Paris. The weight of the new Popp car, seating fifty persons, is 16,000 pounds when empty.

In order to gain a still higher economy, the motor is compound and the air is reheated twice.

The motor being compound (or with two cylinders) can, according to its needs at various points of the route, work with either double or single expansion.

By means of a special regulating apparatus, the several combinations by which the compressed air is admitted into the motor cylinders, for starting, regu-

FIG. 170—COMPRESSED AIR TRACTION IN PARIS. CHARGING STATION ON A PARIS TRAMWAY.

lation of power and speed, stopping, and brakes, operate in a cycle perfectly established and controlled and with the greatest simplicity.

The various parts of the regulating apparatus are operated by a single handle and only require in consequence a single movement.

The entire mechanism is hidden beneath the car body. The body itself remains completely independent of the frame upon which it rests.

The platforms are entirely free.

. . . .

The driver on the front platform has nothing whatever to do but to operate one controlling handle.

The car runs equally well in either direction. At a terminus the driver

FIG. 171—A COMPRESSED AIR CAR USED IN PARIS. POPP SYSTEM.

moves to the other platform, carrying with him the handle. The expense and inconvenience of turn-tables is thus avoided.

MOTOR CAR.

The frame and springs have a very strong, solid and well-built appearance, while the cylinders and all movable parts are inside, and placed between the wheels. The frame is suspended by leaf springs jointed to the axle boxes over the axle centres, while the body is suspended on leaf springs fixed to the end of the framework. This double suspension produces a gentle motion, and facilitates the passage of the car round sharp curves, even in the case of long car bodies. The two axles are connected by connecting rods. One of the axles is worked directly from the compressed air cylinder by means of wheel gearing, consisting of two wheels. The larger wheel is fixed to the wheel axle, the smaller one to the motor shaft, showing the frames of the compressed air cylinders with their piston rods, crank shafts, and the slides with their eccentrics—in a word, the whole mechanism. The above-mentioned gearing runs in oil enclosed in an oil box. The frame is of solid cast steel. The compressed air engine is designed on the compound system with varying expansion. (Meyer.) An attempt has been made in designing the machinery to arrange the various parts so that they should be easily accessible for repairs and removal if necessary. As the engine is worked on the compound principle it is provided with two cylinders; and the compressed air is heated during expansion and before entering the cylinders by means of a coke fire laid on a hopper arrangement which is filled once a day. The compound motor can be worked at double expansion or with direct admission of the compressed air in both cylinders. By means of a special disposition of the slide valves the compressed air can be worked at different degrees of expansion, by its variable admission into the cylinders; whereby also the power of the engine, its speed, the stoppages, and operation of the brakes are perfectly regulated according to the requirements of the service. All these operations are carried out by means of the pair of levers at the driver's hands. As there are no heating vessels or any other machinery on the platform, these are perfectly free, and can be used for passengers—the carrying capacity of the motor car, is therefore, so much increased.

AIR RESERVOIRS AND HEATER.

The air flasks are fixed under the platform (fore and aft) and are charged for the St. Maur lines at 700 lbs. pressure. The chargement is made in less than one minute by means of a pipe emerging from a post at one side. The driver, without having to leave his machine, makes a joint which, by means of a valve and a differential valve piston, establishing the connection between the air pipe and the car tanks. Soon as the full charge is taken in the driver shuts the admittance valve, cuts off the connection with the post and through the loss of pressure the valves close the connection with the pipe and the car goes along without any loss of time. From the air reservoir the compressed air goes first through a pressure regulator, passed to the heater, then to the small cylinder returned to the heater and then to the large cylinder and last through the exhaust pipe. In the heater the air is each time heated to 200 C.

The Popp tramways carry compressed air flasks made of specially prepared steel under and, if necessary, on top of the carriage. The flasks have been made to withstand a pressure of 4,000 lbs. to the square inch. The maximum working pressure used for the cars in St. Maur is 700 lbs. The air for the cars is compressed by three 150 horse-power compressors. The storage capacity of the com-

FIG. 172.—MECHANICAL TRUCK AND FRAME READY TO RECEIVE THE CAR BODY. THE POPP SYSTEM.

pressed air flasks on the Popp car with a maximum working pressure of 2,000 lbs. would be enough to run the car 36 to 40 miles.

CONTROLLING THE CAR.

One of the features of the Popp car is the working of the motor and air brakes. All the required moves which can be asked from a street car are made instantly, as easily and without possibility of mistake on the part of the motorman as can be imagined. The car conductor has before him one wheel and two small handles immmediately below. The use of the left handle is to reverse the motor movement. The right handle to open and cut off the air admission and commands also the safety brake. The wheel commands—1st, the air brake at variable pressure; 2d, the progressive admission to the small cylinder (high prssure); 3d, the direct admission to the small and to the large cylindler (low pressure). The various operations are made with one turn of the wheel. It will be remarked by this that whenever the motorman wants to use the brake before the brake came in use automatically the admission is entirely cut off both in using the safety and variable brake through the handle or the wheel. Outside of these two brakes the Popp car is furnished with an ordinary hand brake.

TRACTION AND CONSUMPTION OF AIR.

The motor is capable of slipping the wheels on a dry rail under weight of 36,000 lbs. The air consumption of the car running on the Saint Maur les Fossees (Seine) lines (3 per cent. ascent) varies from 25 to 35 lbs. per mile. The car runs 10 miles at a speed from 12 to 20 miles an hour.

COST OF PRODUCTION OF COMPRESSED AIR AND ITS UTILIZATION AS A MOTIVE POWER FOR TRAMWAYS.

The cost per horse-power-hour in compressed air reduced to atmospheric pressure and utilized by motors of from 15 to 50 effective horse-power, has been established by numerous trials in Paris. Motors of the above power are principally employed in mechanical traction for tramways. The consumption of air in a compound motor such as is employed in the Popp car, the air being re-heated before its admission to the cylinder to a temperature of 200 C., involved losses in the pipes, small escapes such as may happen in the mechanism, and also cost of operating the wheel brakes, is 30.577 lbs. in compressed air reducing to atmospheric pressure. One steam horse-power-hour at the station where the air is compressed at a pressure of 853 lbs. equals 11 lbs. air reduced to atmospheric pressure. For reheating the air per mile car, 0.50 lbs. coke.

CONCLUSIONS.

It is clear that system of mechanical traction for tramways will have chances of adoption proportionate to its gain in economy of operation; reduction in expense being desirable at once in cost of production at the station, in the motor, and in the consumption by the motor of power.

But it is also necessary that the system be easy to work and direct, and moreover absolutely beyond the possibility of sudden interruption from accident. (In Paris, compressed air without interruption during 13 years.)

It is also necessary that the system proposed should be easily understood by any tramway operator, and that it should not be necessary to preface its consideration by long special technical study.

In the present state of the art of mechanical traction as applied to tramways, it is evident that if economical operation be desired, the supply of power from a central station is indispensable.

Operation by electric conductors carries with it many difficulties for the operator, largely arising from the inevitable complications of a service requiring

FIG. 173—SIDE VIEW OF MOTOR AND TRUCK. THE POPP SYSTEM.

such special knowledge as to make an expert technical staff in constant surveillance a necessity.

With compressed air the method of operation is so simple that there is no necessity for long study of an expert nature before undertaking the handling of that system, while it is at the same time so regular and sure that one is not kept constantly on the alert as is the case with the electric line.

It follows that the manager of a compressed air tramway can really direct its operation without being always at the discretion of an engineering staff, since he is free from apprehension of any serious trouble in his service.

To handle an air compressor is as simple as a pump. Any ordinary mechanic can undertake its management.

The air being stored in advance in great quantities at a time in the reservoirs of the central station—in the distributing pipes, and in the tanks of the motor—interruption of service is practically impossible.

One of the most important advantages of compressed air is that it lends itself so well—incomparably better than any other system—to direct storage, which quality admits of holding in reserve great accumulations of energy with so much ease and economy. So far as accumulation of reserve power is concerned, electricity has incontestibly shown itself greatly inferior to compressed air.

COMPRESSED AIR LOCOMOTIVES.

Under certain conditions in mines or in warehouses where smoke or fire is undesirable, locomotives propelled by compressed air have performed useful service. At Vivian, W. Va., certain of them have been put at work. The new locomotives are approximately 10 feet 5½ inches long, 5 feet 8 inches wide and 4 feet 5 inches high, and weigh 10,000 pounds. It will readily be seen from these figures that they are adapted for running in very small openings. The cylinders are 5 feet 10 inches, and the driving wheels, of which there are four, are 23 inches in diameter. The storage tank has a capacity of 47 cubic feet of air and a working pressure of 535 pounds per square inch, and there is also an auxiliary reservoir. The locomotive main tank is designed for 600 pounds, but the working pressure for the service intended is about 535 pounds. A three stage compressor is used, pumping into a 3-inch pipe line, which serves to connect the compressor to the most convenient point of charging the motors, and also acts as an air reservoir, the compressor and pipe line being competent to withstand a pressure of 850 pounds.

These locomotives, which take the place of mules, are to be used in side entries and in making up trains in the rooms of the mine and delivering the trains to the main entry, where they are handled by steam locomotives. The average length of each side entry is 4,500 feet, with grades of 1¾ per cent. in favor of the loaded cars. The gauge of the track is 3 feet 8 inches, the weight of the rails 16 pounds per yard and the radius of the sharpest curve 24 feet. The locomotives are designed to make the round trip of 9,000 feet, with six cars, with one charge of air and to work on curves of 15 feet radius. The weight of the loaded cars is about 8,500 pounds.

This is said to be the first introduction of any kind of mechanical haulage anywhere for sole use in butt entries and rooms. The low cost of installation and operation and the greater adaptation to the conditions of the service and requirements caused the pneumatic system of haulage to be adopted in preference to electric haulage, although an electric plant had already been determined upon for working the mining machines. *From the Coal Trade Journal.*

THE COMPRESSED AIR LOCOMOTIVE.

There seems to be no question about the utility and economy of compressed air locomotives, for they are in use in many places at the present time and new installations are being built where such locomotives will be used much more extensively than now. Stationary engineers are not practically interested in compressed air locomotives, but compressed air as a motive power is being introduced for a great variety of purposes where it is found economical and quite convenient. Many of the steam plants in office buildings include compressed air machinery of one kind or another in their equipment, and owing to the great difference in economy of the different kinds of air compressors and the method of utilizing the compressed air, the stationary engineer will find it to his convenience and benefit to learn as much on this subject as he can, for its application will become more extensive and the methods of utilizing it in the office buildings more numerous each year.

The compressed air locomotive has an ungainly appearance because it differs from what we are familiar with. The absence of a smokestack makes it look as though it was not all there, but for work and economy it leaves but little to be desired. We shall also find that compressed air machinery about the plant can be utilized for many purposes with a greater degree of economy than some of the steam-actuated devices now being employed, although they may for a time appear out of place when being operated side by side with steam machines.—*National Engineer.*

Mr. J. A. Eisenaker, of Elmira, N. Y., is responsible for the following which appeared in *Locomotive Engineering*:

"I send you sketch of a small engine, driven by compressed air, which is designed for driving boring bar, for boring out locomotive cylinders, or a small lathe or planer, in case of necessity.

The bed plate rests on four wheels, so it can be easily moved wherever wanted. Two blocks are put under the bed plate and fastened to the floor. After being put in line with pulley on boring bar, the air hose is connected and the engine is ready for operation in either direction.

The full air pressure follows the piston to or nearer its dead point, and can be run to most any speed. The valve is very simple in construction—is a square piece of cast iron (length according to length of cylinder); the ports for taking or releasing air are drilled with a ¼-in. drill, also ports B and C in cylinder, and A and D outside of cylinder, for release.

The valve is surrounded by air; a couple of holes are drilled through top of valve, to let air in to the inner part of valve XX.

It will be seen that the air chest is cast on cylinder and projects over both ends of cylinder, and the air-chest cover is fastened on with top bolts.

The valve-reversing arm E causes the movement of the valve, and is regulated by set screw collars SS, to the required stroke of valve, which will be somewhat cushioned, and also the piston, when same comes near its end of travel.

The piston rod extends through back end of cylinder, and on its front end is directly connected to the crank pin, which of course gives the oscillating movement."

The city of Camden, N. J., owns its own system of water supply. The disposal of sewage in the Delaware River from adjacent towns caused the water of that stream to be objectionable. The water is now taken from driven wells, and the system has a capacity of 20,000,000 gals. every 24 hours. The wells are arranged in four (4) groups surrounding the pumping station, three (3) of which are operated by pumping and one (1) by compressed air. Three of these groups of wells are close to the pumping station, and the fourth group is located over 4,000 feet from the pumping station. This group consists of ten wells 8 and 10 in. in diameter. They are operated by compressed air under a pressure of about 47 lbs. per square inch. The air is furnished by an Ingersoll-Sergeant compressor having a steam cylinder 18 inches in diameter, an air cylinder 22 inches in diameter and a stroke of 22 inches. The receiver is 10 ft. 6 in. long and 4 ft. 6 in. in diameter. The air is conducted from the receiver to the wells through a pipe 7¼ in. in diameter, decreasing to 4 inches at the last well. The air pipe down each well is 1½ in. in diameter, with about 60 per cent. submergence, and

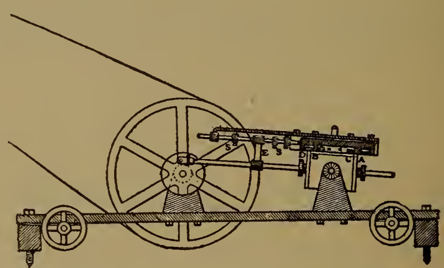


FIG. 174—OSCILLATING AIR ENGINE.

the air escapes through holes in the lower portion. At the head of each well is a broad quarter-bend connecting with the main discharge pipe, and the air pipe passes into it through the flanged shoulder.

THE COMPRESSED AIR LOCOMOTIVE ON THE N. Y. ELEVATED R.R.

Compressed Air has not been enthusiastic in advocating the recent experiments in air traction on the New York Elevated Railroad. These experiments as far as they have been conducted, have demonstrated two points clearly. In the first place, it has been shown that air can be compressed and stored economically and safely at 2,500 pounds pressure. Never before has a compressing plant on so large a scale and of so high a class in design been applied and tested for any such service as this, nor has there ever been, to our knowledge, a case where air has been stored at 2,500 pounds pressure at so low a cost as in the generating plant used in this instance. It has also been demonstrated that this air can be used with reasonable economy in a motor which will pull a train of loaded cars between the Battery and Central Park and return. That this can be done at less expense in fuel and labor than the present system of steam locomotion, is a fact about which there will be little dispute. The locomotive is wasteful in fuel because its engine utilizes only a small portion of energy within the steam; the high pressure exhaust indicates this lack of steam economy. In the case of air produced by compound condensing Corliss engines, we have a horse-power produced at an expenditure of about 2 pounds of coal as against 6 or 8 in the locomotive. This air when used is cut off and expanded in the motor and thus its power is not wasted. But it is not a question between air and steam, but between air and electricity. Both can beat the present system, but in the present condition of pneumatic traction it does not appear to us wise to attempt a case like the Elevated Road until after pneumatic tramcars have been developed and perfected. From an engineering point of view, it would seem easier and safer to develop motors for carrying passengers in street cars first and then lead up to larger things. From the business point of view, the street car field is broader and offers greater opportunity for profit. It would also seem that this field might be cultivated and developed to a paying point at considerably less expenditure, and in a matter of this kind, which at best must be expensive in experimental work, it is wise to count the cost, lest the experiment fail through want of funds, even though its success from a mechanical standpoint is assured.

COMPRESSED AIR HAULAGE PLANT AT NO. 6 COLLIERY OF THE SUSQUEHANNA COAL COMPANY AT GLEN LYON, PENNSYLVANIA.*

(The No. 6 Shaft plant was put in operation in September, 1895, and the No. 6 Slope Motor in May, 1896.)

The plant consists of one Norwalk Three-Stage Compressor, 12½″, 9½″ and 5″ diameters air and 20″ diameter steam cylinder, all 24″ stroke, capacity at 100 revolutions 296 cubic feet free air per minute, compressed to 600 lbs. per square inch. Main pipe 5″ diameter, 4390 feet long, with five charging stations in No. 6 Shaft, and a branch of 3″ pipe 3100 feet long, with three charging stations in No. 6 Slope. Each of these two lines charges a Porter Compressed Air Motor with 7″ x 14″ cylinders, four 24″ drivers, weight about eight tons, with a tank capacity of 130 cubic feet of air at 550 lbs. pressure in the main tank, reduced to 160 lbs. in the 8″ auxiliary tank, 4.2 cubic feet capacity supplying the cylinders. The No. 6 Shaft run averages 4000 feet each way on grades of ½ per cent. to 2¾ per cent., and averaging close to 1 per cent. in favor of the loaded cars. The No. 6 Slope run averages 2100 feet, with nearly the same grades. The mine cars weigh 2800 lbs. empty and about 9800 lbs. loaded, and are hauled in trips of 12 to 20, averaging about 15 cars. The Shaft motor now hauls about 355 and Slope motor 320 cars per day of ten hours. Replacing in the No. 6 Shaft 17, and in the No. 6 Slope 15, total 32 mules, against 27 mules replaced in 1896.

* Paper read at August meeting American Institute Mining Engineers.

The average daily car and ton mileage of each motor was as follows:

	Cars Hauled. 1896	1897	1898		Tons Hauled One Mile. 1896	1897	1898
No. 6 Shaft Motor	355	347.4	356	Empty, in	336	330	338
				Loaded, out	1180	1155	1183
				Total	1516	1485	1521
				Net load	844	825	845
No. 6 Slope Motor	288	288.7	319.2	Empty, in	143	144	160
				Loaded, out	501	504	560
				Total	644	648	720
				Net load	358	360	400
Total both motors, gross (including empties returned)					2160	2133	2241
Net load					1202	1185	1245

The use of steam and air in compressor and motor operation as found by test was as follows:

STEAM.

Indicated H. P., compressor @ 130 revolutions.............150 H. P.
Steam consumption per H. P. per hour, from cards..........34 lbs.
Steam consumption per hour, from cards....................5100 lbs.
Steam consumption per hour, including condensation in line..5200 lbs.
Boiler H. P. required.....................................174 B. H. P.
Evaporation per pound of coal (cylinder boilers)............5 lbs.
Coal required per hour....................................1040 lbs.
Coal required per day, 10 hours...........................10,400 lbs., 4.65 tons
Cost of fuel and firing per day, 10 hours, 4.65 tons @ 50c.....$2.32

AIR.

COMPRESSOR CAPACITY.

Free air compressed per revolution of compressor, 2.96 cu. ft. (from calculation by Norwalk Iron Works Co., no allowance for leakage).
The compressor works 12 hours per day to 10 hours for the motors.
Free air per min. at rated speed 100 revs...................296 cu. ft.
Free air per min. at actual speed 131 revs...................387.8/10 cu. ft.
Free air per day, 12 hours at rated speed, 100 revs............213, 120 cu. ft.
Free air per day, 12 hours at actual speed, 131 revs...........279, 216 cu. ft.

CAPACITY OF AIR MAINS USED AS RESERVOIR—

5 inch line 4380 feet.................... 608 cu. ft.
3 inch line 3100 feet.................... 159 cu. ft.

Both lines..................... 767 cu. ft.

At 600 pounds pressure these lines hold 32,505 cu. ft. free air; capacity of main and auxiliary tanks 134.6 cu. ft. at 508 lbs. pressure (at which pressure they will equalize with main starting to charge at 600 lbs.), 4845 cu. ft. free air.

LEAKAGE OF AIR MAINS.

Loss of pressure standing 12 hours, from 550 to 350 lbs.
Cu. ft. free air lost 11,688 cu. ft. in 12 hours,—974 cu. ft. per hour.
Percentage of leakage to total air compressed, 4 18/100%.

AIR USED BY MOTORS.

(From test of March 29, 1900.)

	Shaft Motor. No. 2 Plane.	Shaft Motor. No. 3 Plane.	Slope Motor.
Number trips empty	3	10	16
Number trips loaded	3	10	15
Average cars per trip, empty	15 1-3	12 7/10	11 4/10
Average cars per trip, loaded	13	13	11 3/10
Average cu. ft. free air per trip, empty	1724	5686	1230
Average cu. ft. free air per trip, loaded	1631	1898	599
Average cu. ft. for round trip	3355	7584	1829

SUMMARY OF DAY'S WORK, 1898.

Shaft No. 6,	356	cars per day,	
6 trips,	15	cars No. 2 Plane	20,130 cu. ft.
20 trips,	13 2/10	cars No. 3 Plane	151,830 cu. ft.
Slope No. 6,	320	cars per day,	
28 trips,	11 4/10	cars, average	51,212 cu. ft.
			223,022 cu. ft.
Free air apparently compressed as above			279,216 cu. ft.
Per cent. accounted for			83 4/10%

The difference 16 6/10% is due to leakage and slip in compressor, leakage of air lines and to changes in temperature.

AIR USED PER TON MILE.

	Gross.	Net.
Average free air used per ton mile, No. 6 Shaft Motor	113 cu. ft.	203 cu. ft.
Average free air used per ton mile, No. 6 Slope Motor	71 cu. ft.	128 cu. ft.
Average free air used per ton mile, both motors	100 cu. ft.	180 cu. ft.

The greater quantity of air used by the Shaft than by the Slope Motor is due to the heavier curves and the switching required, especially at No. 2 Plane, where a portion of the trip is frequently left.

COST OF PLANT, NOT INCLUDING STEAM BOILERS.

Compressor	$2,880.00
Extras for compressor repairs	75.75
Shaft Motor	2,743.63
Slope Motor	2,918.20
Extras for motor repairs	207.93
Air connections, 5″ line (6000 feet)	2,914.32

Air connections, 3″ line (4000 feet)	1,240.46
Steam connections, compressor	278.27
Material for compressor foundations and house, and air washing box	295.27
Labor, compressor house and foundations, and 5″ line, and installing Shaft Motor	1,183.01
Labor, 3″ line and installing Slope Motor	46.95
Foster equalizing valves	372.21
Total cost of plant	$15,156.00

COST OF OPERATION OF PLANT.

Operating Expenses.	1897 179 Days Worked. Per Day.	Per Yr	1898 160 Days Worked. Per Day.	Per Yr.
2 motor engineers, @ $2.10	$4.20	$751.80	$4.20	$672.00
2 brakemen, @ $1.60	3.20	572.80	3.20	512.00
½ one engineer compressor, @ $2.32	1.16	207.64	1.16	185.60
Oil for compressor	.67	119.49	.47	75.94
Oil for motors	.25	45.08	.25	40.94
Repairs for compressors (material)	.10	18.76	.48	76.08
Repairs for compressors (labor)	.06	10.38	.09	15.22
Repairs for motor (material	.16	28.78	.51	81.08
Repairs for motor (labor)	.18	32.77	.23	36.87
Steam for compressor, 150 H. P., fuel and firing	2.32	415.28	2.32	371.20
Total operating expenses	$12.30	$2,202.78	$12.91	$2,066.93
Fixed Charges.				
Interest, repairs and depreciation, 174 H. P. boilers	$1.46	$261.00	$1.63	$261.00
Interest and depreciation of plant, 10% on $15,156.00	8.47	1,515.60	9.47	1,515.60
Total fixed charges	$9.93	$1,776.60	$11.10	$1,776.60
Total cost 2 motors, ½ for each	22.23	3,979.38	24.01	3,843.53
Estimated cost per day, 300 days' work	18.22	5,466.60	18.83	5,649.60

THE COST PER TON MILE.

	1897. (179 Days). Daily Mileage.	Daily Cost.	Per Ton Mile.	1898. (160 Days). Daily Mileage.	Daily Cost.	Per Ton Mile.
No 6 Shaft Motor, gross ton mileage	1485	11.12	75/100c	1527	12.00	79/100c
No. 6 Shaft Motor, net ton mileage	825	11.12	1.35/100c	845	12.00	1.42/100c
No. 6 Slope Motor, gross ton mileage	648	11.12	1.72/100c	720	12.00	1.67/100c
No. 6 Slope Motor, net ton mileage	360	11.12	3.09/100c	400	12.00	3.00/100c
Both motors, total gross ton mileage	2133	22.30	1.05/100c	2241	24.01	1.07/100c
Both motors, total net ton mileage	1185	22.30	1.89/100c	1245	24.01	1.93/100c

THE COST OF MULES DISPLACED BY THIS PLANT.

No. 6 Shaft, 17 @ $126.64	$2,152.88
No. 6 Slope, 15 @ 126.64	1,899.60
	$4,052.48

OPERATING EXPENSE BY MULES.

NO. 6 SHAFT.

	1897. (179 Days). Per Day.	Per Year.	1898. (160 Days). Per Day.	Per Year.
Dèpreciation and interest on 17 mules @ 25 %	$3.01	$538.22	$3.36	$538.22
Feeding, attendance, harness and repairs @ $141.40	13.43	2,403.80	15.02	2,403.80
Six drivers	9.40	1,682.60	9.40	1,504.00
Six couplers and spragmen	8.10	1,449.90	8.10	1,296.00
Total cost by mules	$33.94	$6,074.52	$35.88	$5,742.02
Cost by motor	11.12	1,989.69	12.00	1,921.77
Saving by compressed air	$22.82	$4,084.83	$23.88	$3,820.25

NO. 6 SLOPE.

Depreciation and interest on 15 mules @ 25 %	$2.65	$474.90	$2.97	$474.90
Feeding, attendance, harness and repairs @ $141.40	11.85	2,121.06	13.26	2,121.06
Five drivers	8.00	1,432.00	8.00	1,280.00
Five couplers and spragmen	6.85	1,226.15	6.85	1,096.00
Total cost by mules	$29.35	$5,254.11	$31.08	$4,971.96
Cost by motor	11.12	1,989.69	12.00	1,921.77
Saving by compressed air	$18.23	$3,264.42	$19.08	$3,050.19

BOTH NO. 6 SHAFT AND NO. 6 SLOPE.

Total cost by mules	$63.29	$11,328.63	$66.96	$10,713.98
Total cost by motors	22.23	3,979.38	24.01	3,843.53
Saving by compressed air	$41.06	$7,348.25	$42.95	$6,870.45

Total saving in two years	$14,218.70
Total cost of plant	15,156.00

At the average rate of saving for 1897 and 1898 the entire cost of plant would be saved in 361 working days.

COST PER TON MILE BY MULES.

	1897 Tonnage. Ton Mileage.	Cost.	Per Ton Mile.	1898 Tonnage. Ton Mileage.	Cost.	Per ton Mile.
NO. 6 SHAFT.						
Gross ton mileage...........	1485	$33.94	2.29/100c	1527	$35.88	2.35/100c
Net ton mileage.............	825	33.94	4.11/100c	845	35.88	4.25/100c
NO. 6 SLOPE.						
Gross ton mileage...........	648	29.35	4.53/100c	720	31.08	4.32/100c
Net ton mileage.............	360	29.35	8.15/100c	400	31.08	7.77/100c
TOTAL.						
Gross ton mileage..........	2133	63.29	2.98/100c	2241	60.96	2.98/100c
Net ton mileage............	1185	63.29	5.34/100c	1245	60.96	5.38/100c
COST BY MOTORS.						
Total gross ton mileage.....	2133	22.30	1.05	2241	24.01	1.07/100c
Total net ton mileage.......	1185	22.30	1.89	1245	24.01	1.93/100c
SAVING BY COMPRESSED AIR.						
Gross ton mileage............	....	40.99	1.93/100c	....	36.95	1.91/100c
Net ton mileage...............	....	40.99	3.45/100c	....	36.95	3.45/100c

The capacity of the Shaft Motor is equal to fully double its present work, while the Slope Motor is working at but about one-third of its capacity, while the compressor is doing all that it is capable of, and a second one was ordered April 7th, 1900. To operate the plant to the full capacity of both compressors, which, under the present conditions, would be about 4,500 ton miles gross, or 2,500 net, per day for 300 days per year would bring the cost of operation, including fixed charges, to about $24.60 per day, or 547/1000 cents per ton mile gross, and 984/1000 cents per ton mile net load. While if all the work could be done by one motor under the No. 6 Shaft conditions up to the capacity of the compressor for 300 days per year, using only one crew, the cost of plant would approximate $11,000.00, and the operating expense, including fixed charges, $10.86 per day for 2,400 gross ton miles, equal to 45/100 cents per gross ton mile and 81/100 cents per net ton mile.

A further reduction of cost could be made by reheating the air at the motor by passing it through water at the temperature of steam at 90 pounds pressure, by which method tests have shown a gain of about 50% in air economy. It is probable that by this means, one motor could be run to its full capacity about 3,000 gross ton miles per day with one compressor at a total cost of $10.80 per day, or 36/100 cents per gross ton mile, for 300 days' work per year; the saving of 9/100 cents per gross ton mile, or about 20% over the last mentioned condition, being due only to the greater air economy, the fixed charges and labor cost remaining practically the same.—J. H. Bowden, C. E.

THE PROPOSED UNDERGROUND RAILROAD IN NEW YORK.

Those who object to the proposed Underground Road in New York, on the basis that all underground roads and tunnels are disagreeable places, do not make allowance for recent improvements in construction, ventilation, lighting and traction.

In building a tunnel through Broadway, every machine can and should be operated by compressed air. Power might readily be generated in the basement of a building along the line of the street and transmitted through pipes to the hoists, pumps, drills and excavators. There need be no disagreeable puffing of steam, smoke, or moving about of heavy boilers with their attendant loads of coal, water and ashes. There will be nothing experimental about this, because it has been done on the Chicago Drainage Canal, on the new Croton Aqueduct, and on hundreds of other places of less importance.

Why talk about difficulty in ventilating a road under Broadway, when each train can be pulled by a compressed air locomotive which will puff dry, cool and fresh air into the tunnel at each stroke? The H. K. Porter Co., of Pittsburg, has built and put into successful operation engines for such duty as this. Imagine the trains as close together as those on the elevated roads, and it is not difficult to see the wholesome effect of the locomotives puffing pure air into the tunnel. Compressed air for this purpose should be produced by compound or stage compressors. This is not only an economical condition, but it prevents the oily or burnt odor sometimes noticed in mines which receive compressed air from the common type of non-compound compressor. Mr. E. J. Farrell, the experienced contractor who built the Baltimore tunnel, claims that the wholesome effect of compressed air exhausted into a tunnel is greater than that produced by any other means of ventilation. He has found that the exhaust from six rock drills is better than the effect produced by a No. 6 Baker blower. The six drills deliver about five hundred cubic feet of free air per minute, while the capacity of the blower is four thousand five hundred cubic feet. In the case of the drill, the air does work before it is exhausted into the tunnel; hence its heat is converted into mechanical energy. The blower simply supplies fresh air from the outside and at normal conditions of temperature and pressure.

Chief Engineer Parsons has planned wisely in keeping the tunnel as near the street as possible. It will be more accessible, dryer and more easily lighted. A waterproof lining will keep out the moisture. Compresed air, which should be on tap all along the line, might be used to light the tunnel on the Wells' light principle. This light is now a familiar one in public works, its great luminosity being very marked. The light is more diffused than the electric or any other light. As the combustion is fairly complete, there is not likely to be any injury to the ventilation, though the light might serve the double purpose of lighting and ventilation by being placed directly under vents or chimneys, and thus ejecting large volumes of air from the tunnel.

In the light of recent improvements, there is nothing mysterious or difficult about the construction and operation of underground roads.

ELECTRIC COTTON HAULER AT PORT CHALMETTE, LA.

There has recently gone into operation an interesting electric freight hauling road at Port Chalmette, La., of which we give several views in the accompanying engravings.

Port Chalmette is the big cotton handling port recently constructed just below New Orleans on the Mississippi. At this point over $3,000,000 has been expended in cotton sheds, warehouses, compresses and wharves. The whole forms a town to itself, lighted by its own electric lighting plant, with arc lights and 220-volt incandescent lamps. Connecting the sheds, warehouses, compresses and wharves is a system of narrow gauge tracks for handling the cotton.

The original promoters adopted compressed air locomotives for the work of hauling the cotton about from point to point. At the beginning of the cotton

FIG. 175—COMPRESSED AIR LOCOMOTIVE, PORT CHALMETTE, LA.

season last fall, although four air locomotives were in service, they were unable to cope with the handling and moving of the cotton. The managers were skeptical regarding electric traction, and the underwriters were afraid that electric motors would increase the fire risk. Something had to be done, and done quickly, to handle the large consignment of cotton daily received. A temporary trolley line was constructed and an electric truck provided. An engine and railway generator were hastily secured, and inside of ten days the most important part of the hauling work was being successfully handled by the improvised trolley plant. Its working satisfied both the Chalmette managers and the underwriters, and the result was a contract was made for four electric haulage locomotives. The apparatus was rapidly installed, and by the middle of the cotton season the trolley had supplanted the compressed air locomotives and was taking care of the large and extended haulage system of the entire terminal.

The locomotives are "factory trucks," equipped with two NWP—12 motors, and weighing approximately 15,000 pounds; each is capable of hauling 150 tons on a straight level track.

Current is furnished by a 500-volt railway generator direct coupled to a 300 H. P. Erie City Iron Works engine. The electrical apparatus was furnished by the General Electric Co., through Mr. J. J. Britton, of the New Orleans office.

FIG. 176—COTTON TRAIN AT PORT CHALMETTE—COMPRESSED AIR LOCOMOTIVE.

There are about eight miles of 36-inch gauge-track about the cotton sheds, storage warehouses and wharves.—*Electrical Engineer.*

EDITOR COMPRESSED AIR:

DEAR SIR: My attention has been called to an article in "The Electrical Engineer" of February 17th, 1897, entitled "Electric Cotton Hauler at Port Chalmette, La." As Chief Engineer and General Manager, I planned the entire works of Port Chalmette, and the Belt Railway around New Orleans, and in the same capacity I planned and had built a compressed air plant equipped with pneumatic locomotives, to do the cotton hauling and handling at that port.

During my management these pneumatic locomotives and compressed air system gave entire and complete satisfaction. Repeated tests were made and the results fully described at the time in different technical journals.

I resigned last summer to go to Europe, and during my absence the engineering department and the power plant at Chalmette fell into the hands of a person who had never heard of compressed air until he accidentally happened to see the plant at Port Chalmette. The Chief Engineer was a very good man, who had graduated in the science of engineering as levelman of a cotton compress.

As near as I can learn, it appears that, for instance, he attempted to run the plant without opening the valves supplying the compressed air to the locomotive tanks. At all events, the compressed air plant which up to that date had been a perfect success, all at once appeared inefficient, and the local directors (their inexperience can be readily pardoned), in their anxiety to keep things going, sent for and used electric motors as described in said number of "The Electrical Engineer."

These electric motors have about one-third of the hauling capacity of the pneumatic locomotives, are more expensive on account of the fuel consumed, and have the ever present danger of sparks in a cotton yard.

As soon as the end of the cotton season permits any changes to be made at Port Chalmette, the compressed air plant there will again receive prompt attention. Yours very truly,

A. W. Swanitz, Consulting Engineer.

COMPRESSED AIR AND ELECTRICITY AT PORT CHALMETTE.

A writer who signs himself "G. F. P.," communicates with the *Railroad Gazette* regarding the Electric Haulage plant at Port Chalmette, La., a description of which is given on page 526.

The above journal has the following to say in regard to his communication.

"We have great confidence in the good faith and good judgment of the gentleman who writes the account of the Port Chalmette enterprise; and it is obvious that he is a good observer. We cannot agree with him, however, that the economy of the electric haulage as compared with compressed air has been proved beyond a doubt' at Port Chalmette. The conclusion that the work is done cheaper by electricity is not warranted by the facts presented. It may be correct, but we want more evidence.

"For instance, the statement that the cost of maintaining track under the compressed air haulage is much greater than under electric haulage is, we suspect, theoretical. An experience of about a year with one and half a year with the other, on new track, is not enough to justify so broad a conclusion. If all the details of expenditures on maintenance of track and machinery, of interest on cost of machinery, of fuel and wages account, and of work done, could be gathered, analyzed and compared, the result would be instructive and highly interesting. Until we see such details, however, we suspend judgment on comparative economy.

"Concerning the experience with the compressed air plant, we have some information from another source. The first two air locomotives were furnished by Messrs. H. K. Porter & Co., and were shipped in October, 1895. A third, with greater tank capacity, was shipped in August, 1896. The compressor was furnished by the Norwalk Iron Works. The pipe line was bought and laid by the railroad company, and we understand that the builders of the motors and compressor had nothing to do with the plan of the installation, the capacity of the piping or the arrangements for storing and charging.

"Obviously, there were a number of things to be co-ordinated to get good results. The work of the motors in speed, frequency and loads, the capacity of the compressor, the storage capacity of the pipes, and the points of re-charging should all have been considered. With the work in sight at the outset the first plans were probably good enough. Each motor was expected to make a round trip every half hour and to re-charge directly at the compressor; there were two motors and they charged to a pressure of 600 lbs. per square inch. But the tonnage to be handled quickly developed so as to require three motors, making more frequent trips. For prompt, efficient and economical service there should have been storage capacity enough to equalize the pressure in the motor tanks instantly, or practically so, when connected with the pipe line. There should have been pipes and connections so distributed about the yards and warehouses as to minimize the unprofitable engine mileage in running to and from the charging places. The compressor should have had ample capacity for its work. The fact is that the only provision made for storing air was 1,542 feet of 5-inch pipe. which gave less than one-quarter the volume of storage capacity necessary to get prompt equalization in the motor tanks. Most of the charging had to be done direct at the compressor, which took anywhere from 12 to 18 minutes, and the compressor did not have capacity to supply air to the three motors at the intervals required.

"It is not surprising, therefore, that the compressed air hauling was unsatisfactory, or that, as we have been told, the motors 'lay down out in the field' It would not be surprising, further, to learn that the hauling under these circumstances was costly. Engine crews lost time while running to and from the charging station and while charging from the compressor, and the engines made a heavy percentage of empty mileage. Under all these contrary conditions it would have been surprising if the compressed air hauling had not been expensive.

"On the other hand, the former Chief Engineer and General Manager, who planned the work and started the compressed air haulage, writing to Compressed Air, says: 'During my management these pneumatic locomotives gave entire and complete satisfaction. These electric motors have about one-third of the hauling capacity of the pneumatic locomotives, are more expensive on account of the fuel consumed, and have the ever-present danger of sparks in a cotton yard.'

"But the difficulties and inefficiences developed later with the compressed air haulage have nothing whatever to do with compressed air. They, or others quite as great, would arise with any other system as inadequately planned. We do not understand that the Chief Engineer and General Manager, under whose direction the original air plant was installed, is responsible for its inadequacy. We judge that came about chiefly because there was more work to do than had been anticipated. On the whole, from such information as reaches us, this cannot be looked upon as in any way a satisfactory or conclusive test of the relative economy and efficiency of hauling by compressed air and by electricity.

"There is still another consideration which we have never seen satisfactorily dealt with. This place happens to be one where the fire risk is especially great. The principal business is hauling cotton, and the decks on the wharves and like places are covered with lint. One would say that an electric motor would be considerably more dangerous than a steam locomotive in such a place. Great care must be taken to prevent sparking, and the danger of starting fires by sparks must be constantly great. We have been told that the contract with the electric company requires that there shall be no sparking, and that all rails shall be kept clean at all times, which seems rather a hard condition to carry out. We have indirect information that the motors have really started several fires. On the other hand, our correspondent, who is and has been on the ground in a responsible position, says that there have been no fires attributable to the electric motors. To his testimony, being direct and positive, we must give great weight, but we should say that the immunity must have been secured at great cost in care and vigilance, and we should be very apprehensive of the result if the electric plant were under a management less skillful and faithful."

A NEW GAS-PRESSURE GENERATOR.

FOR INCREASING THE EFFICIENCY OF COMPRESSED AIR FOR TRACTION PURPOSES.

The invention relates especially to pressure generators of the continuous-combustion type, whereby a greater amount of heat is saved and converted into a useful working pressure than has hitherto been possible.

The objects in view are to provide a simple and instantaneous internal-combustion pressure generator where gas or oil vapors or other like rapid combustibles are burned in the retort or combustion chamber with the proper amount of air to form perfect combustion. The burned gases thus formed pass out of the combustion chamber, where they unite or commingle with steam that has been generated in the coils that surround the inner walls of the combustion chamber and pass from the combination to the mixing chamber. The steam issues from said pipes as "saturated" steam and, commingling with the burned gases, forms "superheated" steam, which is used expansively or otherwise in any desirable form of engine, whether it be a reciprocating, oscillating, rotary or steam turbine, but preferably in the latter.

A further object of the invention is to provide an elastic motive fluid having the advantage of both gas and hot air and also steam without their disadvantages—namely, the tendency which gas and hot air have to destroy the sensitive parts of an engine and also the rapid falling off of the pressure—since by the addition of steam the expansive qualities are prolonged and act more as a lubricant than as a destroyer of the lubricating agent.

1 is the combustion chamber, having an opening or neck 2, leading into the mixing chamber 3, both forming compartments within the interior of a proper casing A. Through the bottom of the combustion chamber passes an induction pipe 4 and is made to form a coil and lining B for the retort or com-

bustion chamber, leaving an opening at the center of the coil for the injection pipe 5 to pass through. Then this pipe 4 continues coiling around the inner walls of said chamber until it reaches the crown sheet C, where it also lines the same by being properly coiled, leaving an aperture in the center thereof, so as to not obstruct the passage 2. From thence said pipe 4, after lining all the inner walls or surfaces of the combustion chamber, continues to make a series of flat coils 6, that are suspended within the upper portion of the chamber 1, and finally said coils end by turning up and passing through the central passage of the flat coils 6 and through the neck 2 into the lower end of the mixing chamber 3, being held in position by a suitable bracket 7, through which it passes, and is secured by a nut 8. The bottom of the mixing chamber 3 is made within a convex head, consisting of the crown sheet C, in order that the water of condensation may be drained therefrom by the cock 9. The object of providing the two chambers 1

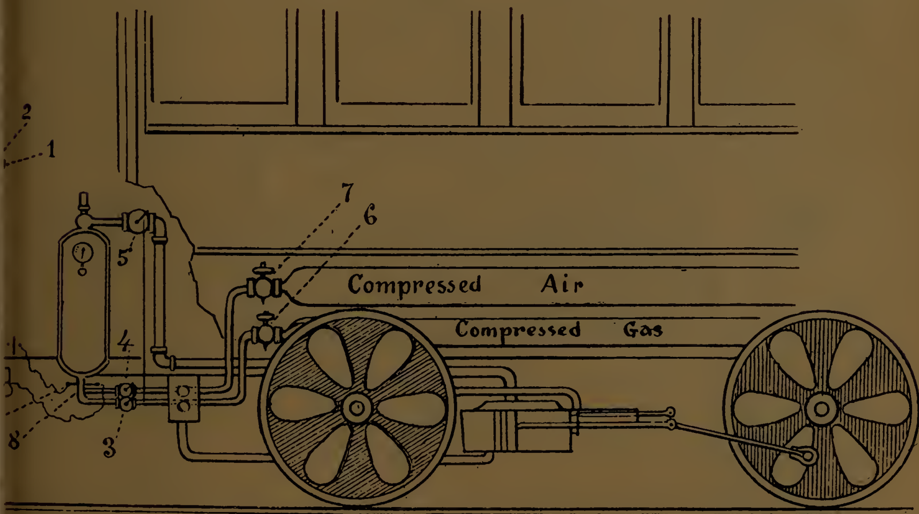


FIG. 177—MOTOR CAR WITH GENERATOR IN POSITION.

and 3 with a flared-neck tube between them is to keep the combustion chamber 1 clear of any steam or moisture, so that only pure air is present to form perfect combustion in combination with the gas or oil vapors. After the products of combustion have passed through the neck 2 into the mixing chamber 3 and have commingled with the steam issuing through the nozzle 10, they then pass out through the eduction pipe 11 to the motor or other suitable point.

Fig. 177 is a sectional view of a motor car, showing the generator in position.

The mode of operating cars that have a central station where air and gas are compressed and then delivered to the individual cars as they come in to be recharged, is as follows:

First recharge the air and gas tanks under seats of cars. Then to start cars pull lever 1 forward gradually, thus opening simultaneously the gas valve

3, the air valve 4 and the throttle valve 5. Valves 3 and 4 receive air and gas in proper proportion from their respective tanks through the pressure reducing valves 6 and 7, through independent pipes, until they reach the burner 8, where they unite and are fired by an electric spark between electric electrodes 9 and 10, and produced by pressing the push buttom 2 with the thumb, at the same time the lever 1 is pushed forward. At the instant the motor starts it pumps water automatically to the steam generating coils located in the combustion chamber of the generator. Thus the working fluid passes out of the generator through throttle 5 to the motor and starts cars.

When it is desired to stop cars, push hand lever 1 backward; this action

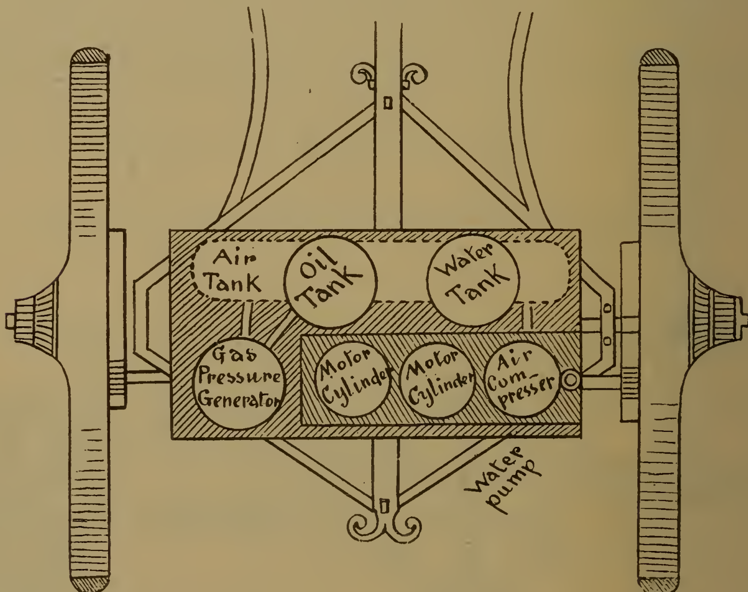


FIG. 178—REAR END VIEW OF HORSELESS CARRIAGE.

closes all three valves, viz., air, gas and throttle, at same time cutting off working fluid supply, thus stopping motor.

Fig. 178 is a sectional view of the rear end of a horseless carriage, showing the generator and motor in position.

In this instance it will be seen that the compressing station is dispensed with. As the plant is "self-contained," the motor doing its own compressing of air and delivering same to a supply tank on board. Said supply air tank is connected by a by-pass to the oil tank (kerosene or gasoline), in order to have the same pressure on top of the oil in oil tank as there is in the air tank, thus feeding the air and oil in proper proportion to the burner at equal pressures.

The oil is first converted into a "fixed gas," "before" it commingles with the air, by a new gas generating burner (not shown here), also invented by Mr. Woillard recently.

The inventor of the above system is endeavoring to secure financial aid to put his invention upon the market.

Interested parties can learn more by addressing the inventor himself.

MINE HAULAGE.

Mr. E. P. Lord, Superintendent of H. K. Porter & Co., Pittsburg, Pa., in a paper read before a recent meeting of the Coal Operators' Association, reviewing the progress of compressed air, and particularly of mechanical haulage by compressed air, says:

"Mining has been one of the most active means of giving prominence to compressed air. In these days of active competition and imperative demand for decreased cost of production, greater economies and improved appliances for cheapening the mining of coal have been absolutely essential to profitable mining. New fields, as soon as developed, have felt at once the necessity of installing the most approved machinery for mining, pumping and haulage; in fact, these improvements have been imperative to keep in business. The mule, which has so long been used for hauling, has been very generally supplanted by more powerful agents, steam, electricity and compressed air. It is to the latter power as applied to the motor for haulage purposes that I intend to principally confine my remarks.

"In much work—in mine tunnels, confined spaces, etc., compressed air has fully demonstrated its superiority over steam or any other power. The work accomplished with it in your own Jeddo Tunnel, at Hazelton, needs no reference to here. Early uses of compressed air hardly presaged the wonderful development and application of this power to-day. For mine haulage it is very largely supplanting the steam locomotive, with its attendant disadvantages, and now electricity is about its only competitor. Until this competition manifested itself, air was generally considered a very undesirable power at best, and in many installations, more particularly haulage, it was not thought of. I do not wish to be construed as saying that electricity and compressed air do not very frequently work in mutual harmony. Each has its own field of work, for which it is singularly fitted, and where no question of competition can arise.

"Electricity can be used in most cases quite successfully for haulage. It can also be used for pumping, and made a success as far as operation is concerned, but in many cases at a large excess of cost over compressed air. But when you come to cut coal with electricity, many operators claim that no such results can be obtained as with compressed air, to say nothing about the increased cost of installation and subsequent operation. I have found it extremely difficult to get any statements from those using electricity for coal cutting, and there is no doubt or question but that there are some veins of coal which cannot be cut with the type of machine which is driven with electricity that could be successfully cut with what is called the punching or pick machine. Where compressed air is superior for transmitting power for coal cutting and pumping, is it not reasonable to conclude that a good deal of consideration should be given to it for haulage?

"Most of our engineers frankly admit that the electric motor is not an economical machine where the use of power is to be variable and intermittent, it being essentially a constant speed machine. If we so block an electric motor that it cannot move, a considerable current of electricity will run through, without doing any work; while a compressed air engine wastes no air or energy in starting, for air only escapes with piston movement.

"The average mine engineer will usually show the liveliest interest when approached on the subject of an air haulage plant; but when he is called upon to choose between air and its very universal and most elaborately advertised competitor, electricity, no doubt he feels that the best known and understood agent is the best and safest in his case, although the compressed air plant, if successfully installed and started, might prove the most economical to his company.

"I am pleased to state that in the introduction of our motor we have found in the anthracite district the most exacting, but at the same time, most tolerant listeners to our claims for recognition; and the reports which have, and are now, reaching us from plants already installed among the operators of your region lead us to hope for, and promise even greater achievements in the advancement of this simple but all-powerful agent, compressed air.

"The last few years have witnessed a very remarkable development of compressors and compressed air apparatus, due, no doubt, quite largely to the active competition of electricity in the many fields where this power is used. The great improvement made in compressors, together with reduced cost, have led to their more extensive adoption and the enlargement of their uses. In all respects its progress has fully kept pace with that of electricity. The compressor people are now called upon to design and construct machines to develop heat and produce cold; to move air with a force only sufficient to press gold into a sensitive tooth, and to blow the shot from a cannon. There is hardly a department of any large shop or manufactory that cannot testify to the remarkable economies that this power, ingeniously applied to various machines, has established. There are not less than 200 distinct and established uses of compressed air—to 90 per cent. of which electricity is inapplicable; and in the remaining 10 per cent., constituting the field open more or less to the other agencies besides air and electricity, we find air generally has the advantage. Except within the last few years, compressed air catalogues have been almost the only literature on this very important subject, while to-day we can hardly pick up an engineering paper without running across some article, paper or special mention of the great benefits that this new power is establishing for its recognition in the mechanical world.

"Comparison with Other Power Agencies.—Compressed air has marked advantages over any other class of haulage, in that it is free to go wherever there is a track laid; the distance run with one charge of air is only limited by the capacity of the motor tanks. Great advancement has been made in the improvements of compressors, pipe lines, pipe connections, motors, methods of charging, etc.; so that for efficiency it is admitted that compressed air runs electricity very close for a long-distance transmission. It is equally efficient and safe in fiery and non-fiery mines, and materially assists ventilation by the air given out by the exhaust. Too much stress must not be laid on this, for efficient ventilation must be provided for in any case; but compressed air is now used for driving mining machines in rooms or in butt entries, ahead of the general work and beyond the range of general ventilation. It not only supplies the necessary power, but furnishes an ample amount of fresh air, thereby materially reducing the risk to life and property. In the butt entries and rooms where ventilation has been difficult, and where, on account of low roofs, light rail, etc., other classes of power have not been introduced, the compressed air locomotive has been installed with very manifest success."

HOPCRAFT'S PNEUMATIC RAILWAY.

We give on these pages two views of a working model railway, about one-tenth of a mile long, which we recently had an opportunity of inspecting under

FIG. 178A —A MODEL PNEUMATIC RAILWAY.

working conditions. The system is one of pneumatic direct propulsion, involving the use of no motive mechanism on the vehicle. Between the ordinary rails, and supported by the sleepers, is fixed a supplementary rail of timber. On this rail is the motor tube, which, in its normal position, *i. e.*, flat, appears as a narrow stretch of heavy canvas tubing. Within this tube, and effectually protected by it, is what would appear as a strip of india-rubber, in reality a tube, but so mounted on a flat wooden core that either side represents a firm, even surface. This motor tube is firmly attached by side fillets of wrought iron to the centre wooden rail. To utilize the power which air under pressure, when admitted to this tube, is capable of exerting, a rubber-tired wheel, wider than the motor tube, revolves freely on its axle, which is attached to the centre of the car, midway between the ordinary wheels. This wheel, by means of a lever in connection with the axle, can be raised from or lowered on to the tube at will, and in conjunction with the brakes is worked by the conductor in charge, who thus has full control of the car. By depressing the wheel on to the deflated surface of the tube, an air-tight joint is formed, and on air under pressure being admitted to the tube, on the side

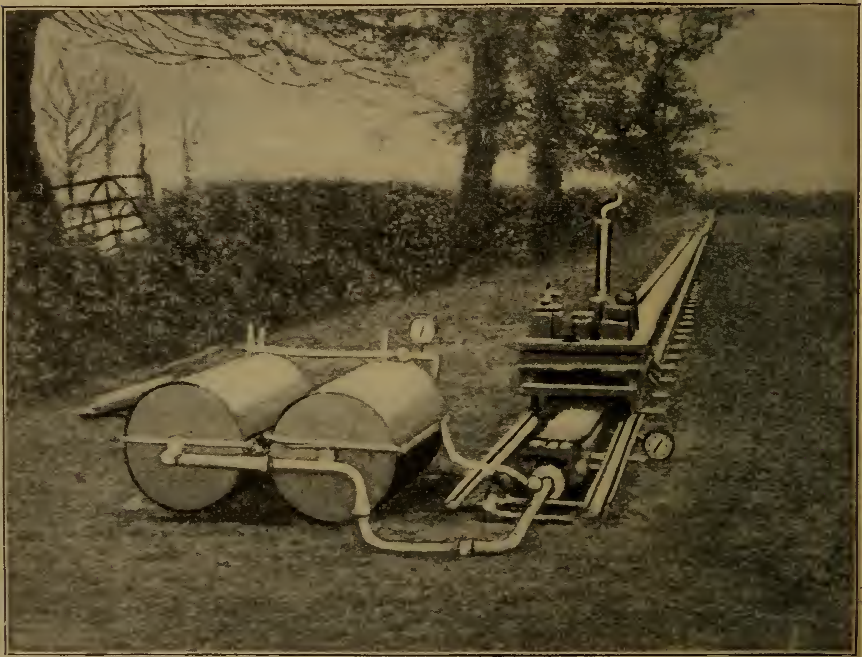


FIG. 179—A MODEL PNEUMATIC RAILWAY.

opposite to that in which the carriage has to travel, inflation takes place, and thus a powerful propelling force is exerted against the wheel, causing the car to travel at a speed practically limited only by the speed of the air in the tube.

In the model illustrated, the motive fluid is carbonic acid gas, stored in flasks in highly compressed state, but reduced before it is admitted into the motor tube to a pressure of about 8 lbs. per square inch. This gas has been employed in order to dispense with an engine and compressor. The guage of the railway is two feet, and the weight of the truck in working order is about half a ton. The line is a dead level for about three-fifths of its length, when it has a slight fall and then a rise. But at the further end is a short length, with a gradient of about

1 in 6, which has been constructed to show the capability of the system for working up an incline. This is shown in one of the illustrations. With a pressure of about 8 lb. in the tube the car could be easily started up this incline. Numerous applications of this system of propulsion suggest themselves; for instance, quick, light railways for exhibition purposes, or for the transport of goods in warehouses and factories. The inventor is Mr. L. Hopcraft, of Kelvedon Common, Brentwood, Essex.—*The Engineer.*

THE BROADWAY TUNNEL.

In December last a fire which destroyed the building occupied by Rogers, Peet & Company, corner Broadway and Warren streets, New York, disclosed the famous Beach Broadway Tunnel, which was built thirty years ago for rapid

FIG. 180—PNEUMATIC CAR IN THE BROADWAY TUNNEL.

transit purposes. It was proposed that compressed air should be used to drive cars through this tunnel. In the Spring of 1870 the tunnel was opened for inspection to the public and crowds of visitors enjoyed a walk through it—many people enjoyed rides through the tunnel in the car which was driven by pneumatic power. The remains of the car are still to be seen. It is elliptical in shape and practically filled the entire tunnel. In City Hall Park, where the tunnel terminates, an air well served as an outlet and inlet for air according as the car was driven by pressure of air on its end down the tunnel from the huge blower or driven back to the place of starting by the suction of air in a reversed direction. Horace Greeley and other distinguished persons took rides in this car.

LONDON'S LOST TUNNEL.

Is there any other city in the wide world where a cast iron tunnel, two and three-quarter miles in length, could lie disused, unknown, lost to the memory of all but a few scientists, for over thirty years, excepting London? I doubt it. For this commercial hub of the universe spins onward at such a rapid rate, that the doings of yesterday are already shrouded in mist, and those of a decade back buried as deeply as if the dust of centuries, not years, lay upon them.

So it is that, under the hurrying feet of millions, even echoing their tramp through the heart of the great city, for long years has lain this almost imperishable testimony to the enterprise, courage, and, alas! misjudgment, of certain of its citizens of the "Sixties." Expert engineers have examined the tunnel and pro-

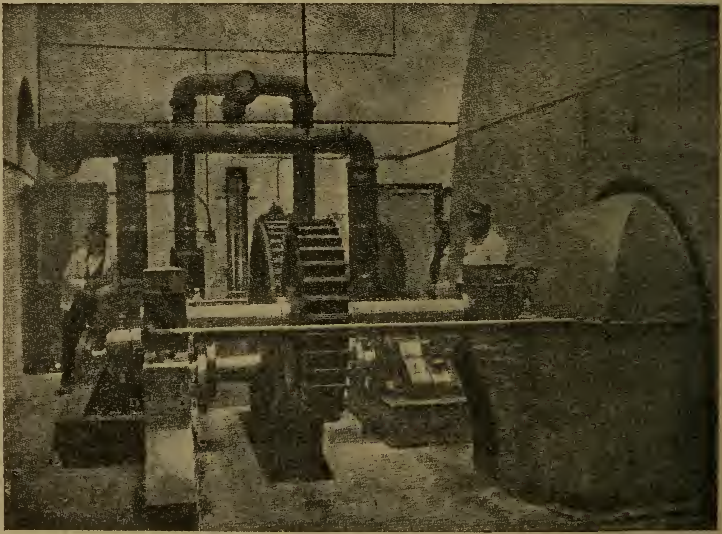


FIG. 181—PNEUMATIC ENGINES, HOLBORN STATION.

claimed it to be composed of the very best metal—"cast iron such as is not turned out to-day," to quote the words of a prominent expert—and but little affected by earth, moisture, or disuse, for all its lengthy interment and neglect. Representing as it does the burial of close on £200,000, is it not simply marvellous that no effort until the present has been made to rescue this valuable property from the fungi and huge, whiskered rats, and turn it to some profitable utility? The answer is that the tunnel had been forgotten, simple lost, and the man who "found" it found a gold mine extending from the G. P. O. at St. Martin's-le-Grand to Euston Station. Should the sanguine hopes of the discoverer be realized—and they are based on the reports of the leading authorities—he has "struck" a payable "lead" that is not likely to be "worked out" until flying machines are as ubiquitous and numerous as hansoms in London streets.

Mr. George Threlfall, a consulting engineer, of 50 Fenchurch street, "found" the tunnel, and the story of his discovery is one of surmounting an almost interminable Alps-of-obstacles, and a period of five years occupied with continual struggle before success crowned his efforts.

The memorable year of 1863 welcomed the abolition of slavery in America, shuddered at the fierce fighting of kin against kin in the Battle of Gettysburg, grieved at the deathbeds of three memorable men—Thackeray, Stonewall Jackson and General Sir James Outram—and showered sunshine and good wishes on the marriage of H. R. H. the Prince of Wales. It saw also the opening of the Pneumatic Dispatch Company's first section of the tube that, later, starting from Eversholt P. O., N. W., passed down Seymour street under the Euston Station,

FIG. 182—TRAIN OF CARS, HOLBORN STATION.

along Drummond street, turning into Hampstead Road, and continuing the length of Tottenham Court Road until New Oxford street was reached, under which it ran, and under Holborn, plunging deeply down the Viaduct, passing below Farringdon street, shooting up into Newgate street, and finally reaching home in the old G. P. O. buildings on the corner nearer Cheapside. The tube, which measures four feet in height by four and a half in width, was erected to carry the mails and postal parcels between the two terminal points and wayside offices by means of pneumatic pressure.

A lad with a pea shooter utilizes pneumatic pressure in propelling his stinging pellets by introducing a force of air behind them; in an inverse manner liquids are imbibed through a straw by sucking the air out, when the interior liquid, thus relieved from pressure, is forced by the weight of the atmosphere on the outside liquid up through the straw. Both these forms of pneumatic pressure were utilized to drive the loaded cars of the Dispatch Company through the tunnel The car ends fitted the tunnel to within an inch all round. The intervening space was closed so as to be perfectly airtight by a flange of stout indiarubber, which clung tightly to the tube's interior. The air was sucked out from in front of a train of cars by an ingenious mechanical arrangement. Two discs of wrought iron, twenty-one feet in diameter, were screwed on to the sides of an iron wheel having sixteen spokes. Between these two discs, and separated from them, stood a third disc of a corresponding size. Thus this cumbersome wheel, complete, contained thirty-two V-shaped cavities. Briefly, it may be said that the revolution of these cavities at a great speed, before huge bell-mouthed pipes, drew by cen-

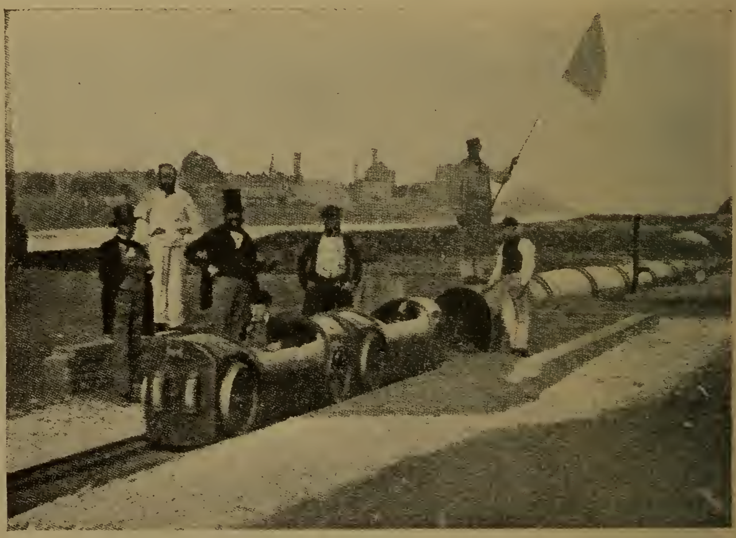


FIG. 183—EXPERIMENTING AT BATTERSEA.

trifugal force the air out of the tunnel along which the cars, drawn by suction, sped at a rate of thirty-five miles per hour.

The tunnel as it stands to-day is made up of cast iron sections in nine feet lengths and nearly an inch in thickness. Each section was cast in one piece, and in shape resembles a "D" lying on its back, with a groove in the corners along which the rails are laid. At the stations hermetically sealed spring doors excluded the entrance of air, so that when necessary a vacuum could be produced before the departing cars. The addition of an engine to revolve the hollow wheel I have described completed the whole outfit of a scheme that was to revolutionize the prevailing forms of carriage and general motion. In a *Times* leader of February 10th, 1863, I have found the following: "Between the pneumatic despatch and the subterranean railway the days ought to be fast approaching when the ponderous goods vans which now ply between station and station shall disappear forever from the streets of London." Over thirty-six years have passed, and the railway van is to-day more ponderous, ten times more numerous, and a hundred times greater danger to those who use the streets. And yet we boast of our progress! Nevertheless, the journalists of those days revelled in dreams of pneumatic enthusiasm; and schemes, that doubtless then appeared well controlled and feasible, to-day are known to have been of the wildest and most improbable. Listen to the exultation-cum-wailing of the *Seven Days' Journal,* apropos of the Pneumatic Dispatch Company under date December 13th, 1862: "We are fast making London a marvellous and unequalled city; and if with all our improvements and inventions we could only devise some means for rendering the three millions of dwellers in it safe from the murderous attacks of garotters and burglars, we should have just reason to be proud of our smoke-covered, but unmatched, capital." Well, the smoke is still with us in greater volume than of old; but the many-tailed cat has tamed the murderous thief, and the Pneumatic Dispatch Company has been resurrected and is promised a new life, with electricity for its vital power.

Yet another reference to "olden times," and the dead past must give way to the living present. The *London Journal,* in 1863, printed this piquant paragraph: "Not only have letters and parcels been transmitted through the tube, but we hear also that a lady, whose courage or rashness—we know not which to call it—astonished all spectators, was actually shot the whole length of the tube, crinoline and all, without injury to person or petticoat." Following on this came a multitude of proposals for pneumatic passenger traction. A trial railway was laid at the Crystal Palace, and proved successful. The Waterloo to Whitehall Pneumatic Railway Company was formed. Great Scotland Yard was fixed upon as a site for one terminal station, and adjoining the Waterloo Station in York Road the other. Excavating and tunnelling were commenced. The river was to be crossed in an iron tunnel resting in a dredged channel across its bed. The *Illustrated Times* of August 17th, 1862, gave a full-sized plate, showing the works in progress, and in accompanying letterpress claimed that, "in its present form, the pneumatic system is simply an adaptation of the process of sailing to railways, the wind being produced by steam power and confined within the limits of a tube." Passengers were to have perfect ventilation, no smoke (excepting tobacco), no steam, no jolting, no vibration, no collisions, and, in fact, none of the disadvantages more or less attendant on any railway line in the kingdom to-day. Although Messrs. T. Brassey & Co. were the contractors for this ideally perfect railway line, I cannot say where it has disappeared to. Evidently it savored too much of Elysium to be allowed to remain on earthly shores.

Many persons, however, made the journey in the Pneumatic Dispatch Company's cars. The *Evening Standard* of April 5th, 1863, mentions "Prince Napoleon and his secretary" as being among the passengers, and an illustration on page 623 shows the Holborn Station—which was located in close proximity to the present Royal Music Hall—with a departing car passenger-loaded. For this plate I am indebted to Mr. T. E. Gatehouse, responsible editor of the *Electrical Review,* Fellow of the Royal Society, Edinburg, a member of the various Institutions of Engineers, Civil, Mechanical and Electrical, besides being a well-known amateur violinist. Mr. Gatehouse entered the service of the Pneumatic Dispatch Company in 1869—in days of his fallow youth—and scores of times made the journey through the tube, lying in the fast-flying cars. "The central station was in High Holborn," he states, "and contained the whole of the motive power. Here the cars changed from one set of rails to another, and the time taken in completing the whole journey from end to end was nine minutes. It was always an exhilarating journey, the air being fresh and cool even on the hottest summer days. From Holborn Circus, where the tube dives down a steep declivity under Farringdon street, the speed was about sixty miles an hour, and in the darkness it felt as if I were sliding down a hill feet foremost. The impetus of this rush would carry the car up the incline to Newgate street. To me, who made the trip for the first time, there was something weird and uncanny in being shot through a tube at a high rate of speed, so near the surface of the roadway that the clatter of hoofs and the rumble of vehicles could be distinctly heard, accentuated frequently by the tallow candle or oil lamp being extinguished by the draught. I

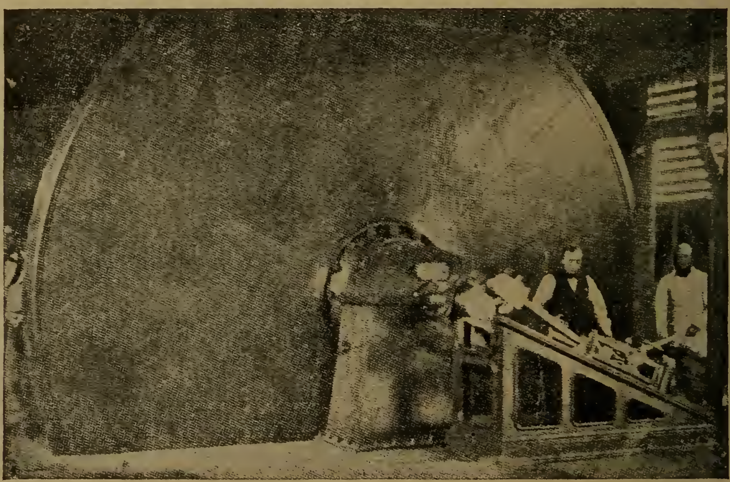


FIG. 184—PNEUMATIC DISPATCH EXPERIMENTAL WORKS AT BATTERSEA, SHOWING PNEUMATIC DISC AND ENGINE.

got so accustomed to the journey that I could tell what corner I was turning, and the street above, precisely, at any moment."

After a period of eight or ten years, the Pneumatic Dispatch Company relinquished operations. At intermittent times only had the line been worked; and quietly, without fuss or flurry, as became the collapse of a gigantic scheme, the end came, and pneumatic propulsion on a wholesale scale received its death-blow in the minds of experts. The insuperable difficulty lay apparently in the impossibility of rendering the tunnel sufficiently air-tight. Leakages of various extents prohibited the creating of a working vacuum, and after the engine power had been increased until it attained six times its original strength, further efforts were considered useless.

The Company had been an extremely powerful one, with rights and privileges guaranteed to it by special Acts of Parliament. Among the directors were the Marquis of Chandos, the Hon. W. Napier, Sir Charles J. H. Rich, Bart., Messrs. W. H. Smith, Thomas Brassey, and others. Mr. John Aird was the contractor of the line, of which Messrs. T. W. Rammell and J. Latimer Clarke were the joint engineers.

It was in 1895 that Mr. Threlfall first entered the disused tunnel, after struggling and squirming through a heap of débris and lumber in a basement of Euston station, alongside Seymour street. For many yards from the entrance of this terminal there was a trough to allow of the air propelling a car to escape and thus reduce the impact on the receiving buffers. An incautious step upon the rotten wooden platform here precipitated the unwary explorer into three feet of stagnant water, but he nevertheless kept his ardor dry, and after several weeks practically completed his inspection of the whole tunnel (excluding the portion below Holborn Viaduct, which he found full of water), and decided that a fair expenditure would put it in working order for the propelling of cars by electricity.

Having discovered the tunnel and realized its effectiveness, the still more difficult duty devolved on Mr. Threlfall of finding its owners, the original shareholders, or their heirs, together with the necessary plans and papers. It was indeed strange that the mouth-open tunnel, separated from a busy street by merely an iron railing and a few steps, should remain undiscovered even by those of our community whose misdeeds or intentions force them to hide from the inquisitive glare of X 2671's bull's-eye lantern and the clink of his handcuffs. In the troublous times of 1883-84, when misguided wretches were attacking with dynamite bombs London's main thoroughfares and buildings, one shudders to think what the knowledge of the tunnel's existence might have led to on the part of these miscreants. Some dynamite, a line of wire, and a battery spark, and the Nihilist, Anarchist, or Fenian might have sat in safety and ripped a track of death and desolation throughout the metropolis. But there are no apparent signs that the tube was ever the hiding place of any human being. Merely a few skeletons of rats, and presumably cats, judging by the size—what a Homeric combat of "fighting against odds" do these crumbling bones suggest!—and here and there umbrella-shaped fungi where the water condensation is greatest.

Stranger almost than the loss of the tunnel was the disappearance of its owners and the papers that would tell who they were. After eighteen months' hard search in government offices and the five parishes through which the tube runs, Mr. Threlfall realized that neither they nor the original contractors had a single plan of the route. It was not until after a wearying system of inquiries half over England and on the Continent that Mrs. Frances Rammell, the widow of the late T. W. Rammell, a famous engineer, was discovered, and, through her remarkable energy, the original plans were eventually brought to light.

To realize the commercial value of the tunnel's discovery and rehabilitation it is necessary to have some slight idea of the extent of mails and parcels passing not only between Euston and the G. P. O., but also between Eversholt P. O., the other local offices en route, and the two main termini. Practically all the heavy post to the north of Great Britain passes through the Euston Station, and the heaviest hour of the day sees a total of eleven tons of postal matter leave the G. P. O. for the Northwestern Central Station. At present, vans carrying from one and a half to two tons each, and taking twenty-four minutes under the most favorable circumstances, make the connecting journey. Heavy traffic, fog, greasy pavements, or other drawbacks to vehicular motion, may double the time occupied. The contract time for the delivery of the mails to the various stations is eight miles an hour, and the enforcement of this rate of speed is one of the G. P. O.'s chief difficulties. For a time motor-cars were tried, but without success. The road to Euston is perhaps the most difficult of all to make progress along, and there is no doubt the tunnel, when fitted, will be an enormous convenience to the postal authorities.

COMPRESSED AIR APPLIED TO TRAVELING MOTORS BY A NEW METHOD.

While compressed air has shown itself a successful rival of electricity in a variety of problems in power transmission, in cases where motive power is to be supplied to traveling motors, the latter has heretofore completely distanced its rival. The great difficulty encountered in using compressed air for this purpose is that the air is necessarily carried on the inside of the pipe, and is therefore inaccessible except at the ends or outlets of the latter, while the electric conductor carries its fluid on its surface, from which the current can be taken at any point along its whole length. This has been an insuperable objection to the use of compressed air at a moderate pressure as a motive power where the motor travels great distances, as in the case of street cars or other traction. The result has been that while electricity has been applied to this use in a way most favorable to economical results, the advocates of compressed air have been obliged to resort to high pressure reservoirs carried on the cars, greatly increasing the cost of power plants, occasioning delay in recharging and a great sacrifice in economy due to the extremely high pressures required.

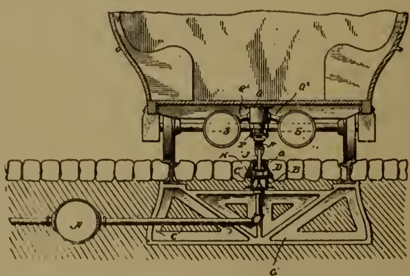


FIG. 185.

In such an unequal contest it is not surprising that electricity has been the victor.

Even in cases where the motor is only required to travel over a limited space, as in traveling cranes and overhead hoists, although compressed air is successfully used, the customary arrangement of flexible hose, supported by carriages, is at best crude and objectionable, occupying as it does much valuable space and in consequence limiting the travel of the motor to a portion of the working space.

The object of this article is to call attention to a recently invented method of applying compressed air to moving motors, which will obviate these difficulties, and will, it is confidently believed, place compressed air in a position to compete with its rival under similar conditions.

This method is exactly analogous to the "trolley system" for electricity; i. e., the line of travel and is drawn thence by the air is carried in conduits parallel to the motor, as required, continuously along the whole length of the line. The device by means of which this is accomplished was designed primarily with a view to its application to street car service, as the cuts indicate, but the principle may be equally as advantageously applied to traveling cranes and other motors of limited travel. In fact, after a description of the device, as applied in street railways, it will readily be seen, without any further explanation, how various other applications can be made.

The figures show the arrangement for a double track road. A (Fig. 185) represents the main conduit or supply pipe, which is laid between the two tracks and supplies air under pressure to cars on both tracks, and its size and consequent construction is, of course, to be determined by the requirements of each case, and depends upon the pressure carried, the number of cars, and the length of the line.

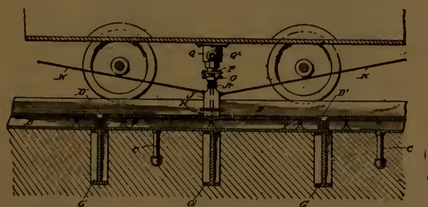


FIG. 186.

This air main is connected at intervals of about 6 feet with the auxiliary main B (Fig. 185) laid in the center of each track, by means of the pipe C.

These auxiliary mains are made of cast iron, and are rectangular boxes about 6 feet in length, and of the section shown in Figs. 185 and 187 being entirely closed, except for a slot C^1, formed in the top the entire length of the casting, into which is fitted a strip of rubber D (Fig. 187), the latter serving as a valve, and having inserted in it at intervals stiffening pieces E of iron, which render the valve rigid transversely but flexible longitudinally.

The strips D are bent downward at their ends, as indicated at D^1 (Fig. 187) and held fast at these points to the main D by a dove-tailed slot D^2, and they are also provided with springs F, which insure their return to the seat after being opened in any part of their length, as will be more fully explained.

Attached to the top of the main B are curbs G, of rolled steel, which form the slot at the surface of the street, and the mains and rails forming the tracks are shown resting on cast iron ties or foot blocks G^1, although this construction might be modified by using wooden cross ties and wooden string pieces to raise the rails to the required level.

The trolley or connecting device consists of a brass box H sliding upon the upper surface of the main B and being where it comes in contact with the valve or the sides of the slot.

The sliding surfaces are to be lubricated by means of oil cups carried on the trolley.

The trolley box H is provided with a small wheel, or valve roll I, which rolls on the valve strip and presses it down immediately on coming in contact with it, as shown in Fig. 188, thus allowing the compressed air to pass into the box H. To the top of the latter is bolted a steel casting J, which is narrowed to pass through the slot and strengthened by ribs, as shown. It is also provided with

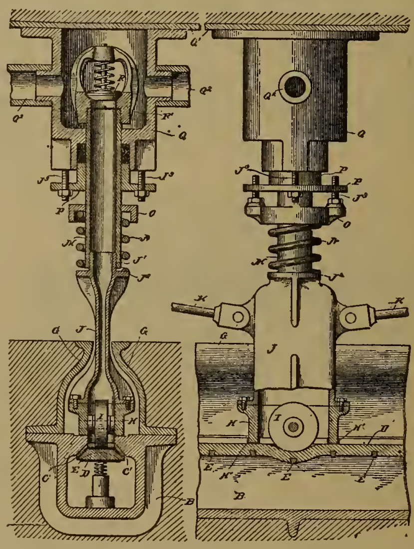


FIG. 187. FIG. 188.

tie rods K to brace it longitudinally. The upper end of the casting J has an extension J^1, which is threaded into the tube M, and resting on its upper flange J^2 is a spring N, which may be adjusted by means of the screws J^3, which bear against the cap plate O and are threaded through the flange of the gland P.

The object of this spring is to compensate for any irregularities in the track and at the same time to overcome the upward pressure at the lower end of the trolley, insuring the latter's remaining firmly on the main B.

The gland P and the stuffing box Q, through which the tube M passes, are fastened to the frame of the car, and the stuffing box fits against a washer plate Q^1, which is placed into position after the check-valve R and its seat-casing R^1, which also serves as a collar on the tube M, have been placed in position.

The air is led from the stuffing box Q by means of the short pipes Q^2 to the reservoirs S, and these serve to equalize the pressure on the motor, and also act as a storage for a sufficient amount of air to start the car if it should be stopped directly on the crossing or turnout, where the trolley would be momentarily disconnected from the supply main.

The motor may be of any ordinary type, as determined by the conditions of the case.

The advantages claimed for this method of street car propulsion are:

First. Economy of first cost.

While the first cost of such a road would be greater than an overhead trolley line it would compare favorably with the underground trolley and be much less than a cable road, while the cost of power plants would be much less than for any of the other systems. All that would be required would be a battery of boilers and a series of steam-driven air compressors, which are much cheaper than either electric or cable machinery, and require less space and consequently less ground and cheaper buildings.

Second. Economy of operating.

As compared with the underground trolley system, the efficiency of the power plants should be about the same, each consisting essentially of a steam plant and a transformer. The efficiency of the line, however, would be greatly in favor of the compressed air system, owing to the leakage from the underground electric conductor, which it is extremely difficult to insulate, and the greater percentage of energy used to overcome resistance in the latter. As the cable system

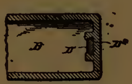


FIG. 189.

is now practically obsolete, it is useless to make any comparison with that, although the advantage would be still greater.

Third. Miscellaneous advantages.

Among these may be mentioned simplicity of machinery, as compared with any electric system, both in the power house or on the car, requiring less technical knowledge to operate or repair, less danger of breakage, in the first place, and less cost to repair when broken. This system also provides the means always at hand for an efficient and quick-acting brake, which is an appliance greatly provided with a soft rubber packing H^1 needed for street car service if high speed is to be attained.

This device, as can be readily seen, can be easily applied to traveling cranes and similar machines, with a saving of space and convenience in operating, but it has another application in which it far surpasses any other system, viz.: Underground railways, because motors operating under this system not only would not vitiate the atmosphere of the tunnel, but would furnish a positive and costless method of ventilation by means of the exhaust, infusing fresh air at all points along the line, and just in the proportion required. This system could be applied to tunnels of existing railways, with the object of ventilation, by using the cylinders of the present locomotives as motors and applying the compressed air while in the tunnel by providing the apparatus with a mechanism for dropping it when nearing the tunnel in a somewhat similar manner to that now employed for taking water from track tanks. When the apparatus was dropped the steam would of course be shut off and the damper closed so as to prevent any smoke, steam or gas from escaping, and the air used as a motive power until the farther end of the tunnel was reached, when the apparatus could be raised and steam used again.

This application could hardly be expected, however, to appeal very forcibly to railway management, as it would entail considerable expense without any immediate visible return, but the vast army of commuters who are compelled to pass twice daily through any of the tunnels leading out of New York, with cars crowded, a temperature of 100 F. inside, and all windows per force tightly closed, would shower blessings on the head of any one who would devise some means of relief.

There are many other minor applications of this device, but the limits of this article preclude anything further at this time. Its object will be attained if it will convince some one of the value of this invention to the cause of compressed air.

W. M. FARRAR.

AIR HOISTS.

Compressed air hoists for the purposes that they are designed for have made an enviable record in machine shops, foundries and other places where air is used. Lately we have heard numerous complaints about the service they give when they are indiscriminately applied to shop work. Some have gone to considerable trouble to make the hoist efficient for all purposes, without satisfactory results; one specific complaint being that air admitted to the hoist to suspend a weight at a fixed point for a considerable length of time, does not do it, as the air will leak and the weight will fall. The superintendent of a prominent manufacturing firm writes COMPRESSED AIR as follows:

"Our experience is that all hoists, as constructed at present, are more or less failures because of faulty valves, poor means of operating valves, and pistons mechanically improper for the service in which they are used. We have been a little unfortunate, probably, in our hoists, in the cylinders. They have been bad, and we have been able to repair some of them, but even after that we have not got to the seat of the trouble. We have tried leather pistons, three snap ring pistons, and hardwood ring pistons. The latter gives us the best satisfaction, yet none of them will sustain the heavy load for any protracted length of time. By that I mean for half an hour. This applies to vertical hoists only, as we do not use horizontal hoists. A hoist that will be simple and effective and which will obviate the difficulties experienced by people who are using them, would be appreciated.

"We have also had difficulty in obtaining a coupling on which the hoist will stay. We blow them off about twice a week."

We will be glad to have the experience of others, and will publish suggestions that may be made bearing upon this subject.

Compressed Air:

The article on air hoists in the last number of Compressed Air may have created a wrong impression on the minds of a great many people who do not use air hoists. Those who use straight lifts know the disadvantages of them and the difficulties attending their use. They also know their good points and what a saving in time and labor they effect with them. The people who do not use air hoists may get the idea that there is no air hoist on the market that will hold

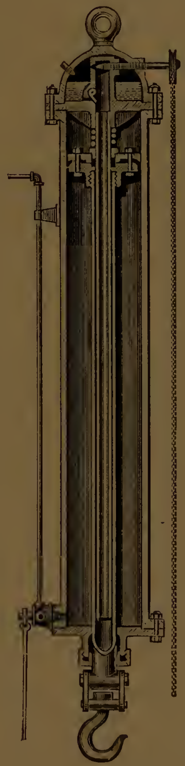


FIG. 190.—RIDGWAY OIL CONTROLLED HOIST.

a load absolutely and without qualification or do successfully any or all the work of hoisting or lowering loads that may be required of it.

There is such an air hoist and we show a cut of it. This is the pneumatic motor hoist made by the Empire Engine and Motor Co. of 26 Cortlandt Street, New York City.

This is a hoist that will do any of the work required of an air lift or electric hoist and do it without the danger or difficulties attending their use for certain classes of work. In the first place there is a great saving of head room as there is no cylinder used, consequently no thought has to be given to the hoist itself in regard to length of lift wanted. The length of chain is its only limit of lifting. It will hoist accurately and steadily one quarter of an inch or twenty-five feet. The method of operating is exceedingly simple: the operator having perfect control of the motor at points. One of the strongest points made in favor of this hoist is its power of absolutely holding any load up to its full capacity at any point of the lift. This point is made without qualification, and the Company guarantee it. It is so constructed that it does not depend on the air pressure at all to maintain the load. In fact, the motor may be detached from frame while load is suspended without affecting the load in the least. Then, too, in starting or stopping or in changing the weight of a load there is no vibration or jumping as in a cylinder lift, consequently no danger of blowing out cylinder heads or hose connections.

When made of brass the tubing is taken just as it comes from the mill, and is neither round or smooth like a bored cast iron cylinder. So the piston must be made a very loose fit, or it will stick while the pliability of leather is depended upon for it to adjust itself to the inequalities and roughnesses of the bore. Such a hoist will leak more or less, of course, but for looks and work it will do fair service and it is cheap.

When steel pipe is used it is bored out, but because it is only a little more tnan ⅛ inch thick, it is hard to keep it round, rarely is bored round, and when the weld is made, always shows up more or less seamy when bored. The leather cup as in the brass pipe is expected to be obliging, and so such hoists while they must leak, for lots of work, will pass muster, and they are cheap.

Then to prevent these air hoists from becoming veritable air guns and shooting the piston through the roof or at least try to do it. When anything goes wrong, elaborate valves must be used. In a little while these valves get leaky of course, and the load won't stay where the owner wants it, and then goes up the plaintive cry we just now hear from your correspondent.

An air hoist needs but one simple valve, and that a cock like you use on your gas fixture which runs for years without a smell, that is all and that is enough. To prevent jerkiness and running away when anything happens, such as the breaking of a chain or the careless throwing on a full head of air when there is no load, we submit our plan of oil governing by putting a quart or two of oil in the piston rod. This with our cast iron bored cylinders costs more than the pipe affairs and is worth more. Whether we can sell them depends; to be determined by how sick people are of the other sort. We have just put it on the market. It is a magnificent tool, but you know how things are, the fellow who makes the cheapest thing that will pass muster knocks the persimmon.

CRAIG RIDGWAY & SON.

Engineers, Founders and Machinists.

Editor Compressed Air:

Dear Sir—Have been a reader of Compressed Air for over a year, and while I am very much interested in air power and hope to see its adoption in many places where it now is not, I am not in a position to put any of it to good use except in the way of keeping up a fresh supply for respiration purposes.

At one time I was quite familiar with clearing up railroad wrecks and I remember the slow process of the hand derrick for hoisting and removing the debris. On a busy road where both main tracks are blocked, this always means a big delay.

Some time ago I happened into the foundry of J. J. Radley & Company, New York, and found there a little motor of the reversible and direct-acting piston type attached to the gearing of an old-fashioned hand derrick and operated by compressed air for lifting heavy loads. This little motor easily lifts 8,000 pounds 10 feet per minute, and by changes in the gearing can be made to lift almost any load.

If this motor was attached to the derricks which are erected on wrecking cars, it would enable wrecking crews to clear up wrecks very much quicker than they do by hand, and I believe it would figure out a considerable saving per wreck. The whole expense of putting in the appliances would not exceed $200; that would buy the motor and an air receiver. Every engine pulling a wrecking car has an air brake pump and can supply sufficient air for all requirements. The receiver should be of good capacity so that rapid work could be done without danger of diminishing the air pressure at a time when most needed. The receiver can be located on the derrick car or under it. From the time the engine is coupled to the wrecking train the work of compressing air may begin, and long before it reaches the wreck a good supply may be laid up. The intervals between each lift are usually long enough to allow the supply of air to be replenished. Should the air fail at any time, which is not probable, the derrick can be operated by hand as usual. It takes at least four men and sometimes more to raise an ordinary coal "jimmy," and it takes several minutes to wind up by hand what can be done in a very few seconds by air. One man to handle the valve is all that is required, and the time saved in raising ten coal "jimmies" would be at least an hour.

I believe some of the larger railroad systems have steam cranes for wrecking purposes, but I know there are many roads which still use only the hand derrick. The work of attaching these motors is not difficult, and to the master mechanics who read your interesting journal I submit my plan, if you will be kind enough to publish it. A SUBSCRIBER.

Harlem, Nov. 8th, 1898.

AIR HOIST IN MINING OPERATIONS.

The Mansfield Coppen Mining Co., in Germany, have installed a compressed air hoist in their mines, as it enables them to raise or transfer the cars from one track to another more expeditiously than heretofore possible by use of the hoisting screw. A compressed air cylinder is arranged upon a movable frame suspended at a height of 6 feet 8 inches. The frame can be moved on the rails with great ease, the air being supplied by an india rubber hose. The piston rod of the air cylinder is connected to a system of levers, which are arranged for the purpose, grabbing and lifting the wagon as soon as the air valve is opened. The releasing and lowering of the wagon is effected by opening the exhaust valve.

AN AIR HOIST FOR MERCANTILE PURPOSES.

Pedestrians who pass the store of the Nason Mfg. Co., 71 Beekman St., New York, are often puzzled by the ingenious method employed in unloading

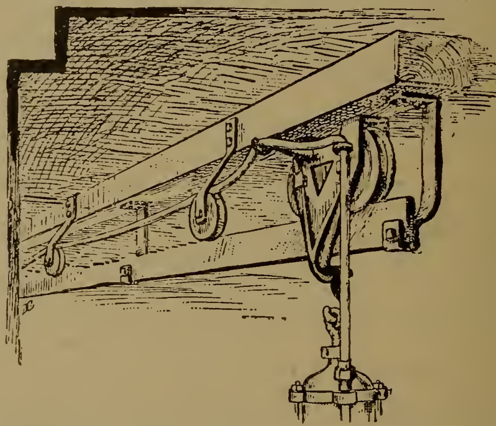


FIG. 191.—THE UPPER PART OF THE HOIST SHOWING TROLLEY AND HOSE.

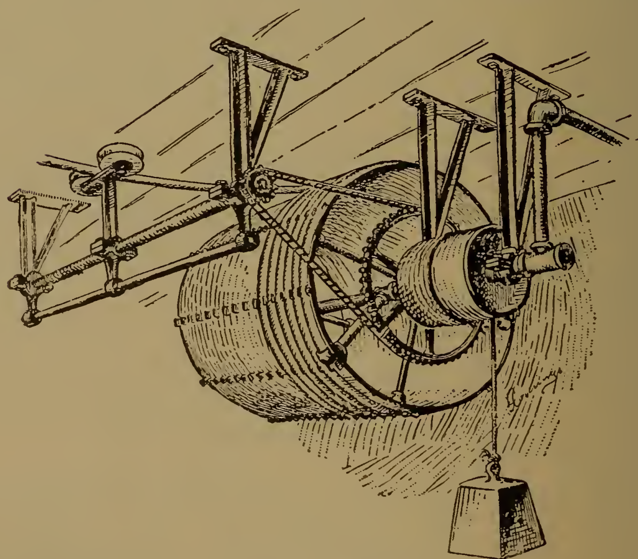


FIG. 192.—HOSE DRUM.

boxes, barrels, radiators, bundles of pipe, crates of earthenware, boilers, ranges, furnaces and innumerable other heavy pieces, from the dray that stands in the street in front of the door. A crane is swung over the sidewalk, and it supports a hanging cylinder which has been conducted from the interior of the store upon the trolley rail of the crane. To the cylinder is attached a line of flexible rubber hose, which being supported on rollers having anti-friction bearers, leads to the rear of the store, where it winds or unwinds upon a metallic drum, as the trolley is pushed backward or forward upon its rail. Compressed air at from 65 to 75 lbs. pressure is supplied to the cylinder through the hose—it being taken in through a stuffing box at the centre of the drum. The air is stored in a suitable reservoir, into which it is pumped by a small compressor—the latter starting and stopping automatically by means of variation in the air pressure.

When the cylinder reaches the proper point it hangs pendant over the load of merchandise; the driver of the dray opens a valve and thus admits the compressed air beneath a piston. A piston rod projects through a stuffing box on the under side of the cylinder, and being provided with a hook, clamps of varying

FIG. 193.—UNLOADING MERCHANDISE IN STORE.

patterns which are hung to it are attached to the article to be unloaded. The valve is closed and another one opened, when the load rises and is then readily pushed into the store and deposited in its proper place along the line under the track.

The cylinder is the oft-described "air hoist," and this particular one, combined with the rest of the apparatus, is known as the "Nason Pneumatic Lift." It was designed and patented by Mr. Carleton W. Nason several years since, and has been in operation at the stores of the Nason Manufacturing Company for about three years, during which time not a cent has been expended for repairs of any sort.

Fig. 191 shows a piece of the track with the trolley on it, and also the means of supporting the hose between the trolley and the revolving drum. This feature is both important and necessary, as it permits of an extension of the line up to, say, 150 feet in length without undue friction.

Fig. 192 shows the reel with the device for winding the hose upon its pitch line, which is accomplished, it will be noticed, by means of a pair of rolls fastened to a carriage which slides upon a lead screw—the latter being driven by a pair of sprocket wheels and chain belting—their dimensions being such that the central point between the rolls is always opposite the point on the drum upon which the hose is to be rolled. A weight suspended from a smaller drum, which is attached to a shaft common to both drums, takes up the slack of the hose between the rolls, and keeps it always under moderate tension.

When our artist appeared upon the scene, a large 4 x 24 radiator was being taken off the dray and into the store. Its weight was about 600 pounds, which is

FIG. 194.

much within the capacity of the lift. The cylinder in use with this hoist being five inches in diameter, it gives a lifting capacity with the air pressure used of about 1,250 pounds. Other stores in the city are about to be equipped with the Nason Lift, and its use may extend to a long list of applications in commercial lines and wherever heavy articles are to be transferred. This hoist is particularly valuable in New York, Boston and other places where narrow streets abound. The load is discharged rapidly and relieves the blockade that so frequently occurs on these streets. Ships may be loaded and unloaded in the same manner. The time that may be saved in discharging cargoes would also play an important part in increasing the facilities and decreasing the cost of ocean transportation.

MINE HOIST.

The hoist (Fig. 195), shown on page 555, is one of Thos. A. Edison's devices used at the Ogden Mine at Edison, N. J.

In the mine compressed air rock drills are used, and when the rock is finally broken and lies upon the bed, a bridge, which is poised transversely across the mine, and it fitted with crane and hoist appliances, is brought to a standstill over the rocks, that are often excavated in lumps weighing four tons (8,960 lbs.). These are chained, and a swinging compressed air hoist is attached. By the ap-

FIG. 195.—COMPRESSED AIR OPEN CUT MINE HOIST.

The swinging cylinder is the Compressed Air Hoist. Five of these hoists are along the rail of the bridge.

plication of air to the cylinder, the rocks are rapidly elevated to where the skips lie, and in which they are placed.

HANDLING BAGGAGE BY COMPRESSED AIR.

The illustration (Fig. 196), on page 556, will at first sight impress our readers as a very desirable and clever use of compressed air.

Mr. G. H. Wall, of Cadillac, Mich., who is connected with the Grand Rapids & Indiana Railroad, last spring built and applied the pneumatic baggage handler shown in our engraving. This device proved itself, in daily work, able to handle heavy baggage more rapidly than it could otherwise be handled, and to, moreover, do away with breakage of baggage. It consists of a very simple arrangement of air cylinder and baggage support. The cylinder rests on the threshold of the car door. The upper portion of the baggage support is semi-tubular in form and is swiveled to the cylinder; and one side of this tubular portion is cam shaped and bears against a plate placed just above the door. Thus when the support is rising it is automatically swung around by the cam action, carrying the baggage into the car. The device is operated by air drawn from the train line to a special reservoir and is handled by the train baggage man by means of suitable cocks on the inside of the car. It has a lifting capacity of 500 lbs.,

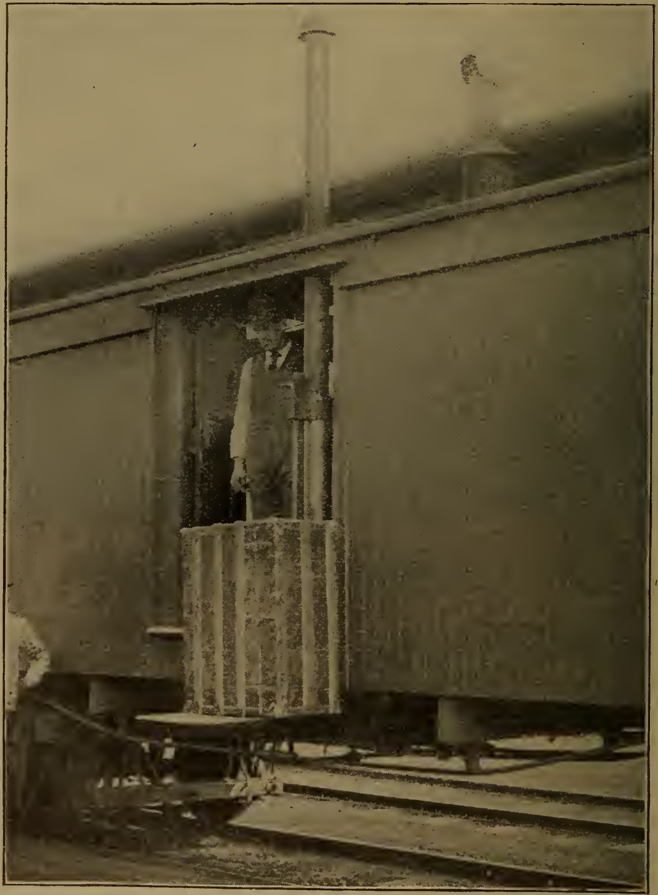


FIG. 196.—BAGGAGE HOIST.

with 70 lbs. of air. An auxiliary spring scale device, located at about the center of the vertical length of the baggage support, provides for weighing the baggage as it is handled. It is said that the time consumed in loading a trunk of 218 lbs. was 3½ seconds, and the time of unloading 5½ seconds. For country stations the above appliance will save many a trunk from being smashed, because only one man usually attends trains at such points, and the result of one man handling a heavy trunk is well known.

CINDER HOIST ON THE D: S. S. & A. R. R.

The accompanying illustrations from the *Railway Age,* show a cinder hoist that has been in successful operation on the Duluth South Shore & Atlantic Railway at Marquette for the past two years. It is operated by air and is estimated to be a money-saver to the extent of at least $600 a year. With this arrangement

FIG. 197.—CINDER HOIST IN D. S. S. & A. RY.

five iron buckets can be hoisted, dumped and replaced in the pit again on an average in 15 minutes, removing in the operations the same quantity of ashes as would take a man with a shovel at least three hours to handle. The ashes are raked from ashpans directly into the ash buckets, and the same is done with cinders in the front end, no shoveling being required. The act of hoisting and dumping is done by the engine hostler and his assistant.

A sunken track will be noticed located parallel with the cinder pit (the distance from centre of cinder pit to centre of this track being about 10 feet), on which is standing a cinder car, which was built especially for this service. One of our views shows the bucket containing the cinders hoisted out of the cinder pit; the other view shows the bucket dumped over the car. When not in use the crane is swung around alongside the end of the round-house.

The hoisting cylinder is hung to a four-wheeled truck on top of the crane, the piston of the horizontal cylinder being attached to the truck. Air is admitted at either end of the horizontal cylinder alternately for pushing out the loaded bucket to the proper position for dumping and pulling it back after being dumped. Air is furnished from the shop air plant. When shops are not working, any engine having its fire cleaned can couple to an air hose coupling attached to the crane and perform the operation of hoisting and dumping the buckets.

The crane has a radius of about 30 feet, and by manipulating the horizontal cylinder properly the buckets may be dumped anywhere on a 32-foot car without

FIG. 198.—CINDER HOIST ON D. S. S. & A. RY.

moving the car until it is loaded. The old way of loading the cinders was to keep a man continually shoveling them out of the cinder pit into the car, at a cost on an average of $50 per month. Now the cost of getting rid of the cinders is practically nothing, as far as labor is concerned. The whole cost of the plant, including the five iron ash buckets, was $2.50.

A TELESCOPIC AIR LIFT.

The cut shows a recently patented air hoist which may be found serviceable in some special situations where a considerable vertical lift is required with only a limited space in which to move. A specially designed valve is used in connection with the hoist, but this it is not necessary to describe, as any valve may be used which will admit compressed air from the service pipe for hoisting and discharge to the atmosphere for lowering, accordingly as the valve is moved in one direction or the other.

As will be seen, the arrangement consists of one cylinder moving within another, with a piston in the inside one and a rod passing down through a central

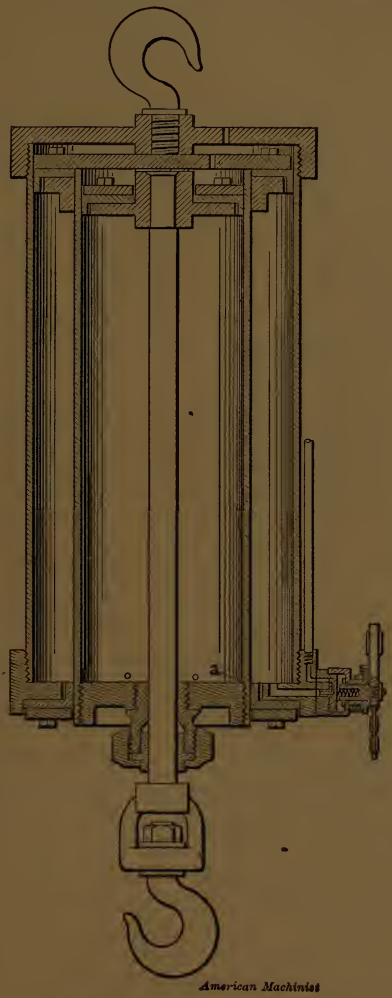


FIG. 199.—A TELESCOPIC AIR LIFT.

stuffing box for hoisting. Obviously more cylinders, one within the other, might be used if a greater vertical travel was required. The cut shows both the inner cylinder and the piston within it at the upper limit of their travel, and sustained in that position, we may assume, by a pressure of air. The area enclosed between the inside of the outer cylinder and the outside of the inner cylinder is somewhat greater than the internal area of the inner cylinder, so that in hoisting the inner cylinder will always be hoisted to the top before the piston within it begins to rise. In lowering, this movement is reversed, the piston first descending and then the cylinder. This is necessary because there is no air passage to or from the interior of the inner cylinder except when it is up, and then holes (*a*) at the bottom are uncovered. With the parts in the position shown, if the valve is gently opened and the air permitted to escape slowly from the outer chamber, it will also pass out from under the piston, and the piston will descend, and when the piston reaches the bottom its cylinder will then begin to descend, if the discharge of air continues. For hoisting, as there must be no pressure above to resist the pressure below, vent holes are provided in the upper heads of both cylinders. Leather packing is used at the top against the inner surface of the outer cylinder and at the bottom against the outer surface of the inner cylinder, and also for the piston inside the small cylinder. The inventors are Charles O. Bulock and Bertram C. Donnelly, Milwaukee, Wis.

A SELF-PROPELLING AIR-HOIST, WITH UNLIMITED TRAVEL.

Following are the description and illustrations of a novel and remarkable traveling air-hoist which cannot fail to excite the interest of shop readers. It is a complete air hoist, which travels as far as the overhead rail extends in either direction, going around curves, or switching to other lines, as required, with a constant connection with the air supply, all under the control of the operator, who rides with it. It is, however, not necessary for an operator to ride with the trolley, as it can be made to travel between points, starting and stopping automatically. In that case the hoist and motor are operated by pendants from the floor. The motor and the hoist, wherever they may be along the line, are both always in full connection with the air supply, and without any hose to look after or any outside connection.

The means by which the air supply is conveyed to the trolley and the connection constantly maintained are not shown herewith but work satisfactorily. Along the runway of I beams is suspended a feed pipe of cold-drawn steel tube, and this is covered by a thin steel casing, which normally is closed, but which is capable of springing apart at the bottom. The air tubes are in 8-foot lengths, and are joined together by couplings which form a bearing for a valve in each with the valve operating mechanism. The couplings and the pipe have a true and uniform continuous surface externally. Surrounding the air pipe is a flexible receiver of such diameter as to allow a given area between the outer wall of the feed pipe and the inner wall of the receiver. The receiver travels with the trolley, and connection is made to the trolley through a hollow arm which is a part of the receiver and extends down through the slot in the casing. The lengths of the feed pipe being 8 feet 6 inches from center to center of valves, the length of the receiver is 9 feet, so that one valve is always open inside the receiver. The ends of the receiver fit the outside of the feed pipe with self-packing stuffing boxes.

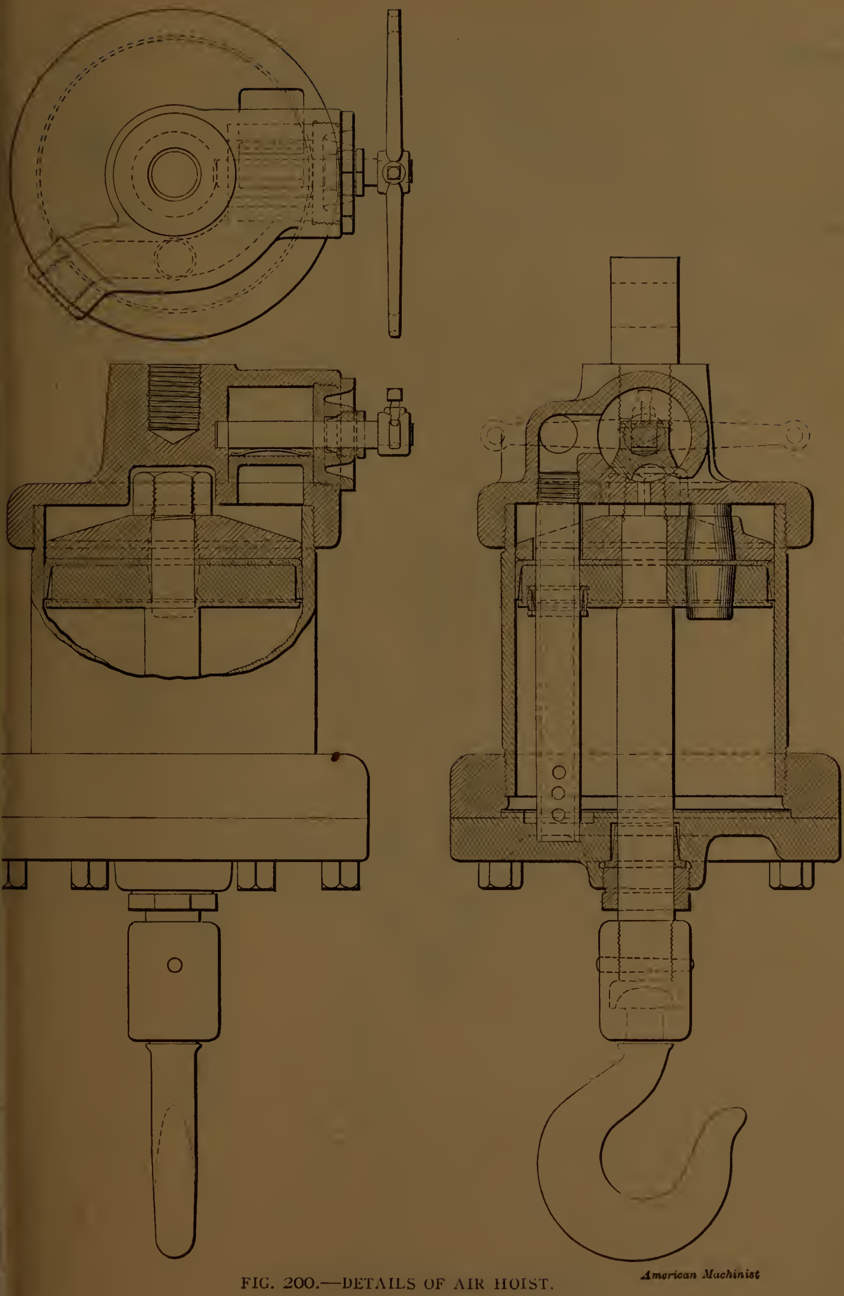


FIG. 200.—DETAILS OF AIR HOIST.

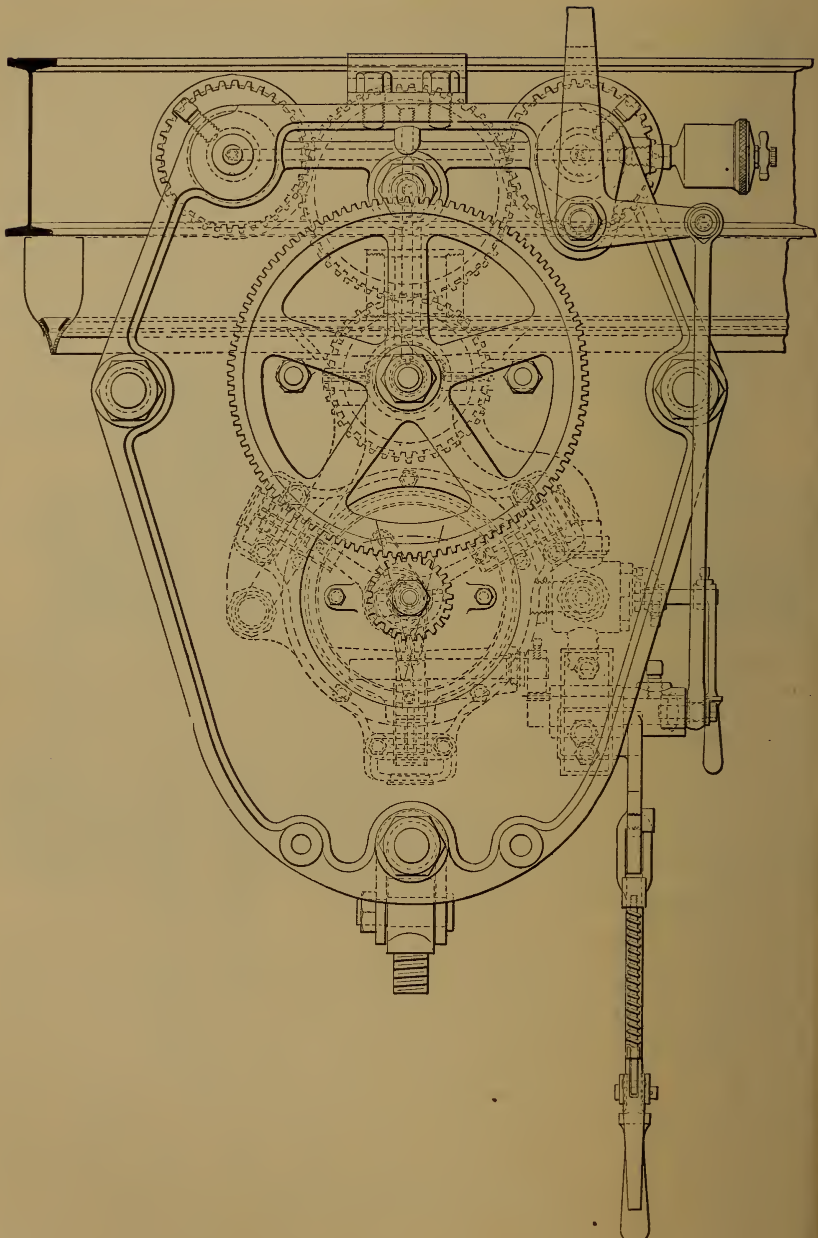


FIG. 201.—TROLLEY AND MOTOR.

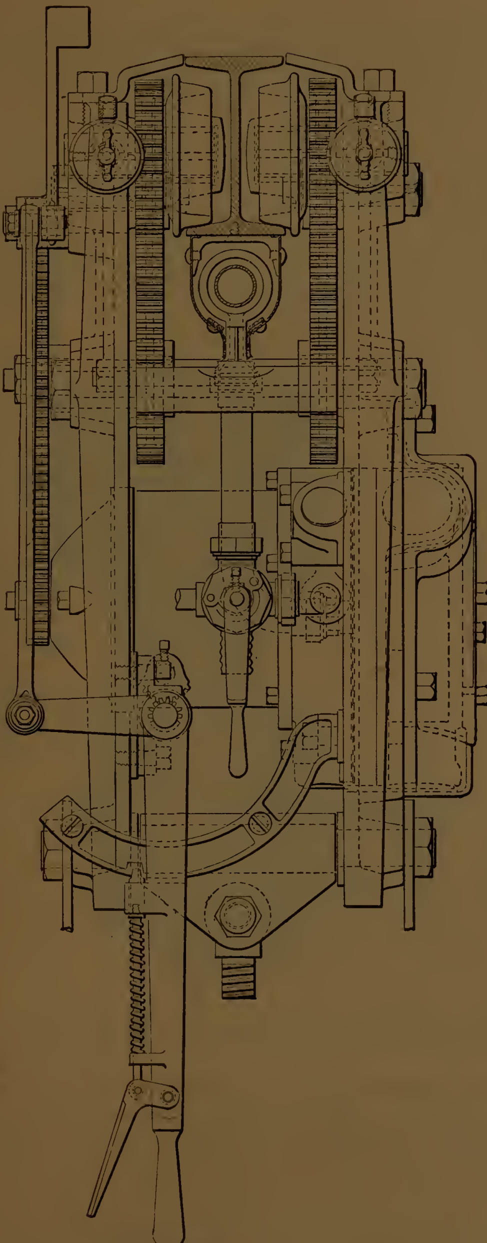


FIG. 202.—TROLLEY AND MOTOR.

These ends, externally, are made conical, so that as the receiver passes along the pipe the conical surfaces raise the tappets attached to the valve levers. The conical mouth of the receiver raises the tappet, and a longitudinal rib within the receiver keeps the tappet up until it emerges at the other end of the receiver. When both tappets of either lever are up the valve connected with the middle of the lever is raised, and when the tappet drops the air valve is closed again. Supposing the receiver to be moving to the left, the right-hand valve is seen to be open, and the first tappet of the left-hand valve lever has been raised. When the second tappet is reached and raised, the left-hand air valve will be open, and almost immediately, if the movement of the trolley and receiver continues, the right-hand valve will close, and thus the valves will be opened successively and the pressure in the receiver will be maintained.

Fig. 201, showing the trolley and motor, requires little explanation here. The motor is of the three-cylinder type. With the pressure applied to the outer ends only of the cylinder the trolley can attain a speed of 400 feet per minute, if necessary. The motor runs at such a speed as to develop all the power required to move the trolley with its heaviest loads; the motor shaft carries a small pinion which connects with the largest gear, and small gears on the same shaft connect with intermediate gears that mesh into gears on wheels on both sides of the trolley. Levers for reversing and for the throttle are provided. After the air has done its work in the motor, instead of allowing it to exhaust into the atmosphere, it is led through another hollow arm back into the casing, which naturally creates a stronger air pressure flowing from within the casing than the atmospheric pressure without, thus preventing the possibility of dust settling on the feed pipe and valves. This exhaust air at the same time carries oil in the form of spray from the motor, which serves to keep the feed pipe well lubricated.

At switching points the pipe casing and beam are broken in order to shift the main track to the switch track. The switch ends of the feed pipes are plugged, and the air supply is led to the other ends of the pipes.

The hoist, Fig. 200, has some original features. In air hoists, as usually operated, the air for hoisting is admitted under the piston, and when the load is to be lowered this air is discharged into the atmosphere, the weight of the load being sufficient to bring it down, although when there is no load the weight of the piston and rod is not always sufficient except for very slow movements. The usual air hoist, therefore, normally has no air pressure upon either side of the piston. In the present hoist there is full air pressure upon both sides of the piston, except when hoisting. The air pressure is conveyed to the lower side of the piston by means of the vertical pipe seen within the cylinder. The upper end of this pipe is in constant communication with the air supply, and the lower end of it in as constant communication with the lower end of the cylinder. There is a stuffing box in the piston where this pipe passes through it. The piston also has on both sides of it a wooden block, which serves as a buffer and prevents the shock of metal to metal when the piston touches either end of the cylinder. No operating valve is connected to the lower end of the cylinder. When a load is to be hoisted the pressure is released from the upper side of the piston and the hoist ascends. For lowering, the pressure is readmitted above the piston. When the pressure is on both sides of the piston there is an unbalanced pressure downward equal to the area of the piston rod below, and this differential pressure operates in addition to the weight of the parts to cause the piston to descend. This apparatus is made by the Pneumatic Crane Co., Pittsburg, Pa.—*American Machinist.*

PNEUMATIC FURNACE DOOR HOISTS AT PARKGATE.

At the Parkgate Iron and Steel Works an effective method of lifting or lowering the doors of the open-hearth furnace by compressed air is in use.

The air is compressed by a Westinghouse pump fixed on to the wall of the power station building. The pump is shown in Fig. 203; besides operating the

FIG. 203.—WESTINGHOUSE AIR PUMP, PARKGATE WORKS.

hoists for the furnace doors it also works some pneumatic tools, and the feed-motion of the hot saw. It gives air at 80 lbs. pressure. This form of pump has for some years been employed on locomotives in connection with the Westinghouse Brake with the most satisfactory results, there being over 30,000 in use for this purpose alone. Owing to their small size, their compactness, portability, and the readiness with which they may be fixed to a post or wall by means of four bolts only, they are very suitable where space is the chief consideration. In mining work, being self-contained, they may be lowered down shafts and suspended by a chain; and, having no dead point, they may be started and stopped from a

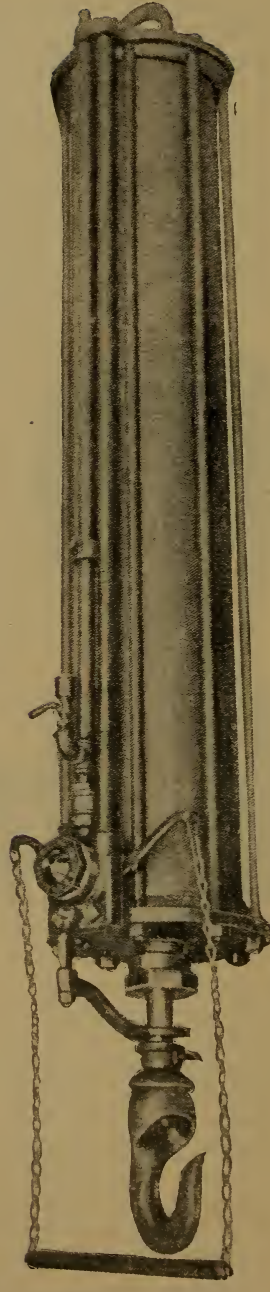


FIG. 204.—VERTICAL PNEUMATIC HOIST.

long distance. The consideration of space was the one which determined their use in the power house at the Parkgate Works. The Westinghouse type of pump is of so familiar a design that we will not take up space in describing it. We may remark, however, that the valves of the air cylinder are of the ordinary description. Each upward stroke admits air below the piston, and discharges air from above the piston; and each downward stroke does the reverse. The valves may be easily removed and examined. The lift of the discharge valves does not exceed 1-32 inch. The pumps have 10-inch air and 10-inch steam cylinders.

The air hoists used at the furnace are of the vertical type, and were furnished by the United States Metallic Packing Company, of Bradford. The hoists are 5 inches diameter and 4 feet stroke, having a lifting capacity at 80 lbs. air pressure of 1,410 lbs. With this size of hoist, 3½ cubic feet of air at 80 lbs. is required to lift the maximum load 4 feet. The hoists have self-closing valves, safety check, oiling device, automatic stop, and ball and socket hook. The cylinders are made of special steel tube. The valve is self-closing by means of a spring, as soon as the hand chains are released. An adjustable stop is attached to the piston-rod, so that the load may always be stopped at the same point if desired. A safety check is fitted so that the load cannot fall in case of the breakage of air hose while hoisting.

Speed adjustment is provided to govern rate of hoisting, or lowering. These hoists are made with a standard lift of 4 feet. The air hoists at Parkgate are provided with balance to take the weight of the furnace door, so that the hoist has only to overcome the difference.

THE DUTTON PNEUMATIC BALANCE LOCKS FOR CANALS.*

By Chauncey N. Dutton, New York, Member of the Institute.

These locks float on compressed air confined in their lower open-bottomed air chambers, whence it displaces water. Each lock carries a gated tank containing sufficient water to float the boats. When one lock descends the other ascends, the descending lock impelling the air from its air chamber into the air chamber of the ascending lock through a 13-foot, valve-controlled connecting type. No compressed air is discharged into the atmosphere or wasted. The moving force is an excess of weight in the descending lock, in which the draft of water is one foot greater, such "surcharge" being 330 tons. The greatest energy-rate is 1,150 horse-power; the average, 115 to 150 horse-power.

At Cohoes, the lift is 144 feet. At Lockport, the normal lift is 57 feet 5 inches, and the extreme lift, when floods raise the upper level, 62 feet 5 inches.

*An address delivered before the Franklin Institute, Philadelphia, November 16, 1897, on the "Pneumatic Balance Locks," approved by the State Engineer and adopted by the Canal Board of the State of New York, to replace five pairs of lift locks at Lockport, and two pairs of guard locks between Lockport and Buffalo; and sixteen pairs of lift locks, known as "The Sixteens," at Cohoes, on the Erie Canal, in New York State. Revised by the author for publication.

The least draft is 12 feet; the width, 28 feet at the bottom and 30 feet at the top; the clear or effective length 310 feet.

They will pass up-stream two boats drawing 12½ feet and carrying each 1,350 tons, or 2.700 tons of cargo per lockage; and down-stream two boats drawing 13½ feet and each carrying 1,450 tons, or 2,900 tons of cargo per lockage.

They will make their stroke in one minute, and, allowing for entry and exit, are expected to detain boats eight or ten minutes.

The locks are built of steel.

Each has an upper, gated lock chamber, and a lower, open-bottomed air chamber containing compressed air, on which it ffoats, and as the volume of its

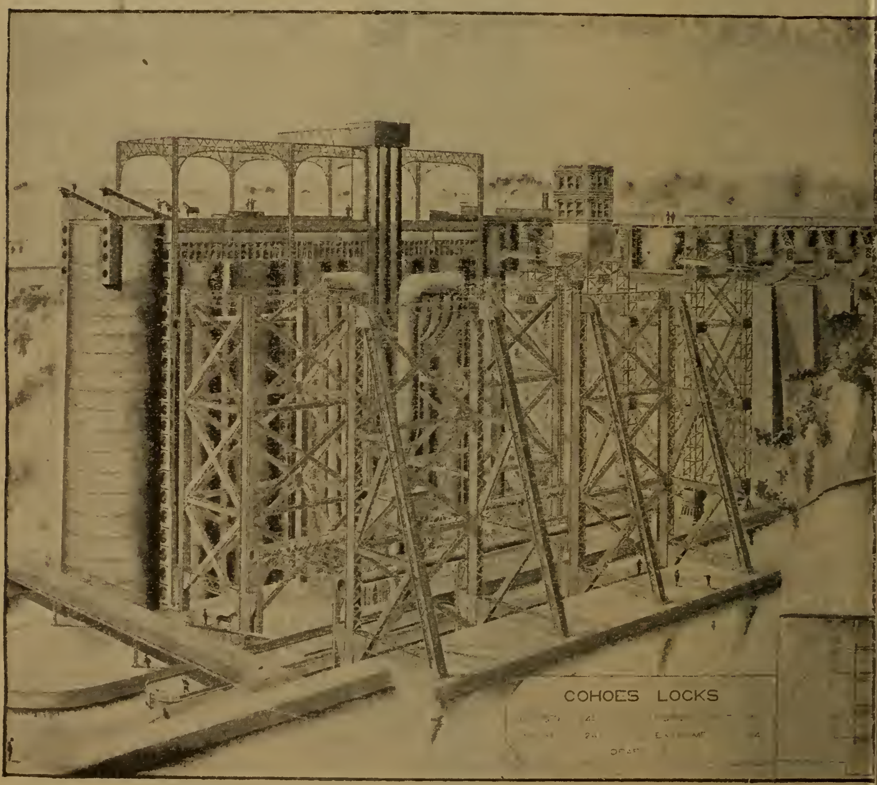


FIG. 205.—COHOES PNEUMATIC LOCKS—ERIE CANAL.

air-charge is varied, moves up and down in a pit or deepened portion of the lower level of the two which they connect.

The locks are kept from tilting sidewise by guides, and from pitching endwise by an automatic leveling apparatus, consisting in fixed racks, anchored to terra firma; parallel racks built on the locks, and hollow built up shafts armed

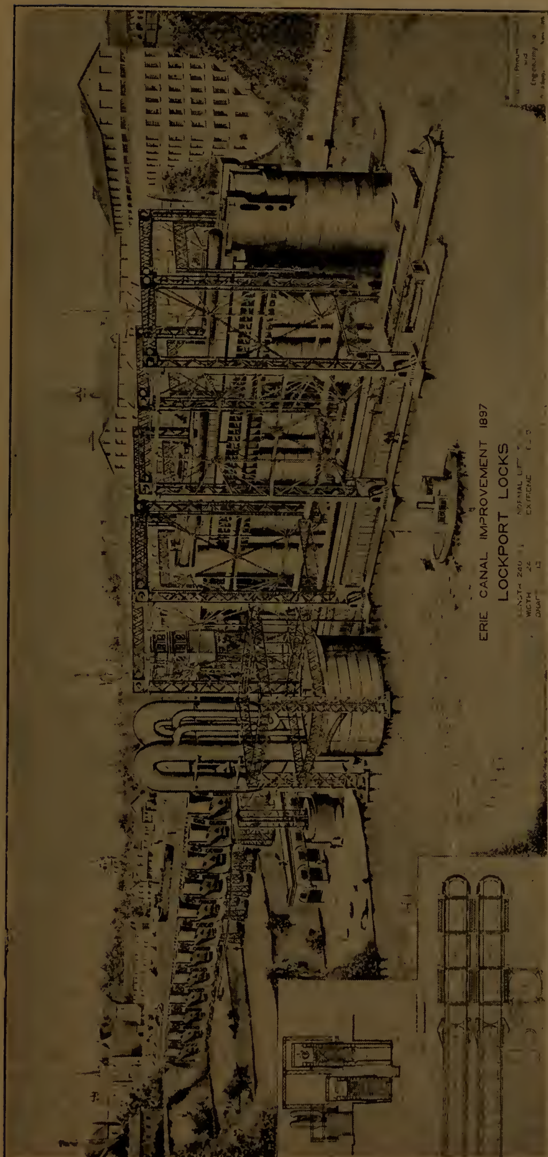


FIG. 206.—PROPOSED PNEUMATIC LOCKS, ERIE CANAL, LOCKPORT, N. Y.

with pinions, which mesh with the opposite parallel racks, on which they hang, without other bearings, and between which they roll when the lock moves.

The air chambers are so proportioned that they automatically differentiate the air pressure, so that the lock which descends forces the elevated lock up against its anchors with an effort exceeding by one-third the weight of said lock and its load, so that it may be connected with the upper level, and used in the roughest manner with entire safety.

The devices to retain the elevated lock against the unbalanced hydrostatic pressure, and the gates and other parts which are liable to ramming, will sustain ramming by boats going 3 miles per hour.

If injured boats sink in a lock, it can be used as a dry dock.

The locks can be raised clear of the water for painting and repairs.

At Lockport, each lock weighs 1,500 tons, and will contain over 4,500 tons of water. The weight in motion exceeds 12,000 tons.

The first locks at Lockport, opened in 1825, passed boats 3 feet 5 inches draft, 14 feet 5 inches wide, 78 feet 8 inches long, carrying 80 tons. They were replaced about 1838 by the present stone locks, which pass boats 6 feet draft, 17½ feet wide, 98 feet long, carrying 250 tons. These locks are in a remarkable state of preservation for old limestone masonry exposed to our northern winters. The stone shows little decrepitation, and most of the joints are still tight, showing that the cement was good.

The detention at the present locks is frequently several hours, and never less than one hour, because the fleets have to be broken up. The new locks will pass double-headers in eight to ten minutes.

The present stone locks cost $698,000. The first estimate for the steel locks, made in December, 1896, was $576,000, but when completed plans were adopted by the Canal Board, June 24, 1897, the estimate was put at $499,000. The market prices of steel and machinery fell sharply in the interim, but have now advanced ,and when the enlarged locks are put under contract, which will be when the Legislature makes appropriation for them, the work will cost about $1,000,000. The Cohoes locks will cost one-half more.

It will be seen that the new locks at Lockport will cost about one and five-eighths the cost of the stone locks. They will handle units twelve times as large in one-sixth of the time. The dollar invested in them has, therefore, more than forty-four times the earning power of the dollar invested in stone locks.

The charactertistic features of the locks may be described briefly as follows:

(1) Compressed air is substituted for water as the element of translation and support of the locks and vessels. Increasing the height of lift does not increase the pressures, and, therefore, locks of any height are practicable and much cheaper in first cost and in operation than a flight of low lift locks.

(2) The working pressures are very much reduced, the maximum being about one and one-half times the draft.

(3) The motion of translation is uniform, having no tendency to accelerate, being regulated by the velocity at which air can pass through the conduits with the given head.

(4) The locks have absolute immunity from falling. The pneumatic lock falls up, if it falls at all. It is pressed up firmly against the anchors with an effort much greater than the weight of the lock and its load. If the anchors yield, the lock is forced up to a height such that the air in the air chamber is expanded to equilibrium with the load, and a volume of water equal in weight to

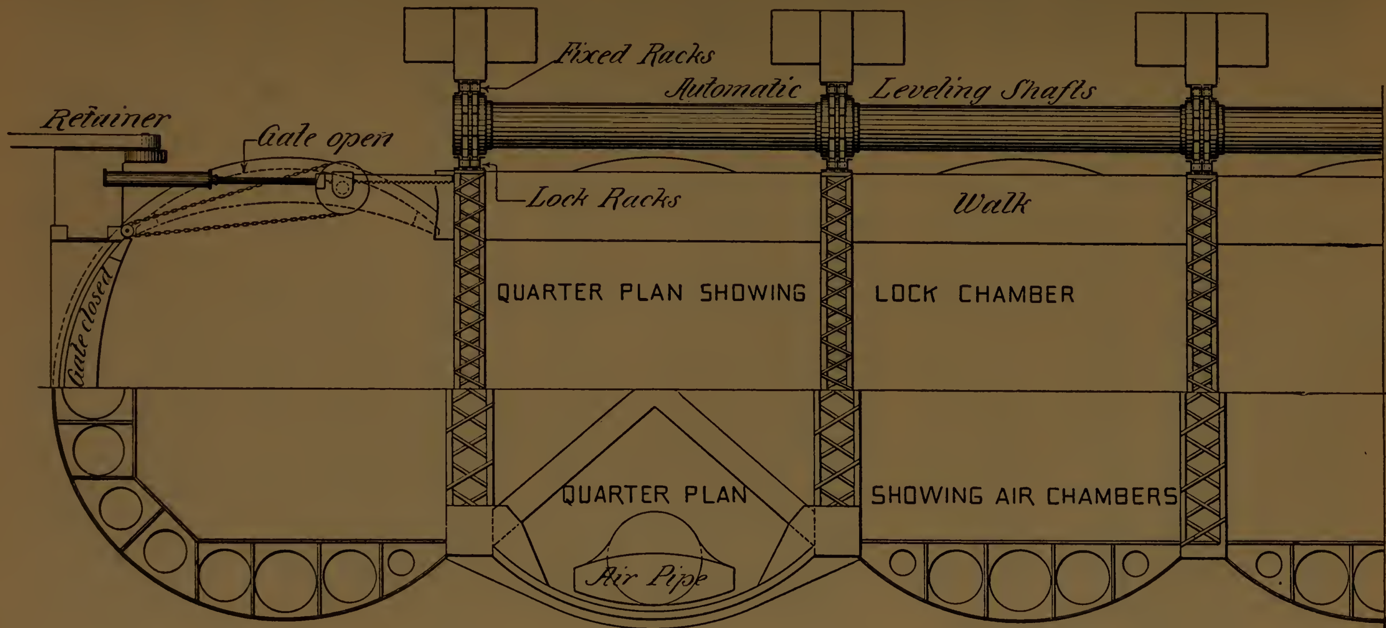


FIG. 207.—PROPOSED PNEUMATIC LOCKS, ERIE CANAL, LOCKPORT, N. Y.

the difference between the load and its initial excess of buoyancy enters the air chamber.

(5) The speed can be very great, because air flows at high velocity with a slight head.

(6) Working the locks in balance, by slight differences in weight, saving 95 per cent. of the water heretofore used, and avoiding heavy currents in the canal sections.

(7) The water-trap valve for controlling the air conduit.

(8) The powerful automatic leveling, or synchronizing gearing, of construction cheap, such that the price per pound does not increase with increased power.

(9) Dispensing with the dry-dock necessary in other types of lift lock and operating the locks directly in the lower level of the canal, in a pit; the pit in which the locks work being part of the lower level.

(10) The substitution of steel, mainly in tension, for masonry in the lock structures.

(11) The substitution of elastic resistance for mere stability due to dead weight, and the consequent reduction of strains due to shock, so that they can be taken care of economically.

The principal elements of design are:

(1) The locks, which float and work in a pit formed in the lower level, and are identical structures, each having an upper gated lock chamber for the vessels and water to float them, and a lower open-bottomed air chamber containing the compressed air on which they float.

(2) Valve-controlled air conduits for transferring air from one lock to the other during translation.

(3) Anchorages to restrain the super-buoyant elevated locks.

(4) Guilding structures to prevent the locks from tilting sidewise.

(5) Automatic leveling, parallel motion, or synchronizing apparatus, to keep them from pitching endwise.

(6) A pneumatic accumulator, which is connected with the elevated lock and maintains a constant working pressure therein, automatically compensating for changes in density and temperature of the adjacent atmosphere.

There are other important elements connected with the locks, which, while desirable, are not absolutely essential, namely:

(7) Hydraulic stops and accumulator-intensifier, by which the elevated lock can be perfectly controlled and adjusted in position.

(8) An interlocker, or sequence machine, which orders the operations incident to the motion of the locks, by means of valve-controlled compressed air transmissions.

(9) Automatic stop machines, one geared to each lock, adjustable to varying water levels, which prevent the locks from running away and automatically control the variations in depth of water when elevated.

A recital of the difficulties will aid in forming a clear conception of the motive and functions. A lock is the heaviest of engineering structures, carries per square foot a load greater than the load per running foot of the heaviest railroad bridge, and is subject to tremendous and cumulative distorting forces, which necessitates that the structure be of simple type and extreme power, and automatically leveled and controlled by apparatus strong enough to beyond preadventure arrest distorting forces in their incipiency and annul their cumulative tendency.

The locks are liable to be bumped and rammed and to have boats carry away the outboard gate and sink with the boat's nose overhanging the end of the lock. A boat in this position, half the length of the lock, or a boat of said length sunk in one end of the lock, would overload that end with a weight equal to the weight of the boat and cargo. The leveling, or synchronizing apparatus, must be powerful enough to sustain this distorting effort and distribute it, and, furthermore, it must be automatic, for were the least interval of time to intervene between the application of the distorting forces and the action of the leveling apparatus, the loaded end would pitch, the water would run off the opposite end and pile up in the loaded end, giving a cumulative effect, combined with shock, which must inevitably destroy any non-automatic apparatus, how strong soever it might be, and ruin the lock.

DESCRIPTION OF THE LOCK STRUCTURES.

The lock structures are identical. The lower part is an open-bottomed air chamber, the roof of which forms the floor of the gated lock chamber.

The air chamber is formed in eight bays, to avoid beam strains and framing in the side walls, which are segments of cylinders tied transversely at the points of intersection. The cylindrical segments do not quite meet, being united by longitudinal plates, and the ties are in double lines, so that by lacing them together stiff transverse strut members can be formed where desired. Strut members are so formed at the bottom and at two intermediate horizontal planes, where chord plates are united with the walls, so that the entire chamber is a huge box girder. In its normal uses the walls and cross-ties are subject to tension only, and are in equilibrium, not tending to change their form, but accidental extraneous forces may tend to cause compressive strains, which the structure will sustain.

The roof of the air chamber, which also forms the floor of the lock chamber, is framed on heavy plate girders.

The hydrostatic pressure on the side walls of the lock chamber is sustained by brackets; those on opposite sides being tied by the floor plates.

The gates are crescent-shaped box girders, moving orbitally on a wheel, and when open lie out of the way in segmental side pockets.

The seating faces are concentric with the vertical axes about which the vertical axes about which the gates move orgitally.

The gate-opening engines have each a cylinder 14 inches bore, 8 feet stroke, the piston moved by compressed air, the piston rod carrying a cut steel rack, 4 inches pitch, 7 inches face, which meshes with and turns a pinion keyed to one end of a shaft, on the other end of which is a sprocket wheel geared by a Yale & Towne 9-16 inch chain to a sprocket wheel on a vertical shaft, secured in bearings on the gate post. This driving shaft has spur pinions at top and bottom, which mesh with pin-wheel segments on the gate. When the piston moves, the connected rack turns the shafts and pinions and operates the gate.

The gate is lightened by a flotation chamber, which floats 74 per cent. of its weight, leaving 26 per cent. on the wheel to give stability. The air which fills the flotation chamber is constantly renewed, so that the gate will not get loggy.

The gates which are liable to be rammed contain elastic trusses, with a yield of 10 inches, which cushion the blow and deliver it to the gate posts, so that ramming has no effect on the gate itself until the elastic trusses are broken.

The gate openings are slightly wider than the locks, so that the jambs are not liable to ramming, being protected by the guard timbering on the lock walls, which is as elastic as possible, to that end being supported in the centres of the plates on rubber cushions, so that the effect of impact is distributed over a number of brackets and lessened by the elasticity of the guard timbering, its rubber supports and the plates.

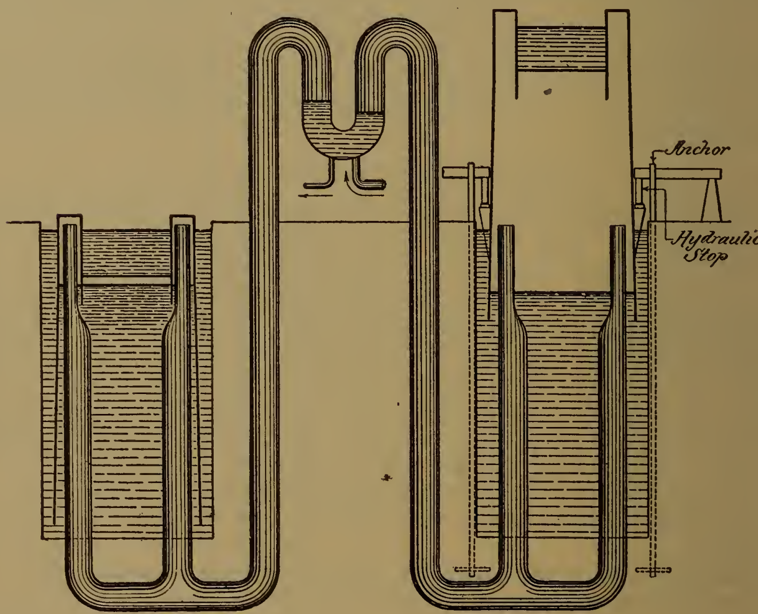


FIG. 208.—AIR CONDUIT AND VALVE.

When the lock is elevated, as aforesaid, it is superbuoyant, having an excess lift exceeding the accidental increase of load which might occur through the sinking of a loaded boat, and this excess lift is restrained by anchors, which are steel plates secured to the bed rock, and encased in asphaltic concrete piers. On them are built the side guides and the fixed racks of the leveling apparatus. These are disposed in four transverse lines at the end and alternate intermediate sections of the bays.

When the ascending lock comes to rest, its momentum is absorbed without shock, by hydraulic stops swiveled on the anchorages, with which the elevated lock engages, by brackets armed with timber contact pieces, which are readily movable, to allow the lock to be raised clear of the water for painting and repairs.

AUTOMATIC LEVELING, OR SYNCHRONIZING APPARATUS.

During the years which have been devoted to developing the pneumatic lock, many different types of leveling apparatus were considered and more or less worked out, but were all prohibitive in cost, especially on a large scale. The characteristic features of that adopted are that it is always in action; has only rolling friction, normally sustains only its own weight, has the minimum wear and abundant end clearance, which prevents binding and temperature strains. It

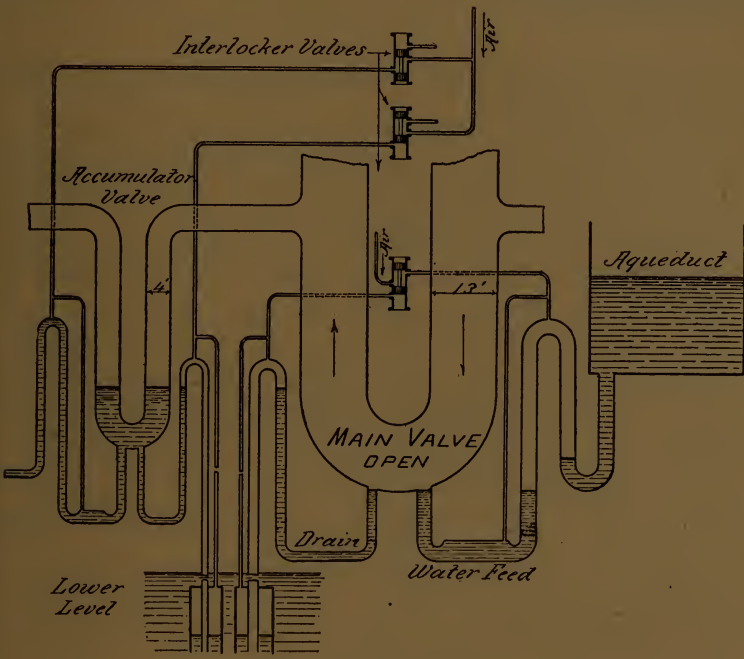


FIG. 209.—AIR VALVES.

can be made of any power, and the larger it is made, the less will be its cost per pound. It does not require nice workmanship, or careful adjustment. It is what engineers call a "brute."

Its elements are vertical racks securely anchored to terra firma, parallel racks built integral with the lock; hollow riveted steel, rolling shafts parallel with the locks and carrying pinions which mesh with the opposite parallel racks on the lock and on terra firma, the shaft having no bearings, but hanging upon its engaged teeth. When the locks move, the shafts roll between the racks and traverse one-half the stroke of the lock.

The preferred form of rack is the ladder type, with pin teeth. Small lock pinions may be cast. For large locks they must be built up of rolled steel, the core a forged drum, the blanks rolled steel rings with involute cut teeth. Such a gearing would give undue wear, were it always subject to maximum working pressures, but for a lock it is, perhaps, the ideal form, as normally the teeth carry only the weight of the shafts; the maximum pressures, due to accidental unequal loading, being infrequent. In the Lockport locks the shafts are 4 feet in diameter, made of inch plate.

The pinions are double, cut on rolled blanks, 6 inches thick, the involute teeth 16 inches pitch, 60 square inch section at pitch line, 16 pinions and 960 square inches of metal in the teeth being in action.

The outside rack stringers are 15-inch channels, with inch webs, and the teeth 6-inch pins, riveted in.

AIR CONDUITS.

The air main is 13 feet in diameter, and will transfer the entire air charge from lock to lock in one minute, with 330 tons surcharge in one lock.

The connection with each lock is by two open-ended standpipes, 10 feet diameter, which extend from the bottom of the lock pit considerably above the water surface, under hoods formed in the lock body. From their ends rock-cut tunnels run to the risers, which connect with the main valve.

The main valve is a "U" bend, provided with water inlet and drain pipes, so that the bend may be trapped with water and untrapped to shut off or permit the flow of the air.

The water-supply and drainage to and from the valve is controlled by pneumatic weirs, which are the reverse in principle of the air valves. A water-feed pipe extends from the upper level of the canal to the lower part of the main valve, and is formed like an S, with upper and lower bends. A similarly formed drain connects to the bottom of the main valve, rises to an upper bend and descends into and is sealed in the water of the lower level.

Air-supply pipes lead from the upper bends of the said water-feed and drain pipes to a 6-inch double-acting air valve, which is part of the interlocking machine in the operator's house. When this 6-inch air valve is moved to "feed" the air to the weir of the water-feed, and to "waste" the air of the drain weir, the air pressure enters the upper bend of the feed and seals it against the passage of water; at the same time the air pressure wastes from the upper bend of the drain and the water drains out of the main valve, opening it to a passage of the air.

When it is desired to close the main valve, the 6-inch air valve at the interlocker is moved to "feed" the air pressuse into the weir of the drain and to "waste" air from the weir of the feed. The air escapes from the feed weir and permits water to flow from the upper level into the main valve and seal it, and such water seal is prevented from escaping by the air-trap in the upper bend or weir of the drain.

Similar valves, 4 feet in diameter, open into the legs of the main valve and connect by a 4-foot main with a pneumatic accumulator, which may be thereby connected with or cut off from either lock.

PNEUMATIC ACCUMULATOR.

The pneumatic accumulator is a cylindrical bell, or open-bottomed air tank, having an upper weight chamber filled with water, and gives a constant working air pressure. When a lock is elevated it is immediately connected with the accumulator, which maintains a constant working pressure and automatically compensates for varying density and temperature in the adjacent atmosphere, which would otherwise vary the working pressure.

INTERLOCKING APPARATUS.

In order to prevent the operator from making mistakes, all the operations necessary to translate the locks are controlled by an interlocking apparatus, or sequence machine. This machine has five levers, on vertical interlocked stems, which are geared to horizontal shafts carrying-cranks directly connected with the

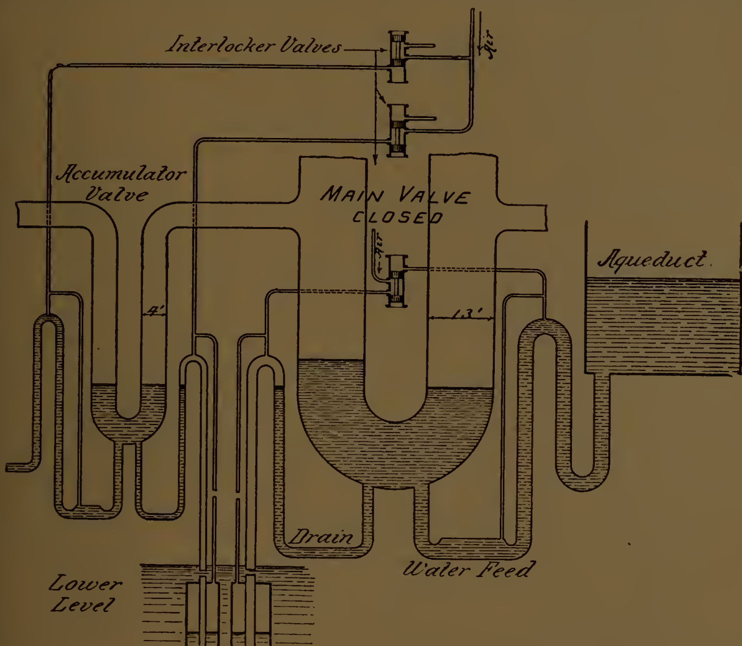


FIG. 210.—AIR VALVES.

stems of air valves, so that when the operator swings a lever he directly operates an air valve, and at the same time locks the lever behind him and unlocks the lever in advance, in order of sequence.

All the transmissions are by compressed air, and are controlled by the aforesaid valves of the interlocker, and critical motions are further controlled by stops operated by compressed air piped to them from valves at the gate posts, so that if any gate be off its seat the apparatus is firmly locked and cannot be moved until each and every gate is properly seated.

The interlocker is in a three-story operator's house, all the valves and pipes being in the lower, the operating story containing only the levers and the table which carries them.

The tubular valves have balanced spools, cup-leather packings and bronze-lined shells.

AUTOMATIC STOPPING MACHINES.

The automatic stop machines prevent the locks from rising too high, or running away, and control the amount of surcharge taken on the elevated lock, which is the working force of the system. To this end, they control the hydraulic valves of the hydraulic stops.

Because air is elastic, the motions of the ascending and descending locks are not exactly synchronous, the ascending locking leading the descending lock. Therefore, stop machines are independent for each lock. They operate only when the lock is in the upper limit of its stroke, and are adjustable to compensate for varying heights of water in the upper level.

Each lock operates its machine by chain gearing turning its main shaft, which carries a drum having a differential thread, one end being of 1-inch pitch, the other 36-inch pitch, the latter cut in an enlarged part, the slow thread being idle, merely keeping the parts in mesh while it is not desired that the lock should function the machine.

The thread moves a sliding bar, which has on one face a differential tooth meshing with the thread of the drum, and on the other an operating face, consisting in a rack and plain guiding surfaces coincident with the pitch lines of the rack. Engaged with this bar is a pinion segment, having a toothed portion and plane faces tangent to the pitch circle.

During the greater part of the lock stroke the differential tooth meshes with the slow thread on the drum, the plain faces of the bar and segment engage, and the machine does not function. When the lock approaches the upper limit of its stroke, the differential tooth meshes with the quick thread, the rack meshes with the toothed portion of the segment, and the machine functions; the shaft carrying the segment being connected with a parallel crank shaft by double gearing, the gears on the crank shaft being loose and rotating it by ratchet gearing, so that it is always turned in the same direction, whichever way the segment may be rotated. One end of the crank shaft connects by a crank and link with the main hydraulic valve. The other connects with a positive differential crank motion directly actuated by compressed air from the interlocker, and such that dead centres are avoided and the slip of the valve is taken up twice during the complete cycle. The lock opens and closes the hydraulic valve by rotating the segment. The operator opens the said valve, and takes up slip, and brings it to a fixed position by admitting compressed air to a piston of the differential apparatus, which is so geared that when the differential crank rotates 144°, the valve crank rotates 210°, and when the lock rotates the valve crank 150°, completing its revolution, the differential is rotated 216°, and completes its revolution.

HYDRAULIC ACCUMULATOR INTENSIFIER.

This machine gives the operator perfect control of the elevated lock. It is so designed that by operating a valve it will give either a higher or lower working pressure. When the lower pressure is admitted to the hydraulic stops, the lock will retract the stops and raise the accumulator weight. When the higher pressure is admitted to the stops, they will force down the lock.

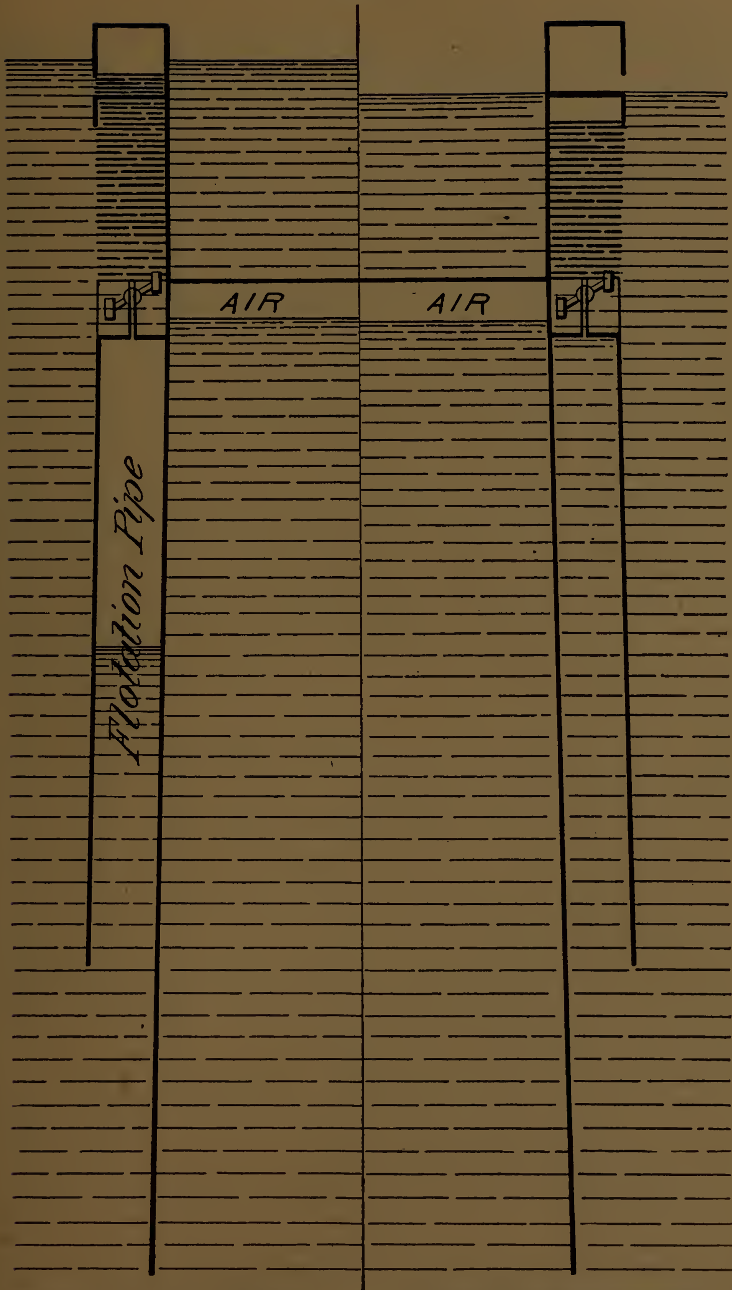


FIG. 211.—LOCK FOUNDERED. LOCK AFLOAT—READY TO ASCEND.

The weight is a tubular concrete block, with an annular water tank for increasing the load. The frame is central in the well of the weight and sustains the hydraulic members, which are a lower 20-inch cylinder, a 20-inch ram carrying the weight and bored to form the cylinder for an upper $11\frac{1}{2}$-inch ram working therein.

The two cylinders are connected by a valve-controlled pipe. When the valve is closed, all of the water expelled from the 20-inch ram is piped to the hydraulic stops, the pressure being 1,086 pounds. When the valve is open, one-third of the water expelled from the 20-inch cylinder goes into the $11\frac{1}{2}$-inch cylinder and intensifies the pressure, raising it to 1,623 pounds.

This is an example of work equivalent. The work done is the descent of the accumulator weight. If all of this work goes into the stops, their work collectively is equal to the volume swept through by the accumulator ram at low pressure. If but two-thirds of the water passes to the stops, and one-third goes to the intensifier, it is evident that the same work must be done by the stops in a stroke two-thirds of the stroke of the weight, and, therefore, the pressure must be increased one-half.

The machine is also a mechanical proof of the mathematical summation of series. In the case given the intensifier ram is practically one-third the area of the accumulator ram. Therefore, when the valve is opened, the pressure in the accumulator cylinder reacts through the intensifier cylinder and raises the pressure in the accumulator one-third. This one-third reacting in the same manner, raises it one-ninth. The one-ninth increase raises it one-twenty-seventh, which raises it one-eighty-first, which raises it one-two-hundred-and-forty-third, and so on to summation:

$$\frac{1}{3}+\frac{1}{9}+\frac{1}{27}+\frac{1}{81}+\frac{1}{243}+$$

et cetera, the sum of which is one-half.

OPERATOR'S CONTROL OF THE ELEVATED LOCK.

Swelling the Boats In and Out.—Experience proves that the entry and exit of boats to and from locks is much easier if water flows with the boats. Therefore, the ascending lock holds a depth of water considerably exceeding the least working draft, and when it approaches the upper limit of its stroke is automatically stopped, with the water in the lock chamber on a level with that in the aqueduct, so that as soon as the space between the adjacent lock and aqueduct gates is filled with water the said gates can be opened, without adjusting water levels, thus making a great saving in time. A further saving is made by swelling the boat out into the aqueduct. To do this, the operator moves a lever at the interlocker, which opens the main hydraulic valve, the intensifier valve being at such time closed, whereupon the lock retracts the hydraulic stops, rises and discharges its surplus water into the aqueduct, swelling the boat out, the upward motion of the lock being properly automatically arrested by the automatic stop machine.

As the boat which is to be locked down enters the lock, the operator swings a lever in the interlocker, which simultaneously opens the hydraulic valve and the intensifier valve, bringing the intensifier into action, the hydraulic stops forcing down the lock, which takes on a surcharge of water, which swells in the boat, the downward motion being properly automatically stopped. If now the gates be closed, the elevated lock is ready for its traverse.

AUTOMATIC CONTROL OF THE DEPRESSED LOCK.

In order to avoid nicety of adjustment and loss of time in connecting the depressed lock with the lower level, said lock founders until its downward motion is arrested and cushioned by the floating power of the cushion chambers at the sides of the lock chambers. There are longitudinal flotation chambers beneath the cushion chambers, from which the air is discharged as the lock is immersed, so that the lock may founder; after which both gates are opened, so that the water can come in behind the boat, as it is drawn out, giving it free motion.

The lock descended surcharged with water and now contains a maximum draft. In order to ascend, it must be lightened. For this purpose there are vertical long flotation pipes, of small cross-section, which, when the lock is elevated, communicate with the atmosphere and take in a charge of air at atmospheric pressure. As the lock descends this air is held and compressed, its pressure being a maximum and its flotation a minimum when the lock is in its lowest position; at which time valves are automatically opened, permitting this air to rise from the narrow vertical pipes to the long horizontal flotation chambers. As it rises, the water pressure on it diminishes and it expands to nearly atmospheric pressure and regains its original volume and maximum floating power, automatically increasing the flotation of the lock so that it floats with just the desired depth over the sill.

The minimum draft is 12 feet. Draft ready to ascend, 12 feet 6 inches. After the lock is elevated and connected with the aqueduct, it rises 6 inches, expels this surplus into the aqueduct, swells out the boat, and has its minimum draft over the sill. To take in the surcharge of water and swell in the descending boat, the lock is forced down 18 inches and descends with 13 feet 6 inches over the sill.

AUTOMATIC INCREASE AND EQUATING OF AIR PRESSURE.

While the lock is moving, it is obvious that the air pressure cannot vary greatly from the pressure which would be in exact equilibrium with the load. If the walls of the chamber were parallel, the working margin of excess pressure must be greater, because the pressure of equilibrium would necessarily increase as the lock rose and the immersed portion of its walls became less; therefore, the locks are equated, so that the working pressure or pressure of equilibrium is constant, the sides being splayed, so that the projected area against which the pressure acts increases in a constant ratio from the upper towards the lower portion of the air chamber, with the decreased immersion of the walls.

When the elevated lock is arrested by the stops, it is necessary for its safe use that the air pressure and the flotation be increased some 30 per cent. This is done automatically by the descending lock.

The horizontal area of the air chamber is considerably larger than the floor of the lock chamber, such excess equaling the sums of the areas of the horizontal segmental projections of the air chamber beyond the line of the lock

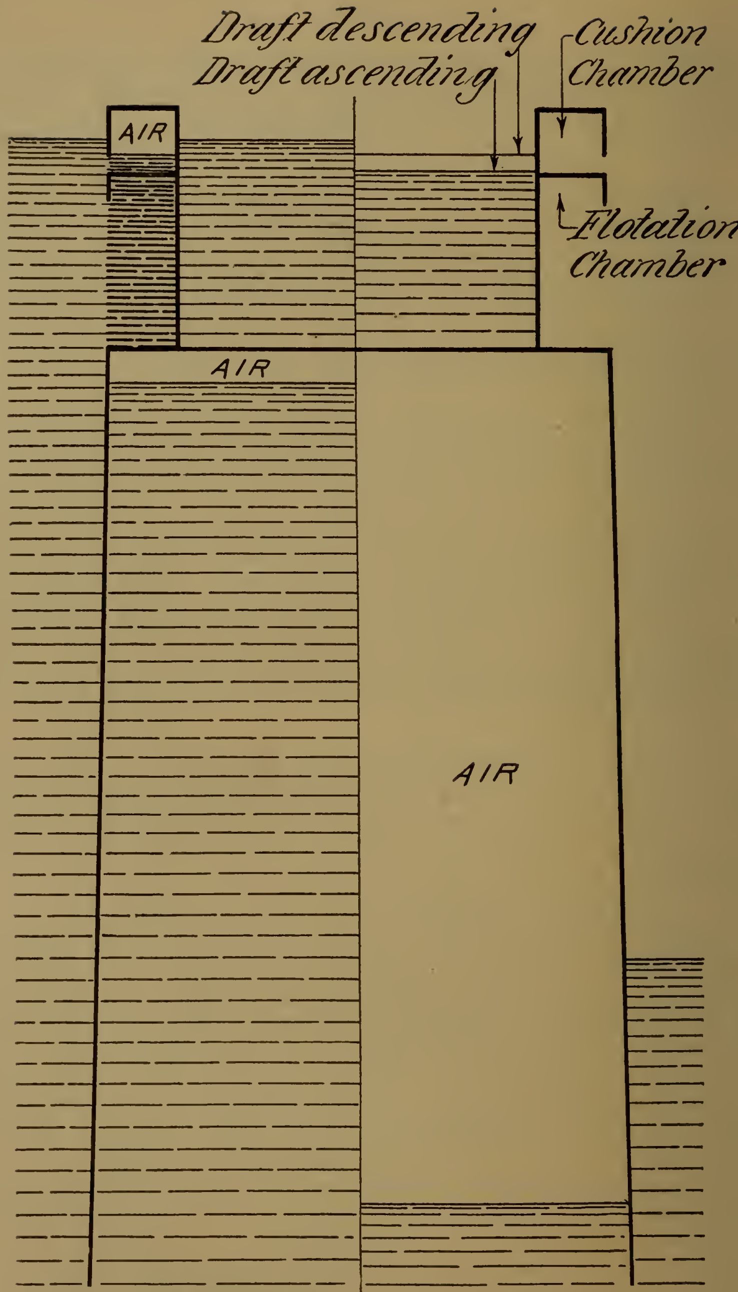


FIG. 212.—LOCK FOUNDERED. LOAD AND AIR PRESSURE MAXIMUM.

LOCK ELEVATED.

chamber. When the lock is elevated, there is no water on these plates, but as the lock descends they become immersed, and the weight of water upon them is necessarily carried by the air charge, the pressure of which is thus increased and becomes a maximum when the lock is at its lowest position; and this automatic increase of pressure is transmitted to the elevated lock, and there acts on the larger pressure surface at the lock bottom, and thus automatically provides the excess of buoyancy necessary to safe use.

ELASTIC RETAINER FOR ELEVATED LOCK.

While the lock is moving it is not subject to disturbing forces, except that of the wind, but when it is elevated and connected with the aqueduct, the unbalanced hydrostatic pressure tends to force the lock away and break the joint; and because boats might ram the outboard lock gate, it is necessary that the connection have flexibility to cushion the blow. These ends are compassed by tension retainers, which are I-bar cables, 220 feet long, hanging in catenaries, anchored at one end to the bed rock, at the other retaining the hydrostatic pressure in the end of the aqueduct, or in the lock when connected, the connection being retaining wheels, 12 inches thick, 5 feet diameter, with 15-inch journals, adjustable in bearings formed in the end frames of the retainers, the wheels engaging shoulders on the lock, which are runways planed on heavy steel castings, riveted into and forming flanges of the portal columns of the lock body. A blow will pull the cables into flatter curves, the endwise motion cushioning the shock.

The joint is made water-tight by a dilatable rubber tube, secured to the aqueduct face, and seating at any point on a flat timber apron provided on the adjacent end of the lock. The tube is cured flat, and remains so when deflated. To make a joint, it is inflated by compressed air admitted from a valve of the interlocker. The space between the gates is flooded and emptied through pipes controlled by pneumatic weirs, which, in turn are controlled by air pipes leading to valves at the interlocked.

POWER PLANT.

There is a 36-inch double-balance turbine, belted to a duplex air compressor, to a four-cylinder, high-pressure hydraulic pump, and to a dynamo for lighting. Also a high-pressure air tank, and a tank for the hydraulic supply, it being intended to operate the hydraulic apparatus with 500° test petroleum.

AQUEDUCT.

The necessity of operating the old locks while the new ones were being built compelled the use of an aqueduct, 393 feet long, to connect them with the upper level. This aqueduct is so designed that the strains due to the static load oppose and cushion the strains induced by collision of vessels using the aqueduct. This principle develops the full elastic quality of the steel, makes the sides four times as flexible, and the flange strains less than one-eighth as great as those obtaining in aqueducts heretofore designed; the builders of which apparently ignored the destructive effect of shocks or assumed that the boats could be drilled so as not to collide.

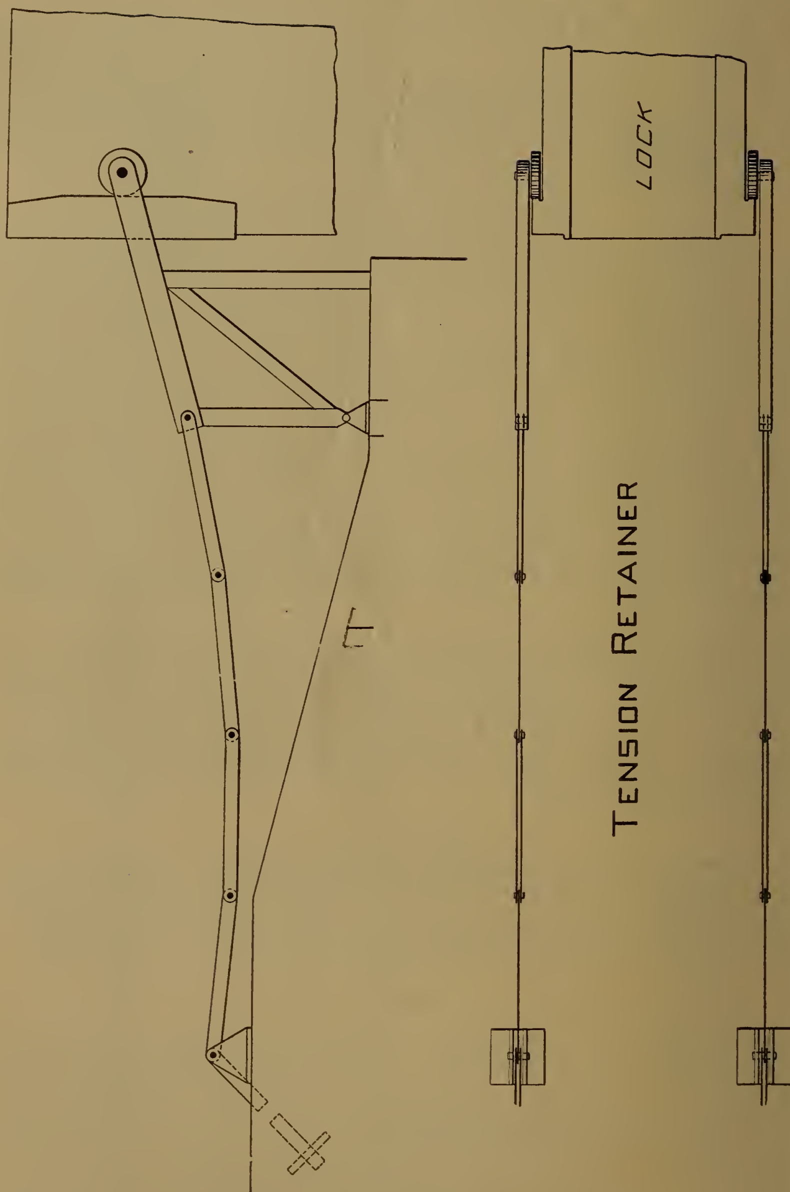


FIG. 213.

In structures of the old type the flange strains in the frames are due to the sum of the static and shock moments, and the elastic cushioning movement of the side walls is that due to the variation in the one kind of strain, for example, tension, to which the flange is subjected. In the design exhibited, the flange strains are equal to one-half the difference between the static and shock moments, and reverse from tension to compression, or vice versa, so that the elastic movement is four times as great, the greatest which the metal is susceptible of without injury.

GENERAL PRINCIPLE OF CONSTRUCTION.

The floor is not framed, but suspended at the edges, and the weight thereon exerts an inward pull on the frames in opposition to the hydrostatic pressure on the sides. By suitably proportioning the parts, these forces can be given any desired ratio. The inward moment of the floor exceeds the sum of the outward moments, and induces compression in the upper and inner flanges, and tension in the outer and lower flanges below the floor line. When a boat strikes the side, the stresses are reversed.

This particular design could not be applied to the end bays, where the gates are located. Therefore, the principles were applied in a different manner, the flat floor being carried by transverse girders spliced to the side walls, which are framed as girders and connected to the inner vertical flanges of the frames which are suspended from their outer flanges on links and pins, so that under the static load the outer and under flange is in tension, and the upper and inner flange in compression. When the boat strikes one side, its shock is cushioned by the elasticity of the entire frame, and before it can have a destructive effect, it must reverse the strains in both flanges, swing the end of the aqueduct to one side and somewhat raise it. This design can be made much more effective with an equal weight than that adopted for the intermediate bays, because the shock is cushioned by the elasticity of the entire frame, whereas the other design cushions by the elasticity of half the frame.

As the designs for the aqueducts have been very materially improved since this address was delivered, the reader is referred, for full information concerning them, to U. S. patents 621,470, of March 21, and 626,321, of June 6, 1900, issued to the author.

While every precaution has been taken in the design to prepare the structure safely to resist a maximum shock, the interior of the aqueduct is protected with elastic timber guards, which, if they be properly maintained, will absorb the greater part of the shocks without much strain to the structure. But, obviously, a structure which may be put into the keeping of incompetent men, appointed for political purposes without regard to their fitness, must be so designed that no fool can cripple it, so that it might be wrecked by improper use. Therefore, the aqueduct is designed with such great care, and is much more costly than would be desirable were it owned and operated by a private corporation, which would exercise reasonable care in its use and maintenance. The same is also true of the locks.

HOW THE LOCKS WORK.

The depressed lock floats and requires no care. The elevated lock is connected with the pneumatic accumulator, and the air pressure in it is 8⅛ pounds per square inch, which expels from it a weight of water 30 per cent. greater than the weight of the loaded lock, giving it the excess buoyancy necessary to its safe use; said excess buoyancy being restrained by the anchors. When the elevated lock first ascended, it engaged with the retainer the joint was packed by inflating the rubber pipe, the space between the lock and aqueduct gates was flooded with water, the gates were opened, the boat was swelled out into the aqueduct, to accomplish which the hydraulic valve controlling the stops was

Low Pressure in Ascending Lock, High in Descending.

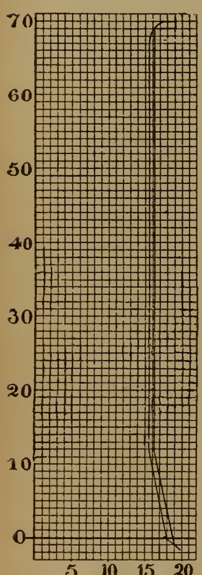


FIG. 214.

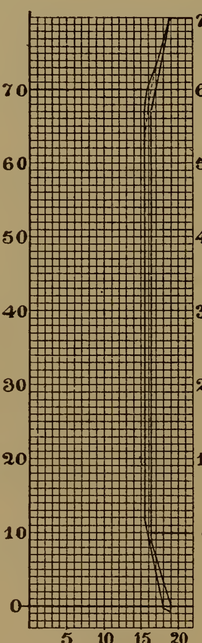


FIG. 215.

Descending Lock. Ascending Lock.

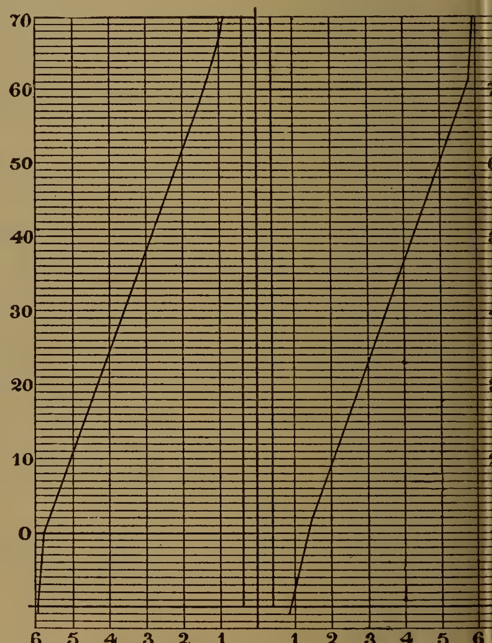


FIG. 216.

Vertical ordinates read stroke in feet. Abscissas read feet of water pressure, or "head" on air charge, in Figs. 214 and 215; and in Fig. 216 read 100,000 of cubic feet of compressed air as distributed between the two locks during their cycle, the central ordinate indicating the position of the valve and the adjacent rectangles the conduits. In Fig. 1 the stroke of the descending lock reads downwardly, with the motion; in Figs. 2 and 3 all strokes read upwardly so as to show relatively coincident conditions in the two locks.

opened and the lock retracted them and raised 6 inches. As the descending boat entered the lock, the intensifier was brought into action, the lock was forced down 18 inches and took on its surcharge of water, swelling in the boat, such lock motions being automatically stopped by the stop machine. The gates of the depressed lock, and the adjacent gates of the elevated lock and aqueduct can now be closed, and the space between them drained. The accumuator valves are now closed, the main valve is opened, and the air expands from the elevated lock into the depressed lock, raising it and at the same time lightening it as it rises, by reducing the extraneous load of water on the projecting horizontal segmental plates at the tops of the air chambers. This function continues until the air in the elevated lock has expanded to less than equilibrium with the weight thereof, so that the elevated lock can descend, at which time the depressed lock has been raised so high and the extraneous load thereof so decreased, that the pressure of equilibrium therein is less than in the elevated lock, from which time the depressed lock ascends until it is fully elevated and is brought to rest by the hydraudic stops, and the elevated lock descends until the segmental plates at the tops of the air chambers are immersed and begin to take on the extraneous load, which increases as the lock descends, and the plates are immersed to greater and greater depth, such extraneous load and the air pressure becoming maximum when the lock has descended to its lowest position. This maximum pressure acts in the elevated lock at the large bottom portion thereof, and induces therein the excess buoyancy necessary for its safe use. The main valve is then closed, and the accumulator valve opened, connecting the accumulator with the elevated lock, which can then be connected with the aqueduct. Both gates of the depressed lock are then opened, which is thereafter automatically floated to a higher position relatively to the surface of the water of the lower level, in which it floats, so as to contain the draft of water with which it should ascend.

The pneumatic lock will wholly change the conditions of canal construction. Heretofore, the range of usefulness and the location of canals have been limited by the water supply available for feeding the locks from the summit level, and it has been necessary to maintain the water level within narrow limits; and the large amount of water and the heavy currents necessary in locking have necessitated a constantly running supply and spill ways for the escape of such supply, when the locks were not operated. The small lift of the Leonardo locks necessitated the selection of gentle slopes for the lock sites, which, in many cases, involves soft foundations. In canals planned with pneumatic locks, the most economical plan will be to make the levels as long and the locks as high and few in number as possible. Guard locks and the waste of water can be entirely dispensed with, and the summit level can be utilized for storage, its banks being high enough to contain the highest and its bottom low enough to give the desired draft at the lowest water, the variation being taken up at the lock. In most canals the heavy tonnage is one way, and down hill. In such cases the descending tonnage will not only operate the lock, but also lift water to the summit level. It will be seen that the first cost of canals and their demands on the water-supply are reduced to a minimum. Application of steel to the locks reduces their cost of installation, operation and maintenance as greatly as it has reduced such costs in other engineering structures. The State authorities estimate that the saving in wages at Lockport will exceed interest on the entire cost, and at Cohoes such saving will be double the interest on the cost of installation, so that building the Cohoes locks will save an actual profit. In ship canal locks the saving will be in ratio increasing with their size.

THE APPLICATION OF COMPRESSED AIR TO CRANES AND HOISTS.

As it is now conceded that compressed air has become the most useful and economical addition to a modern manufacturing establishment, and as many shops are now thus equipped, a brief description of its application to cranes and hoists would be in keeping with the times, although this is but one of the many uses to which compressed air is applied. The objection urged by many against the use of compressed air for a traveling crane has been, that there was no practical way of carrying air to the crane where a long travel was used, but as different cranes

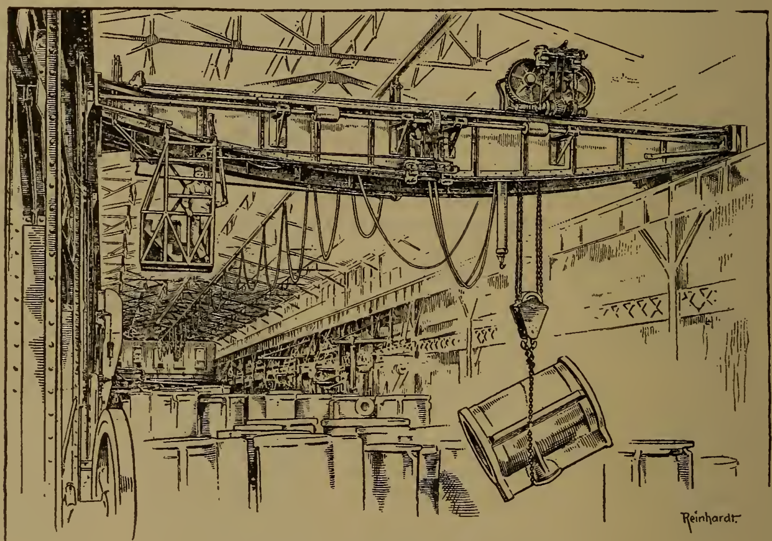


FIG. 217.—COMPRESSED AIR CRANE.

are now in successful operation, a description of some of these should quiet their apprehension.

The Ingersoll-Sergeant Drill Co. have for a long time been ardent advocates of compressed air as a power for cranes, and have fitted up their shops at Easton, Pa., completely with such; the following description being of cranes in continuous operation at their works.

Figure 217, here illustrated, is a cut of a 20-ton traveling crane in their main machine and erecting shop, the crane having a span of 40 ft., and a travel of 460 ft. As it is shown by the cut, each movement of the crane is controlled by a separate engine, the three engines being piped to the valve box in the cage, where three levers control the movements of the crane. In order to avoid the complication of a link and two eccentrics for each cylinder of the duplex engine, a special engine was designed, the cylinders of which have two sets of ports, one direct and the other crossed, but having a common exhaust, the valves having both a rocking and a shifting motion with one eccentric only used for each cylinder. A double set of supply piping is run from the valve box in cage to each engine, so that when the levers are moved in either direction, opening the air to either pipe, the engine valves are shifted by the air coming in on one side and the engine has the desired movement. When the lever is reversed, the air passes through the other pipe, the valve is shifted to the other end of chest and the engine is reversed in its movement.

As the hoisting engine on the carriage of the crane moves the length of the crane, the two pipes carrying the air to this engine are only run to the centre of the crane and fastened to the girders. Two lengths of hose are run from there to the engine, the hose being placed one in front of the other that one will pass through the other, and both only sufficient length to reach from the centre of the girder to the end. The engine which gives the transverse motion to the crane is

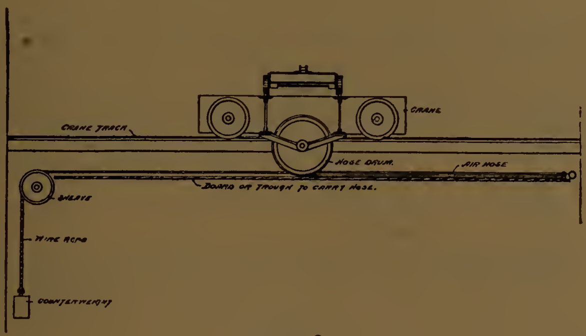


FIG. 218.

set on the opposite end of crane and draws the carriage backward and forward with a wire cable.

Probably the most interesting part of the crane to the general observer, is the novel method of carrying the air to the crane. As is clearly shown by the cut, this is accomplished by a continuous hose built up of 50 ft. lengths coupled together, each coupling being made in combination with a swiveled sliding block, which slides on the overhead rail bolted to the roof truss and preferably made of I beams. In the centre of each length of hose is a clamp to hold the hose, also made with a swiveled slide. The hose is fastened to the building at one end and to the crane at the other, it being suspended at intervals of 25 ft. to the overhead rail by the swiveled slides. As the crane moves away from the hose, the hose is pulled along, each length straightening out and pulling the next length. On the return travel of the crane, as the sliding blocks come together, the hose falls in loops, the swivel in slide allowing each loop to turn around to its natural position, which is at right angles to the overhead track. It is thus seen that each loop of the hose requires only the room occupied by one sliding block on the rail, which was made 6 in. long, so the hose for the entire travel of 460 ft. occupies only 9 ft. at one end of the shop where the crane is never used.

The above method of transmitting air has been in successful operation for some time at these works and has never caused any trouble, and as it is such as can be used in all cases regardless of the length of travel, it can be recommended as the best method as has yet been devised. Should it become necessary to put in a second crane, the hose would be attached to the opposite end of the building and slide on the same overhead rail.

Where a crane is used where there is no overhead room for the hanging hose, the arrangement shown in Fig. 218 will be found very simple and effective. This consists of a wooden drum hung at one end of the crane and of sufficient size to carry the length of hose required. One end of the hose is fastened to one end of the building, the other end being held to the hollow shaft of the hose drum, said shaft having sleeve and stuffing box at the end through which the air passes to the hoist. Underneath the hose is a board or trough on which the hose lies as it is unwound. On the same drum with the hose is a ¼ in. wire rope wound between the coils of the hose. One end of the rope is fastened to the drum, the other end passing through a sheave at the end of the building, and having a weight sufficient to turn the drum attached to same. Referring to Fig. 218, as the crane moves to the left, the hose, being held stationary at the right, will unwind the drum,

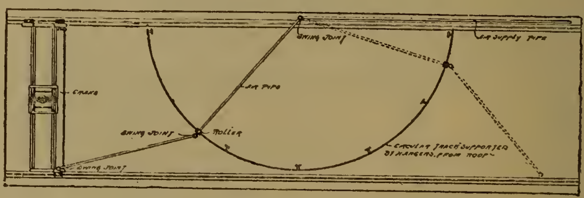


FIG. 219.

which will at the same time wind up the rope, or if moved to the right the rope will unwind the drum and wind up the hose. The weight on the end of the rope is made to keep the hose and rope taut and to wind up the hose, the sheave wheel allowing the weight to move up and down, this being necessary owing to the difference in diameter of the rope and hose and the corresponding difference in the length of a coil of rope or hose on the drum. The movement of weight for 100 ft. of travel of crane is about 5 ft. The one objection to this arrangement of crane is that if the travel of crane is long, the drum must be large reducing the effective span of the crane.

Fig. 219 shows a hand power crane with an air lift used in the foundry cleaning shed. Two pipes with swing joints carry the air to the crane; the centre joint being made with a roller runs on a circular track hung from the roof, which in this building is very low. The limit of travel with this crane is about three and one-half times the span, but can be used in many places where hose may be objectionable.

In the foundry of this establishment there is a Compressed Air Power Traveling Crane similar to that shown on Fig. 217, and a Craig Ridgeway Pneumatic Hydraulic Jib Crane which uses compressed air instead of steam for putting the water under pressure. This crane uses the same water continuously, the air only being discharged as the weight is lowered.

The air hoist has lately been receiving considerable attention, many valuable improvements having been made which make the hoists more convenient and easily handled and bring them into general use wherever light lifting is required. The two general methods of applying the hoists, in addition to being used on a traveling crane, are first, where they are attached to the trolley of a jib crane, receiving their air through a hose leading from an air pipe at the crane post to the hoist, the latter being thus at all times ready for use; and second, where the hoist is hung to a trolley running on an overhead rail. With this latter method, the air pipe is made with outlets at specified places wherever the hoisting is required, each outlet having a length of hose with a valve and quick acting coupling attached to same. The hoist is moved along the rail to where required, the air hose coupled to it, the load lifted, the hose uncoupled, and the hoist with its suspended load is ready to be moved by hand or cable to wherever the overhead rail will carry it. This is very quick in its operation, unlimited in its application, and is by far the best method that has as yet been devised for the handling and conveying of merchandise of any description and weight from one location to another, or wherever an overhead rail can be conveniently carried.

In conclusion, it should be remembered that compressed air is a power economically produced, clean and convenient to handle, and understood by all, so that wherever used, men of ordinary intelligence can be employed to operate the machinery and keep it in order. WM. PRELLWITZ.

PILLAR AND GANTRY CRANES OPERATED BY AIR MOTORS.

The Gantry crane was made for the flask yard of Dennis Long & Company (manufacturers of cast iron water and gas pipe), Louisville, Ky. It has hoisting longitudinal and cross-travel movements, all operated by independent compressed air motors. The capacity is five tons. The span center to center of track rails is 30 feet. The girders extend 10 feet beyond one end frame, which is open to allow the passage of the hook with the suspended load. The open space is 8 feet and has a full width for a height of 19 feet. The greatest lift of hook from the ground to the highest position is 22 feet. The extreme travel of the trolley on the girders is 34 feet 10 inches. The length of travel of the gantry on the surface tracks is about 250 feet. Air is furnished to this crane by means of flexible hose, which is carried on a large reel, not shown in cut. The operator is placed on top of the girders where the levers appear, in a position so that he may overlook the handling of the load. This crane has been very successful, and has been in actual operation for over two years. The expensive trestle work is avoided in the use of this form of crane, and the extension longitudinally is limited only by the yard room at hand.

The pillar crane, shown herewith, is one of five (all duplicates) furnished the C., C., C. & St. L. R. R. (Big Four) for their coaling stations. They are used for both coaling locomotives and removing ashes from ash pits. The column is made of cast iron and the over all height is 8 feet 6 inches. The radius of the hook is 12 feet. The cylinder hoist is 12 inches in diameter and has 6 feet stroke. It is furnished with a quick acting valve, and loads are handled very quickly when necessary, also slowly, as may be desired, the operation being under perfect control. These cranes are capable of coaling a large freight locomotive in from ten to twelve minutes, using half-ton buckets.

The Whiting Foundry Equipment Company, Harvey, Ill., who installed the above, has recently furnished a prominent steel manufacturing concern in the West with modified air hoists, to be used for charging billets into a reheating furnace, and also for raising table for mill. The pushers first mentioned are 14

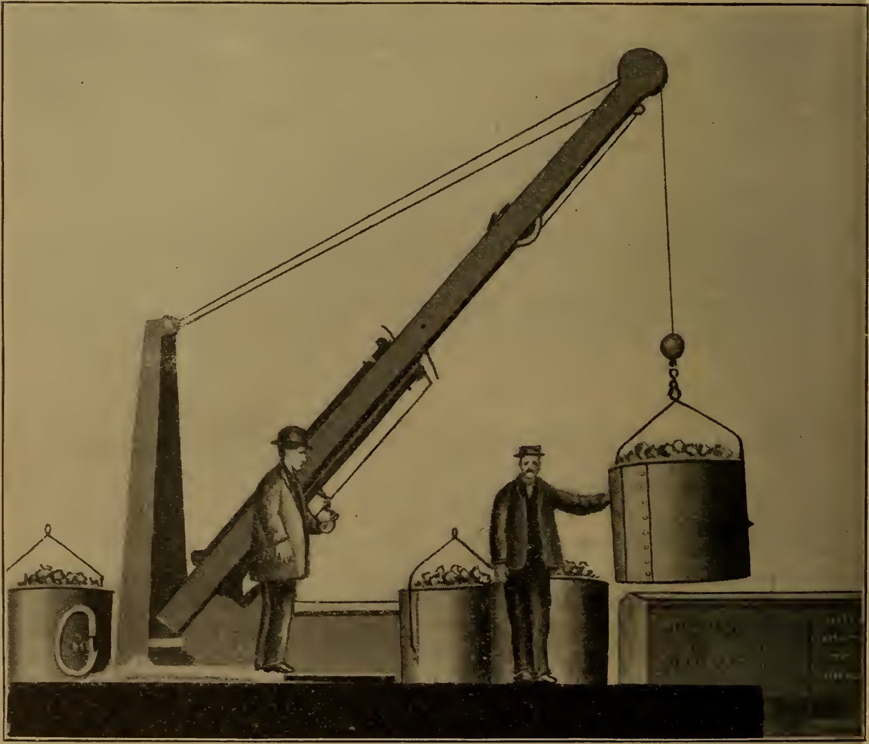


FIG. 220—PILLAR CRANE.

inches in diameter and have a total stroke of 8 feet; are operated by air for both forward and reverse movements, being fitted with automatic attachment cutting off the supply when the limit of the stroke is reached at each end.

SOME CONVENIENT DEVICES IN A RAILROAD YARD.

The two accompanying engravings show how compressed air is utilized in the yard of the Northern Central Railroad at Sunbury, Pa.

The sand house containing the sand supply is at the right of a post carrying a pipe, on the end of which is a short length of hose, which is dropped into the sand box opening. The building contains four sand dryers, arranged so that as the sand passes through the dryers it drops over a screen and into a large hopper, from which it is finally fed into a receptacle so arranged that the opening for the latter can be closed, air pressure put in and sand blown from this receptacle to the pipe and to the locomotive sand box.

Fig. 221 is of the ash hoist and shows the same arranged for two ash-pits with track on which cars may stand to be loaded with ashes between the two pits. The ashes are drawn from the ash pan, and the cinders from the

FIG. 221.—ASH HOIST.

smoke box, directly into a bucket, which can be moved lengthwise of the pit on a track, which is laid at the bottom. In this way they can be located conveniently under the locomotives and then moved under the frame and lifted by the hoist, which can also be made to traverse across the frame and dump the ashes into the cars.

Another device is the Fig. 222, a coal wharf at Sunbury. This is also operated by compressed air. The cars containing coal are brought up on the low trestle at the back, where the coal is dumped from the hopper cars into coal dumps, which are moved longitudinally under the coal trestle and brought to a central point after being loaded where they are turned, weighed and brought to one of the two hoists shown elevated to the platform and run on a transfer car, which moves the whole length of the wharf and deposits the loaded car at any

FIG. 222.—COAL WHARF.

track, and also removes the empty cars in the same way, but in the reverse direction. The transfer table is also operated by compressed air, the same being done by a small air motor.

WATER AND AIR.

An all-important question, nowadays, is how to secure an adequate and wholesome supply of water. It interests the manufacturer, the farmer and the water committees of both large and small communities. Its importance cannot be over-estimated.

Until within a few years the supply taken from surface streams was considered sufficient, but droughts and ever-present impurities have shown the necessity for a more careful study of the subject, and as a result we have heard from all sections the decision to bore through the crust of the earth and tap the subterranean streams which are known to exist almost everywhere. Sometimes this water-bearing strata has been found within 20 or 30 feet of the surface, as, for instance, on Long Island. And again, it has become necessary to bore 1000 to 2000 feet, as is the case quite often in Texas.

The water secured from these underground sources is more wholesome and less apt to be contaminated than that taken from the surface streams, and this is because the sand and gravel through which it percolates acts as a filter more effectually than any device patented by human being. Whenever it is reported that this or that town's water is impure and dangerous to public health, it will be found that the source of supply is a surface stream, and seldom, if ever, do we hear of sickness caused by water derived from underground sources.

After having drilled the well and tapped the subterranean stream, the problem seems to be how to bring the water to the surface; for as a rule the well does not flow of its own accord. Deep well pumps of innumerable patterns and designs have been constructed, and while each claims to be better than the other, they all seem to have their drawbacks. Their capacity is always limited, they require power out of all proportion to the work performed, and seem to have a

FIG. 223.—DR. JULIUS POHLÉ.

faculty for getting out of order at the wrong moment; the cause usually being that a rod has been either broken or bent, or a valve or plunger become worn. All of this entails endless expense and annoyance, and makes the problem more serious than at first thought.

When the water level in the well rises within suction reach, a piston pump is usually employed; and while there are a great many good makes on the market, the same objection is applicable to them as to the deep-well plunger type, and should the water level drop more than 25 or 28 feet below the surface, they become useless.

The problem seems to have been solved, however, by what is known as "The Air Lift" system—that is, raising water by means of compressed air. It was patented in 1892 by the late Dr. Julius G. Pohlé. His process is a novel one, because it does away with all moving parts in the well, such as valves, rods, plungers, etc. Needless to say, his claim of "simplicity" is borne out and its economy and value are attested to by its adoption throughout the country by large numbers of Water-works and manufacturing establishments.

The process consists of placing two properly proportioned pipes in the well, one for discharging the water at the surface or tank, and the other for conveying the air into the well. These two pipes are connected at the bottom by what is

FIG. 224.—RAISING WATER BY THE POHLÉ AIR LIFT AT H. LANG CO.'S FACTORY, NEWARK, N. J.

commonly known as a foot or end piece, the air pipe being connected at the other end to the air compressor.

The compressed air is then forced through the air pipe into the foot piece and water pipe, and by its inherent expansive force, layers or pistons of air are formed in the water pipe, which lift and discharge the layers of water through the end of the water discharge pipe at the surface or tank.

At the beginning of the operation, the water surface outside of the pipe and the water surface inside of the water pipe are at the same level; hence the vertical pressure per square inch are equal at the submerged end of the pipe, outside and inside. As the compressed air is forced into the lower end of the water pipe, it forms alternate layers with the water, so that the pressure per square inch of the column thus made up of air and water, as it rises inside of the water pipe, is less than the pressure per square inch outside of the pipe.

Owing to this difference of pressure, the water flows continually from the outside to within the water pipe by gravity force, and its ascent through the pipe is free from shock, jar, or noise of any kind.

These air sections, or strata of compressed air, form water-tight bodies, which in their ascent in the act of pumping, permit no "slipping" or back-flow of water. As each air stratum progresses upwards to the spout, it expands on its way in proportion as the overlying weight of water is diminished by its discharge, so that the air action, which may have been, say 50 lbs. per square inch at first, will be only 1.74 lbs. when it underlies a water layer of four feet in length at the spout, until finally this air section when it lifts up and throws out this four feet of water, is of the same tension as the normal atmosphere; thus proving that this pump is a perfect expansion engine.

As the weight of the water outside of the discharge pipe (the head) is one-third greater per square inch than the aggregate water sections within the pipe when in operation, it follows that the energy due to this one-third greater weight is utilized in overcoming the resistance of entry into the pipe, and all the friction within it.

A peculiar and very important feature of the "Air Lift" system is that it invariably increases the yield of the well from two to three times. At a recent test made by the City of Bethlehem, Pa., the yield of a well which was normally at the rate of 200 gallons per minute, was increased to 627 gallons per minute, or just three times, which is something remarkable.

In breweries it is desirable that the water be at as low a temperature as possible, and quite a number have installed Air Lifts because of the fact that the water raised by this system has been reduced as much as two degrees in temperature. This is ascribed to the expansion of the air abstracting the heat from the water with which it is in close contact.

Prof. Thos. M. Drown of the Lehigh University, some time ago stated that the success of filtration is very largely dependent upon aeration. It is claimed that this is accomplished in a great degree by the Pohle system, and is no doubt true, as the air sweeping through the water mechanically scrubs and cleanses it.

The value and advantages of Dr. Pohle's system are just becoming known, and the day is not far distant when it will be universally adopted:

Because of its simplicity.
Because of its economy.
Because it pumps all the water the well will yield.
Because of its tendency to increase the yield of the well.
Because it aerates and purifies the water.
Because with one compressor any number of wells can be pumped.
Because it cools the water.

H. HELLMAN.

PUMPING BY AIR.

AN IMPROVED SYSTEM FOR PUMPING OIL WELLS BY THE USE OF COMPRESSED AIR.

The third of a series of patents covering a process for pumping oil wells has just been issued to Mr. M. W. Quick, of Titusville, Pa., and as this system involves many new features and promises to supplant all other pumping powers, the Derrick, has caused an investigation to be made, and is able to present the first authentic account of the invention and to furnish those interested in the production of oil with the main points which distinguish the Quick system from all others.

In this system air is compressed to from 14 to 17 pounds initial pressure; conducted through the field in pipes; to the main line, lateral lines run to the wells and connect the motors employed in pumping; the utilized air is exhausted into a secondary system of pipes which conduct it back to the compressor for restoration in its original pressure. The utilized air is thus kept in continuous circuit and meteorological changes in the atmosphere are prevented from interfering with either the compressors or motors.

The crowning feature in this invention is an automatically actuated valve connected with each motor, which regulates the pumping strokes by the quantity of fluid pumped. A well that has accumulated a head of oil will be pumped with regular strokes at the rate of from 15 to 30 per minute until the fluid is exhausted when the pumping motion is suspended, or reduced to a speed so slow that the eye cannot detect it, until there is an accumulation of fluid, when the regular strokes again pump it off.

Mr. Quick has also succeeded in bringing the speed of a gas engine under automatic control so that it is regulated entirely by the consumption of air in operating the wells. An engine so regulated will start up at the rate of say 250 strokes per minute, provide power for pumping off the wells, and then the increased pressure will check the engine down to the lowest safe speed or to about 100 strokes per minute. An engine so regulated responds to the requirements for power as readily as does a steam engine with a Fisher governor, and the adjustment can be made for any desired maximum and minimum speed.

The advantages claimed for this sytem are many, among the most radical of which we present the following as being fully demonstrated in the operation of the powers now showing practical results:

Each well is operated separately and can be run with any desired speed, the lifting stroke being with the same rapidity whether the strokes during a given time are few or many.

A given production can be pumped from one well, or from a number of wells with the same consumption of central power.

Each well connected with the system is operated by an individual air motor, the strokes of which are automatically regulated by the fluid pumped.

The requirements for initial power are in perfect harmony with the final results obtained.

There is no "churning" of the fluid by unnecessary pumping and the formation of rod wax is obviated.

The natural gas pressure may be maintained in wells for the purpose of forcing the product into the drill holes.

By the operation of the motors a pumper is enabled to locate interferences with the pumping outfit and decide whether it is leaky tubing, stuck valves, worn cups or parted rods.

The rapid lift and comparatively slow drop permits running sand to settle without interference with the working valves.

Lines for the transmission of power may be buried where they extend through towns or cultivated fields.

Railroad and other crossings, uneven surfaces, precipitous bluffs and streams of water present no obstructions to the transmission of power.

The system is not interfered with by brush fires, falling trees, ranging cattle, ice, snow or storms.

The central power plant may be located at any desirable point where it can best have attention.

There are no wearing joints requiring attention and repair.

There are no distance limits in the transmission and distribution of power.

Compressed air from the system may be employed in operating field pumps for gathering oil, for deliveries to pipe lines or for pumping water.

The lightest pipe may be employed, old engines changed into efficient compressors and the materials so employed continued in service indefinitely.

The wear of cups, working valves and rods is reduced to the lowest possible minimum and wells require less roust-about attention.

A pumper can run a greater number of wells, get along with less tools, use less fuel, have little if any expense account and get better production results.

The system may be installed during any season of the year and in far less time than is necessary to put in pull powers.

At the present time three Quick powers are in successful operation; two on properties of the United States Oil Co. at Saint Marys, W. Va., and one on the property of the McGraw Oil Co. (in which Mr. Quick is interested, near Tidioute, Pa.).

On the property of the McGraw Oil Co., twenty-three wells, covering a field about three-fourths of a mile long, are being pumped with a 16 x 12-inch compressor (made from an old oil well engine) and an expenditure of about six-horse power.

The perfection of this system has occupied the attention of Mr. Quick and his associates for more than three years, during which time many additions to the junk pile have been made. At the present time, however, it is not known in what direction improvements are either possible or desirable. In fact, success far beyond anticipations has been the reward for persistent efforts.—*Oil City Derrick.*

PUMPING BY COMPRESSED AIR.

Pumping water and other liquids by means of compressed air presents an attractive field for inventors, and a number have entered it with enthusiasm—some with undoubted success, while for the work of others it is yet too early to judge it fairly.

The attractive and most promising traits of compressed air for application to this purpose lie in the possibility of transmitting a great amount of energy an indefinite distance through small pipes, and then storing it for an indefinite time without serious loss; in the convenience, comfort and freedom from danger with which it can be applied; and, in some methods, the exceeding simplicity and cheapness of the necessary apparatus. One difficulty, not insurmountable, but requiring the utmost care in designing and in construction, is leakage of air. The other and chief difficulty lies in the loss of much or all of the energy of expansion possessed by the compressed air. In some designs there is no pretense of utilizing the energy of expansion either through ignorance of the extent of the loss incurred or through a desire to make a simple and cheap, and therefore, a salable pump.

We may put all compressed air pumps into one of three classes:

First. Those that apply the air pressure indirectly through the medium of an engine with piston and piston rod exactly as in steam pumps.

Second. Those that apply the air pressure *direct* without the intervention of a piston, etc.

Third. Those that lift the liquid by the effect of bubbles liberated in a pipe.

To the first class belong the majority of pumps operated by compressed air. It is not the purpose of this paper to discuss that class, but it should be said that it is capable of all the variations found in steam pumps, with the one drawback that steam has not, viz., freezing when a high rate of expansion is attempted without reheating. While reheating is desirable to prevent freezing, and still more so to economize energy, it adds complication and cost, which must seriously retard its introduction in small plants.

The general action of the second class, direct air pressure pumps, such as are now on the market, can be understood by reference to figure I. Suppose the vessel submerged and filled with water. Now, if compressed air enters through the pipe C, the water will be driven out through the pipe A. When the vessel is thus emptied, a mechanism operated by a float will close the compressed air inlet and open an outlet so that the compressed air will escape into the atmosphere. As the air thus escapes, water will rise through the valve D, and refill the vessel. When the vessel is thus refilled, the compressed air inlet will again be opened and the outlet closed by some mechanism operated by a float, thus making the whole action automatic. Such pumps can be made of simple construction, with reasonable certainty of action and at moderate cost.

All these merits are apparent or can be easily demonstrated to a would-be purchaser; but the fault in such a pump is not so apparent nor so easily demonstrated. Moreover, the agent will be sure not to allude to it. This fault is the loss of all the energy of expansion. To show how serious is this loss the table below is inserted, showing the maximum theoretic efficiency for such pumps at different heights of lift. Of this, not more than two-thirds, or at most, three-fourths, can be realized in practice.

Height in feet to which water is lifted.	Maximum theoretic efficiency of air used without expansion.
34	0.72
68	0.61
102	0.54
170	0.46
238	0.42
306	0.39

It will be noticed that the efficiency of such pumps decreases rapidly as the lift increases; hence we may be justified in using such for low lifts where it would be folly to apply them to high lifts. There is a legitimate field for such pumps,

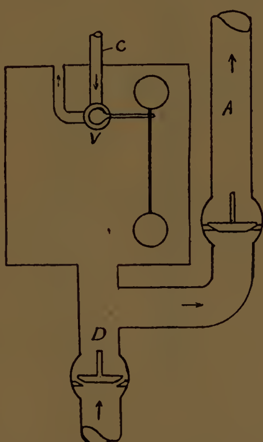


FIG. 225.—DIRECT AIR PRESSURE PUMP.

but we should know its limit and keep them within it. In justice to such pumps it should be said that they can and should be more efficient, as well as more durable, than the non-expansive piston pump.

Inventors have attempted to make a direct air-pressure pump that will utilize the expansive energy of the air. The writer has discovered in the United States two patents for such (Nos. 474,388 and 139,538). In both, the complicated and imperfect mechanical details bar all possibility of success. However, the main idea—the same in both—is correct, and, in the writer's opinion, capable of being carried out sucessfully. This idea is to have two vessels of the general nature of that shown in Fig. 225, and instead of allowing the compressed air to escape into the free atmosphere, it is, after the vessel is emptied, conducted back through the compressor and into the other vessel; thus using the same air over and over again, one vessel filling with water while the other is emptying. By this means it will be seen at once that none of the energy of expansion of the air is lost. The problem, then, remains to make the details simple, economical and sure of action. The problem is interesting from both a mechanical and an economical point of view. It also offers a good opportunity for "mathematical gymnastics."

We will now consider briefly the third class, in which water is raised by the effect of bubbles liberated in a vertical pipe. This has recently come to be known as the "Air Lift Pump," which name was given it by the "Engineering News" in an article of June 8th, 1893. (The article gives a very complete history of the air lift pump).

In construction it is the simplest of all pumps, the only essential being an open pipe, set approximately vertical with its lower end submerged, and some means of injecting air into the pipe below water-line. Each bubble of air

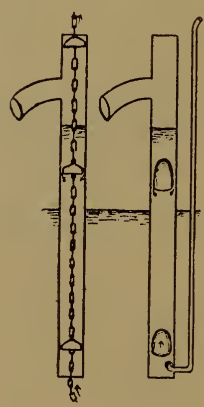


FIG. 226.—CHAIN AND BUTTON PUMP.

liberated within the pipe, by virtue of its buoyancy, exerts a certain force upward, tending to lift the column of water within the pipe. It is the accumulated lifting force of a number of bubbles that produces the action of the air lift pump. From this point of view the general principle of the action is easily comprehended, but a mathematical analysis of its action with a view to determining best proportion, is by no means simple.* Indeed, the difficulties are such that probably experiment alone will determine what are the best relations between depth of submersion, height of lift, volume of water discharge, volume of air used, area of discharge pipe, etc.

In this kind of pump, as in others, a large percentage of the energy put into the system may be lost through neglect of proper proportions and adjustments. A considerable proportion of the energy will always be lost by the bubble slipping through the surrounding waters, whether the whole be ascending

* See "Theory of the Air Lift Pump," Journal of the Franklin Institute, July, 1895.

or not. In this respect the air lift pump is very similar to the well-known "chain and button" pump as commonly used for lifting water from cisterns. In the latter we know that if the motion of the chain is too slow, all the water will slip by the buttons and remain in the cistern. So in the former: if the bubbles are too few or too small, or the lift too great, no water can be brought up. The difficulty lies in that the rubber buttons in the one case, and the bubbles of air in the other, *do not make water-tight pistons.* A bubble cannot be made to occupy the full cross section of a pipe under circumstances in which the air lift pump must act.

The writer is aware that a patent has been allowed for an air lift pump in which the claim is made that the bubble does fill the whole cross section of pipe, and that therefore they act as pipe-fitting pistons. The same claim is reiterated with great stress in all the literature on the subject issued by agents for said patent. If this claim can be realized for a series of bubbles, it can be realized with a single one. Does any one think it possible to make a single bubble remain stationary in a pipe under the given conditions? Or will it be claimed that when an air lift pump is in action and the air supply is suddenly cut off, that the "pipe-fitting pistons" of air will stand still in the pipe? Such must be the result if the claim is correct. Common sense, experience and science all oppose this claim. Let the advocates of the claim devise an experiment to prove it.

ELMO G. HARRIS.

Experiments with a glass tube, applied in the manner of the Air Lift Pump, will show clearly defined piston like sections of air and water, the discharge of air and water being intermittent and almost uniformly regular. When air is first admitted to the pump the water in the pipe above the point of air admission is blown out in a solid stream, as the shot is discharged from a gun.

If this is true, why may we not expect that the succeeding volumes of water which, through the head, are able to get above the air jet, are discharged in the same way? There is a continuous struggle going on between air and water to get into the eduction pipe, and notwithstanding the fact that air is admitted in a continuous stream, its admission is not continuous, because the water at times practically shuts it off. These interruptions are, however, of very short duration.

The secret of the Air Lift Pump action is in the high velocity with which the air and water are discharged through the eduction pipe. Without this high velocity there would be no piston like sections except perhaps in a small glass tube model where capillary attraction takes the place of velocity.

Let us imagine a case where the eduction pipe is ten feet in diameter, and admit air—say through an 8-inch pipe—to a Pohlé foot piece, there will be nothing but bubbling of air up through the water and no piston like sections will be formed; but let us suppose that this air pipe is 5 or 6 ft. in diameter and that it has a free discharge under several atmospheres, is it not easy to understand, that under such conditions, the air might occupy the entire section of pipe and that it might discharge the water like a gun shot? Is it not also easy to understand that there will be a high velocity of movement excited upward through the eduction pipe, and that we will either have a discharge of air alone, a discharge of water alone, or an intermittent discharge of both? This intermittent action takes place provided the air pressure at the foot piece is about equal to the water pressure due to its head. The two must be almost completely balanced, and it is because of a conflict for supremacy or a change of pressure between air and water, which goes on at all times, that the piston like sections are formed. If it is admitted that these sections are formed at any time and that the velocity of movement upward is great, it is not difficult to understand the Pohlé Pump exactly as Dr. Pohlé invented and patented it.

PUMPING BY COMPRESSED AIR.*

BY E. A. RIX.

My object in this paper is not so much to enter into an elaborate description of the various methods of compressed air pumping, as to touch on points which seem to have been heretofore neglected by those who have written on the subject, to suggest some new methods and to encourage, if possible in the building of pumping machinery, to design something specially adapted for the use of compressed air.

Compressed air has been handicapped from the very beginning in the matter of pumping, because it has been used with stock pumps which have been designed in general for boiler feeding and tank purposes, and no particular regard has been paid to the matter of cylinder proportions and appropriate pressures. Compressed air users in the same manner have been obliged to utilize old steam motors of all kinds, the general assumption being that steam motors are equally adapted for the use of compressed air. I will plead guilty to having committed this error on many occasions, and the remarkably poor efficiencies which I have obtained have led me to investigate the matter and to become a firm advocate for the designing of special motors for compressed air machinery. Great attention is paid to the designing of motors for the use of steam, even to the very smallest detail, and yet compressed air, which is almost doubly as expensive as steam to produce, has been compelled to take any misfit for its use, and it has been condemned right and left for lack of economy, and has had a difficult time to maintain its proper existence in the face of the results it has produced in many cases with motors which were designed for something entirely different.

Those who are informed on the subject are perfectly well aware that steam and compressed air, while following in general the laws of perfect gases, are not similar enough in their phenomena to be used in the same motor, the general difference being that for similar terminal pressures the points of cut off are different. Air, also, does not condense, which permits unlimited multiple reheating.

There has been sufficient development made in the line of air compressors, so that now the attention of manufacturers should be turned to the constructing of economical air motors; and among the first to inaugurate this reform should be the pump builders, for pumps, as ordinarily furnished for compressed air, have

*Paper read before the Technical Society of San Francisco.

the poorest economy of any compressed air machinery, not even excepting a rock drill.

It is not necessary to revolutionize shop methods nor to carry an expensive stock of specially designed pumps in order to accomplish the results desired. It seems to me that merely pointing out to an intelligent customer the fact that his pocket will be vastly benefited by having a pump specially constructed for his work will be a great help at the moment ,and as soon as it becomes generally known that great advantages are to be gained thereby, many people will abandon the old methods and the reform will be inaugurated.

I shall endeavor in this paper to point out some economical methods of pumping water by compressed air, and to suggest how others might be accomplished. Let us consider generally the various methods used to lift water by compressed air, and compare them in such a manner that those interested may better understand the subject, thus enabling them to improve upon these methods when occasion offers. It is discouraging to those who believe that compressed

TABLE 51.

FOR 100 GALLONS PER MINUTE. 200 FEET HIGH.

	No. 1.				No. 2.				No. 3.			
Ratio of Air to Water Cylinder.	Quantity of free Air.	Gauge Pressure.	H. P.	Efficiency.	Quantity of free Air.	Gauge Pressure.	H. P.	Efficiency.	Quantity of free Air.	Gauge Pressure.	H. P.	Efficiency.
1–1	134	11.0	29	17%								
1.5–1	153	48.8	21	24								
1.75–1	169	36.6	19.5	25								
2–1	181	27.5	16.2	30	130	50	18.2	27	170	50	23.8	21
2.25–1	197	22	15	33								
25–1	206	17.6	13.5	37	137	40	16.4	30	178	40	21.5	23
3–1					145	33	15.2	33	180	33	19	26
3.5–1					152	29	15	33	185	29	18.5	27
4–1					158	25	13.5	37	205	25	17	28
5–1					176	20	12	41.5	225	20	14.7	34

air occupies an economical as well as a useful field to see the various tables, rules and computations offered to the public for calculating the amount of air required to lift. water, without a word of explanation that might temper the almost general conclusion that compressed air is a very expensive luxury. It would require a stout heart and a long purse to put in a compressed air pumping plant if the verdict of the various quantity tables were final. One consulting these authorities, would invariably conclude that the efficiencies were so low that only pressing necessity would decide in favor of compressed air.

The percentage of efficiency credited to compressed air in these tables ranges from 15 to 30 per cent. No mention is made of possibilities beyond these numbers, and one is left but the one conclusion—that from four to seven horse power must be furnished to the compressor in order to produce a net yield of one horse power in water pumped, and particularly is this discouraging when enterprising advocates of electricity keep emblazoned before us all that imposing array of efficiencies that seem to almost jostle the revered 100 per cent. from its pedestal. Moreover, all this is misleading besides, for there are efficiencies to be obtained in the proper use of compressed air in pumps that are more than satisfactory, that in fact are difficult to exceed in many instances, and I have tried to make it clear in this paper how to practically realize these results.

As an example of the information given by some of the catalogues published by builders of compressed air machinery, take an example of one hundred gallons of water pumped two hundred feet high. What is the quantity of free air and the pressure required in direct-acting pumps? Reference is made to the table (51), containing extracts from three publications. One hundred gallons per minute, raised 200 feet high, requires, theoretically, 5 horse power. Comparing this with the table, we find that the efficiencies range from 17 to 40 per cent., the pressure from 110 to 20 pounds, the volumes from 225 to 130 cubic feet of free air per minute, and the cylinder ratios from 1 to 1 to 5 to 1. It will also be noted that the pressures required for the same cylinder ratios vary 150 per cent. The air pressures given are all receiver pressures, or pressures in the main air pipe, which fact is not mentioned, leaving one to draw the conclusion that, no matter what the pressure in the main is, it is only necessary to install a pump with a large cylinder ratio and use low pressures.

Compressed air in mining is used for driving rock drills, for hoisting and pumping, and the average pressures carried in the mains correspond very nearly to the steam pressures formerly used for the same work, and 90 pounds gauge, independent of altitude, seems to be the standard pressure. This being the case, these tables and pumping data should all be calculated from some such standard basis, with proper co-efficients for variations from the standard pressure, and a table giving the proper cylinder ratios, for different heads, using the standard pressures as a basis, would, it seems to me, be more helpful to those who wish to consult tables for guidance.

In this paper we shall assume 90 pounds to be the standard pressure carried in the mains and that it takes 20 brake horse power to compress 100 cubic feet of free air per minute to that pressure at sea level with a single stage machine. This is more than is called for by the catalogues, but observations from a great many compressors, of many makes, justify me in this statement, and pressures all along the line will follow the same rule.

There appear to be six general forms of compressed air pumps:

First—Displacement pumps for full pressure only.
Second—Displacement pumps using expansion.
Third—Direct acting pumps for full pressure only.
Fourth—Direct acting pumps using expansion.
Fifth—Air lift pumps, single and combined with displacement chambers.
Sixth—Pumps operated by independent motors.

The notations employed will be gauge pressures, unless otherwise specified. Temperatures are expressed in Fahrenheit degrees. The altitude is at zero; that is to say, sea level, and the atmospheric pressure is rated at 15 pounds for the sake of convenience, and one gallon of water, which equals .134 cubic feet, raised one foot high, is the unit of work to be performed.

The first general system of pumps, as before classified, viz., displacement pumps for full pressure only, appear to be the simplest of all, and are those which would naturally be first suggested to the mind. If we have a closed vessel containing water, having a discharge pipe, let us say 210 feet high, connected to its bottom, and if we force air at 90 pounds pressure slowly into this vessel, the air will rise to the top of the vessel and water will be discharged exactly equal in volume to the volume of air forced in, and (90x.068) + 1, or 7, will represent

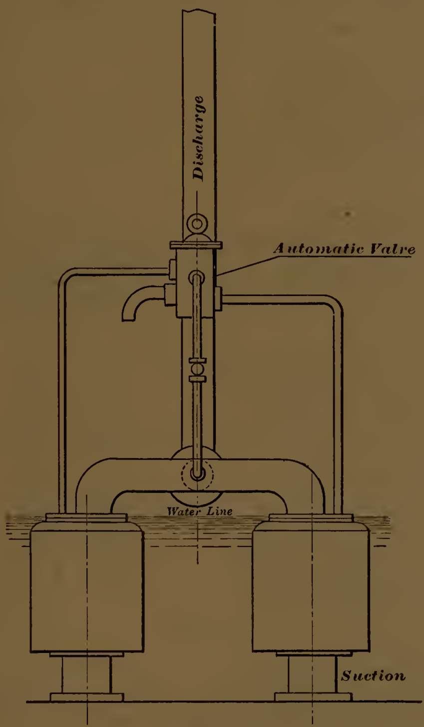


FIG. 227.

the number of cubic feet of free air required to raise each cubic foot of water. Inasmuch as practice will require a certain additional pressure to give a dynamic head, and as there is a certain amount of pipe friction to overcome, and as some air also is absorbed by the water, the number 7, before stated, can properly be made 9 cubic feet of free air used to 1 cubic foot of water pumped, or, expressed in foot gallons: 1 cubic foot of free air at 90 pounds will perform 1/9x210-.134 = 175 foot gallons. The 1 cubic foot of free air has received 1/5 horse power, or 6,600 foot pounds of work expended upon it. 175 foot gallons = 175x8.3 pounds, the weight of 1 gallon = 1,452 foot pounds, or an efficiency of practically 22 per cent., and it will be observed later on that this is better than most ordinary direct acting pumps will do with cold air as ordinarily used.

The efficiency of this system may be increased 15 per cent. by compound compression, or, if the water to be pumped has a higher temperature than the air, as, for instance, in the Comstock, where the water is 120 degrees, the absolute temperature would be 580 degrees, and the efficiency would then be 22 x 580-520 = 24.5 per cent. Assuming, for this illustration, that the Comstock is at sea level, the air in this system of pumping may be likened to a flexible plunger having 1 square foot area, making one stroke per minute, and the actual length of stroke equal to the number of cubic feet of compressed air furnished per minute, diminished by the absorption, leakage, clearance and equivalent quantity necessary

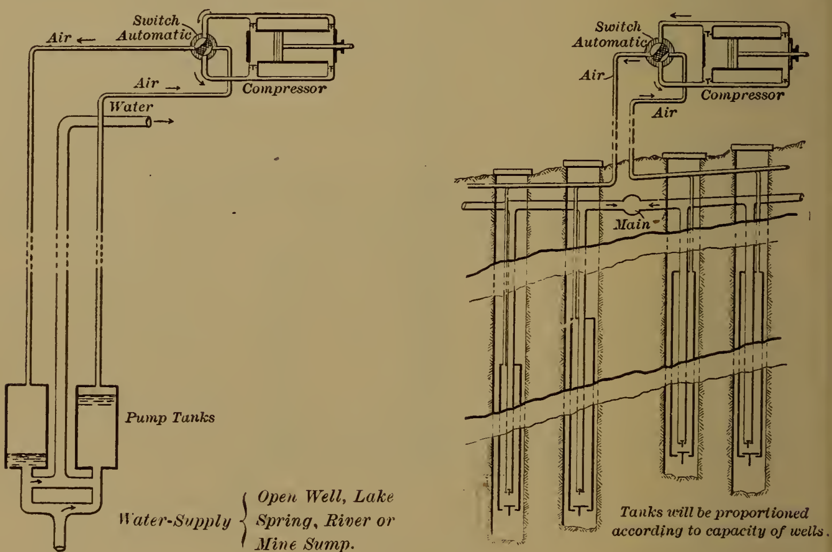
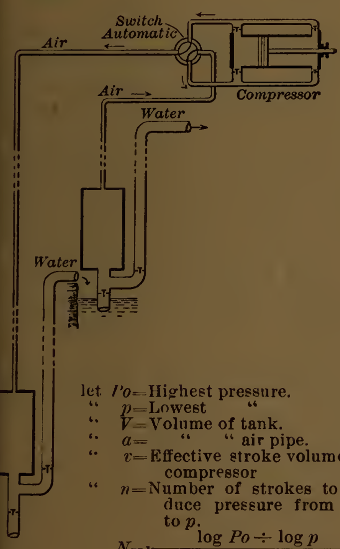


FIG. 228.

to furnish dynamic head and friction and increased or diminished by the ratio of absolute temperature of air and water. It would be proper to range the efficiency from 15 to 22 per cent. The chambers of this pump must be submerged, which limits its usefulness. In a sump, or tank, in a mine, and for lifts within range of ordinary compressors, say up to 250 feet, it will still probably exceed the efficiency pounding of this system, however, will be of the ordinary direct acting pump.

One can readily see that it exhausts its chambers into the atmosphere at full pressure, and all the expansive work contained in the air is lost. A proper compressor, suggested later on, which will utilize some of this expansion and increase the efficiency materially. Without reflecting, perhaps, engineers have generally discarded this system as too primitive and uneconomical, whereas, in fact, in many instances, it is cheaper by far to install, and often would exceed the efficiency of a direct-acting pump. For handling sewage, or material which would obstruct or destroy pump valves, its utility gives it a desirable place, but over and beyond this a well-constructed pump of this type has a right to be properly considered in comparison with ordinary direct acting pumps. In the pumps of this type there are generally two chambers, so that while one is filling, the other may discharge, and thus insure a steady delivery, but frequently single vessels are found adequate, and in some cases prove to be the proper installation. The diagram, Fig. 227, gives a general idea of this type of pump.

As may be imagined, the inlet and outlet of the compressed air in the original pumps of this class were controlled by floats, which are unreliable and limit to a great extent the size and shape of the vessels, and the clearance was excessive. The modern type, however, has eliminated all of these uncertainties, and the pump of the Merrill Pneumatic Pump Co. has a differential controlling valve, situated above the chambers, and this valve is automatic and positive, and the chambers are free from floats. A large number are in use, and being free from many complications which exist in ordinary pumps, they may be classed



let Po = Highest pressure.
" p = Lowest "
" V = Volume of tank.
" a = " " air pipe.
" v = Effective stroke volume of compressor
" n = Number of strokes to reduce pressure from Po to p.

$$N = \frac{\log Po \div \log p}{\log(v+a+v) \div \log(V+a)}$$

NOTES ON OPERATION.

One tank (or group of tanks) is emptied by air pressure while the other is drawn full by suction, the air charge being so adjusted that one tank is drawn full of water just when the other is emptied.

THE SWITCH

Can be automatically operated in either of three ways:

1. By means of the suction in the intake to compressor which depends on the height to which water must be drawn in filling the tanks.
2. By a mechanism that will throw the Switch at a given number of compressor strokes—the number required being that which will empty one tank and fill the other.
3. By an electrically controlled mechanism, the circuit being controlled either by floats in the pump tanks or by a pressure gauge on the in-take pipe.

ADVANTAGES.

1. The expensive energy in the compressed air is fully utilized.
2. There are no moving or delicate parts outside the compressor room except the check valves on water pipes.
3. One compressor can pump water from any number of sources.
4. In mine drainage the tanks may be submerged to any depth.

FIG. 229.

alongside of ordinary direct acting pumps, where submersion is possible. There is no reason why lifts in two or more stages would not be entirely feasible with this pump.

Class No. 2 consists of displacement pumps using more or less expansion. This class of pumps is best exemplified by the Harris system, owned and operated by the Pneumatic Engineering Co., of New York, and this system is extremely interesting simple and economical, and I have no doubt, would prove satisfactory in many cases, especially in mines having a steady flow of water at reasonable heads to be handled.

This system consists in displacing and elevating the water precisely the same as in Class 1, with the difference that while in Class 1 the water is immediately exhausted from the water vessels into the atmosphere and all its energy of expansion lost, the compressed air in the latter system is allowed to do work in expanding against the compressor piston and thus, theoretically speaking, all its expansive energy is saved, but practically the manufacturers claim the losses in leakage and friction to be about 15 per cent., a statement which deserves credence.

The action of the pump is as follows: There are two chambers placed within suction limit of the sump, or submerged, as desired. An air pipe leads from the compressor to the top of each chamber. There is a single water discharge connected to both chambers, and a single suction. The system is so arranged that while one chamber is filling the other empties, and an automatic switch plays the important part of regulating the entrance and exit of the air. The system is a closed one, and only leakage is replaced automatically.

Suppose one of the chambers filled with water; the air is then admitted at such pressure that the water is expelled and the air pipe and chamber are full of compressed air at the pressure of the water lift, or slightly more. The other tank has in the mean time filled with water. At this point the automatic switch connects the air pipe of the empty chamber with the intake of the air cylinder and the air pipe of the other chamber with the discharge of the compressor cylinder. It is evident that instantly the air in the first chamber will expand through the compressor and equalize the pressure in the empty air pipe of the second chamber and all clearances. This part of the expansion is lost, but it amounts to but little. The compressor now transfers the air from the first chamber to the second, displacing the water in the second, and the air from the first chamber thus does work upon the air compressor piston in expanding from full pressure to zero. When zero pressure is reached in the first chamber, if it is not submerged, the compressor continues to draw air from it until the water rises and fills it. At this point the first chamber is ready to be discharged, but if there has been leakage the second chamber has not received enough air to complete its discharge, and this is now supplied by a check valve in the intake pipe, which is set to open at a suction pressure slightly above that necessary to draw the water into the chambers. If the chambers are submerged, an ordinary check valve will automatically supply any deficiency in the quantity of air. The second chamber, being completely discharged, the automatic switch reverses and the cycle is complete. Of course, everything depends upon the reliability of the switch, which is placed on the air pipes near the compressor, where the engineer can see its operation and adjust it if necessary. It can be automatically operated in three ways: First, by means of the suction which occurs in the intake pipe to the compressor when the water is drawn above its outside level in one of the chambers; second, by a mechanism that will throw the switch at some assigned number of strokes of the compressor, the proper number being that which will empty one chamber and fill the other; third, by an electrically controlled mechanism, the circuit being made and broken by a pressure gauge on the intake of the compressor, or by a float in one of the chambers.

In Figs. 228, 229 and 232 we have diagrams and data supplied me by the Pneumatic Engineering Co., which will be interesting to those who care to investigate this extremely interesting and economical method of pumping by compressed air.

Fig. 231 gives a problem of pumping under 90 pounds pressure which shows in detail the range of the work on the air compressor piston during the progress of changing the air from one water chamber to the other. It will be noted that the net work is even less than the full pressure work at 90 pounds pressure, thus showing that the compression work is practically eliminated, and 90 pounds pressure can be transferred from one receiver to the other at less than one-third of the power required to fill a receiver at 90 pounds pressure, consequently this system should be at least twice as economical as the regular displacement system. The disadvantage is that it requires an independent plant and a double set of air pipes. I have no hesitancy in placing the efficiency at from sixty to seventy per cent., and consider it a very desirable system for mine station pumping.

DIRECT ACTING PUMPS.

The ordinary direct acting pump is the best known of all power pumps, and is the typical example of a motor driven, displacement pump. Its efficiency suffers on account of its large clearance, its apparent inability to realize full stroke and the ill-advised selection of cylinder proportions. In general it is given a mechanical efficiency of 65 per cent. It is not an absolutely complete displacement pump, because the valves are generally arranged to cut off just before the completion of the stroke in order to exhaust the inertia of the moving parts by the time the stroke is finished, and this gives a slight expansion in the cylinder, but this may be neglected in general and the pump put in the displacement class.

If a pump uses full pressure only, it is evident that the more full pressure a compressor diagram shows, the greater will be the efficiency of the system. The lower the air pressure the less the compression work and the greater the proportion of full pressure work, consequently the lower the pressure the more efficient the system. This really refers to the compressor and not to the pump, for the pump works the same whether it receives air at 10 pounds pressure from the compressor or whether it has been expanded from a receiver having a higher pressure, provided the temperatures are constant. If we look for the best efficiency then from direct acting pumps we must put in an independent compressed air system and carry a low pressure. We can hardly imagine that this would be generally done, and consequently we must count on the standard pressure of about 90 pounds for our economies and proportions.

After comparing the various tables of compressed air quantities for direct acting pumps, it appears that the calculations of William Cox are most reliable, and they agree very nearly with practical results that I have noted. He, however, like the others, considers that the pressure used by the pump is receiver pressure. His principal formulæ are as follows, based on 100 feet per minute of piston speed. Other speeds will naturally be in proportion.

Diameter water cylinder $=$ .54 gallons raised.

(Diameter air cylinder) 2 $=$ .5 x head x (Diameter of water cylinder) 2 $\times$ gauge pressure.

Volume of free air = .63 x (Diameter of air cylinder) 2 x (1 + .068 gauge pressure) and, in general, without regard to any factors but quantity, head and pressure, we have the volume of free air = .093 foot gallons gauge pressure x (1 + .068 gauge pressure).

In using these it must always be borne in mind that the pressures given are receiver pressures; that is to say, that the compressor furnishes air to the mains at pressures called for in the tables, and if any higher pressures are carried in the mains, such as 90 pounds, and if then the air cylinder of the pump is so large that the air is wiredrawn to it, then the quantities of compressed air given should be multiplied by a constant, such as given in Column 6, Table 52, when the pipes are short between the main and the pump, as occurs generally in a shaft.

The constants in Column 6 are simply about 70 per cent. of the ratio of the absolute temperatures due to the expansion of the air from 90 pounds to the pressures indicated in the tables, and the horse power will not be the power required to raise the pressure from atmosphere to the working pressure, but always that required to deliver it into the mains. This fact makes sorry work for efficiencies.

Inasmuch as most pumps are in the shaft near the main, a very short pipe connects them to the main, and the air is expanded through this short pipe to the pump, for pressures less than that in the main. This expansion reduces the temperature of the air entering the pump to quite a marked degree. Not by the theoretical amount due to the pressure drop, for some heat from external sources can be supplied, and wiredrawing furnishes a disputed amount also. While I have made no experiments on this subject, I have assumed that less heat would be given to this expanding air than a good water jacket would take out of the air during compression, and I have assumed the temperature to drop 70 per cent. of that, due to the pressure drop. This reduces the air volume and adds to the quantity consumed by the pump and consequently lowers its efficiency.

It would be good practice to let this cold air gain normal temperature before reaching the pump cylinder, which can be done by passing the water being pumped into an enlargement in the discharge pipe within which is a coil through which the air is passed, but if no such device is used and the air pressure in the mains is 90 pounds, we shall find that the table (Table 52), expresses about the real condition of affairs for a pumping effort of 10,000 foot gallons.

In explanation of the table:

10,000 foot gallons = 83,000 foot pounds = 2.5 horse power, theoretical.

Column 1—Gauge pressures in air cylinder of pump.

Column 2—Volume of free air required, calculated from Cox's computer, No. 76.

Column 3—Horse power corresponding to above volume, calculated from same computer.

Column 4—Ratio of the gauge pressures in Column 1 to 90 pounds, standard mining pressure.

Column 5—Adiabatic temperature ratios corresponding to the pressure ratios in Column 4.

Column 6—Gives the practical temperatures, ratios being 70 per cent. of 5.

Column 7—Is Column 2 multiplied by Column 6.

Column 8—Horse power calculated for Column 7 by Cox's computer, No. 76.

Column 9—Percentages of Column 3.

Column 10—Percentages of Column 8.

Conclusions from table:

First—The lower the air pressure in the main, with cylinders designed properly, the greater the efficiency, reaching as high as 30 per cent.

TABLE 52.

1	2	3	4	5	6	7	8	9	10
Press. of Air.	Volume Cox.	H. P. Cox.	Ratio Comp. Referred to 90 Lbs.	Adiabatic Increase Ratio.	Practical Increase Ratio.	Increased Volume.	H. P. at 90 Lbs.	Eff. Cox.	Eff.
20	113	8.4	3	1–37	1–26	142	28.5	30	9
25	103	9	2.6	1–32	1–22	125	25	27	10
30	97	9.6	2.3	1–27	1–19	115	23	26	11
35	93	10.1	2.1	1–24	1–17	108	21.5	25	11.5
40	89	10.6	1.9	1–2	1–14	101	20	24	12.5
45	87	11.2	1.7	1–16	1–12	97	19.7	22	12.6
50	85	12.0	1.6	1–14	1–11	94	19.1	20.5	13
55	82	12.5	1.5	1–12	1–09	89	18	20	14
60	80	12.6	1.4	1–10	1–07	85	17	19.8	14.7
65	79	13	1.31	1–07	1–06	84	16.8	19.3	15
70	78	13.4	1.24	1–06	1–05	82	16.4	19	15.3
75	77	13.6	1.17	1–05	1–04	80	16	18.5	15.6
80	76	14	1.1	1–04	1–03	78	15.6	18	16
85	75	14.5	1.05	1–02	1–02	76	15.2	17.5	16.5
90	74	14.8	1	1–0	1–0	74	14.8	17	17

10,000 foot-gals. = 83,000 foot-lbs. = 2.5 H. P. theoretical.

EXPLANATION OF TABLE.

Col. 1—Gauge pressures in air cyl. of pump.

Col. 2—Is the volume of free air required, calculated from Cox's computer.

Col. 3—Horse power corresponding to above volume, calculated from same computer.

Col. 4—Ratio of Gauge pressures in Col. 1 to 90 lbs. Standard Mining Pressure.

Col. 5—Adiabatic temperature. Ratios corresponding to pressure ratios in No. 4.

Col. 6—Are practical temperature ratios, being 70% of No. 5.

Col. 7—Is Col. 2 multiplied by Col. 6.

Col. 8—Is H. P. calculated for No. 7 by Cox's computer 76.

Col. 9—Are percentages of Col. 3.

Col. 10—Are percentages of Col. 8.

Second—The efficiency drops immediately if the air is expanded through the throttle into an air cylinder which requires less pressure than the main.

Third—At standard mining pressure of 90 pounds the efficiency is about 17 per cent. with properly designed cylinders, and probably drops as low as 12½ per cent. in pumps where "just one turn of the valve is open."

Fourth—Very little loss occurs in using pressures within 10 per cent. of the pressure in the main, which is ample to impart proper dynamic head to the pump.

If compound compression should be used, then the efficiencies mentioned can be increased 15 per cent., and they will range then as high as 34.5 per cent. for low pressures, and from 19.55 to 14.5 for standard mining pressures.

If the air is reheated, so that the pump cylinder receives it at 300 degrees Fahrenheit, and if no account is made of the cost of reheating, then the efficiencies for low pressure and simple compression will be 42 per cent., and com-

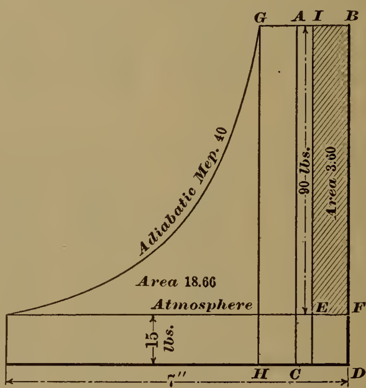


FIG. 230.—DIAGRAM OF ORDINARY DIRECT-ACTING PUMP.

pound compression 48 per cent., and for standard mining pressures, for simple compression, 24 to 17.5 per cent., and for compound compression, 27½ to 20 per cent.

According to the above table, at standard mining pressure the efficiency, using cold air, is 17 per cent. at maximum. According to our statement, if 20 horse power produce 100 cubic feet of free air per minute compressed to 90 pounds, 1 cubic foot will cost 6,600 foot pounds of work. Seventeen per cent. of this would be 1,122 foot pounds of useful work that the one cubic foot of free air would perform; 1,122 foot pounds is 135 foot gallons.

I have measured the exhaust of many pumps using air at from 80 to 90 pounds, and I have found their work to be approximately 135 foot gallons for each cubic foot of air, and I have used this figure in all my calculations for ordinary pumps, properly proportioned. Thus, to lift 200 gallons a minute 200 feet high, would be 40,000 foot gallons. This, divided by 135, would require 300 cubic feet of free air compressed to 90 pounds, which in turn requires 3 x 20, or 60 horse power to produce it. If compound compression be used, I increase the 135 foot gallons by 15 per cent. and call it 155 foot gallons, and if reheating is used, in either case, I increase the 135 by the ratio of absolute temperature which I am satisfied the pump receives.

The efficiency of the direct acting pump is seen from diagram 230, as follows:

With a simple compressor the M. E. P. of compression is a little more than the M. E. P. adiabatic, say, 40 pounds. This corresponds to an area on this card of M. E. P. = Area x Spring Length of Card 40 = A x 15-7, or 280-15 = 18.66 square inches. The adiabatic volume of G, B, D, H shrinks to A, B, D, C before arriving at the pump. The pump having a mechanical efficiency of 65 per cent., the volume 1 B, F, E is all that really does useful work. That area is .60 x 6 = 3.60 square inches, and 3.60-18.66 = 19 per cent., which compares nearly with our other figures.

We found simple displacement pumps, Class I, giving 175 foot gallons of work, and direct acting pumps, Class II, giving 135 foot gallons of work. This might be anticipated, because in Class I the air is used isothermally throughout, the pressure is always exactly what is necessary and clearance is small and no mechanical movements to overcome.

Referring again to Table 52, and remembering that we have assumed 90 pounds as our standard pressure in the mains, we note how serious a loss we would entertain if we used a pump having such a large air cylinder that the working pressure was only 20 pounds. One not skilled might expect to get 30 per cent. efficiency, but he would really get about 10 per cent., or just 300 per cent. out of the way, and this justifies the remark that I have heretofore made that these catalogue tables are misleading. Except for extremely small quantities and for sinking pumps, I cannot justify the use of simple, direct acting pumps for compressed air service.

Simple displacement pumps, mentioned in Class I, can be made to use the air with at least partial expansion, and I suggest the following for consideration and experiment. It is new to me, and occurred to me while searching for a cheap and economical means to do some air pumping. We will take the same problem of work at 90 pounds pressure, and, in order to make the problem simple, I have made it purely theoretical, and we can supply whatever efficiency coefficient we deem appropriate.

THE COMPOUND DIRECT-AIR-PRESSURE PUMP WITH ADJUSTING RECEIVER.

Computations for Proportioning the Parts and a Graphical Presentation of one Cycle of Operation.

SYMBOLS AND NUMERICAL VALUES.

P'' = Absolute Maximum pressure in lower tank.
P''' = " " " " upper "
P' and P'' = " Minimum " " either "

a' = Volume of air pipe to lower tank.
a'' = " " " upper "
V' = " " " lower "
V'' = " " " upper "
R = " " " Receiver.
v = " compressor stroke.
n = Number of compressor strokes.

Pn = Variable pressure in tanks.
W = " work per stroke.
Vn = " water volume delivered per stroke.

FORMULAS.

$$V''=\frac{P'(v'+a')+p''\ a''-p'\ a'}{P''}-a'' \qquad I$$

$$R=\frac{P''\ (v''+a'')-P'\ (v'+a')+p'\ a'-p''\ a''}{P'-P''} \qquad II.$$

$$Pn=Po\left(\frac{v+a}{v+a+v}\right)^n \qquad III.$$

Po = initial pressure, Pn that after in strokes.

$$N=\frac{log.\ Po-log.\ Pn}{log.\ (v+a+v)-log.\ (v+a)} \qquad IV.$$

$$Wn=P\ x\ v\ log.\ \frac{Po}{Px} \qquad V.$$

$$Vn=\frac{Pn}{P'}\ v \qquad VI.$$

The proper value for v is found by trial in Eq. IV.

THE PROBLEM.

Proportion a System to lift 66 cu. ft. (500 gals.) per minute 200 feet in the lower stage and 650 gals. (87 cu. ft.) per minute, 175′ in the upper stage. Assuming lengths of air pipes to be 500′ to lower and 300′ to upper tanks.

Note:—In the following computations it is assumed that no change in temperature occurs and friction of air and of water in pipes is neglected.

SOLUTION.

Horse Power:—From figures given above the average net Horse Power = 55. But the max. rate of work per stroke is 10,900 ft. lbs. (see ordinate at K.) Assuming the compressor to work at 90 revolutions (or 3 strokes per sec.) this will give about 60 H. P.

Air Pipes:—If the volume of compressor stroke is previously known the max. velocity in air pipe of known area can be found by observing that immediately after switching the whole volume of compressor stroke goes through the air pipes.

Otherwise an approximate rate is: The max. air volume = 6 times the average water volume discharge. In this case the rule gives 5.5 cu. ft. per sec. of air at 102 lbs. Hence select air pipes 4″ diam.

Tanks:—They should not be less than 10 times the vol. of air pipe. Hence assume V′ = 450 cu. ft. Then if no receiver were attached V″ would be computed by Eq. I. which would give $V'' = 525$; but by conditions of the problem, V'' must be $= 1.3\ V' = 585$. This requirement can be satisfied by attaching a receiver whose volume will be computed by Eq. II. Whence $R = 497$. In practice make V'' and R larger to permit adjusting, which can be done by pumping water in or out of R.

Notes on the Operation:—When air is switched out of V'' it expands into pipe a' and thereby drops from 91 lbs. to 88 lbs (G'' to A) then compressor forces air into V' but no water will be delivered until pressure in V' reaches 102. In the mean time pressure in V'' will be worked down to 79.5 which will require 47 strokes (see A to B' and A to B'').

When air is switched out at V' we will have $V' + R + a'$ at 102 lbs. while

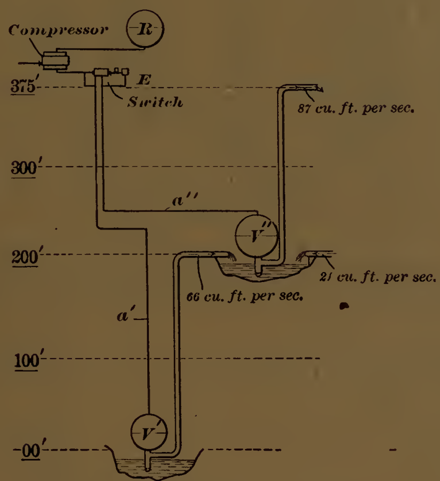


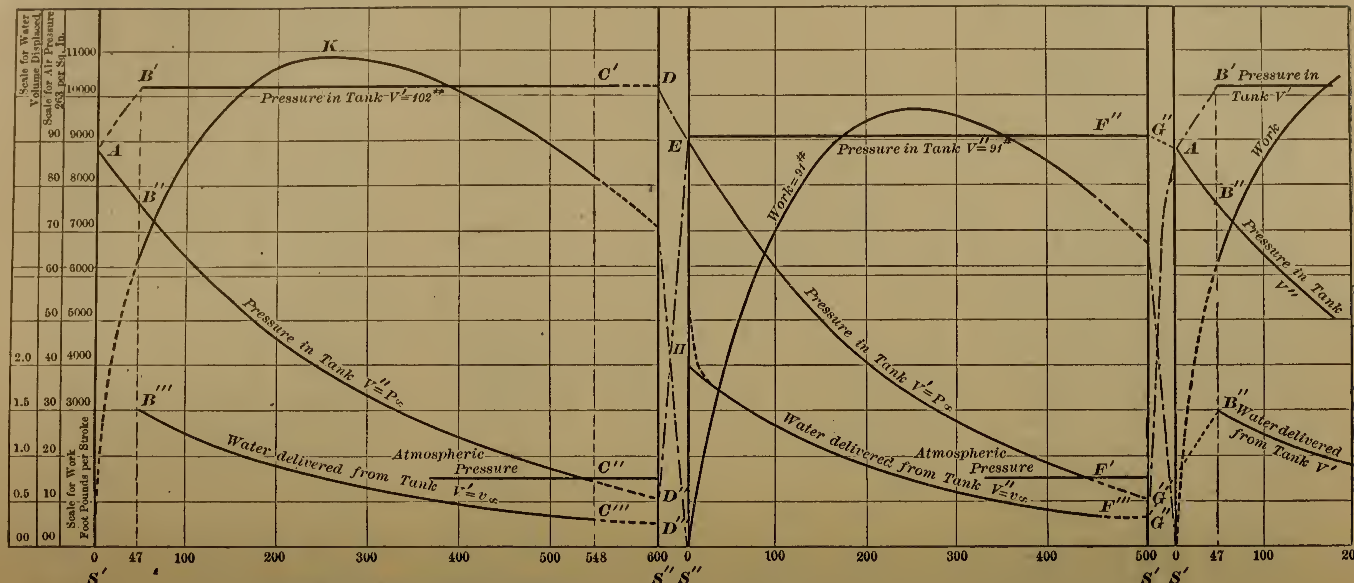
FIG. 231.

only 91 lbs. is necessary to force water out of V''. Hence water will discharge without further action of compressor until all pressures drop to 91 lbs.

The volume of water thus displaced will be 96 cu. ft. This cannot be properly shown on the diagram. It occurs between D''' and E''' but as these points are coincident in time the effect will be to run the delivery curve up as shown in the dotted line near E'''.

Formulas III and IV do not apply after Pn falls below atmospheric pressure, for V' (or V'') is then a variable. Hence the broken lines between C and D and F and G are not computed.

The two lines in each pair of heavy verticals S'' S'' and S' S' are coincident in time. The intervening space is for convenience in showing connections between curves.



Number of Compressor Strokes.

FIG. 232.

TABLE 53.—HARRIS' COMPOUND PRESSURE PUMP.

A. E. Chodzko.

Number of Double Strokes.	Pn Absolute Pressure per Sq. In. after Expansion.	$\frac{Po}{Pn}$	$\frac{Pn}{Po}$	$\left(\frac{Pn}{Po}\right)^{\frac{1}{r}}$	Effective Adiabatic Work of Compression and Delivery. Foot-Lbs.	Effective Isothermal Work of Expansion. Foot-Lbs.	Net Work of Compression and Delivery. Foot-Lbs.
1	88.9	1.18	0.847	.89	25,704	19,580	6,124
2	73.5	1.39	0.719	.79	24,768	15,991	8,777
3	64.1	1.63	0.614	.71	23,509	12,937	10,572
4	54.4	1.92	0.521	.628	22,824	10,339	12,485
5	46.2	2.27	0.44	.557	21,270	8,142	13,128
6	39.2	2.66	0.376	.497	19,960	6,267	13,693
7	33.3	3.14	0.318	.441	18,360	4,687	13,673
8	28.3	3.7	0.27	.39	16,517	3,347	13,170
9	24	4.36	0.23	.349	15,480	2,195	13,083
10	20.4	5.13	0.195	.31	13,738	1,231	12,507
11	17.3	6.05	0.166	.28	12,845	401	12,444
12	14.68	7.13	0.14	.246	11,088	–296	11,384
							141,040

Work of simple compression of 80 cu. ft. of free air to 90 lbs. gauge at 6600, 528,000

Work of compound compression 80 cu. ft. of free air to 90 lbs. gauge at 6600, 446,306

Efficiency of the system referred to compound is therefore, $\frac{446{,}306}{141{,}040} = 3.09$

and referred to simple is $\frac{528{,}000}{141{,}040} = 3.75$

Po initial absolute pressure in tank.

final " " in compressor = 90 lbs. *g.* = 1047 lbs. absolute.

Pn absolute pressure after the *n*th double stroke.

Pa " atmospheric pressure.

$$Pn = Po\left(\frac{V+a}{V+a+v}\right)^n$$

V volume of tank = 8 cu. ft.

a " pipe = 3.24 cu. ft.

v " compressor cylinder = 2 cu. ft.

$Pn = 104.7 \times 0.849^{\,n} \diagdown \log. Pn = 2.019947 + n \times \bar{1}.928965.$

Effective isothermal work of expansion.

$We = 267.87\, Pn - 4233.6.$

Effective adiabatic work of compression.

$$We = \frac{v}{r-1}\left[r\ \left\{P_1\left(\frac{Pn}{P_1}\right)^{\frac{1}{r}} - Pa\right\} - \left(Pn - Pa\right)\right]$$

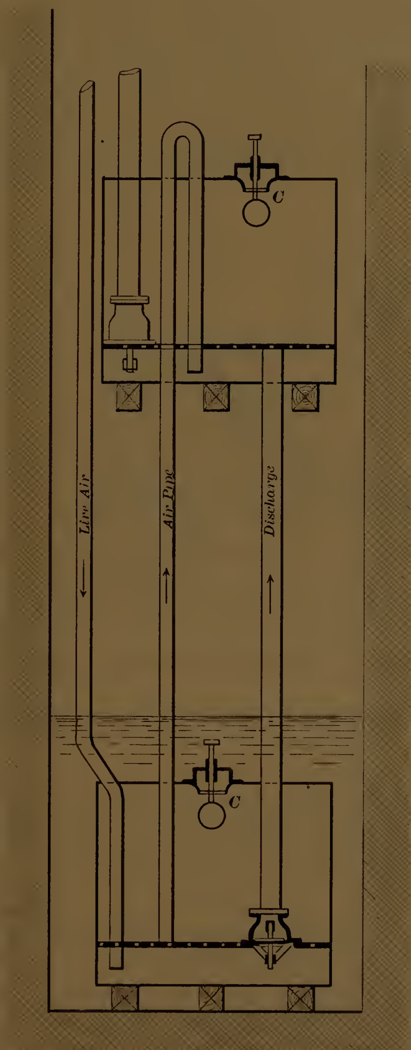
Theoretical actual work done in lifting water $= 8 \times 62.5 \times 2.10 = 105,000$ foot-lbs. allowing 85% mechanical efficiency. Real work done = 89,250 foot-lbs.

$$\frac{89,250}{141,000} = 63.3\%$$

Suppose we have six equal-sized tanks, A, B, C, D, E, F (233), arranged above each other at distances that we shall shortly determine. Suppose tank A, submerged in a sump and an air pipe conducting compressed air at 90 pounds to this tank. From each tank to the one above there is an air pipe leading from the bottom of the lower tank to the top of the upper one, as shown. From each tank to the one above, there is a water discharge tank leading from the bottom of the lower one to the bottom of the upper one, as shown, and having a check valve on its lower end to keep it full of water. From tank F the discharge is to the surface G. On each tank is a check valve, C, opening the tanks to atmosphere whenever the pressure falls to atmosphere within the tanks, and closing them whenever the water rises against them. Now if tank A be full of water, and air at 90 pounds be admitted the water will be displaced into the tank B, a distance of 210 feet, just as it did with the Merrill pump, but when the water is all discharged from A, and just before the water discharge pipe is uncovered, the air pipe leading to tank B is uncovered and the air passes up into tank B, expanding against the water and pushing it up into tank C, a distance equal to one-half the absolute pressure of 90 pounds. This must be so, because tanks A and B being equal the pressure becomes 37.5 pounds in both of them when they contain air and not water, so now we have the water in C at 87 feet above B, and in a similar manner it will be pushed into D and E and F, and finally out at G, distances 46 feet, 25 feet, 14 and 6 feet, respectively, corresponding to 1/3 and 1/4, 1/5 and 1/6, the absolute pressures of 90 pounds. When F is empty the whole system is full of expanded air at 2.5 pounds, at which pressure it exhausts into the atmosphere. No mechanism is necessary except the one small valve mechanism similar to the Merrill device, and this admits air into A at proper intervals. The rest of the tanks take care of themselves. If fine economy is not required, only the water pipe need connect the tanks; the air pipe may be eliminated and also the check valves in the water pipes, and the air will drive the water from tank to tank and finally escape. The check valves C will then drop open and air may be again admitted at A. The water pipes, being always full, do not form clearance. It matters not how much water is left in the bottom of the tanks so long as they are all alike. That does not form clearance, and, so long as the tank is full before the valve switches, there is practically no clearance. The air as admitted to the tanks is made to bubble up through the water in small bubbles, through a false bottom, and thus the expansion is made isothermal.

The system can be made double, or in any number of units, so that the discharge may be constant. The objection to the system for shaft work is in the space required for the tanks, which might not be objectionable in some places. For outside pumping it would be efficient and easy to install. As to economy, not much of a calculation is necessary to show that if the Merrill pump did 175 foot gallons of work with one cubic foot of free air, at 90 pounds, and lifted the water 210 feet, this system with the same air will do 175x388-210, or 320 foot gallons, because it has lifted the water 87 + 46 + 25 + 14 + 6 feet, or 178 feet further, or a total of 348 against 210. This makes the efficiency 22 x 388-210, or 40 per cent., quite an advance over the efficiencies of direct acting pumps.

Another peculiarity is that although 90 pounds pressure corresponds to 210



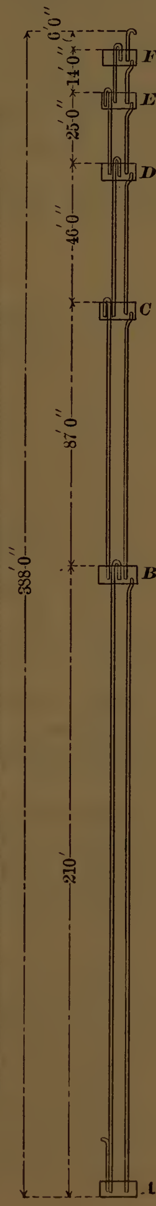


FIG. 233.
MULTI-CHAMBER LIFT WITH EXPANSION.

feet head, it is lifting water 388 feet, so that the cylinder ratios, as it were, are inverse.

If we now study diagram 234, made up from the action of this pump, and allowing that the expansion is isothermal, we have A, B, D, C as the original volume at 90 pounds in the first tank. This expands to E, F, D, I in the second tank, and so on to atmosphere after leaving the sixth tank. It is evident that the triangular areas A, T, E, etc., six in all, are the expansion losses, but when it is considered that these expansions furnish the dynamic head that overcomes the element of time and pipe friction, we see that even if there is loss, it is necessary, and if the air had expanded along the isothermal line we would have been obliged to have added to our initial pressure and quantity to have overcome these resistances, consequently, as a pump, it has a high efficiency, for it utilizes about all

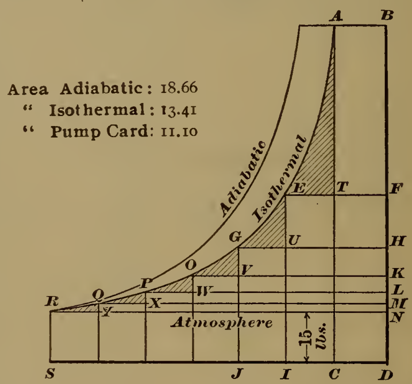


FIG. 234.—DIAGRAM OF MULTI-DISPLACEMENT PUMP USING EXPANSION.

the expansion energy of the air. To calculate it from the card without planimeter, we have as follows:

The card being 7 inches long, 7 atmospheres high and 1 atmosphere to the inch, we have:

M. E. P. isothermal—28.89 pounds.

We know that Area of Card x Spring-Length = M. E. P.; therefore, M. E. P. x Length-Spring = Area, or, in this case, 28.89x7-15 = 13.41 square inches.

The card being lined to square inches, it is easy to add up the effective area, and we find it to be 7 + 7/2 + 7/3 + 7/4 + 7/5 + 7/6-7x1-.05, the latter being the area R, Q, Y, or 18.15—7.05=11.10 net area. The curve area being 13.41, the efficiency of the pump = 11.10-13.41, or 82 per cent., and for the efficiency of the system with simple compression, we have as before, the adiabatic area 18.66, and the work area 11.10 divided by this, gives 59 per cent. efficiency for the system. Allowing for it the same ratio of losses, viz., 7 to 9, as we did the Merrill, we have 59x7/9 = 413-9 = 45 per cent., net, nearly the same figures we had before. With a compound compressor I should look for 50 per cent. efficiency in this system, and I hope the suggestion will prove interesting enough to encourage some one to try it.

We come now to what I deem the most interesting and useful class of compressed air pumps, viz., the motor displacement pumps, using more or less expansion, otherwise called compound, or multi-cylinder pumps.

COMPOUND OR MULTI-CYLINDER PUMPS.

Judging by results, these are very little understood, even by the people who build them, so far as their use of compressed air is concerned. The general idea has been that if the expansion of air produces such low temperatures that it frequently freezes a simple pump to a stop, it would be an unwise proposition to try further expansion in a compound pump, and consequently the compressed air users have practically avoided multi-cylinder pumps.

I shall hope to show that even a triple or quadruple cylinder pump may be not only operated safely but economically with no further addition of heat than that supplied by the water itself.

Before that, however, I shall speak of the phenomenon of freezing. This is a very simple matter, easily explained and easily prevented. The compressed air being used at full pressure in the pump cylinder, is then exhausted, and, doing its expansion work within and about the exhaust ports, reduces their temperature until ice is formed in the exhaust, which finally closes the opening. I believe the action to be cumulative, and on the same principle used in making liquid air, for I have noticed that when once the pump cylinder becomes quite cold the choking proceeds more rapidly, the idea being that the colder the air previous to exhaust the colder will be the exhaust, which in turn makes the cylinder colder and thus the cumulative action goes on rapidly. I have heard that makers have advised short ports and conically tapered ones, with no threads, to avoid freezing. I have seen pumps with steam injected and pumps with fires under them, and pumps submerged in a tank of water, all to avoid the freezing. Where it is not desirable to reheat pumps with steam or hot air, there are, to my mind, two simple methods of avoiding freezing. First, tap the discharge main with a quarter inch pipe, draw down the end of this pipe until the hole is the size of a knitting needle, introduce this small pipe well into the exhaust of the pump, and let a small amount of water continually discharge therein. It will keep the temperature of the metal above the freezing point, and thus prevent freezing. The loss of water is very small. A pump doing 10 H. P. actual work, and using 250 cubic feet of free air, weighing about 20 pounds, would use, I should judge, about 10 to 12 lbs. of water per minute, or 1½ gallons would be ample for the work. Or, if it is not desirable to waste this water, exhausting through a coil of thin pipe placed in a chamber, through which the suction or discharge water circulates, will furnish heat enough to the expanding air to prevent freezing.

The second method for preventing freezing would be to use compound pumps, properly arranged. This you will note is exactly contrary to the generally accepted practice. Inasmuch, however, as a compound pump is so different from two simple pumps having the same sizes of cylinders and using the same pressures, and inasmuch as the temperature drop on the initial cylinder is about one-half that of an equivalent simple pump, it is evident that it will not freeze, and if the exhaust be carried through a copper coil over which the water which is being pumped flows freely, the air will become about the same temperature as the water, and it will, thus reheated, pass to the compound cylinder at the same temperature as it entered the initial cylinder, and, passing from this cylinder, it will exhaust without freezing, and the pumping economy will be advanced 30 per cent. or more. Each cylinder would thus dispose of about half the reduction of temperature. If, however, no water heater was introduced between the cylinders, the initial cylinder would discharge the air at a large temperature drop into the second cylinder. This gives a cumulative effect to the cooling at the exhaust of the second cylinder, and rapid freezing up would result. This has led every one to believe compound pumps impracticable for cold air, but by the introduction of the water heated coil between the cylinders, without cost for the heat, the compound pump will not freeze and will be more economical. It is evident that the lower the range of pressures the less the range of temperatures and consequently the less liability to freezing.

To return now to the compound, direct acting pump: Compound pumps of the better class can be given a mechanical efficiency of 70 per cent., which covers

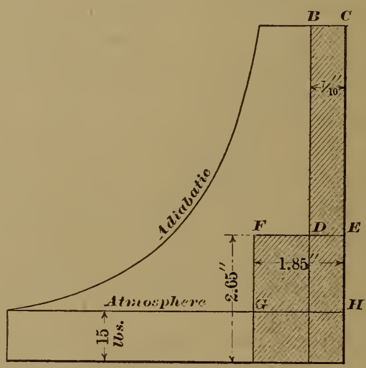


FIG. 235.—DIAGRAM OF COMPOUND PUMP, WATER REHEATED.

the losses in the air and water cylinders and the friction in the pipes, with an allowance for dynamic head. Their economy depends upon the character and amount of the reheating applied to the air.

There are four general classes:

1. Reheating with the water pumped.
2. Extraneous heating before the initial cylinder.
3. Extraneous heating before the compound cylinder.
4. Extraneous heating before both cylinders.

In the first class for mine pumping the temperature of the water may be generally assumed to be 60 degrees, and the heater is a shell filled with copper tubes and preferably made a part of the suction pipes, the water flowing around the tubes through which the air is exhausted from the first cylinder to the second. A steam heater, of the Wainwright type, gives the idea, and about one square foot should be allowed to every five cubic feet of free air. As stated before, its action is to restore the compressed air exhausted from the initial cylinder to normal temperature, thus delivering it to the second cylinder at the same temperature as the first, just reversing the action of the inter-cooler during compression, and inasmuch as the cylinders use the air at practically full pressure, the expansion takes place in the reheater, and the diagram, 235, shows what takes place as far as economy is concerned. B, C, E, D is taken at 70 per cent. of the volume furnished to the pump to cover the mechanical efficiency. This expands to 2.65 times its volume (when the initial pressure is 90 lbs.), in the reheater, and F, E, H, G is the volume given the second cylinder. The areas = .7 x ·(7-2.65) = .7 x 4.35 = 3.045 + (1.855 x 1.65) = 3.06 = 6.1 square inches. It will be noted that the work in both cylinders is alike—6.1-18.66=32.7 per cent., against 19 per cent. that we figured by the same method for the simple pump. A very large gain and costing nothing to maintain, the first cost of the heater being small. I cannot conceive of a more forcible argument in favor of compound pumps.

For compound compression this efficiency will be increased to 37.5 per cent. If our simple pump did 135 foot gallons of work, then this style of compound will

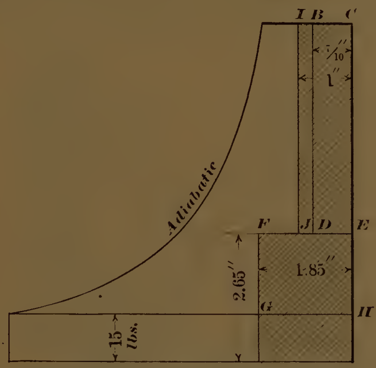


FIG. 236.—COMPOUND DIRECT-ACTING PUMP. REHEATED TO 300° BEFORE THE INITIAL CYLINDER.

give 135 x 32.7-19 = 232 foot gallons for a cubic foot of free air compressed to 90 lbs. gauge.

In compound pumps where we have extraneous heating previous to the admission of the air into the initial cylinder, let us suppose the heating to be to 300 degrees Fah., this will be sufficient to increase the volume from 7/10 in our former example to 1, in other words, to offset all the mechanical losses in the pump, and the initial cylinder will be full of air at 90 lbs., and at 743 degrees absolute or 283 degrees Fah. When the air is exhausted from this cylinder into the low pressure cylinder there is an expansion ratio of 2.65 between the cylinders, provided there is a small receiver between the two cylinders, the temperature will drop a ratio of 1.32, or, considering the losses by radiation, will reach 60 degrees again and will enter the low pressure cylinder in precisely the same condition that it did in the former case, and with the same volume, consequently we have no gain in this way of reheating, except for the initial cylinder, unless the heating be carried so that the cylinder will receive it at more than 300 degrees, which might not be practicable. In Fig. 236 we have added the area 1, B, D, J to our diagram, Fig.

235, and the area of useful work will be 1 x 4.35 + 3.06=7.41, and, the compression area being 18.66, the efficiency is $\frac{7.41}{18.66}$= 40 per cent., against 32.7 per cent. in the former case, and for compound compression this will be 46 per cent., and the foot gallons of work will be 280 for each cubic foot of free air compressed to 90 lbs. gauge.

If, however, there be a reheating between the two cylinders to about 300 degrees Fah., then the volume entering the low pressure cylinder will be increased about 1.43 per cent., and instead of 1.85 as in Fig. 236, it will become 2.65 and occupy the area shown as K, E, H, L, as per Fig. 237.

The useful area in this card will be 4.35 + 4.35 = 8.70, and it will be noted that the work is the same in both cylinders, and the final efficiency will be $\frac{8.70}{18.66}$ = 46 per cent., and if compound compression is used it will become 53 per cent., and the foot gallons of work which it will perform will be 326.

It will be noted that the points K and I are on the isothermal curve, which means that we have utilized completely the full pressure work within the isother-

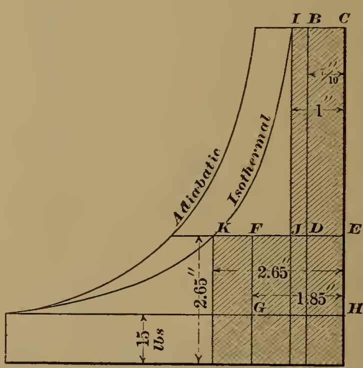


FIG. 237.—COMPOUND DIRECT-ACTING PUMP REHEATED TO 300° BEFORE INITIAL AND LOW PRESSURE CYLINDER USING FUEL PRESSURE ONLY.

mal curve, using two expansions, and if three cylinders be used, and proportioned by the same rule, we make a still further gain and our diagram, Fig. 238, will give 54 per cent. for simple compression and 62 for compound compression, and the foot gallons of work it will perform will be 383, and these figures are perfectly practical and rather under the mark.

It is easy to see that more cylinders would add to the economy, but inasmuch as three are practical and four are too many, we may as well stop here, and for more economy on this system the reheating must be carried higher, and inasmuch as 400 degrees is perfectly practical and as easy to obtain as 300 degrees, this would add 16 per cent. to our percentage of card area, and would give 63 and 72 per cent., respectively, and our foot gallons of work would be 444 foot gallons, and the dotted lines on the diagram will represent the shape of the card and show how it may extend over the isothermal curve. This I call the practical limit.

In the diagrams shown I have always assumed that the second or third cylinders are so proportioned that there is no increase of pressure by reheating, simply increase of volume.

We have seen that a cubic foot of free air at 90 lbs. pressure will perform, under proper conditions, 444 foot gallons of work. This is 3,685 foot lbs., which may be decreased 5 per cent. as the cost of reheating, making net 3,500 foot lbs. of work. On account of the 70 per cent. efficiency of the compound pump, we gave it one cubic foot of free air in our calculation and called it 7/10. The air itself must be given credit for this, and if in the 70 per cent. efficiency pump it did 3,500 feet of work it really was yielding up $\frac{3500}{70}$, or 5,000 foot lbs.

It takes 5,600 foot lbs. of work to compress this air in a compound compressor. The air has, therefore, shown in its work an efficiency of 90 per cent. as a motive power at 90 lbs. pressure, in triple, compound, direct-acting pump cylinders, triple reheated to 300 degrees, a result entirely different from what we are generally almost forced to believe.

Fig. 239 is a copy of a pair of actual cards illustrating the principle of full pressure working. It will be noted that the expansion shown is small, and if the

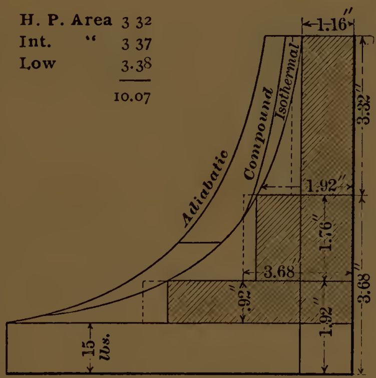


FIG. 238.—3-CYLINDER REHEATED COMPOUND PUMP, USING FULL PRESSURE ONLY.

reheater had a little larger capacity the diagram would be rectangular. Unfortunately, at the time these cards were taken, the pump was throttled, and the air was wire-drawing from 70 lbs. to 50, so that its efficiency is diminished. The pump, however, was delivering 396 gallons per minute 390 feet high and consuming 600 cubic feet of free cold air at 50 lbs. pressure, and giving 250 foot gallons per cubic foot of free air, at 50 lbs. pressure, with an efficiency, referred to 50 lbs. of 65 per cent., referred to 70 lbs. of 52 per cent., the total energy from 70 to 50 being lost in the throttling of the pump. It illustrates, however, our proposition and confirms our figures.

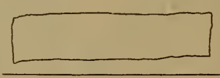
I believe that it is the idea in general that the best result in compound pumps using compressed air is to get as much expansion within the cylinders as is possible, and the highest efficiency which could be obtained in this manner would be when there is no drop whatever between the high and low pressure cylinder, and the air is expanded to atmosphere in the low pressure cylinder, as shown by the ideal card, Fig. 240. This would require heating to 454 degrees Fah., the temperature of adiabatic compression.

The practical action of a once reheated compound pump is as follows: The air enters the high pressure cylinder, we will say, at a temperature of 200 degrees, and at 100 lbs. pressure. This air operates at full pressure throughout the whole stroke, and there is no drop whatever in its temperature. The exhaust valve opens; there being a considerable space between the high and the low pressure cylinder, in the shape of pipes and clearances, and, if there be an intermediate reheating, in the additional space for the reheater; the pressure immediately drops, we will say, to 50 lbs., and the temperatures suffer in adiabatic proportion to the absolute pressures.

This expansion from 100 to 50 lbs. does no work whatever and is entirely lost. The volume of air shrinks in proportion to the absolute temperature, and then passes into the low pressure cylinder, and immediately commences to expand therein as the piston commences to move. Here will be a case of adiabatic expansion, for the temperature in the cylinder must drop as the pressures drop, and

JULY 30, 1900. TEMPERATURES

Between Heater and Throttle	248°	Air Gauge,	70 Lbs.	
" Throttle and H. P. Cylinder..	200°	Water Gauge,	160 "	No. 13.
Exhaust H. P.	78°	Stroke,	14½ Lbs.	W. H. P. H. E.
Inlet L. P.	289°	Revs. p. m.,	24	Spring 40.
Exhaust L. P.	134°	H. P. Cylinder,	16 inches.	



JULY 30, 1900. TEMPERATURES

Between Heater and Throttle..........	229°	Air Gauge,	72 Lbs.	
" Throttle and H. P.	196°	Water Gauge,	160 "	No. 11.
Exhaust H. P.	76°	Stroke,	14½ Lbs.	W. L. P. P. E.
Inlet L P.	283°	Revs. p. m.,	23	Spring 16.
Exhaust L. P.	133°	L. P. Cylinder,	25 inches.	

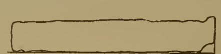


FIG. 239.

the expansion takes place adiabatically to the end of the stroke, where, with a terminal pressure, we will say, of ten lbs., it drops out into the atmosphere at a temperature probably a few degrees below that of the atmosphere.

The M. E. P. of the expansion from 50 lbs. down to, say, 10 lbs. is not a very large proportion of the total possible expansion work of the air from 100 lbs. down to 10 lbs., and this is still further reduced by the fact that while we have the expansive work in the low pressure cylinder we have also a variable back pressure on the high pressure cylinder, which means an unequal load on the piston and a consequent variable speed.

An attempt has been made to realize the work of expansion between the two cylinders, but owing to the natural mechanical construction of the pump it is impossible to realize more than a small part of it, and I believe the correct method of operating these pumps is to do all the expanding between the cylinders and restore the volume by reheating, and use only full pressure in the cylinders. We avoid any temperature drops in the cylinders and we have a constant pressure therein and a consequent constant speed and constant back pressure.

In a compound pump the proportion of the low pressure cylinder to the high will then be larger than is in use at present, for the low pressure cylinder will be operated at its terminal pressure throughout the stroke; in other words, the card will be rectangular.

We believe that instead of using two cylinders, with a greater ratio of areas, that it would be better to use three cylinders and proportion the areas between them, so as to have the terminal pressure desired. In this way the drop between the cylinders would be small, and the opportunity to take advantage of double heating would be considerable, and the ideal situation, theoretically speaking, would be where a large number of cylinders would be in operation, one after the other, with only a sufficient drop between them to give them the necessary dynamic

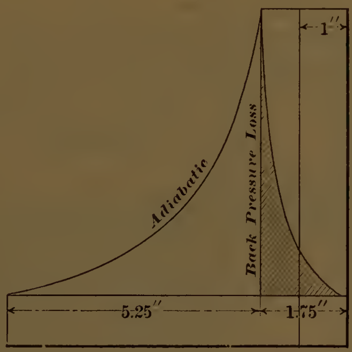


FIG. 240.—IDEAL COMPOUND CARD. AIR HEATED TO 454° FAH.

head. The combined card would then represent a series of steps considerably overlapping any possible card that could be made by an adiabatic expansion.

If it were possible ordinarily to expand without drop from the initial pressure, there would be no criticism of ordinary methods, but, inasmuch as a drop must be made, the question naturally arises, is it not better to make the complete drop and take advantage of the situation when the drop occurs and which is neglected when a combination is made of half drop and half expansion? The Comstock offers every possible opportunity for this kind of a proposition. The temperature of the water is 120 degrees, and the pump and the water and the intercoolers and the air and everything will always be at that temperature, except if the air expands in any one of the cylinders, and it is well known that air is such a poor conductor of heat that no matter if the cylinder walls be hot it will drop its temperature in expanding; in other words, the expansion in the cylinders would be adiabatic, whereas, if a complete drop is made and the temperature restored between the cylinders, and then it is used in the cylinders at full pressure throughout the stroke, it will approach nearer an isothermal expansion for the air than in any other kind of a practical method with direct acting pumps.

The economical expansion of air must ever be the exact reverse of the economical compression of air, and the ideal air compressor would be one of many stages with a small rise in pressure between each two stages, just sufficient to keep the air moving, and an intercooler to take out the small increment of heat for each stage, making practically rectangular cards between the stages; and the natural reverse of this, for the economical expansion of air, would be a multitude of cylinders with sufficient drop between them to maintain a circulation of the air, and reheaters between each two cylinders, making a practically rectangular card for expansion in each cylinder.

As illustrating the principle which I advocate, attention is called to the diagrams Fig. 241, which are from a compound pump with the air reheated before entering the initial cylinder to 165 degrees Fahrenheit. This pump is doing fair work, raising 450 gallons per minute 424 feet high. It receives air at 63 pounds gauge and 165 degrees Fahrenheit, takes air at practically full stroke, exhausts into the pipe connecting the two cylinders, drops to 35 pounds gauge and gradually expands, as back pressure against the high-pressure piston, until 12 pounds is reached. The low-pressure piston receives the pressure at 27½ pounds and the air is expanded to 11.5 pounds, and it then exhausts against 2 pounds back pressure into the atmosphere.

Assuming the volume of the high pressure cylinder to be one cubic foot, and having no clearance, etc., inasmuch as we are about to make a comparative statement, we find that the foot pounds of work on the high-pressure piston is 6.797 foot pounds, and on the low-pressure piston, 1,581 foot pounds, a total of $8,378.5 foot pounds.

Now let us consider another method. If we use the air at 63 pounds on the same high-pressure piston and let the exhaust make a complete drop to 11.5, pounds, the work on the high-pressure piston will be 7,416 foot pounds, and if we reheat the air in the receiver to 165 degrees and make the low-pressure cylinder of such a size that after receiving the air at 11½ pounds it will exhaust at 2 pounds, thus preserving the relation of the previous problem, the cylinder ratio will be 3.06 and the work on the low-pressure cylinder becomes 4,186 foot pounds, making a total of 11,602 foot pounds, or a gain of 40 per cent.

Suppose we make it a triple cylinder pump and make each cylinder do the same work and reheat to 165 degrees before the first and between each two, and use the same two pounds back pressure, then the initial cylinder will take the pressure at 63 pounds and do 4,550.4 foot pounds, the intermediate will take the pressure of 31 pounds and do 4,450.4 foot pounds of work, and the low-pressure cylinder will take the pressure at 12.4 and do 4,550.4 pounds and exhaust at 2 pounds back pressure, making a total of 13,651 foot pounds, or a gain of 64 per cent. The pump is now doing about 220 foot gallons of work. If we add 64 per cent. to this we will have 360 foot gallons. We claimed 383 in our former diagrams, for higher reheating, which checks results quite nicely. The cylinder ratio in the above will be for equal work in the cylinders, the cube root of the ratio between initial and absolute pressures, 1.7, making the pressure 63, 31 and 12.4, respectively. The atmospheric pressure was in this case 13.5 pounds.

Your attention is particularly called to the difference between steam and air practice, for here is a triple expansion, so called, operating with 63 pounds initial pressure properly. The number of cylinders that could be properly used would have to be determined by practice, the limit being when their mechanical deficiency offsets their economy.

There are many places where it would be inadvisable to use fire or steam for reheating, on account of heat or annoyance or expense, and it is in such situations that what I term a water reheater will supply enough heat units to render the pumping economical. A general illustration is given in Fig. 241, which shows

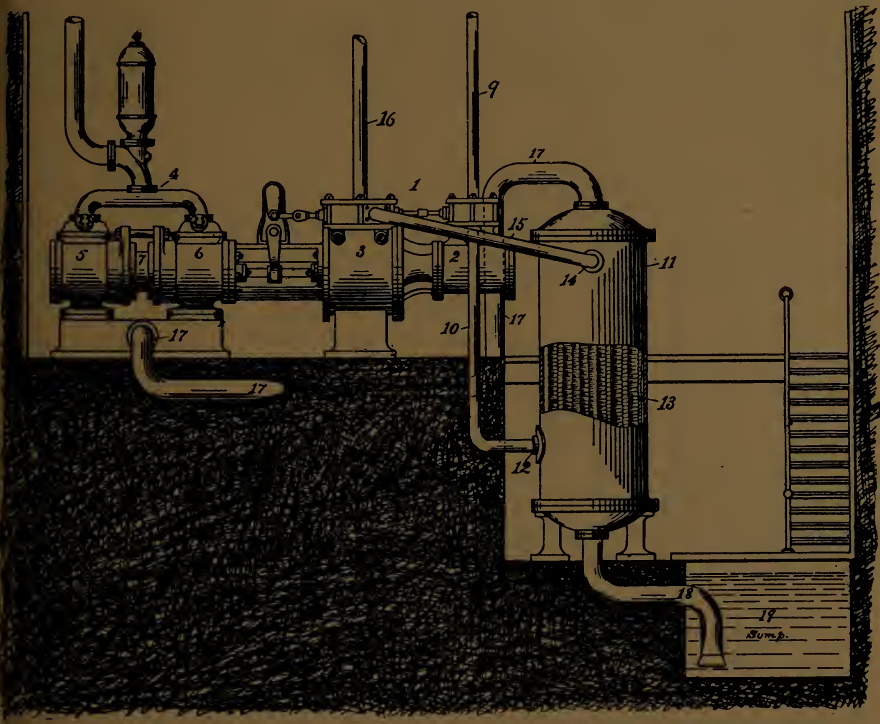


FIG. 241.—DEVICE FOR WATER HEATING OF AIR.—PAT. JUNE 7, 1898.

how the suction water may, in passing around corrugated copper tubes, render valuable service in heating the air.

In actual practice the difference in the number of revolutions of the compressor to do the same work speaks immediately for the economy of the apparatus. In pumping muddy water through the reheater the deposit of mud on the tubes could be readily detected by noticing the increased air consumption. It is very evident that the more successive air cylinders on a pump, the less drop in pressure will be made from one cylinder to another, and, consequently, less dropping of temperature. It is for this reason that in a multi-cylinder pump water at ordinary temperatures, acting through a number of cylinders, will yield up as many and perhaps more heat units for useful work than a high temperature reheating before the first cylinder. It gives more time for correction, and with air, which is a poor conductor, time is required.

Referring to our last example, using three cylinders, it is evident that if the water was at 60 degrees Fahrenheit the only difference in results would be the increased volume due to the higher temperatures. This we counted as 1/5. Deducting, therefore, 20 per cent. from 13,651 foot pounds, we have 10,921 foot pounds, which would be accomplished on the water-heating plan, which is more than was accomplished by heating the initial cylinder of a compound pump to 165 degrees. Please note that this heating costs nothing, and the extra cost of the pump should not be considerable. If by water reheating a triple cylinder pump will do 300 foot gallons per minute, the cost for pumping water would be one-

FIG. 242.—CARDS FROM COMPOUND PUMP 14″ + 24″ CYLINDER. HEATED TO 165° BEFORE INITIAL CYLINDER.

half what it would be in an ordinary direct-acting pump, which power saving would of itself soon pay the cost difference.

COMBINATION OF DISPLACEMENT AND AIR LIFT.

It seems proper under the head of air lift pump to speak of the Wheeler Pneumatic Pump, which is a combination of displacement and air lift, and can be used in places where there is no proper submersion for the air lift. In fact, the system might be called an air lift system with artificial submersion, shown generally in Fig. 243.

The pump has two displacement chambers and an automatic valve attached, similar to the Merrill pump, and the displacement action takes place similarly, one chamber filling while the other empties, the exhaust being into the atmosphere and the expansive work of the air being lost. The Merrill pump discharges from the chambers directly to the final point of delivery, while the Wheeler pump keeps the discharge pipe filled with water at a certain height, and an air jet at its lower extremity "air-lifts" this water to the final delivery. H. C. Behr, Esq., tested this pump during 1899, and his conclusions in his report are as follows: That the efficiency of the machine, as tested, is such as to compare not unfavorably with the ordinary steam or air driven direct acting pumps of moderate size and as used underground in mines; that the operating expenses could generally be expected to be considerably lower than for such pumps on account of the slight cost for repairs and the replacement of worn parts; that it should require less skill and experience to operate and maintain this pump than a direct acting pump. The efficiencies found might be somewhat increased in cases where a very efficient compressing plant is available. The efficiency will not compare favorably with high-class, air-driven compound pumps reheated. The objection to the pump is that it is not capable of raising the water by suction, and is thus incapable of charging itself. It must be submerged, or the supply must be higher than the water chambers.

The Wheeler device, Fig. 243, permits the displacement to take place with low pressures, and thus adds to the efficiency. The table marked Fig. 19 accom-

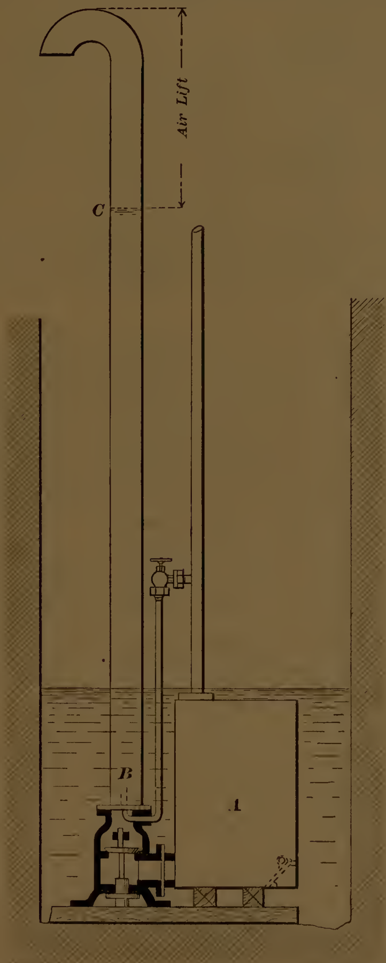


FIG. 243.—A IS DISPLACEMENT CHAMBER RAISING WATER TO C, WHEN AIR FROM PIPES AT B COMPLETE THE LIFT.

panies Mr. Behr's report. Test No. 21 shows the best efficiency, viz., 30 per cent. air pressure, 33.75 pounds work done; 4 horse power; water lifted, 1,271 pounds; quantity of air, 7.78 pounds per minute. Comparing this with the results obtained in the discussion of air lift and simple displacement pumps we have: Air pressure, 33.75 pounds—10 per cent. for dynamic head, equals 30 pounds for active pressure. The equivalent head is 70 feet, consequently the water will stand 70 feet in the discharge pipe and the air lift will be 35 feet, giving a submersion of 2 to 1, and air lift pressure of 33.75 pounds.

Referring to the tables of air lift experiments, tables marked Table 55, we find that 2 cubic feet of air to 1 of water will do the work. There was practically 20 cubic feet lifted, making 40 cubic feet of air required at 33.75 pounds pressure, or 4.80 horse power. The displacement of 20 cubic feet of water at 30 pounds required 22 cubic feet of air at 33.75 pounds pressure. Allowing 10 per cent. clearance, which was 72 cubic feet of free air, this, at 12 horse power per 100, equals 8.64 horse power, 8.64+4.80=13.44 horse power, almost identical with results shown in the table. There can be no question but that the economy of this system could be greatly enhanced by using the expansive force of the air that is lost in exhausting from the displacement chambers, and one of the easiest means of doing this is on the principle which I suggested for the multi-stage displacement pump, as illustrated in Fig. 233.

CUMMINGS, OR TWO-PIPE, SYSTEM.

This is a simple system, consisting in compressing the air to a high pressure, say 200 pounds per square inch, the idea being that full-pressure motions are more economical the nearer you approach full pressure. For instance, from 0 to 100 pounds we observe quite an extended compression curve, while from 800 to 900 pounds there would practically be no curve, but simply full pressure work, the part one wishes to utilize in direct acting pumps.

Take the card No. 1, Table 55, and it will be noted that the compression area is A, B, C, E only, the area, A, F, G, H, being always back pressure. The area of the compression is, therefore, 8 square inches; the work done is calculated at 70 per cent., as with the other examples, and this area will be 3.04; 3.04-8 degrees=38 per cent., and if reheating be used to 300 degrees and the exhaust be cooled off before returning to compressor, the efficiency will be 50 per cent., almost double the efficiency of the ordinary direct acting air pump. If now we look at diagram No. 2, where we compress from 90 to 180 and exhaust at 90, we have an efficiency of 50 degrees cold, which would be increased by 7-5 if reheated to 300 degrees, or 70 per cent. These percentages are probably marred by frictions and leakages which I have no means of ascertaining, but I should judge these could be kept within 10 or 15 per cent., making the simple pump show an efficiency of probably from 50 to 60 per cent., with compound compression.

These pumps can also be compounded with considerable gain, but it would easily form the subject for another paper. I wish to remark that I cannot understand why this system has not been pushed for compressed air station pumping. I believe it will be very satisfactory and economical, and some day will be extensively used. It has one advantage over the Harris system inasmuch as the back pressure is constant, and ordinary pumps may be operated with it. The principal objection is the high pressure and consequent leakage and the double set of pipes and joints. This system should be regarded with high favor.

TABLE 54.—RESULTS OF TEST OF WHEELER PNEUMATIC PUMP.

By H. C BEHR.

I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.
Test Number.	Average Air Pressure Above Atmosphere.	Weight of Air Used, Lbs., per Minute.	Weight of Water Pumped, Lbs., per Minute.	Number of Pump Strokes, Approximate, per Minute.	Water, H.P. Work Realized, Water Lifted to Height of 105 Feet.	Efficiency Based on Comparison of Work Returned, with Least Work Theoretically Needed for Compression.	Efficiency of Compression in Ordinary Practice.	Total Efficiency Product of Columns VII and VIII, Multiplied by 85/100 for Efficiency of Compressing Mechanism.	Operating. Work Spent. Indicated Work of Stream or Power.
	Lbs. per sq. in.	Lbs.	Lbs.	Per Min.	H. P.	Per Cent.	Per Cent.	Per Cent.	H. P
5	41.000	12.270	1,971	18.00	6.271	42.48	69.4	25.02	25.0
14	39.000	12.050	1,948	18.50	6.198	41.75	70.6	25.05	24.7
13	39.000	9.137	1,481	15.50	4.712	44.00	70.6	26.40	17.8
2	34.500	13.106	1,888	17.00	6.007	41.91	73.3	26.08	23.0
12	34,500	9,079	1,423	15.00	4.528	45.52	73.3	28.36	15.9
21	33.750	7.780	1,271	12.75	4.033	48.09	73.8	30.17	13.3
15	33.500	11.020	1,716	16.25	5.460	46.04	73.9	29.90	18.2
1	33.000	13.687	1,935	18.00	6.158	42.08	74.2	26.53	23.2
6	30.375	5.770	785	8.20	2.497	42.80	75.8	27.40	9.1
3	29.500	13.060	1,668	....	5.309	40.56	76.3	26.30	20.
22	29.250	9.810	1,426	14.50	4.386	44.86	76.5	29.24	15.0
20	29.125	7.650	1,102	11.00	3.506	46.12	76.7	29.90	11.7
4	27.250	13.800	1,633	15.50	5.196	39.33	78.0	26.07	19.9
17	24.125	10.080	1,160	13.00?	3.690	39.84	79.5	29.90	13.7
9	24.125	5.340	730	7.75	2.323	50.15	79.5	33.90	6.8
10	23.750	10.120	1,133	11.00	3.605	40.43	79.8	27.40	13.1
18	19.625	7.390	608	6.00	1.935	33.54	82.2	23.40	8.2
11	19.500	9.397	834	8.25	2.654	36.35	82.3	25.40	10.0
19	19.375	7.600	626	8.50	1.992	33.89	82.4	23.70	8.4
7	19.000	9.780	856	7.80	2.724	36.35	82.6	25.50	10.0
8	14.500	7.140	350	4.00	1.114	24.14	85.0	17.44	6.3

Column Pipe 4 Inch Diameter.
Lift, 105 Feet.

NOTE—Test No. 16 was thrown out on account of uncertainty of speed counter observation.

TABLE 55.—TABLE OF EXPERIMEN

1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
Number of Tests.	No. of Compressor Strokes per Min.	Pressure per Sq. Inch in Receiver.	Weir Head, Inches.	Length of Water Pipe Below Surface of Water. Ft.	Length of Water Pipe Below Surface of Water. Ft.	Temperature in Receiver. Fah.	Temperature of Air in Room. Fah.	Temp're of Water at Weir. Fah.	Quantity of Water Pumped per Sec. Cubic Feet.	Weight of Water Pumped per Sec. Lbs.
1	59	31.15	4.1	75.55	55.78	77°	72.6°	68°	.0799	11.25
2	45	27.86	3.8	75.55	55.78	78°	70.7°	68°	.1488	9.3
3	30	25.64	3.	75.55	55.78	79°	74°	68°	.0824	5.15
4	59	30.69	5.2	35.53	55.5	74°	72°	71.6°	.3259	20.37
5	46	26.4	5.1	35.53	55.5	78°	71.6°	68°	.3105	19.41
6	30	24.78	4.6	35.53	55.5	78°	73.2°	68°	.2398	14.99
7	22	24.16	4.25	35.53	55.5	78°	72.5°	68°	.1968	12.3
8	60	24.1	3.85	54.7	36.33	78°	73°	70°	.1538	9.61
9	35	17.58	3.15	54.7	36.33	78°	73°	70°	.0931	5.82
10	22	16.17	2.6	54.45	36.58	74°	74°	69°	.0576	3.6
11	60	20.58	3.2	63.16	27.87	80°	77°	69°	.0968	6.05
12	60	18.75	2.1	70.66	20.37	76°	72°	69°	.0338	2.11
13	38	15.29	2.75	63.16	27.87	80°	74.5°	70°	.0663	3.96
14	19	12.28	1.65	63.16	27.67	79°	75°	71°	.0185	1.16
15	34	12.35	3.4	31.5	20.	79°	71.5°	69°	.1126	7.04
16	60	20.46	4.5	25.25	26.25	69°	66°	67°	.2270	14.19
17	41	15.80	4.3	25.25	26.25	70°	66°	67°	.2026	12.66
18	22	12.52	3.74	25.25	26.25	70°	66.5°	67°	.1439	8.99
19	60	22.13	5.	20.25	31.25	72°	67.5°	69°	.2954	18.46
20	27	15.22	4.5	20.25	31.25	72°	68°	69°	.2270	14.19
21	22	14.52	4.4	20.25	31.25	72°	67°	69°	.2146	13.42
22	60	23.12	5.4	15.25	36.25	74°	67°	68.5°	.3593	22.45
23	30	17.46	5.2	15.25	36.25	73°	69°	69°	.3259	20.37
24	19	16.2	4.72	15.25	36.25	73°	69°	69°	.2531	15.82
25	60	17.05	2.8	36.	15.5	74°	69.5°	69.5°	.0693	4.33
26	34	10.17	2.3	36.	15.5	74°	70°	70°	.0424	2.65
27	18	7.46	1.25	36.	15.5	73°	70°	70°	.0093	.58
28	60	15.87	1.5	41.	10.5	76°	72°	70°	.0146	.92
30	60	31.66	4.1	75.78	55.	82°	70°	108°	.1799	11.24
31	60	31.66	2.9	75.78	55.	84°	71°	110°	.1691	10.57
32	28	25.28	4.1	75.78	55.	84°	71°	114°	.0757	4.73
33	60	31.66	4.1	75.8	55.	81°	70°	116°	.1799	11.24
34	60	31.28	4.1	75.8	55.	80°	70°	82°	.1796	11.24

H AIR LIFT PUMP.

12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.	23.
Pumped in 24 h'rs. Gallons.	Work per Sec. of Pumping the Water. Foot Lbs.	Air at 75° Fah. Compressed per Second. Cubic Ft.	Work of Compressing Air per Second. Foot Lbs.	Resistance in Water Pipe. Foot Lbs.	Resistance of 3 Bends in Air Pipe. Foot Lbs.	Resistance of 3 Bends in Air Pipe. Foot Lbs.	Resistance of 5/8 in. Nozzle in Air Pipe. Foot Lbs.	Resistance of Circular Bend in Water Pipe. Ft. Lbs.	Resistance Due Velocity of Discharge. Foot Lbs.	Sums of Work of Pumping & Resistances as Determined. Foot Lbs.	Efficiency of Pump. Per cent.
16,576	850	1.086	2616	832	652	80	88	8	63	2583	33
96,4	703	.878	1864	481	325	39	38	5	37	1628	38
53,495	389	.552	1180	159	155	19	14	1	13	1050	33
31,578	724	1.086	2569	1050	458	80	88	15	58	2473	28
01,204	690	.846	1842	570	400	48	48	10	68	1834	37
55,39	533	.552	1155	325	155	19	14	4	33	1083	46
99,662	437	.405	834	160	97	11	11	2	18	736	52.4
50,329	526	1.104	2269	631	580	89	86	9	12	1933	23
37,325	318	.644	1072	118	190	29	28	2	14	699	30
52,726	196	.405	636	36	77	11	11	5	4	340	31
21,902	382	1.104	2046	137	281	89	86	2	44	1021	19
42,962	149	1.104	1851	401	514	89	86	6	15	1260	8
11,988	250	.669	1051	106	194	35	34	2	12	633	24
72,965	70	.350	450	8	54	8	8	0	1	147	16
47,696	222	.616	795	80	137	28	28	2	15	508	28
31,285	358	1.104	2039	618	495	89	86	15	115	1775	18
98,247	320	.754	1175	280	230	41	39	7	52	969	27
93,286	226	.405	528	66	65	11	11	1	12	392	43
47,296	374	1.104	2147	832	537	89	86	20	152	2090	17
39,061	287	.497	748	167	110	18	17	4	32	635	37
32,826	272	.405	589	118	71	11	11	3	22	507	46
11,183	342	1.104	2209	926	582	89	86	25	141	2091	16
64,01	311	.552	911	352	111	19	14	10	66	883	34
44,906	241	.350	550	133	59	8	8	3	25	477	44
27,475	156	1.104	1800	182	398	89	86	5	34	950	9
6,026	93	.616	880	37	123	28	26	1	7	315	11
9,461	21	.331	288	2	36	7	7	0	14	73	7
16,575	38	1.104	1712	38	360	89	86	1	7	619	2
09,577	852	1.104	2685	836	674	89	86	9	65	2611	32
44,054	801	1.104	2685	792	674	89	86	9	70	2521	30
49.554	359	.515	1091	92	161	19	18	1	7	719	33
16,575	852	1.104	2685	836	674	89	86	9	65	2611	32
16,575	851	1.104	2666	836	674	89	86	9	65	2610	32

AIR LIFT PUMPING.

While the air lift system of pumping has been brought recently to the attention of the public, it is not a new thing, there being records of its use more than 100 years ago.

The honor of putting the air lift system in practical shape is due to Dr. Julius Pohlé, who came to San Francisco from Arizona, where he had been experimenting with several plants, one with a lift of 300 feet. Dr. Pohlé established himself at the office of Rix & Firth, who interested themselves to the extent of expending considerable money in experiments to determine the efficiency of the system. A ten-inch well was sunk sixty feet deep on a piece of property belonging to the Mechanics' Institute, San Francisco. The bottom was cemented, a gallows frame 75 feet high was erected over it, and a tank and weir constructed over the well to measure the water flow. Air and discharge pipes were arranged

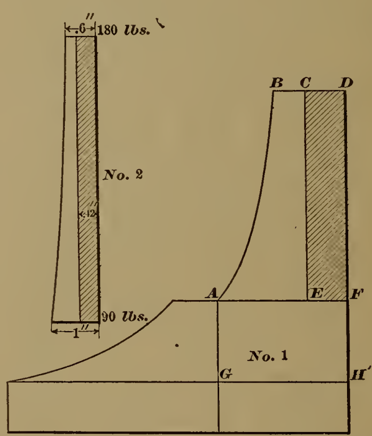


FIG 244.—DIAGRAM ILLUSTRATING THE CUMMINGS SYSTEM.

so that many different ratios of lift and submersion could be tried. The compressor had a compound air cylinder, actuated by a Corliss engine of 50 horse power. The well-known civil engineer, Mr. B. M. Randall, conducted the experiments, and they were made on August 27, 1899. The results showed efficiencies as high as 52 per cent. The records of this test were tabulated, and I have reproduced them for this occasion, not only for the information the table contains, but as an interesting point in the history of air lift pumping, for it is the first record of results.

Messrs. Brown and Behr tested the experimental plant referred to, and in a paper read before this society in 1890, stated that the greatest efficiencies were obtained when the submersion of the pipe was twice the lift, and at this an efficiency of 50 per cent. was obtained.

Quite extensive experiments have been made in Germany, to determine the efficiency of the air lift, and their results fall somewhat short of the percentages obtained in this country. The efficiency was the ratio of work in discharged water

Head.	Quantity of Free Air.	Quantity of Water, Gallons.	Air P. in Receiving.	H. P. of Air.	H. P. of Work Performed.	Efficiency.	Submersion.	Ratio Air to Water.
39	170	750	37	20	8	40	60	1.7–1
30	150	400	20	11	3	27	45	-1
35	170	600	39	21	6	30	70	2.2–1
32	100	500	39	12	4	33	87	1.5–1
22	50	187	10	2	9	45	30	2

TABLE 56.—EXPERIMENT IN ARTESIAN AIR LIFT PUMPING.

Depth of Well.	Size of Casing.	Natural Flow.	Height to Raise Casing to Stop Flow.	Submersion.	Quantity of Free Air.	Air Pressure.	H. P. to Beneath Air.	Pumping Head.	Quantity of Water Pumped, Gallons.	H. P. in Water	Efficiency.	Ratio Air to Water.
950	5 & 8	200	6′	180	135	73	24	33	1,300	11	46	.8–1
950	5 & 8	200	6′	110	135	41	165	30	800	6	36	1.3–1
950	5 & 8	200	6′	146	135	56	20	32	900	7	35	1.2–1
700	7	20	1	100	120	38	16	30	800	6	38	1.2–1

TABLE 57.—TABLE FOR AIR LIFT PUMPING.

Dia. Air Cyl.	Stroke.	Cu. Ft. Free Air at 100 Revs.	Cu. Ft. Free Air at 125 Revs.	Suitable Pumping Heads.	Quantity Pumped at 100 Revs. in Gallons.	Quantity Pumped at 126 Revs.	H. P. Required 100 Revs.	H. P. Required 125 Revs.	Ratio of Submersion to Lift.
60 TO 100 LBS. PRESSURE.									
10	12	92	108	80–120	200-175	232–205	12–17	15–20	3–2
12	15	165	195	80–120	350–310	420–370	22–32	26–36	3–2
14	16	245	288	80–120	525–465	620–550	35–45	38–55	3–2
30 TO 60 LBS. PRESSURE.									
12	12	132	152	40–80	330-285	380–325	12–18	14–20	3-2
14	15	229	270	40–80	570–500	675–580	22–30	25–35	3–2
16	16	312	368	40–80	780–670	920–800	30–40	35–50	3-2
10 TO 30 LBS. PRESSURE.									
14	12	183	216	10–40	640- 450	850- 540	8–18	10–22	3-2
16	15	293	345	10–40	1000- 730	1200- 860	13–30	15–35	3–2
18	16	408	480	10–40	1400–1000	1700–1200	18–40	21–50	3–2

to the indicated compressor work, and ranges from 45 to 30 per cent., with smooth pipes—a lift of 50 feet, and a submersion of from 4 to 3 to 3 to 2.

The amount of water discharged increases with the quantity as well as the pressure of air, but the efficiency falls away very rapidly when the output is forced. A submersion of 50 feet and a height of discharge of 25 feet, with increasing quantities of air, gave quantities of water from 4 cubic feet to 15 cubic feet per minute; the quantity of air varied from 7.6 to 105 cubic feet per minute, and the ratio of free air to the water lifted varied from 1.96 to 7.60 cubic feet of air to 1 cubic foot of water, the efficiency being in a like proportion.

In another set of experiments, with lifts from 43 to 230 feet, submersion from 92 to 400 feet, from 2.9 to 5 cubic feet of air was required per cubic foot of water pumped, and the pressures from 30 to 160 pounds. The quantity that can be handled is practically unlimited.

It is safe to calculate on velocities in the pipe from 4 to 8 feet per second, and it will take from 2 to 3 cubic feet of atmospheric air per cubic foot of water pumped for heights from 15 to 50 feet and from 50 feet to 160, I should figure, on from 3 to 4 cubic feet of air per cubic foot of water. I believe for very low heads the air consumption may be still further decreased and 1.5 cubic feet of air will lift a cubic foot of water 20 feet high.

Engineering News, Vol. 37, Page 140, gives some interesting data on air lift pumping at Rockford, Ill. The pumping was done from 4 wells, 84 feet, 82.5 and 59 feet from surface to water while being pumped and 7½ additional into a tank, with an air pressure of 76 pounds per square inch. The wells were close together. A 2½-inch pipe led from the reservoir to each well, and a 1½-inch pipe was continued in the well casing, with 225 feet submersion. The discharge was 2,000,000 gallons per 24 hours. From the steam indicator diagrams, 124 horse power was used. The average yield was 1,401 gallons per minute, and the net work done was 24 horse power, or an efficiency of 20 per cent. A 14 x 22 duplex compressor made 96 revolutions to do the work. This would give about 600 cubic feet of free air. About 200 cubic feet of water was pumped, or 3 cubic feet to 1, a result which is average. The efficiency is low, because the compressor took too much power. In a compound compressor 600 cubic feet of air should be compressed to 76 pounds for an expenditure of not to exceed 100 horse power. This would make the efficiency about 25 per cent. The air pressure was excessive and was due, no doubt, to the small well casing, because with proper well pipes, 50 pounds air pressure would have been ample.

I have not yet succeeded in making any general rules for sizes and capacities for air lift pumping. There is generally a surprise waiting for you, no matter what you do. There should be some particular relation of all the quantities concerned that would give the best results, and yet for a considerable variation either way, in submersion, and air pressure, the quantity of water will remain the same. The relation between the diameter of the discharge pipe and the velocity of water seems to be a delicate one. I should think that 5 feet per second would establish a good proportion. The air pipe must be large enough to minimize the friction loss. The initial air pressure will, of course, be that due to the submersion, and will decrease after the discharge begins, until with a 3 to 2 submersion the pressure will correspond to a head of about one-half the submersion plus the lift. In flowing artesian wells, the best results seem to be obtained by giving deep submersion, small air quantity and high pressure.

Sand may be cleared from a well by filling the air reservoir with air at a high pressure, then suddenly releasing it, the air pipe having first been given quite a submersion. The sand comes out in masses and can be seen distinctly. In the illustration submitted herewith the column of water measured over 100 feet above the mouth of the well. It will be noted that about 20 feet above the mouth of the

FIG. 245.

well there seems to be a general radiation in all directions from one center of the water sprays. It would seem that a bubble of compressed air had been carried up there and then suddenly expanded. The efficiency of the air lift will naturally increase directly in proportion to the temperature of the water.

The air lift has a special field of usefulness and will scarcely be given over to much competition with other pumps. When a large quantity of water must be brought out of a small casing, no other method would be so satisfactory. If an artesian well fails to deliver to the proper point by a few feet, no other system could make it deliver its water so efficiently. For example, at Alvarado one of the large artesian wells refused by about two feet to flow into the general cachement basin; nothing could be done but to pump it, and it would have required a centrifugal pump capable of handling 1,000 gallons a minute to restore the required quantity. A one-inch compressed air pipe inserted 155 feet into the well, and consuming 6 horse power of compressed air, stimulated the well to complete action.

The plain open air pipe seems to be the best manner of ending the air pipe in the well, and whether it point up or down is not material. Dividing the air into minute bubbles by fine perforations seems not to do as well as the open pipe. I have compounded the air lift into several lifts, one discharging into the other, with fair results, but it would be better to discharge each section into an open tank and let the water dispose of its air bubbles.

The greatest general efficiency of the system will become apparent under conditions where the number of wells that can be operated by an engine plant do not yield enough water without lowering the surface of the water too far. Let us say that normally the water stands at 20 feet from the ground, and in order to get the quantity from six wells they are lowered to 80 feet. By sinking perhaps six more wells some greater distance away, and the air-lifting all twelve, the pumping may be done at a head of only 40 feet. This would be possible, of course, with pumps, but not practical. In general and within pumping limits of 120 feet, I shall conclude that from 50 to 60 per cent. efficiency is possible, but 30 to 40 will probably be nearer the average plant.

Table 56 is from actual experiments made last year, and Table 57 gives some general requirements for air lift pumping which may prove useful.

MOTOR-OPERATED PUMPS.

This class consists of pumps belted or geared or direct connected to any kind of engine. There is no doubt that with Corliss engines, coupled directly to pumps, the mechanical efficiency is as high as 85 per cent. Let us take an example on this basis, using compound compression, and the engines being cross compound, and double reheated, to 300 feet, or 7-5 increase of volume. The comparison of curve areas, Fig. 246, shows that an efficiency of 88 per cent. should be obtained. This, it must be understood, is for a station pump, where all proportions are specially designed for the one object in view.

No account in any of my calculations is taken of reheating. The expense is small, and, I should think, might be taken as 5 per cent. of the economy, consequently this sum should be deducted from all of my reheating calculations. It costs practically the same to heat to 300 or 400 as to 200, provided the reheater is close to the motor, where it should be. The amount of air required by engines per horse power will vary from 25 to 5 per cent., according to the amount of reheating and amount of expansion used.

All admit that the loss in the compressed air problem is one of heat. The air is all there; none of it gets away. All admit that if this heat can be stored

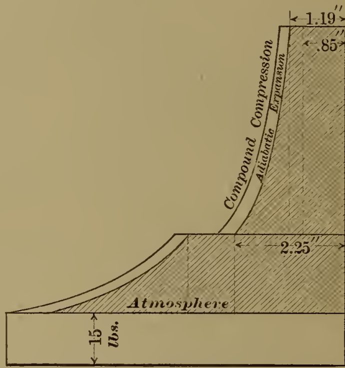


FIG. 246.—DIAGRAM OF COMPOUND DOUBLE REHEATED AIR MOTOR FOR PUMPING.

and a sufficient quantity added to overcome leakage and clearance, we should get back our original expenditure, less, of course, the mechanical losses in the motor. Inasmuch as in compound compression to 90 pounds the temperatures need not

TABLE 58.

RECAPITULATION.
90 Lbs. Air Pressure on Main.

Kind of Pump.	Foot Gallons.	Efficiency Simple C'mpress'n	Efficiency Compound
Direct Acting Simple	135	19	20
Direct Acting Simple 300 reheated	180	24	28
Direct Acting Compound Water reheated	232	32	375
Direct Acting Compound 1 Cylinder Heated 300	280	40	46
Direct Acting Compound 2 Cylinder Heated 300	326	46	53
Direct Acting Triple 3 Cylinder Heated 300	383	54	62
Direct Acting Triple 3 Cylinder Heated 400	444	63	72
Plain Displacement	175	22	25
Wheeler Displacement	34% for 34 lbs. pressure.		
Multiple Displacement	320	40	46
Harris Displacement	60 to 70%		
Merrill Displacement	175	22	25
Cumming System	35 to 70%		
Compound Motor Pumps	50 to 80%		
Direct Acting Triple Water Heated	300	42	48
Pohle Air Lift	30 to 60% heads less than 200 feet.		

exceed 225 degrees at any time, what is there to hinder our returning this and much more besides, when we have 500 degrees at our service? I have used 430 degrees in a Corliss motor with excellent results, and believe another 100 degrees could have been added. The whole question is one of temperature, and the successful solution lies in special and intelligent adaptation of the forces at our service. Too many have condemned compressed air without a hearing, and I hope these remarks may stimulate some one to give special attention to the pump problem and give us some pumps worthy of the atmosphere which they now so generously use.

In conclusion, it may be stated that I do not wish to be understood as giving absolute values to the quantities mentioned in this paper. Others may find in their experience that I may have allowed too little or too much for mechanical efficiencies, or that I have assumed too high a standard pressure. This does not interfere with the comparative values of the various systems, which is the real point toward which I have desired to direct your attention.

Editor of "Compressed Air":—

On reading an article in the last number of your useful little journal, entitled "Pumping by Compressed Air," I was somewhat surprised to see that you attributed the working of the Pohlé Air Lift Pump and its kind to the air acting as a piston, forcing the water in sections to a higher elevation, on the same principle as that of a common chain and button pump.

I believe this is the wrong conception of pumping water under the conditions in question.

I have had occasion to experiment very largely in this direction, and before active work I adopted a different theory that was fully proven by later practice.

This was that the air, mingling with the water after its discharge from the air pipe, lightened the water to the extent of its impregnation, and so creating a mixture whose equilibrium can only be established with the solid columns of water surrounding it by its raising higher.

This height will be proportionate to the amount of air in volume contained in the water.

This theory can be nicely illustrated by bending a glass tube in the shape of a letter "U" and placing soap-suds in one leg and water in the other; it will be seen that the lighter suds will rise to a height compared to the solid water in proportion as they weigh in bulk.

Upon this theory I have obtained the best results in lifting water.

I first reasoned that if this was the correct theory, the slower the air traveled upward the longer I would have it to do the displacement act, and I accordingly constructed a jet on the end of the air pipe similar to the opening in a common steam-whistle, so that I would divide the air into as small particles as possible, knowing well that it required a longer time for a small bubble to travel upward than it did for a larger one.

The results attained fully justified my theory.

Comparison with an air nozzle of the Pohlé type, with the same amount of opening, gave a difference of 10 per cent. in favor of my construction.

I will also say that there was no eduction pipe used; the air pipe was simply lowered down in the 8-inch well to a depth of 160 feet, and the water was lifted about 30 feet. EUGENE BIDDISEN.

The Portland Gold Mining Co.,
Victor, Colo., July 30, '96.

LIFTING WATER BY COMPRESSED AIR.

It is only within recent years that moderately deep well pumping by means of compressed air has become at all common. Under favorable conditions the system possesses several decided advantages over all other methods. Among

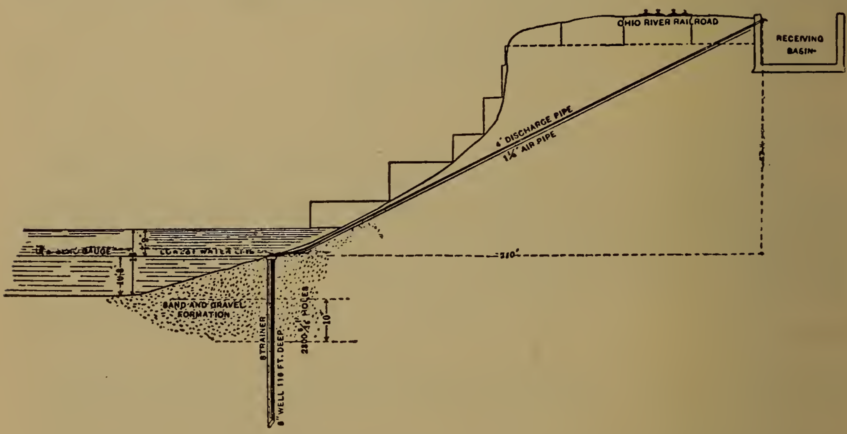


FIG. 247.—LIFTING WATER BY COMPRESSED AIR.—PROFILE OF POINT PLEASANT WATER WORKS.

these may be mentioned the absence of all moving parts, in the way of valves, pistons, rods and packings necessarily located a hundred feet, or several times that distance, down in a well where they are difficult of access at all times, and which sooner or later become worn or broken, when they must be taken out to be repaired. All these parts are done away with in the air lift system. Nor does sand or grit affect the working of this system in any manner. There is not a valve or attachment of any sort whatever placed in the well, simply two ordinary pipes. The necessary machinery is located in the engine room, where it is readily accessible at all times.

The object of this article is chiefly to illustrate two quite novel features in the adaptation of the system to pumping water from muddy streams flowing in deep channels. To make this entirely clear, a brief description of the air lift system will not be out of place.

First, there must be an air compressor—that is, an engine that condenses or compresses air to the necessary pressure—discharging into a metal tank called the air receiver. To this a pressure gauge and safety or escape valve are attached, which are identical in all respects to those commonly found on steam boilers. From the receiver a small gas pipe is led to the well and thence downward to near the bottom, where it enters the water discharge pipe; or a series of air conducting pipes may be attached to the receiver and connected to a series of wells situated closely together or remotely at varying distances.

Suspended in each well is a water discharge or conducting pipe, also reaching nearly to the bottom or as far down as may be desired. This pipe may be of any desired size, but is usually several times that of the air pipe in the proportion of 4 diameters to 1, or 4 to 1¼, depending on circumstances.

The air pipe is usually arranged to follow closely along and outside the discharge pipe to its lowest extremity, where it is fitted with a return bend and nipple, as shown in illustration, Fig. 248. It will be observed that the air from the receiver is thereby discharged upward directly into the bottom of the water discharge pipe. It has been the practice of some engineers to attach a brass nozzle at the extremity of the air pipe. Various styles of these are offered, some being patented, for which the makers claim decided advantage; but it has been ascertained that in this case nothing is better than something (anything). A free discharge of air directly into the foot of the suspended discharge pipe is all that is necessary.

The effect of discharging highly compressed air into the bottom of the discharge pipe is to displace some of the water in it, lessening the gravity of what remains until overcome by the greater pressure of the solid column of water outside of the discharge pipe within the well. Both the air and water in the suspended pipe are forced upward by this resisting pressure and discharged at the top of the well or outlet of the suspended pipe. It will therefore be apparent that as long as there is sufficient depth and flow of water into the well to constantly refill the discharge pipe, and air is supplied to reduce the gravity of that in the discharge pipe, the operation, as described, will continue.

There is, however, one important condition to the successful operation of the air lift system. There must always be ample depth of water in the well to insure sufficient resistance at the foot of the discharge pipe to force the lightened column inside the discharge to the top of the well. This is termed "submergence."

Well informed engineers who have made a study of the system say the submergence should be 50 to 60 per cent. By this is meant 50 or 60 feet of water to each 100 feet depth of total lift. That is, if the well is, say, 200 feet deep, and it is desired to discharge the water into a tank situated 50 feet above the top of the well, there must be not less than 125 feet (50 per cent. of 250) to 150 feet (60 per cent.) of water in the well at all times. A less depth would probably render the system useless, as the resisting pressure would be insufficient.

It is customary to discharge the water directly into a tank or receiving basin situated immediately above or closely alongside of the well, with very short, if any, lateral conveying pipes.

During the past 12 months there has been constructed at Point Pleasant, W. Va., on the bank of the Ohio River, a water works employing the air lift system to obtain water from the river, in which this practice was radically changed.

All the machinery was located above the highest known flood line, which is over 60 feet above the lowest river stage (U. S. zero gauge). The franchise granted the water company was for a combined water and electric light plant,

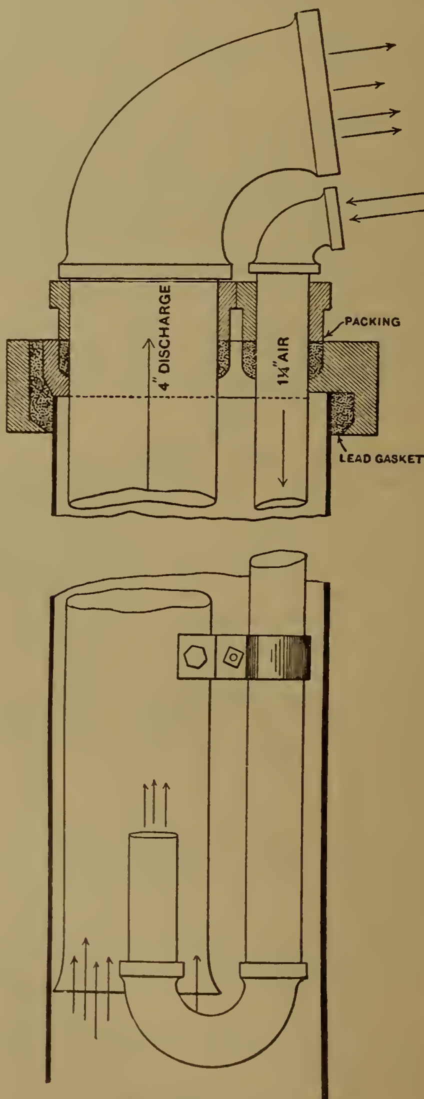


FIG. 248.—AIR LIFT.

and specified that water was to be taken from the Ohio River. The most desirable site obtainable for the works was about a mile above the town, but the Ohio River Railroad tracks at this point were too close to the river bank to permit the erection of the works on the river side of the railroad. The power and pumping house had therefore to be located about 200 feet distant from the top of the bank, about 400 feet laterally from low water point in the river and 67 feet above it, as shown in Fig. 247.

To have constructed a pumping well of sufficient depth and size to accommodate pumps to draw water from the river channel at zero stage and a tunnel to the river would have made the cost of the works so great that sufficient capital could not have been secured to erect them. Some other and less expensive system had to be adopted. Manufacturers of water works machinery were consulted and various plans and systems considered. Finally it was determined to adopt the air lift system, and a hydraulic engineer was employed to make specifications and plans. He proved so unreliable or ignorant of what was required that his services were dispensed with.

The Howell & Shanklin Construction Company, of Charleston, W. Va., were then invited to submit plans and specifications. These were promptly adopted, and a contract was made with them to erect the works entire, which were completed to the last detail just as planned and specified by them.

The use of the air lift system would require wells deep enough to obtain a submergence sufficient to overcome the 67 feet bank lift, plus the depth of the wells and friction of about 500 feet of discharge pipe from the wells to the receiving basin placed obliquely up the river bank. Just here the algebraical x in the problem was found.

At a meeting of the Central States Water Works Association, held in Cincinnati, September, 1899, the writer sought information regarding the application of the air lift system to such situations.

When it was stated that it was the intention to take water from wells sunk in the channel of the Ohio River and discharge it into a basin situated as described, the discovery was made that the problem was not only new, but of very doubtful solution. There was no reliable information obtainable from that source on this particular feature of the enterprise.

Later, an engineer, representing one of the oldest builders of air compressors and who has had many years' experience in this line, after a personal examination reported the situation to his firm, who declined to furnish machinery with any guarantee of success because of the probability that when the air reached the sloping pipe up the bank it would pass the water and escape, the water returning to the wells.

Nothing daunted, the contractors proceeded with the works. Presuming that the wells would always be full if located and sunk at low water line, it was decided to make them 110 feet deep. The calculation was based on 60 per cent. submergence as being ample to overcome both lift and friction.

Fig. 247 is an exact copy of a profile of the river bank made by the city engineer of Point Pleasant, and clearly shows the difficulty encountered. Careful soundings of the river channel were made, and it was found that there were several feet depth of sand and gravel forming the river bottom at this point. Well casing 10 inches inside diameter was driven to the rock, about 40 feet in depth. This casing was perforated with hundreds of ¼-inch holes, commencing at about 10 feet from the top, and extending about 10 feet downward. After the 10-inch casings were in place 10-inch holes were drilled in the underlying rock 116 feet deep and cased 8 inches inside diameter from bottom to top. This casing was also perforated similarly to the outer one, only the holes were larger —5-16 inch. The space between the two casings was tightly calked at the top to prevent water entering the wells at this point. Four-inch discharge pipes and

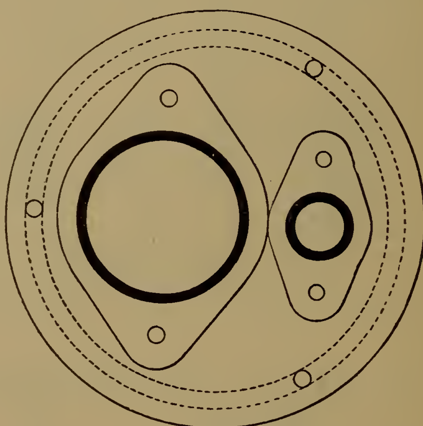


FIG. 249.—CAP AND GLAND FOR WELL HEAD.

1¼-inch air pipes were properly fitted and suspended in each of the wells, with their extremities 110 feet below the top of the 8-inch casing.

Both pipes were suspended from a water tight cap, Fig. 249, resting on the top of the 8-inch casing shown in Fig. 248. It will be observed that no water can enter these wells except through the perforations in the casings, which are 10 feet to 20 feet below the flowing water in the river. None can enter at the bottom. It was the desire to allow the river water to enter the wells only through the perforations after having passed through the strand strata mentioned, which would serve as a filter. Before proceeding further, I wish to state that this feature has proved successful beyond expectation. However muddy the river may be, the water taken from the wells is bright and sparkling at all times.

Just when the wells were completed and the pipes in place, and extended up the sloping river bank a short distance, the river rose over the wells. The pump and air compressor builders were weeks behind promised delivery, and for two months the wells stool unused as described. In the mean time, the reservoir, receiving basin and power house were completed and the work advanced as fast as possible. Just as soon as the air compressor was in place the air pipes were connected up and the wells tested before the discharges were extended to the receiving basin. One well was found with a deposit of sand in the bottom reaching 5 feet above the foot of the discharge pipe. Several unsuccessful efforts were made to force air into this well. The river having receded, the air pipe was disconnected at the top of the well and a ⅜-inch gas pipe coupled and lowered. It stopped 5 feet from the bottom. It was churned a few minutes and soon went down the remaining 5 feet. Again the air pipe was coupled and the air pressure increased to 90 pounds per square inch. The effect was almost startling, but gratifying. The obstruction was cleared out very quickly. No other system of pumping could possibly have accomplished the clearing out of this well of the sand deposit.

The discharge and air pipes to each well are independent. That is, each well has a separate discharge to the receiving basin and a separate air pipe from the receiver. These are carefully graded and are not exposed at any point except where the discharges pass through the top of the walls of the receiving basin, and have open discharge.

The power house is a good substantial brick structure immediately alongside the Ohio River Railroad. It contains the steam boilers, a 200 horse-power Corliss engine, electric dynamos, air compressor and forcing pump. These are all placed on separate and substantial foundations. No machinery is attached to the walls of the building. All the machinery, both pumping and electric, is belt driven from friction clutch pulleys on a line shaft. All the machinery is very substantial and capable of performing its duty without strain. The air compressor is 14 inches diameter by 18 inches stroke, with mechanically operated valves. It is speeded to 96 revolutions, and has a capacity of 312 cubic feet of free air per minute. The required working pressure is from 45 to 50 pounds, varying with different river levels.

The discharge of water is not constant, however, but irregular or intermittent, as though the air and water formed alternate strata or volumes within the discharge pipes. It varies with the depth of water in the river, ranging from 1 volume of water to 8 volumes of free air to 1 to 6. As the river is constantly rising and falling and frequently is 25 to 40 feet deep over the wells, the pressure on the sand surrounding the wells is constantly changing and affects the capacity of them as well as the necessary air pressure to pump them.

The reservoir is situated about 1½ miles distant and at 225 feet elevation. It is built of vitrified paving brick laid in Portland cement with 18-inch concrete bottom and roofed over with slate. Water is taken from the receiving basin by belt driven triplex outside packed plunger pumps, 9 inches diameter by 12-inch stroke, operated at 37 revolutions per minute, delivering about 22,000 gallons per hour.

As there is no demand in the town for electric current during the day, the works are operated at night only. Usually the air compressor is operated one night, and the following night the forcing pumps. The water received the previous night in the settling or receiving basin has about 12 hours to become cleared of any sand brought with it from the wells before going to the reservoir. This basin has a capacity of about 225,000 gallons; the reservoir about three times this quantity. The construction of the receiving basin is the same as the reservoir. The engine has ample power to operate all the machinery at the same time. Two men only are required to attend the combined plant. The entire plant, including power house, lot, reservoir site, rights of way, mains, hydrants, wells, lines, machinery, arc light, all included, cost $55,000. In addition to the public and private consumption of water, two busy railroads are consumers. All customers are served by meter and therefore there is practically no waste.

There can be no doubt that water taken by air in this manner is purified to some extent, the admixture of air serving to oxidize and destroy organic matter. Samples of the water taken last January are still bright and sparkling, have no odor and remain apparently unchanged. There probably is not another town of 5,000 inhabitants in the country that has a better or more complete combined water and light works. Certainly there is not another town of any size on the banks of the Ohio River from Pittsburgh to Cairo that has better water, if as good.

The works have been in constant operation since January last and have been visited by many interested parties. The system demonstrated at Point Pleasant will beyond doubt be repeated elsewhere. That it is regarded as a paying enterprise we have but to repeat the president's statement made to the writer a week ago, "There is no stock for sale, and not a single share was sold at less than par." The pump and compressor were built by the Stillwell-Bierce & Smith-Vaile Company, of Dayton, Ohio.

What has been accomplished at Point Pleasant can be done at hundreds of other small towns similarly situated where there is no water works. Here it has been demonstrated that bright, sparkling water can be obtained from a muddy, filthy stream without the use of chemicals or mechanical filters.

Just use the filter nature has so abundantly supplied at the bottom of such streams, and by proper arrangement of the pumping system combined with an electric lighting system, thus economizing the operating expenses to a minimum, establish first-class water and electric service on a paying basis when neither separately would pay operating expenses.

The air lift system is undoubtedly the simplest as well as the best of all known methods of serving such towns with good water. Nor is the system less applicable to larger towns, as well as to factory and domestic supply.

Artesian wells, or wells supplied from land sources, generally yield hard water or water highly charged with mineral salts. The water at Point Pleasant is soft, pleasant and wholesome. The railway companies using it speak very highly of it. It is simply Ohio River water freed of filth and all objectionable matter that renders it so disgusting at many towns along the stream.

Clark Howell, in *The Metal Worker.*

PUMPING WATER BY AIR.

While much has been said of the Air Lift and its advantages over other systems of pumping water, it is not always clearly understood what such an outfit consists of, and we therefore give the following illustration.

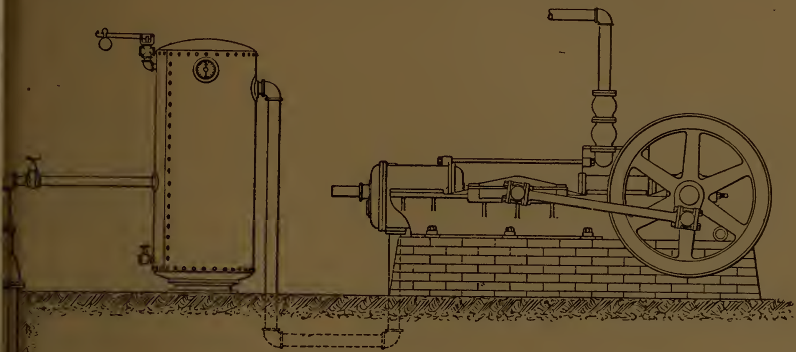


FIG. 250.

As will be seen, the outfit includes an air compressor, which may be either steam-actuated or belt-driven; an air receiver to equalize the flow of air to the well, and the piping in the well.

The compressor is located in the engine room, where it is always under the eyes of the engineer; and as compressed air can be conveyed for miles without loss, the well may be any distance away.

The air receiver may be placed either inside or outside of the engine room, whichever is preferable. If located outside, the pressure gauge can be attached to one of the walls of the engine room.

The method of piping a well differs, we are told, according to its general conditions and the quantity of water to be pumped. No two wells are alike, and consequently the method of piping which might be applied to one would be unsuited to another. This, however, is not very generally understood.

In the accompanying illustration the method of piping consists of using the well casing as the water discharge pipe and simply putting a small air pipe down in the well, with a special device attached at the bottom through which the air escapes. Another method consists of placing the air and water pipe alongside of one another in the well, connecting them at the bottom with an end piece. A third method places the water discharge pipe into the well, the air passing down through the annular space between the well casing and the water pipe. While each is different from the other, yet the principle as patented by the late Dr. J. G. Pohlé is the same—i. e., the water is raised by compressed air.

The advantages of the air lift system appear numerous. At the Fort Madison, Ia., Water Works, it pumps 3,000,000 gallons of water a day from a well 12" in diameter and only 100 ft. deep. At the Charleston, S. C., Water Works about 300 tons of quicksand was raised with the water. This would not have been possible with any other pump. At the Ocean Grove, N. J., Water Works twenty wells are operated by one compressor; the wells are widely scattered and some of them are almost half a mile away from the engine room. At the Asbury Park, N. J., Water Works it helps to purify the water by precipitating the iron with which it is strongly impregnated.

COMPRESSED AIR FOR SUPPLYING WATER.

By C. W. Wiles, Supt., Delaware, Ohio.

The system of supplying water from deep wells by an air lift or air compressor, is one not in general use in this country, and has to some extent been an experiment; but the results have justified the opinion that for moderately flowing wells, or wells having a head not more than 25 or 30 feet below the surface, being too low to draw from by ordinary suction pumps, the application of compressed air at some distance below the top has largely increased the supply of water.

The water supply of The Delaware Water Company, at Delaware, Ohio, is taken from a circular well 25 feet in diameter, brick lined, and 24 feet deep, with an excavation of 5 feet in the rock. Connected with well is a gallery of an average depth of 18 feet down to the rock, 295 feet long by 7 feet wide, covered with slabs of stone and earth, by which water is gathered to further supply the well. With plenty of water in the gravel bottom this well furnished in abundant supply of good water for the city, but in the extreme dry season of 1895 the amount of water was so limited that steps were taken for further supply.

A 6-inch well was bored through the gravel bottom 20 feet, and cased; then through the solid rock of various kinds to a depth of 255 feet in all, a continuous flow of water was developed, to the amount of 65,000 gallons in 24 hours. This not being sufficient for the demand, an Ingersoll-Sergeant Air Compressor, Straight Line Class "A," with steam cylinder 12 inches in diameter, by 14 inch stroke, air cylinder 12¼ inches in diameter by 14-inch stroke, 116 to 155 revolutions per minute, capable of furnishing 213 to 285 cubic feet of air per minute, at 50 to 80 lbs. pressure, was installed; a receiver, 36-inch diameter, 6 feet high connecting from which a 3-inch pipe conducted the air to the well; about 100 feet from the top of the well a 1½-inch pipe takes the air 144 feet down into the well, ending in an inverted funnel to deflect the air upwards.

With 40 lbs. of air pressure at the receiver the flow of the wells is increased to 500 gallons per minute; this flow has been maintained at different times for 14 hours continuously without any apparent diminution of the flow, the well requiring from 60 to 70 minutes to recover its natural flow after the air is romoved.

The flow of water from this well is conducted direct to the large circular well from which it is taken by the pumps.

The power required to develop this flow is 15 to 25 horse power, and is taken from the same boiler that operates the pumps, with a small addition to the amount of fuel.

This method has proven very satisfactory and has given excellent results.

The application of this method of raising water on a larger scale is in operation at Indianapolis, Ind., where from some 27 wells of 8 inches to 10 inches in diameter, 18,000,000 gallons of water per day is supplied to the city. A similar plant to the one at Delaware, Ohio, is in operation at LaGrange, Ill.

AIR JET PUMPS.

During a recent trip to the Missouri-Kansas zinc mining district I made quite a study of pumps, and the idea of using air in this mine pumping service occurred to me, and abides with me still. I started in as a matter of curiosity, for there is a prevalence of curious old walking beam pumps in that locality, but in studying the causes for the existence of this old curious pump in such numbers I came to study the requirements of the mines, which lead to an impression that air might enter as a factor of some magnitude in this industry. The mine depth will average about one hundred feet—varying from forty to two hundred—and quite a variety of pumps are in use. The old walking-beam pump is nothing but a straight pipe with a working barrel and piston near the bottom end, and it has peculiar advantages during the process of shaft sinking which accounts largely for its continued use. It is provided with a slip joint below the working barrel, which can be extended as the shaft deepens—to about twelve feet—and then there is only a top joint to screw on when the operation may be repeated. Also, it is very little in the way—only a pipe standing down in a corner of the shaft—and it is not so liable to get damaged during the firing of a blast, for it presents no working points to view, and a few pieces of plank stood up around it is all that is required in the way of protection. It seems that no modern pump has yet been devised that will meet such requirements and the result is that the old lift pump is put in for shaft sinking, and usually remains there for continuous service.

Some years ago there grew up among some southwestern sawmills a practice of using air for pumping under some peculiar conditions. There was plenty of water to be had—under ground—and the easiest, quickest and cheapest way to get it was to drive pipes, or bore wells. The depth of the water under ground was such that to suck it out with a surface pump was not satisfactory, and to put a pump down to the water called for the digging of a shaft. A builder of air compressors conceived the idea of running an air pipe down inside of the well or driven pipe and forcing the water out with compressed air—and it worked to the general satisfaction of the users.

Now, when I got to studying this mine pump question that using of compressed air to drive water up a pipe came to my mind and I began to make inquiries concerning its use—if it had been tried. It looked as if this ought to simplify the thing, even beyond that of the old walking-beam pump, but I was turned down in my ideas at first start by the theory that it requires something like sixty per cent. of the well to be filled with water before the air service could be made to do the work, or, in other words, if one wanted to pump water from a forty foot mine he would have to have a well pipe a hundred feet deep. Of course I knew a little something about this matter, and could understand that it would require a little water at the bottom of the well, but I did not like being stumped with the idea in such strong terms. I suggested that the pumping service could be divided into relays up along the pipe, and before leaving the territory I found that there was something being done in that line. A man was driving water out of a mine with air and said he could handle it all right with a depth of ten feet in the bottom of his pipe. I think his well was something like a hundred feet deep, and the way he did it was something like this: He had an

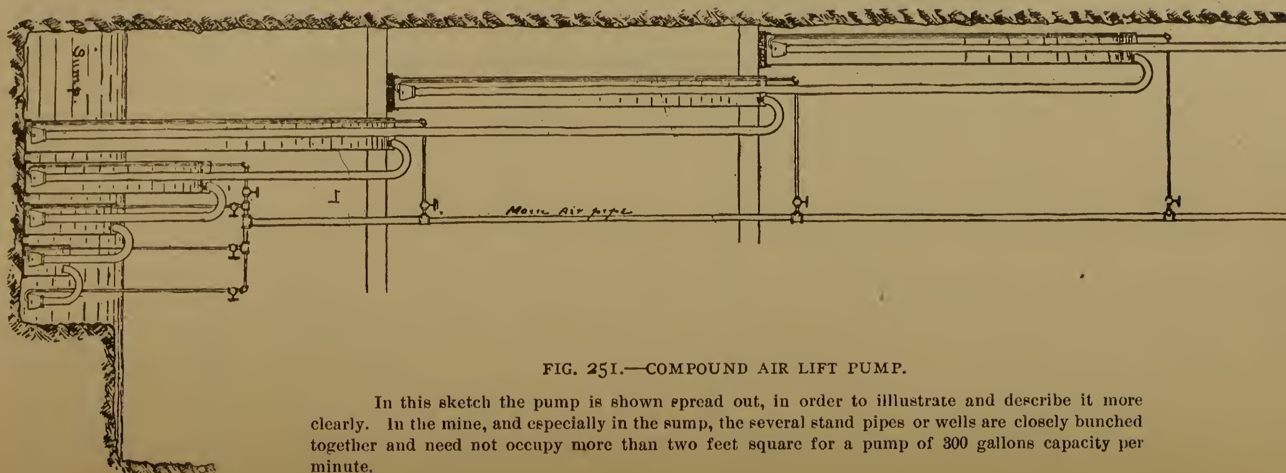


FIG. 251.—COMPOUND AIR LIFT PUMP.

In this sketch the pump is shown spread out, in order to illustrate and describe it more clearly. In the mine, and especially in the sump, the several stand pipes or wells are closely bunched together and need not occupy more than two feet square for a pump of 300 gallons capacity per minute.

air jet at the very bottom of the pipe—piped down inside the main pipe—and about half way up he had another that would open when the water reached that point going up the pipe, and this one would then take up the burden of the work.

The idea that is still clinging to me is something after this plan; it seems to me that a series of air jets could be so arranged, with a line of small piping inside the main water pipe, that water could be lifted from any depth, and I offer the idea for study and experiment. A pump after this plan would be even less in the way, and more convenient in shaft sinking than the old lift pump that has clung on so long, but whether the idea is practical or not I am not able to say just now, and can only offer the matter herein as a subject for consideration. The valves along the line would seem to require some automatic appliance for their operation, etc., but it looks plausible. TAYLOR.

The contribution above appears to be in the line of compounding what is known of the Pohlé Air Lift Pump which ordinarily lifts the water in one stage. The idea has been suggested before and we show a sketch outlining the method. This system has been adopted somewhere, but we do not know just where, and are not in a position to say anything as to its economy. It can readily be seen where it would have advantage over the old Cornish or walking-beam pump, as it would not require packing or replacing of parts. The Pohlé Air Lift system having none of these and consisting simply of two properly proportioned pipes without valves or barrels instead of the Cornish or walking-beam type of pump. An ordinary sinking pump of the Cameron type is frequently used and operated with compressed air. Such a pump is subject to wear because of grit or acid in the water just as is the Cornish pump. The Air Lift possesses many advantages in pumping water where the conditions admit its use.

San Francisco, Cal., July 21, 1899.

Editor COMPRESSED AIR:

I notice your quotation of an inquiry by J. T. B., and reply by the *National Engineer,* in your July number regarding the operation of a proposed air lift. I do not know who J. T. B. may be, but if he follows the advice given he will fail to get water. Here are the corrections that should be made to the reply:

The well will be better without the 5″ casing advised. The well casing 6″, is better, by the difference in friction.

The flow will never be steady, but intermittent.

With the submergence given (125′) the supply of air will have to be between 14 and 15 times the water flown.

The reservoir pressure will be the submergence + friction of air pipe, i. e., 125 lbs., x .434 + say, 5 lbs. or less than 60 lbs. It will take 6 lbs. to start it.

If the well is operated singly, no receiver is necessary or advisable.

Finally, the air will operate with an efficiency less than 20 per cent. This efficiency is entirely independent of compressor efficiency. G. S. D.

WATER WORKS AT DIXON, ILL.

The water supply at Dixon, Ill., is derived from three artesian wells, seven inches in diameter, and from 1,630 to 1,800 feet deep. Two of the wells flow into a reservoir of 500,000 gallons capacity. When the reservoir is empty, these two wells flow at the rate of 566 gallons per minute, but when it is full and the well tubing submerged, the flow drops to 123 gallons per minute.

When this amount of water, together with the flow of the third well, is sufficient for ordinary requirements, it was not adequate during the summer months, and to increase the supply at a minimum expense, it was decided to install the air lift system.

The air compressing plant was furnished by the Ingersoll-Sergeant Drill

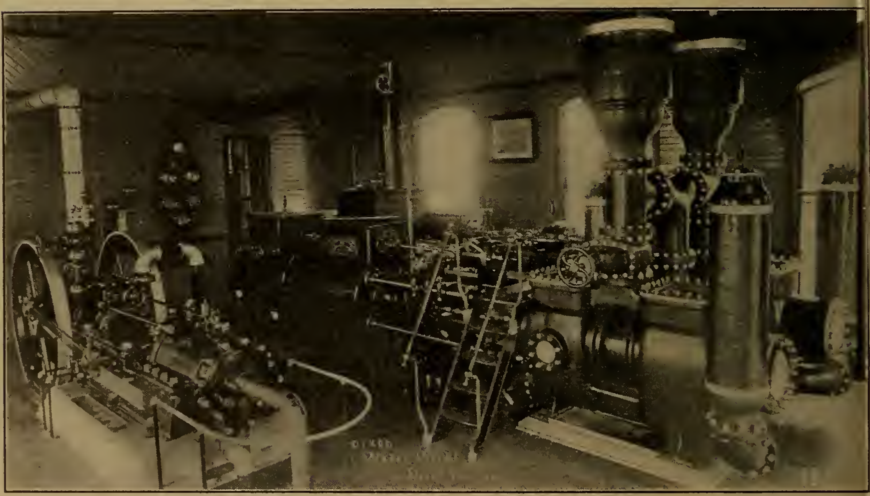


FIG. 252.—PUMPING PLANT AT DIXON, ILL.

Co., of New York, and included a Class "A" Piston Inlet Air Compressor, having 14″ diameter steam cylinder, 16¼″ diameter air cylinder with 18″ stroke.

At a recent test of the two wells flowing into the reservoir, they were able to secure 1,261 gallons of water per minute by the air lift, with the reservoir empty, and 1,212 gallons per minute with the reservoir full and the well tubing submerged. This increase is equivalent to almost ten times the flow of the wells under the latter conditions. The compressor is operated at only 56 revolutions per minute.

The accompanying illustration shows the engine room at the water works station. The large Gordon & Maxwell pumping engine shown in the illustration has a capacity of 2,500,000 gallons in 24 hours, while the small compressor to the left, running at only 56 revolutions per minute, is pumping nearly four-fifths of this amount from only two wells. If connected to all three wells, the compressor would readily deliver into the reservoir all the water the large pumping engine could possibly handle.

SOME FIGURES ON THE COST OF PUMPING WITH THE POHLE AIR LIFT.

The Pohlé Air Lift Pump is one of the most valuable of the many applications of compressed air, and though comparatively new, its developments have been rapid. It has been applied widely to the raising of sub-surface waters which lie below the reach of suction pumps, and in some instances it has replaced the suction pump where the conditions did not imperatively call for the air lift system, because of its many advantages. Many manufacturers located along the banks of rivers, lakes, etc., who are now obtaining their water by means of crude direct acting steam pumps or through the city or village pumping station, can reduce the cost of the water supply materially through the use of a pneumatic pumping plant. There are few figures available as to the cost of pumping under this system, and the following may be of interest.

We will assume a manufacturing plant, say 1,000 feet away from the best location for wells, or from a surface body of water. In the latter case, the pneumatic displacement pump may be used, hung from piles or otherwise suspended in the water. The air lift may be used by drilling wells close to the edge of the water, or a better quality of water in sufficient volume is often obtainable from driven wells some distance away.

With the air lift the plan of pumping involves the use of an air compressor located where the expense of attendance is least; an air receiver adjacent to this compressor; a pipe line for conveying the air from the receiver to the wells; a number of wells drilled to a depth proportionate to the height of lift and the depth of the water strata below the surface; air and water pipes running down inside these wells representing the pumping apparatus proper; a tank located close to the wells and at such height that the water flows by gravity to the point of consumption through a distributing system of pipes carried beneath the reach of frost.

In many cases the introduction of the air lift may be effected at little expense, often involving the purchase only of an air compressor, a receiver and a small amount of pipe, but in the following it is proposed to estimate on a basis which will cover the greatest amount of expense likely to be incurred with a view of showing particularly that the interest and depreciation charges under the most extreme conditions are not under any circumstances likely to develop into formidable figures. The following figures are all approximate and are intended to be in all items well on the safe side:

Estimated cost of Air Lift Plant to raise 1,500,000 Gallons per Twenty Hours, or 1,250 gallons per minute. Total lift, seventy-five feet.

Duplex air compressor complete ready for foundation and piping, estimated	$2,500.00
Air receiver	135.00
85 H. P. of boiler with feed pumps, etc., bricked up and ready for use, including building and value of ground so occupied, at $15.00 per H. P.	1,275.00
Tank, say 19,000 gallons capacity (15′ x 14′ 6″) including suitable timber frame work to bring tank 75 feet above water level	300.00

Two 12 inch wells, each 135 feet deep, cased, at $4.00 per foot.........	1,080.00
450 feet 7⅝ inch light casing (water discharge pipe) at 60 c. per foot in place	270.00
500 feet of 3 inch casing (air pipe in wells) at 15 c. per foot in place...	75.00
1,000 feet of 4 inch air line from receiver to wells at 23 c. per foot in place	230.00
1,250 feet of 12, 10 and 8 inch cast iron distributing main, leaded joints, from tank to works, laid below frost (air line laid in same trench) at $1.00 per foot............	1,250.00
All pipe and fittings not covered in the above estimate, say............	150.00
Compressor, receiver and tank foundation, say 18,000 brick laid in cement at $12.00 per 1,000............	216.00
Excavation for foundations, say 75 cubic yards, at 33 1-3 c. per yard..	25.00
Allowance for ground space and buildings occupied by compressor and receiver	400.00
Special automatic, governing mechanism............	75.00
Erecting and starting expenses of compressor plant............	75.00
Freights	100.00
Royalty	400.00
Contingencies, sundries, etc............	164.00
Total estimated cost of complete plant ready to run as above..........	$8,750.00

As before stated, this is intended to include everything which may be considered as a legitimate expense in this connection. In many cases the buildings, boilers, tanks, wells, pipe lines, ground space and other items do not represent a present expense, being already on the ground. From the above figures we may estimate the cost of operation as follows:

COST OF OPERATION.

Engineer, double shift, at $2.25 per day, $4.50; 1-5 time chargeable to pumping plant, per day............	$ .90
Fireman, double shift, at $1.75 per day, $3.50, on the basis of one man required for each 250 H. P. of boiler for 85 H. P., per day............	1.19
Fuel, 85 H. P., 20 hours, say 4¼ tons at $2.00 per ton, per day.........	8.50
Oil, waste and sundries, say............	.60
Interest on investment of $8,750.00 at 5%, figuring eleven 25-day months or 275 working days per year, per day............	1.91
Deterioration, covering sinking fund, repairs, etc., providing for renewal of complete plant every ten years, same basis as interest but 10% per day............	3.18
Insurance and taxes 1% as above, per day............	.32
Total estimated cost of pumping 1,500,000 gallons per day, 75 feet high under the above conditions............	16.60

Cost of each 1,000 gallons ($16.60 ÷ 1,500), $0.01107.

Kent, quoting the National Meter Co. as authority, gives the cost of water in the states as follows:

Average minimum price per 1,000 gallons in 163 places, .094.
Average maximum price per 1,000 gallons in 163 places, .28.
With extremes ranging from 2½ c. to $1.00 per 1,000 gallons.

As a usual thing, the water rate in most manufacturing cities in the Central States runs in the neighborhood of 8 c. to 10 c. per 1,000 gallons supplied. In some of the larger Eastern cities it runs up to 12½ c., and even higher for manufacturers, and in some cities of the second and third class goes as low as 5 c. per 1,000 gallons. At 5 c. per 1,000 gallons, the yearly water bill on the above basis amounts to $10,625.00.

And at the figure given above,

01107	4,566.37
A yearly saving on the above basis of................................	$6,058.63

This equals a profit of 69 1-5% on the estimated investment of $8,750.00, or is the same as a dividend of 20% on an investment of $30,293.15. With the actual cost of the plant less than is figured above, as it would really be in the majority of cases, the saving would show still better. In many cases the operation of the plant does not involve the extra expense of engineer and fireman, and these items may be deducted. In other instances the fuel cost, either through the use of high duty air compressors or through lower cost of coal, may amount to much less. The only other items which amount to much are those of interest and deterioration, and we have already seen that these have been taken on the outside extreme. In a plant pumping about 3,000,000 gallons per 20 hours 75 feet high, where the cost of the fuel delivered is 85 c. per ton, but the other expenses are figured even more liberally than is shown by the above estimate, the cost per 1,000 gallons is about, .0084 cents.

And in the same case, but pumping 50 feet high, about .006 cents.

In another case involving the handling of about 15,000,000 gallons of water 30 feet high every 24 hours, using compound condensing compressors, and with coal at $2.00 per ton, other figures being estimated on a very generous basis, the cost nets about $2.50 per million gallons, or about 2½ mills per 1,000 gallons. In many cases a belt compressor may be used, bringing the under-loaded factory engine up to an economical load without involving any extra expense for attendance or fuel. Such plants can after be put in at comparatively little expense and will frequently pay for themselves several times over in the first year. The cost of pumping does not run very high per 1,000 gallons, even in the smaller plants, and when used on a large scale, the system compares very favorably indeed with the best of other methods. In some cases water of inferior quality is being used at a considerable disadvantage because of its accessibility. In one instance river water highly impregnated with sulphur coming from coal mines above, resulted in an expense of $5.00 to $8.00 per day from the grooving and pitting of rolls in a steel working establishment. The effect on the boilers was very bad and represented an important item of expense in repairs and extra fuel burned. In such a case as this, it might be well to go off even a mile to sink wells in some desirable location, the superior quality of the water so obtained reducing in many ways the cost of manufacture. Again, with a copious and inexpensive water supply, condensers may be attached to the main engine resulting in a saving of 20% to 30% of the whole fuel bill. In some instances deep well pumps have been thrown out and the air lift installed, primarily because of the thorough aeration of the water resulting in throwing off most of the sulphur and other objectionable qualities. Where river or other surface water is good the wells may be drilled close to the edge, the water flowing down from the top of the wells, and the system automatically adjusts itself to any variation of the river level. In many cases where there is a heavy strata of sand or gravel level with the river bed, this strata may be used as a natural filter by placing the wells some distance away and the quality of the water much improved.

Where a part of the water only is used at a high elevation about the works, it is an easy matter to put in a supplementary air lift taking its supply from the distributing main and raising it in a second or compound lift to the point desired, thus avoiding the expense of raising the whole volume of water to the full height. The compressed air may in many instances be used to great advantage for other purposes about the works. There are already some 70 or 80 different applications of compressed air in railroad machine shops, and there is hardly a manufacturing business of any kind in which the use of compressed air would not reduce materially the expense in some important departments.

Properly installed, little care from a competent engineer is required. The compressor may be arranged to be regulated by the water consumption so that the fuel consumed is proportionate to the amount of water used, thus leaving little for the engineer to look after except to see that the oil cups are kept filled. In point of durability the air lift stands by itself. There is nothing about the two plain open-ended pipes in the well to require attention until they are rusted through. A good air compressor requires no more expense in this direction than any good steam engine. Using steam hot from the boilers with an economical rate of expansion the condensation is reduced to a minimum. It is a common sight to see a long line of steam pipes running down to a direct acting pump a considerable distance from the boiler. Authorities estimate that with fuel at $2.00 per ton, every 2" pipe uncovered costs $1.00 per year for condensation. With air there is no condensation. The direct acting form of pumps referred to frequently require from 175 to 200 lbs. of steam per H. P. per hour, while an economical air compressor does its work on 15 to 40 lbs., according to type. The common form of water pump frequently consumes 50% of its power overcoming its own friction. The friction of a good air compressor is usually down to 10%, and may run down to 5%. A careful study of the system will prove very interesting, and it will often be found that it pays well to use the air lift even in those exceptional cases where the cost of the water is not materially reduced because of the other incidental features in economy.

As the figures given may create the impression that the cost of pumping with a small plant may run disproportionately high, we will investigate in that direction also. In most small plants an inexpensive belt or steam actuated compressor may be used, entailing no additional attendance expenses and no extra boiler, building, or tank investment, and in some cases, there would be no additional cost for well, piping, etc. Excluding tank, boilers and building, but making proper allowance for well, piping, steam driven compressor, receiver, foundation, freights, erection, etc., assuming that the tank and well are close to the work, we find that for a plant to pump 175 gallons per minute, or 252,000 gallons per 24 hours, 75′ high, the total investment is not likely to exceed $1,500.00. The interest, deterioration, insurance and tax charges, as above, aggregating 16% net on

this sum per day..	$ .87
A proportionate allowance for fuel at $2.00 per ton, attendance, oil, etc., should not exceed per day....................................	2.50
Total cost of pumping 252,000 gallons per day......................	$ 3.37
Cost per 1,000 gallons..	.01 1-3
Cost of this amount of water at 5 c. per 1,000 gallons, per year of 275 days	3,465.00
And at 1 1-3 c. per 1,000 gallons..................................	924.00
Net saving effected per year with a plant costing $1,500.00............	$2,541.00

or a dividend of 169% on the investment. Certainly one had better borrow the money, even at a high rate of interest if necessary, rather than neglect such a saving as this. In many instances a surprising saving may be effected when the water is now being obtained by means of deep well pumps or other similar apparatus by throwing the outfit aside and installing the more economical Air Lift System.

GEORGE R. MURRAY.

USE OF COMPRESSED AIR IN A SALT WELL.

In the fall of 1897, Messrs. Nuttall and Hubbell of the Buckley & Douglas Co., Manistee, Mich., conceived the idea of making an application of compressed air to salt wells for the purpose of pumping the brine. By employing two machines, an air pipe was sunk to a depth of from 900 to 1,000 feet, and the results were of a very satisfactory nature. The success of the method being assured, the Buckley & Douglas Company immediately ordered an Ingersoll-Sergeant air compressor and began preparations for putting in the new system. The compressor was set up and put in running order about the first of July of last year. It has a steam cylinder twenty inches in diameter, a low pressure air cylinder twenty-two inches in diameter, a high pressure air cylinder nine inches in diameter, all having a common stroke of twenty-four inches. With this machine running at eighty revolutions per minute, 840 feet of free air is admitted through the intake pipe, the large cylinder compressing it to a sixty-pound pressure. After passing through the pipes and cooling, the high pressure cylinder continues the compression until it has attained a pressure of between four and five hundred pounds, thereby reducing 840 cubic feet to a volume of 30 cubic feet at a pressure of 840 lbs. to the square inch; each cubic foot of compressed air contains as a result, 28 cubic feet of free air at that pressure. This pressure is sufficient to keep in constant flow night and day three of the two thousand foot wells, 260 gallons of brine being discharged every minute from each. If the company desires they would be able to supply the entire demand by operating but two wells night and dav.

The firm has also adopted a novel application of compressed air tools at the Salt Block. The salt is dumped in vast storage rooms below their grainers or vacuum pans, from 16 to 20 feet deep. When the salt is packed it has been found necessary before to use picks, grub hoes, etc., to quarry and break up the salt, so as to pack it into barrels. The vacuum pan salt being very fine grain and containing a large percentage of brine becomes very hard and compact, so that it is very difficult to break it up for packing. During the past season laborers were scarce, and they could not get men to break up the salt ready for packing. In this emer-

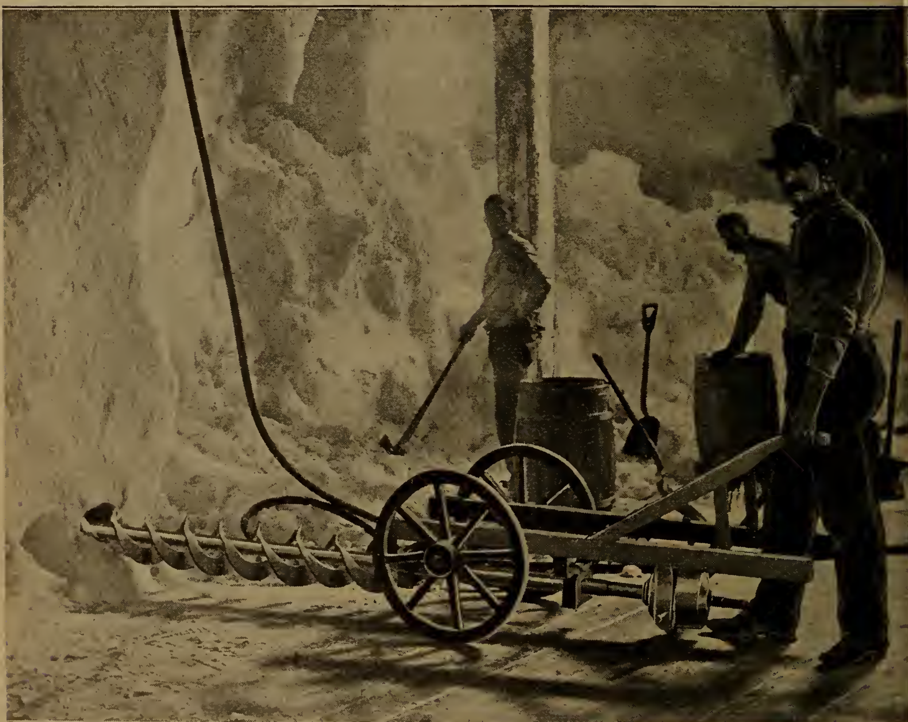


FIG. 253.—BOYER PISTON AIR DRILL OPERATING AUGER FOR BORING IN SALT BLOCK.

gency, the arrangement shown in the cut was brought into play. A truck was made with a horizontal shaft, to which was attached a ten-inch spiral auger, six feet long, and operated by the No. 2 Boyer Piston Air Drill, furnished by the Chicago Pneumatic Tool Company. The operator advanced the truck to the base of the salt wall, and the auger would penetrate a depth of 6 feet in 45 seconds. The holes were drilled as closely together as possible, and in from one to three hours, the section thus undermined would fall and break up all ready for packing, so that it was then only necessary to shovel it into barrels and head them up. By the use of this machine two and one-half days in a week, it was found that thirty packers would do the work which had previously required sixty packers, and the most laborious part of the work having been removed, no further difficulty was encountered in securing men to pack the salt.

IMPROVED PNEUMATIC DISPLACEMENT PUMPS.

The application of air pressure directly upon liquids contained in submerged receptacles of suitable design as a method of pumping, is old and well known to Pneumatic Engineers as the "Displacement System."

While from a theoretical standpoint the efficiency of the "Displacement System" is low, its adaptability, by which existing economical sources of power

FIG. 254.

may be utilized for the production of the required air pressure, irrespective of the relative location of the source from which the water is taken, the low cost of installation when compared with an isolated pumping plant of the usual type, and the remarkable low cost of maintenance more than offsets the low efficiency and renders the system desirable and applicable to many cases.

The displacement types of pneumatic pumps shown by the accompanying illustrations, embody recent improvements upon the construction formerly brought out by the writer, many of which, installed during the past five years, pumping water under favorable conditions, are giving entire satisfaction to the purchasers.

These early patterns consisted of one or more iron chambers adapted to be submerged in the liquid pumped, having liquid ingress and egress openings closed by suitable valves, and an air valve for controlling the supply and release of air pressure to and from the submerged chamber.

The air valve was placed in the chamber or directly on top, below the water level, or outside of the chamber above the water level. In all cases the movement

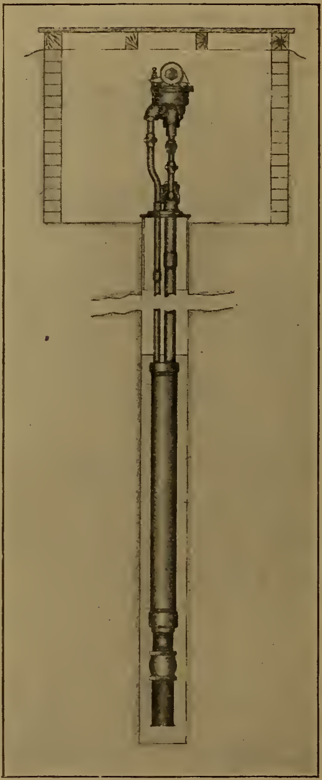


FIG. 255.

of the air valve was controlled by floats, within the water chamber, arranged to actuate the air valve directly, or connected with supplemental valves which governed the main valve.

The mechanical difficulties encountered with these early constructions, and the objections thereto are chiefly as follows:

FIRST.—The limited available actuating power of all kinds of floats suitable to be contained within the water chamber, rendering the pump inoperative if the air valves become clogged or stick.

SECOND.—The very great tendency of closed floats to collapse or fill with water under high pressure. With open end floats, the excessive loss of air required to displace the water which enters the mouth of the open end float, until the air entrapped therein corresponds to the external working pressure.

THIRD.—The possible disarrangement of the floats, or air valve mechanism, from the rapid influx or efflux of water. The injurious elements—sand, mud or sediment, and the chemical action of the water which causes the air valves to leak and stick.

FOURTH.—The inaccessibility of the working parts, requiring the removal of the entire pump to make repairs of however slight a nature.

The improvements embodied in the writer's new type of displacement pumps consist mainly, of the entire elimination of floats, the removal of all valve-

FIG. 256.

actuating mechanism from the water chamber, and the placing of a self-contained air valve above the water level, thereby avoiding the difficulties mentioned.

Figure 254, is a sectional view through the chamber of a single-acting type of the improved pump, showing the water admission and discharge valves, and the absence of all other moving parts below the water level.

The automatic air valve which is the subject matter of U. S. Patent No. 609,943, August 30th, 1898, consists of a main air valve controlled by an auxiliary valve, both of which are driven by differentiated pistons on which the air pressure is applied. By this means the valve motion is prevented from hanging up in a central position.

The movement of the air valve is predetermined and adjusted to the maximum filling capacity of the water chamber, which is so proportioned as to exceed the discharge capacity, thereby insuring complete filling of water chambers.

Pliable cup packings held out by brass tension rings are used on the piston valves to prevent air leaking. These cup packings, working in composition cylinder linings, are subject only to the action of compressed air, from which sufficient lubrication is obtained by the oil taken up during compression of the air.

In practice it has been found that these cup packings are exceedingly durable, wearing for several years and remaining pressure-tight. Being accessible they are easily and cheaply renewed if necessary.

The automatic air valve may be placed just above the water level or any distance away from the water chambers, as shown by the bored well displace

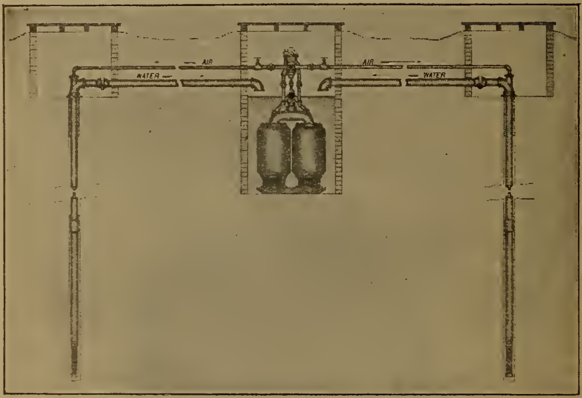


FIG. 257.

ment type (Fig. 255). It is preferable, however, to place the air valve near the water level to avoid the loss of air required to fill the connecting air pipes above. When the water chamber is nominally submerged the velocity of influx will carry the water in the air pipes some distance above the water level, and to a still greater height by an increased submergence. With the bored well displacement type (Fig. 255), there is usually sufficient submergence to reduce the clearance loss very materially.

The water chambers are made in various forms and sizes to conform to the conditions of the sources or wells from which the water is taken.

The single-acting types are adapted for moderate service up to 50 gal. per minute capacity.

For heavier service the duplex types (Fig. 256) are recommended.

Figure 257 represents a "combination plant" pumping from one or more wells by modified types of the well known "Pohlé Air Lift," discharging therefrom into a receiver well at the surface, from thence by a "Duplex Displacement Pump" to any desired point of delivery above the surface.

With this combination water may be effectively delivered at distant elevated points, by a single Air Compressing plant, from bored wells having a submergence only sufficient for the economical operation of the "Air Lift" in discharging at the surface.

These pumps are manufactured by the Merrill Pneumatic Pump Co., 141 Broadway, New York. F. H. MERRILL.

PNEUMATIC DISPLACEMENT PUMP.

We give below a full description of the Pitcher and Sargent (Somerville, Mass.), Pneumatic Water Raising Device as an example of direct displacement pneumatic pump.

When water of a considerable depth is to be raised vertically upward, the "Air Lift" system furnishes a most practical means. It is, however, very often

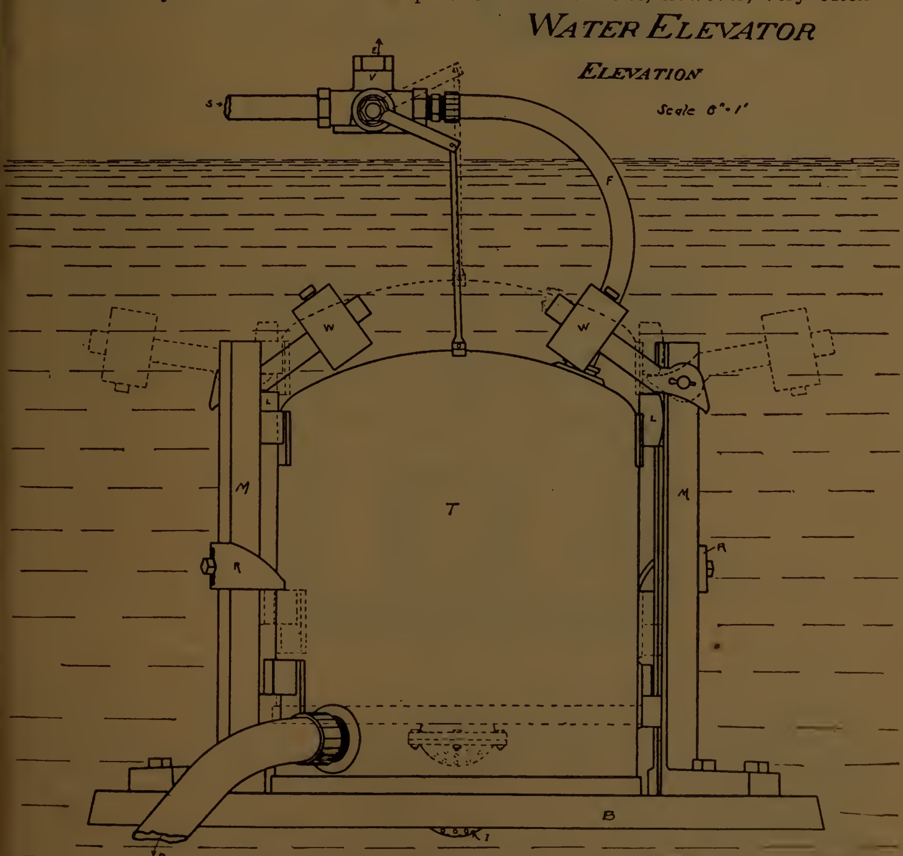


FIG. 258.

necessary to convey water, horizontally as well as vertically, to some height from shallow wells, springs and lakes by means of power generated at some distance from their sources of water supply. In such a case the Pneumatic Direct Displacement system is most practicable.

In this system air is compressed at the most convenient place, and then conducted to a displacement tank submerged in the water to be raised. This tank

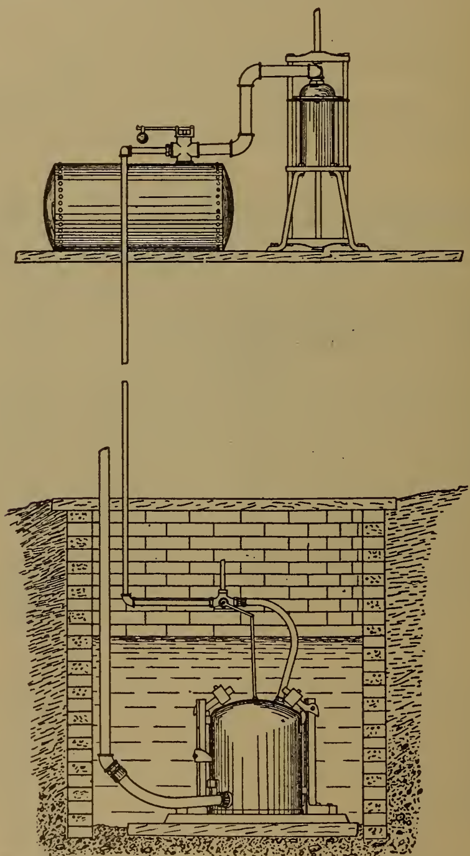


FIG. 259.

is provided with an air inlet and outlet and a water inlet and outlet. Compressed air is admitted to top of tank and displaces the water driving it out at bottom through a conducting discharge. The tank is again filled automatically with water and the operation is repeated.

The difficulty giving rise to different kinds of displacement water raising devices is in the mechanism for automatically filling the tank with water. To accomplish this, it is necessary to shut off the supply and open the exhaust for air while the tank is filling with water, and to shut the exhaust and open the supply for air when the tank has filled.

This device involves the displacement principle and overcoming the above difficulty by a simple but effectual means. The cylindrical tank T (Fig. 258) is fitted to slide vertically in standards M, which are mounted properly on metal base. The standards bear two weighted levers W, which engage with lugs L on tank, V is an eighth turn three way valve which controls the compressed air supply and exhaust. The operation is as follows: compressed air enters at S, passes through flexible pipe F to top of tank, driving water out through flexible pipe D to reservoir. When the tank is full of air, its buoyancy overcomes the weight of levers W, it rises to dotted position, shifting the valve so that air supply is shut off, and air in tank escapes through F, to free air at E. The weighted levers now hold tank up until it has filled with water through I. When full of water the weight of tank causes it to drop to original position and process is repeated.

To work properly, the tank when submerged and full of water should weigh one-half force due to its buoyancy when full of air. The efficiency of a displacement pump is 100 p. c., when the volume of water raised is equal to the volume of air (at effectual pressure) allowed to escape. By adjusting the weights W on the levers in this device, you are able to so balance the tank that it will not fall until it has entirely filled with water, thus avoiding any clearance space in top of tank to be filled with air before the water can be forced out. In fact, the tank fills so quickly that the water rushes up the pipe F and out the exhaust E (provided the valve is near the surface of water) before the inertia of the tank and weights is overcome and the tank falls. Under this condition, and disregarding leakage, loss of power is minimum.

Fig. 259 shows also the air compressor used with windmills, the plunger working from under side and attached directly to pumping rod of mill by side rods and cross heads.

DRIVING PUMPS BY COMPRESSED AIR.

BY WILLIAM COX.

"Compressed air may be, and should be, much more extensively used than it has been hitherto for operating pumps."

It must not be supposed, however, that any common steam pump, having attached to it a pipe supplying air under any hap-hazard pressure will perform satisfactory service. To insure such various details relating to the manifold operations to be performed must be carefully considered and duly taken into account, so that from the variety of conditions presented, a harmonious whole may be evolved. And even then, when the installation, if it may be dignified by such a term, has been made with judgment and due regard to the exigencies of the case, high economy must not be looked for or expected, as the common direct-acting pump, no matter how driven, is and will ever be a waste producer. Taking the pumps, however, as they are generally met with, the object of this paper is to present in as simple a manner as possible the conditions which must be fulfilled, so that with the material at hand, or easily secured, the best results may be obtained.

In what follows the following nomenclature is observed throughout:

D_s or D_a = Diameter of steam or air cylinder in inches,
d = Diameter of water cylinder in inches,
l = Length of stroke in inches,
n = Number of single strokes per minute,
p_s = Piston speed in feet per minute,

$$= \frac{l \times n}{12}$$

E = Useful effect, efficiency or corrected capacity,
G = Gallons of water required to be discharged per minute, (U. S. Gallons of 231 cub. ins.),
P = Gauge Pressure of the air in pounds per sq. in.,
V = Equivalent volume of free air required,
h = Head in feet to which the water is to be pumped,
p = Resistance per square inch on the pump piston = 0.433 h.

The first point which presents itself for our consideration is the quantity of water that is required to be handled, with the corresponding necessary diameter of the water cylinder of the pump, so as to secure good results in this part of the system. The formula giving the theoretic discharge of any pump cylinder is:

$$G = \frac{0{\cdot}7854d^2 \times l \times n}{231}$$
$$= 0{\cdot}0034d^2 \times l \times n$$
$$= 0{\cdot}0408d^2 \times p_s \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

By transposition we have

$$d^2 = \frac{G}{0{\cdot}0408p_s} \text{ whence}$$
$$d = 4{\cdot}95\sqrt{\frac{G}{p_s}} \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

and allowing for a piston speed of 100 feet per minute, which is very commonly assumed as reasonable, we have:

$$d = 0{\cdot}495\sqrt{G} \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

The following table, calculated from Eq. (1), gives the theoretical discharge of water cylinders of various diameters, in gallons per minute, the piston speed being assumed throughout as being 100 feet per minute;

TABLE 59.

Diameter of Water Cylinder.	Discharge.	Diameter of Water Cylinder.	Discharge.
2 inches.	16·32 c. ft.	9½ inches.	368·22 c. ft.
2½ "	25·50 "	10 "	408·00 "
3 "	36·72 "	11 "	493·68 "
3½ "	49·98 "	12 "	587·52 "
4 "	65·28 "	13 "	689·52 "
4½ "	82·62 "	14 "	799·68 "
5 "	102·00 "	15 "	918·00 "
5½ "	123·42 "	16 "	1,044·48 "
6 "	146·88 "	17 "	1,179·12 "
6½ "	172·38 "	18 "	1,321·92 "
7 "	199·92 "	19 "	1,472·88 "
7½ "	229·50 "	20 "	1,632·00 "
8 "	261·12 "	21 "	1,799·28 "
8½ "	294·78 "	22 "	1,974·72 "
9 "	330·48 "	24 "	2,350·08 "

By means of this table the size of the water cylinder required to discharge a given quantity of water, on a basis of a piston speed of 100 feet per minute, is at once approximately seen. Thus, to deliver 100 gallons a minute, a 5-inch cylinder would be evidently required.

It is well, however, to note that for pumps having but a short stroke, 100 feet piston speed per minute is excessive, as it causes too frequent reversal of the valves, while for long-stroke pumps this speed may be somewhat increased.

The above discharges are the theoretical ones, which are far from being attained in practice. It would be safer and more correct, therefore, to assume as a general rule that the capacity of the water cylinders should be increased by at least 20 per cent., to cover losses arising from looseness of the piston valves, etc. The simplest way of doing this is to add 20 per cent. to the required discharge, and then find in the table the size of the water cylinder for this increased discharge. Thus, in the above case, 100 gallons × 1.20 = 120 gallons, for which by the table a 5½-inch cylinder would be necessary. If it should be preferred to work this out directly by formula we have:

$$d^2 = \frac{1 \cdot 20G}{0 \cdot 0408ps}, \text{ whence}$$

$$d = 5 \cdot 4\sqrt{\frac{G}{ps}} \quad \ldots\ldots (4)$$

and for 100 feet piston speed

$$d = 0 \cdot 54\sqrt{G} \quad \ldots\ldots (5)$$

Having thus calculated the diameter of the water cylinder which will at the given piston speed deliver the required quantity of water, we must next determine the diameter of the air cylinder, and the working pressure of the air which will raise the required quantity of water to the desired height.

The first thing to be done here is to decide upon a suitable pressure of the air. For several reasons high pressures are not recommended, the chief one being that of economy, seeing that, although a lower pressure will require a greater volume of free air, yet the proportionate and absolute cost of the power necessary to operate a larger sized air cylinder (which consumes the greater volume of free air at the lower pressure) is considerably less.

The steam or air pressure required to raise water to any given height is found by the formula.

$$P = \frac{p \times d^2}{Da^2}$$

$$= \frac{0{\cdot}433h \times d^2}{Da^2} \quad \ldots\ldots (6)$$

transposing which, on the assumption that the pressure P has been previously decided upon, we have for the size of the air cylinder:

$$Da^2 = \frac{0{\cdot}433h \times d^2}{P} \quad \ldots\ldots (7)$$

As in the water cylinder considerable losses occur, so in the air cylinder such are inevitably met with, owing to clearance, leakage, etc. Assuming these to be 15 per cent. of the piston displacement, formula (7) becomes:

$$Da^2 = \frac{0{\cdot}433h \times d^2 \times 1{\cdot}15}{100P}$$

$$= \frac{0{\cdot}5h \times d^2}{P} \quad \ldots\ldots (8)$$

Taking the case already referred to, where it is required to deliver 100 gallons of water per minute, using a 5½-inch water cylinder, and assuming that the height to which it is to be raised is 80 feet, and that an air pressure of 20 pounds be used, we have by Eq. (8):

$$Da^2 = \frac{0{\cdot}5 \times 80 \times 5{\cdot}5 \times 5{\cdot}5}{20}$$

$$= 60{\cdot}5$$

and $Da = 7{\cdot}8$ inches.

It would, therefore, be reasonable, as well as safe, in such a case to select a pump having say 8 x 6-inch cylinders and 12-inch stroke.

The next and last point, which is one of considerable interest, is the volume of equivalent free air required to do the work thus determined. For this purpose we have the formula:

$$V = \frac{0{\cdot}7854Da^2 \times l \times n}{1728} \times W_2$$

$$= 0{\cdot}00545Da^2 \times ps \times W_2 \quad \ldots\ldots (9)$$

in which the first expression gives the required volume of *compressed* air, while the second one, W_2, reduces this volume to its equivalent volume of *free air*, being a simpler form of expression for:

$$\frac{P + 14{\cdot}7}{14{\cdot}7} = 1 + 0{\cdot}068P.$$

By this formula the value of W_2 for 20 pounds pressure is:

$$1 + (0.068 \times 20) = 2.36$$

and inserting this value in Eq. (9) we have for the example given:

$$= 77.8 \text{ cubic feet.}$$

$$V = 0.00545 \times 60.5 \times 100 \times 2.36$$

Assuming, as before, a piston speed of 100 feet per minute and adding 15 per cent. to the volume of free air required, to compensate for frictional and other resistances, we have:

$$V = 0{\cdot}63 \times Da^2 \times W_2 \quad \ldots\ldots (10)$$

which gives 90 cubic feet of free air required to pump 100 gallons of water per minute to a height of 80 feet, the pressure of the air being 20 pounds per square inch, the diameter of the water cylinder 5½-inches, the diameter of the air cylinder 7.8 inches, and the piston speed 100 feet per minute.

It must, of course, be understood that these formulas do not cover undue losses occasioned by friction in the delivery pipes, when these are either of too small diameter or considerable length. This point is an important one and requires equally careful consideration, so as to reduce this friction to a minimum. Space does not allow of this problem being gone into here, as to do it justice would require an article to itself.

From what precedes, it will be seen that the formulas required for solving problems relating to pumps driven by compressed air, are:

For the diameter of the water cylinder............Eq. (5).
For the diameter of the air cylinder..............Eq. (8).
For the volume of free air.......................Eq. (10).

It is frequently desired to know in a simple manner how many cubic feet of free air at a certain pressure would be necessary to pump a given quantity of water to a required given height, without, for the time being, considering the sizes of the air and water cylinders or the piston speed. That this can be done, although not generally so supposed, and that by a very simple formula, will now be explained.

FIRST:—*Theoretically.*

Eq. (1) gives

$$G = 0{\cdot}0408 d^2 \times ps$$

whence

$$d^2 = \frac{G}{0{\cdot}0408 ps} \quad \ldots\ldots (11)$$

Eq. (7) stands

$$Da^2 = \frac{0{\cdot}433 h \times d^2}{P} \quad \ldots\ldots (7)$$

Inserting the value of d^2 as given in Eq. (11) in Eq. (7) we have

$$Da^2 = \frac{0{\cdot}433 h}{P} \times \frac{G}{0{\cdot}0408 ps} \quad \ldots\ldots (12)$$

Again, we have by Eq. (9)

$$V = 0{\cdot}00545 Da^2 \times ps \times W_2 \quad \ldots\ldots (9)$$

From equations (12) and (9) we obtain

$$V = 0{\cdot}00545 \frac{0{\cdot}433 h \times G}{P \times 0{\cdot}0408 ps} \times ps \times W_2$$

and by cancelling and reducing

$$V = 0{\cdot}05784 \frac{h \times G}{P} \times W_2 \quad \ldots\ldots (13)$$

the only quantities requiring to be known being

h=the head in feet to which the water is to be pumped,
G=the number of gallons of water to be pumped, and
P=the pressure of the air to be used.

SECOND:—With the various losses taken into account, as explained in the last article,

Eq. (11) with 20 per cent. added gives

$$d^2 = \frac{120}{0{\cdot}0408 \times 100} \times \frac{G}{ps}$$

$$= \frac{G}{0{\cdot}034ps} \quad \text{.......... (14)}$$

Eq. (7) with 15 per cent. added gives us

$$Da^2 = \frac{0{\cdot}5h \times d^2}{P} \text{same as .... (8)}$$

Combining equations (14) and (8) we have

$$Da^2 = \frac{0{\cdot}5h}{P} \times \frac{G}{0{\cdot}034ps} \quad \text{.......... (15)}$$

Again, equation (9) with 15 per cent. added gives us

$$V = 0{\cdot}0063 Da^2 \times ps \times W_2 \quad \text{.......... (16)}$$

and by combining equations (15) and (16) we obtain

$$V = 0{\cdot}0063 \frac{0{\cdot}5h \times G}{P \times 0{\cdot}034ps} \times ps \times W_2$$

and by canceling and reducing

$$V = 0{\cdot}093 \frac{h \times G}{P} \times W_2 \quad \text{.......... (17)}$$

in which, as before, the only quantities required to be known are

h=the head in feet to which the water is to be pumped,
G=the number of gallons of water to be pumped, and
P=the pressure of the air to be used.

Let us now take the example given in detail in the last article, and see how nearly the results agree. We have given

h=80 feet,
G=100 gallons,
P=20 pounds, and
W_2 for P=20 pounds=2.36,

we have therefore by Eq. (17)

$$V = 0{\cdot}093 \frac{80 \times 100}{20} \times 2{\cdot}36$$

$$= 87{\cdot}8 \text{ cubic feet of free air}$$

as against 90 cubic feet found previously. The slight difference is, however, explained and fully covered by two or three items being taken in the former paper approximately, such for instance as the diameter of the water cylinder, which is 5.4 inches by the formula, and not 5.5 inches, which was taken from the table, which allows a slight over-volume of delivery (3.42 gallons).

The solution of the problem by this direct method therefore fully agrees with the step-by-step one, and for a preliminary study of any case which may arise, is very much simpler.

If it be found that such a quantity of free air is available, other details required for making the installation a success, can now be obtained by means of equations (14) and (8), which give in a very simple manner the diameters of the water and air cylinders, based upon any suitable piston speed.

Thus, by Eq. (14) and assuming a piston speed of 100 feet per minute, we have

$$d^2 = \frac{G}{0.034 p_s}$$
$$= \frac{100}{0.034 \times 100}$$
$$= 29.41, \text{ and}$$
$$d = 5.4 \text{ inches.}$$

Then by Eq. (8) we have

$$D_a^2 = \frac{0.5 h \times d^2}{P}$$
$$= \frac{0.5 \times 80 \times 29.41}{20}$$
$$= 58.82, \text{ and}$$
$$D_a = 7.67 \text{ inches.}$$

It is the writer's opinion that equation (17) will be found exceedingly useful by mining and other engineers who may have to figure upon the use of compressed air for driving common pumps.

Another question which will also be of interest, although it may sometimes be overlooked, is the question of power cost. As previously stated, high powers are not, when examined from this standpoint, recommended.

The horse-power required by the air cylinder of a compressor is

$$H.\ P. = \frac{0.7854 d^2 \times M_p \times p_s}{33000} \qquad (18)$$

and the volume of free air compressed by the same is

$$\frac{0.7854 d^2 \times p_s}{144} \qquad (19)$$

The horse-power required therefore by the air cylinder to compress one cubic foot of free air is found by dividing Eq. (18) by Eq. (19) which gives

$$P = \frac{0.7854 d^2 \times M_p \times p_s \times 144}{0.7854 d^2 \times p_s \times 33000}$$
$$= \frac{M_p}{229} \qquad (20)$$

The following table gives the mean effective resistance, or mean pressure M_p to be overcome by the air cylinder piston to produce various terminal pressures,* and the horse-power required by the air cylinder to compress one cubic foot of free air to the same terminal pressures, calculated from Eq. (20).

* *From* Compressed Air, *by Frank Richards, A. S. M. E.*

TABLE 60.

Terminal Pressure P	Mean Pressure P	Horse-power per cubic foot of free air.
20 pounds,	14.4 pounds,	0.0628
25 "	17.01 "	0.0743
30 "	19.4 "	0.0847
35 "	21.6 "	0.0943
40 "	23.66 "	0 1033
45 "	25.59 "	0.1117
50 "	27.39 "	0.1196

Referring again to Eq. (17) we may transpose it and obtain

$$h \times G = V \frac{P}{0 \cdot 093} W_2$$

and if we substitute for $\frac{P}{0 \cdot 093 W_2}$ the term X, we have

$h \times G = V \times X$ ....(21)

The following table gives the values of W_2 and $0.093\ W_2$ for different pressures, with the corresponding values of X.

TABLE 61.

Pressure P	W_2	$0 \cdot 093 W_2$	$X = \frac{P}{0.093 W_2}$
5 pounds,	1.34	0.12462	40.122
10 "	1.68	0.15624	64.004
15 "	2.02	0.18786	79.846
20 "	2.36	0.21948	91.124
25 "	2.70	0.25110	99.562
30 "	3.04	0.28272	106.324
35 "	3.38	0.31434	111.344
40 "	3.72	0.34596	115.620
45 "	4.06	0.37758	119.180
50 "	4.40	0.40920	122.190

This table enables us to obtain in a very simple manner the volume of free air required to pump any given quantity of water to any desired height. Thus, to continue the example already referred to,

$h \times G = 80 \times 100 = 8{,}000,$

and dividing by X or 91 (omitting decimals) we have for 20 pounds pressure

$$V = \frac{8000}{91} = 88 \text{ cubic feet of free air,}$$

which is practically identical with the solution already found by means of Eq. (17).

If we now combine Tables 60 and 61, we obtain the following one, which will be often found useful:

TABLE 62.

V × X = h × G	P	V	H. P.
9112	20 pounds,	100 cub. ft.	6.28
9956	25 "	" "	7.43
10632	30 "	" "	8.47
11134	35 "	" "	9.43
11562	40 "	" "	10.33
11918	45 "	" "	11.17
12219	50 "	" "	11.96

Taking the previous example, we have, therefore, for the horse-power required by the air cylinder

$$\frac{6{\cdot}28 \times 88}{100} = 5{\cdot}53 \text{ horse power.}$$

It has been stated that high pressures are not economical. Let us, therefore, work out the foregoing example with an assumed pressure of 40 pounds, so as to be able to judge of the altered conditions.

We have, therefore, in the first place, from Table 61

$$\frac{h \times G}{X} = \frac{80 \times 100}{115{\cdot}6}$$

$=69$ cubic feet of free air.

Now, by Table 62 we have

$$\frac{10{\cdot}33 \times 69}{100} = 7{\cdot}13 \text{ horse-power.}$$

We see, therefore, that although there is an economy of 88-69=18 cubic feet of free air to be compressed, yet the power-cost of doing the work is 7.13-5.53=1.6 horse-power greater. Other cases, if similarly worked out, would demonstrate the same fact.

Formula (21) which is

$$h \times G = V \times X$$

shows

1st.—For a given pressure, the volume of free air required varies *directly* as h × G.

2d.—If the product of head into quantity of water is the same in different cases, the pressure will vary *inversely* as the volume of free air required; or the volume of free air required will vary *inversely* as the pressure employed.

3d.—For equal values of $\frac{h \times G}{V}$, the pressure necessary will be the same.

Thus, if V = 100, h = 100 and G = 100, then X = 100, which is equivalent to a pressure of 25 pounds, as per Table 61.

So also, if V = 100, h = 50 and G = 200, X = also 100, and consequently as per same table, the pressure required will likewise be 25 pounds.

I trust that it has been clearly shown that the volume of free air required and the power-cost can be ascertained without any reference to the sizes of the air and water cylinders, and that these are questions of detail to be afterwards considered in accordance with the formulas given, when working out plans for an installation.

Of course, the losses I have taken may vary from those stated, as much depends upon the pumps employed and the care used throughout in making the installation. The same method of treatment must, however, be followed in all cases.

In connection with what I have already written, it may be desirable sometimes to ascertain in a ready manner the ratio which should exist between the air and water cylinders so that the best results may be obtained. Equation (8) supplies this information in the simplest form. It is

$$D_a^2 = \frac{0{\cdot}5h \times d^2}{P}$$

from which we obtain by transposition

$$D_a^2 : d^2 = 0{\cdot}5h : P \quad \text{.........................} (22)$$

or, to express it so that it may be easily memorized,

Area of air cylinder is to area of water cylinder as half the head is to the pressure.

or again, we have

$$D_a : d = \sqrt{0{\cdot}5h} : \sqrt{P} \quad \text{...................} (23)$$

that is,

Diameter of the air cylinder is to the diameter of the water cylinder, as square root of half the head is to square root of the pressure.

Taking the example already given, where h=80 feet, and P=20 pounds we have

$$D_a^2 : d^2 = 40 : 20$$
$$= 2 : 1$$

or

$$D_a : d = \sqrt{2} : \sqrt{1}$$
$$= 1{\cdot}414 : 1$$

It will be clear from what has been written in the first article that the FIRST point in every case to be carefully ascertained is the diameter of the water cylinder and the piston-speed, *after which* the required diameter of the air cylinder can be easily found by means of the above ratio-formula.

The diameter of the water cylinder depends upon the quantity of water to be pumped per minute and the piston-speed; or, in other words, the volumetric capacity of the water cylinder per minute is the sectional area of the cylinder multiplied by the length of stroke in inches, and the number of single strokes per minute. This product, which is the capacity in cubic inches, divided by 231, gives the capacity in U. S. gallons per minute. Reduced to its simplest form, this becomes as in Eq. (4)

$$d = 5{\cdot}4\sqrt{\frac{G}{p_s}}$$

In the above example we assumed G=100 and p_s=100 feet per minute, so we have

$$d = 5{\cdot}4\sqrt{\frac{100}{100}}$$
$$= 5{\cdot}4 \text{ inches}$$

Given then, d=5.4 inches, clearly

$$D_a = \frac{d \times \sqrt{2}}{\sqrt{1}}$$

$$\text{or } D_a = 5{\cdot}4 \times 1{\cdot}414$$
$$= 7{\cdot}64 \text{ inches,}$$

which agrees with the result already obtained, if in place of D_a=5.5 as previously given, we take D_a=5.4 inches as above. It should be remembered that the diameter 5.5 inches was taken from Table 59, and is correct for 102 gallons, but a little too much for 100 gallons. Of course, cylinders are not made to decimal sizes, such as 5.4 inches, but to fractional diameters as 5½ inches.

The following table gives the *ratio* of the diameter of the air cylinder to the diameter of the water cylinder for different heights to which the water is to be pumped, and for different air-pressures, the diameter of the water cylinder being taken throughout as 1 inch:

TABLE 63.

Ratios of diameter of air cylinder to diameter of water cylinder.

Height, Feet.	PRESSURES.						
	20 lbs.	25 lbs.	30 lbs.	35 lbs.	40 lbs.	45 lbs.	50 lbs.
50	1.12	1.00	0.91	0.84	0.79	0.74	0.71
100	1.58	1.41	1.29	1.20	1.12	1.05	1.00
125	1.77	1.58	1.45	1.34	1.25	1.18	1.12
150	1.94	1.73	1.58	1.45	1.37	1.29	1.22
175	2.09	1.87	1.70	1.58	1.48	1.39	1.32
200	2.24	2.00	1.82	1.69	1.58	1.49	1.41
225	2.37	2.12	1.94	1.79	1.68	1.58	1.50
250	2.50	2.24	2.05	1.90	1.77	1.67	1.58
275	2.62	2.35	2.14	1.98	1.85	1.75	1.66
300	2.74	2.45	2.24	2.07	1.94	1.82	1.73
325	2.85	2.55	2.33	2.16	2.02	1.90	1.80
350	2.96	2.64	2.42	2.24	2.09	1.97	1.87
375	3.06	2.74	2.50	2.31	2.16	2.04	1.94
400	3.16	2.83	2.58	2.39	2.23	2.11	2.00
425	3.26	2.92	2.66	2.46	2.30	2.17	2.06
450	3.35	3.00	2.74	2.53	2.37	2.24	2.12
475	3.44	3.08	2.82	2.60	2.44	2.30	2.18
500	3.53	3.16	2.89	2.67	2.50	2.36	2.24

Ratios for intermediate heights and pressures may be obtained by interpolation.

Example. 200 gallons of water to be pumped to a height of 125 feet, the air-pressure being 25 pounds. Piston-speed 100 feet per minute.

We have in the first place

$$\text{Diameter water cylinder} = 5{\cdot}4\sqrt{\frac{200}{100}}$$
$$= 5{\cdot}4 \times \sqrt{2} = 7{\cdot}64 \text{ inches.}$$

Now, by Table 63, we find under 25 pounds pressure, in line with 125 feet height, the ratio 1.58 to 1, so that the diameter of the air cylinder should be

$$7.64 \times 1.58 = 12.1 \text{ inches.}$$

In practice these two sizes will of course not be met with, so to secure the pumping of the required quantity of water we may safely select a pump with an 8-inch water cylinder. Then, according to the ratio of 1.58 to 1.0, we should have an air cylinder of $8 \times 1.58 = 12.64$ inches diameter. If a 13-inch cylinder could be had, it would about fill the requirements; but as such a combination is hardly likely to be met with, we should probably have to take a 12 inch, and try to force the air-pressure up to 28 pounds, which is about the interpolated value by the table for a ratio of 1.50 to 1.0, or 12 to 8 inches.

By following as near as can be the ratios set forth in Table 63, and slightly adjusting piston-speed and air-pressure so as to counterbalance any slight variation of diameters of the cylinders, water may be pumped in any quantity to any height, with the least volume of free-air possible, in accordance with Eq. (17). Common pumps may then do their work economically (relatively), and compressed air will be looked upon as a valuable and not a wasteful agent. To repeat an old saying, *Use, but do not abuse.* Of course, if the pumps are of the best, and in good condition, the various losses may be slightly reduced, and somewhat more favorable results may be obtained.

Example. It is required to raise 200 gallons of water per minute to a height of 125 feet, the maximum air-pressure being 30 pounds.

The quantity of water being considerable, and requiring necessarily a fair sized cylinder, let us assume a piston-speed of 120 feet per minute.

We have in the first place by Eq. (4)

$$d = 5{\cdot}4\sqrt{\frac{G}{ps}}$$

$$= 5{\cdot}4\sqrt{\frac{200}{120}} = 6{\cdot}97 \text{ inches.}$$

Now, by Table 63, we see that for 30 pounds pressure and a height of 125 feet, the ratio of the cylinders is 1.45 to 1.0, which gives for the air cylinder 10.1 inches, or say 10 inches for the air cylinder and 7 inches for the water cylinder.

We then have for the volume of free-air required, by Eq. (10)

$$V = 0{\cdot}0063 D_a^2 \times p_s \times W_2$$

$$= 0{\cdot}0063 \times 100 \times 120 \times 3{\cdot}04$$

$$= 229{\cdot}8 \text{ cubic feet.}$$

To verify this result, and to see how near it approaches the ideal, we have by Eq. (17)

$$V = 0{\cdot}093 \frac{h \times G}{P} \times W_2$$

$$= 0{\cdot}093 \frac{125 \times 200}{30} \times 3{\cdot}04$$

$$= 235 \text{ cubic feet.}$$

Allowing for the decimals in the different equations, we see that the results obtained by the two methods substantially agree. We may, therefore, say that for the case under consideration a better combination could scarcely be had than that found as above, namely 10 by 7 inch cylinders, 30 pounds air-pressure, and 120 feet piston-speed.

TABLE 64.

Driving Pumps by Compressed Air. *

Table:– giving the volume of free air, at pressures of 20 to 50 pounds, required to pump any given quantity of water to any height, with the corresponding horse-power required by the air-cylinder to do the work. *Compiled by William Cox.*

h×G	P = 20 lbs		P = 25 lbs		P = 30 lbs		P = 35 lbs		P = 40 lbs		P = 45 lbs.		P = 50 lbs		h×G
	V	H-P	V	H-P	V	H-P	V	H-P	V	H-P	V	H-P	V	H-P	
500	5.66	0.39	5.18	0.42	4.86	0.45	4.64	0.48	4.46	0.50	4.33	0.53	4.22	0.56	500
1000	11.32	0.78	10.36	0.84	9.72	0.90	9.28	0.96	8.92	1.01	8.66	1.06	8.44	1.12	1000
1500	16.98	1.17	15.54	1.26	14.58	1.35	13.92	1.44	13.38	1.51	12.99	1.59	12.66	1.68	1500
2000	22.64	1.56	20.72	1.68	19.44	1.80	18.56	1.92	17.84	2.02	17.32	2.12	16.88	2.24	2000
2500	28.30	1.95	25.90	2.10	24.30	2.25	23.20	2.40	22.30	2.52	21.65	2.65	21.10	2.80	2500
3000	33.96	2.34	31.08	2.52	29.16	2.70	27.84	2.88	26.76	3.03	25.98	3.18	25.32	3.36	3000
3500	39.62	2.73	36.26	2.94	34.02	3.15	32.48	3.36	31.22	3.53	30.31	3.71	29.54	3.92	3500
4000	45.28	3.12	41.44	3.36	38.88	3.60	37.12	3.84	35.68	4.04	34.64	4.24	33.76	4.48	4000
4500	50.94	3.51	46.62	3.78	43.74	4.05	41.76	4.32	40.14	4.54	38.97	4.77	37.98	5.04	4500
5000	56.60	3.90	51.80	4.20	48.60	4.50	46.40	4.80	44.60	5.05	43.30	5.30	42.20	5.60	5000
5500	62.26	4.29	56.98	4.62	53.46	4.95	51.04	5.28	49.06	5.55	47.63	5.83	46.42	6.16	5500
6000	67.92	4.68	62.16	5.04	58.32	5.40	55.68	5.76	53.52	6.06	51.96	6.36	50.64	6.72	6000
6500	73.58	5.07	67.34	5.46	63.18	5.85	60.32	6.24	57.98	6.56	56.29	6.89	54.86	7.28	6500
7000	79.24	5.46	72.52	5.88	68.04	6.30	64.96	6.72	62.44	7.07	60.62	7.42	59.08	7.84	7000
7500	84.90	5.85	77.70	6.30	72.90	6.75	69.60	7.20	66.90	7.57	64.95	7.95	63.30	8.40	7500
8000	90.56	6.24	82.88	6.72	77.76	7.20	74.24	7.68	71.36	8.08	69.28	8.48	67.52	8.96	8000
8500	96.22	6.63	88.06	7.14	82.62	7.65	78.88	8.16	75.82	8.58	73.61	9.01	71.74	9.52	8500
8834	100.–	6.89	91.52	7.42	85.86	7.95	81.98	8.48	78.80	8.92	76.50	9.36	74.55	9.90	8834
9000	101.88	7.02	93.24	7.56	87.48	8.10	83.52	8.64	80.28	9.09	77.94	9.54	75.96	10.08	9000
9500	107.54	7.41	98.42	7.98	92.34	8.55	88.16	9.12	84.74	9.59	82.27	10.07	80.18	10.64	9500
9.652	109.26	7.53	100.—	8.13	93.82	8.69	89.58	9.27	86.10	9.75	83.59	10.23	81.46	10.81	9.652
10000	113.20	7.80	103.60	8.40	97.20	9.00	92.80	9.60	89.20	10.10	86.60	10.60	84.40	11.20	10000
10288	116.26	8.02	106.58	8.64	100.–	9.25	95.47	9.88	91.77	10.39	89.09	10.91	86.83	11.52	10288
10776	121.98	8.40	111.21	9.05	104.74	9.70	100.–	10.34	96.12	10.88	93.32	11.42	90.95	12.07	10776
11218	126.99	8.75	116.14	9.42	108.97	10.10	104.04	10.77	100.–	11.32	97.09	11.89	94.62	12.56	11218
11547	130.71	9.01	119.63	9.70	112.24	10.39	107.16	11.09	103.00	11.66	100.–	12.24	97.46	12.93	11547
11847	134.11	9.24	122.75	9.95	115.17	10.66	109.95	11.37	105.69	11.96	102.61	12.56	100.–	13.27	11847
12500	141.50	9.75	129.50	10.5	121.50	11.25	116.00	12.0	111.50	12.62	108.25	13.25	105.50	14.0	12500
15000	169.8	11.70	155.4	12.6	145.8	13.50	139.2	14.4	133.8	15.15	129.90	15.90	126.6	16.8	15000
17500	198.1	13.65	181.3	14.7	170.1	15.75	162.4	16.8	156.1	17.68	151.55	18.55	147.7	19.6	17500
20000	226.4	15.60	207.2	16.8	194.4	18.00	185.6	19.2	178.4	20.20	173.20	21.20	168.8	22.4	20000
22500	254.7	17.55	233.1	18.9	218.7	20.25	208.8	21.6	200.7	22.72	194.85	23.85	189.9	25.2	22500
25000	283.0	19.50	259.0	21.0	243.0	22.50	232.0	24.0	223.0	25.25	216.50	26.50	211.0	28.0	25000
27500	311.3	21.45	284.9	23.1	267.3	24.75	255.2	26.4	245.3	27.78	238.15	29.15	232.1	30.8	27500
30000	339.6	23.40	310.8	25.2	291.6	27.00	278.4	28.8	267.6	30.30	259.80	31.80	253.2	33.6	30000
32500	367.9	25.35	336.7	27.3	315.9	29.25	301.6	31.2	289.9	32.82	281.45	34.45	274.3	36.4	32500
35000	396.2	27.30	362.6	29.4	340.2	31.50	324.8	33.6	312.2	35.35	303.10	37.10	295.4	39.2	35000
37500	424.5	29.25	388.5	31.5	364.5	33.75	348.0	36.0	334.5	37.88	324.75	39.75	316.5	42.0	37500
40000	452.8	31.20	414.4	33.6	388.8	36.00	371.2	38.4	356.8	40.40	346.40	42.40	337.6	44.8	40000
42500	481.1	33.15	440.3	35.7	413.1	38.25	394.4	40.8	379.1	42.92	368.05	45.05	358.7	47.6	42500
45000	509.4	35.10	466.2	37.8	437.4	40.50	417.6	43.2	401.4	45.45	389.70	47.70	379.8	50.4	45000
47500	537.7	37.05	492.1	39.9	461.7	42.75	440.8	45.6	423.7	47.98	411.35	50.35	400.9	53.2	47500
50000	566.0	39.00	518.0	42.0	486.0	45.00	464.0	48.0	446.0	50.50	433.00	53.00	422.0	56.0	50000
52500	594.3	40.95	543.9	44.1	510.3	47.25	487.2	50.4	468.3	53.02	454.65	55.65	443.1	58.8	52500
55000	622.6	42.90	569.8	46.2	534.6	49.50	510.4	52.8	490.6	55.55	476.30	58.30	464.2	61.6	55000
57500	650.9	44.85	595.7	48.3	558.9	51.75	533.6	55.2	512.9	58.08	497.95	60.95	485.3	64.4	57500
60000	679.2	46.80	621.6	50.4	583.2	54.00	556.8	57.6	535.2	60.60	519.60	63.60	506.4	67.2	60000
62500	707.5	48.75	647.5	52.5	607.5	56.25	580.0	60.0	557.5	63.12	541.25	66.25	527.5	70.0	62500

Diving Pumps by Compressed Air. —(Continued.)

Table:— giving the volume of free air, at pressures of 20 to 50 pounds, required to pump any given quantity of water to any height, with the corresponding horse-power required by the air-cylinder to do the work.

Compiled by William Cox.

h×G	P = 20 lbs.		P = 25 lbs		P = 30 lbs		P = 35 lbs.		P = 40 lbs.		P = 45 lbs.		P = 50 lbs.		h×G
	V	H-P	V	H-P	V	H-P	V	H-P	V	H-P	V	H-P	V	H-P	
65000	735.8	50.70	673.4	54.6	631.8	58.50	603.2	62.4	579.8	65.65	562.9	68.90	548.6	72.8	65000
67500	764.1	52.65	699.3	56.7	656.1	60.75	626.4	64.8	602.1	68.18	584.5	71.55	569.7	75.6	67500
70000	792.4	54.60	725.2	58.8	680.4	63.00	649.6	67.2	624.4	70.70	606.2	74.20	590.8	78.4	70000
72500	820.7	56.55	751.1	60.9	704.7	65.25	672.8	69.6	646.7	73.22	627.8	76.85	611.9	81.2	72500
75000	849.0	58.50	777.0	63.0	729.0	67.50	696.0	72.0	669.0	75.75	649.5	79.50	633.0	84.0	75000
77500	877.3	60.45	802.9	65.1	753.3	69.75	719.2	74.4	691.3	78.28	671.1	82.15	654.1	86.8	77500
80000	905.6	62.40	828.8	67.2	777.6	72.00	742.4	76.8	713.6	80.80	692.8	84.80	675.2	89.6	80000
82500	933.9	64.35	854.7	69.3	801.9	74.25	765.6	79.2	735.9	83.32	714.4	87.45	696.3	92.4	82500
85000	962.2	66.30	880.6	71.4	826.2	76.50	788.8	81.6	758.2	85.85	736.1	90.10	717.4	95.2	85000
87500	990.5	68.25	906.5	73.5	850.5	78.75	812.0	84.0	780.5	88.38	757.7	92.75	738.5	98.0	87500
90000	1018.8	70.20	932.4	75.6	874.8	81.00	835.2	86.4	802.8	90.90	779.4	95.40	759.6	100.8	90000
92500	1047.1	72.15	958.3	77.7	899.1	83.25	858.4	88.8	825.1	93.42	801.0	98.05	780.7	103.6	92500
95000	1075.4	74.10	984.2	79.8	923.4	85.50	881.6	91.2	847.4	95.95	822.7	100.70	801.8	106.4	95000
97500	1103.7	76.05	1010.1	81.9	947.7	87.75	904.8	93.6	869.7	98.48	844.3	103.35	822.9	109.2	97500
100000	1132.0	78.00	1036.0	84.0	972.0	90.00	928.0	96.0	892.0	101.0	866.0	106.00	844.0	112.0	100000
125000	1415	97.5	1295.0	105.0	1215	112.5	1160.0	120.0	1115	126.2	1082.5	132.5	1055	140.0	125000
150000	1698	117.0	1554	126.0	1458	135.0	1392	144.0	1338	151.5	1299.0	159.0	1266	168.0	150000
175000	1981	136.5	1813	147.0	1701	157.5	1624	168.0	1561	176.8	1515.5	185.5	1477	196.0	175000
200000	2264	156.0	2072	168.0	1944	180.0	1856	192.0	1784	202.0	1732.0	212.0	1688	224.0	200000

Directions.— Multiply the gallons of water to be raised per minute by the height in feet to which the water is to be raised. Opposite this product in the first and last columns, headed h × G, find under the different pressures the cubic feet of free air per minute and the horse-power required. Intermediate values of h × G give directly proportionate results for the various pressures at the head of the different columns.

Note:— h = height in feet to which the water is to be raised. G = gallons of water to be pumped per minute. V = cubic feet free air required per minute. H-P = horse-power

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NORWICH SEWERAGE WORKS.

Owing to its configuration and geological conditions it has been a matter of some difficulty to provide Norwich with an efficient system of sewerage, and some of the most eminent engineers of our time have been consulted and engaged in trying to drain the city effectually. Up to the year 1865 the city was drained by over 300 different sewers, all of which delivered their contents into the river Wensum, with the result that it was polluted to an alarming extent. At this period the late Sir Joseph Bazalgette was called in to prepare a scheme for the drainage of the city. He proposed a deep main sewer on the southern side of the river, into which all the tributary sewers from both sides of the river were to discharge by gravitation to the outlet at Trowse, where the main pumping engines, which were to be capable of lifting 2½ million gallons of sewage per day to the sewage farm at Wittingham, were to be erected. These works were carried out in 1871.

The difficulties in constructing the main deep outfall sewer were, however, very great, and when completed it was found to be so leaky that the quantity of water pumped at the Trowse pumping station was 5,000,000 gallons per day, or just twice the ultimate quantity provided for by Sir Joseph Bazalgette. The cost of pumping thus became very heavy, the coal consumption being about eight tons per day.

All the attempts made to render the leaky sewer water-tight by lining it with cast iron tubing, &c., proved futile, and in 1887 the Corporation, on the advice of Mr. P. P. Marshall, the then city engineer, decided on:—(1) The construction of a new main outfall sewer at a higher level than the old one, and the abandonment of the old one. (2) The adoption of the Shone system for raising

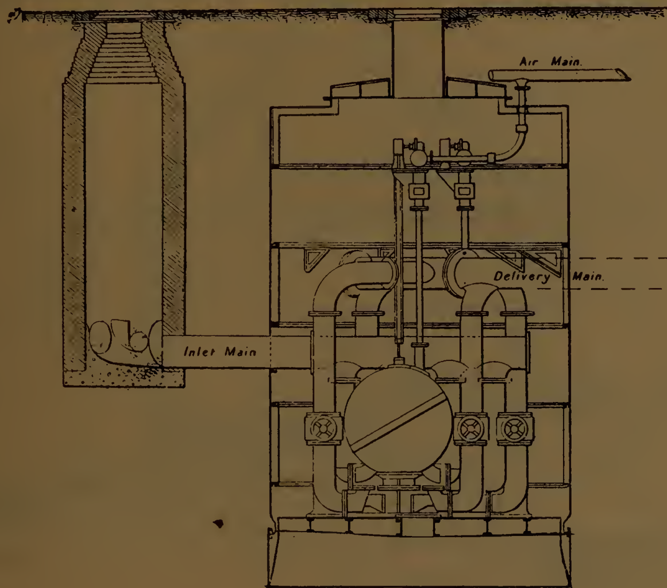

FIG. 260.

the sewage of the low-level districts into the new main outfall sewer. (3) The re-drainage of the whole of the city on the separate system. The air required for working the ejectors is compressed by means of the water power which is available in the river Wensum at the New Mills, where formerly two under-shot water wheels were worked, but which only gave about five horse power each The water-power now works two Victor turbines, which give 40 to 50 brake horse-power each, one of which is sufficient to compress all the air for operating the various ejectors required to drain the low-lying parts of the city. The New Mills belong to the town, and as flour mills they were let to tenants for a mere nominal rent. By thus utilizing the Wensum river water, the working cost of the motive power for raising the sewage from the low-lying area becomes practically inappreciable. The ejectors at all the stations are in duplicate, and are placed in chambers of cast iron tubing, sunk below the level of the street surfaces. These chambers or stations were sunk in the same manner as cast iron cylinders used for bridge foundations are sunk. The bottom parts of the castings are provided with a strong cutting edge, to facilitate the work of sinking them. The soil was excavated from the inside of the pits sunk to contain them, and wherever necessary it was removed under air pressure, the entrance tube to the chamber being provided with an air lock. Heavy pumping, which might have proved destructive to adjoining properties, was thus avoided, and no difficulty was found in sinking the chambers in the water-logged subsoil to their proper depth.

The ejector stations Nos. 2, 3 and 3A discharge into one of the inverted syphons which starts in Duke of York street, just above Bishop's Bridge, goes

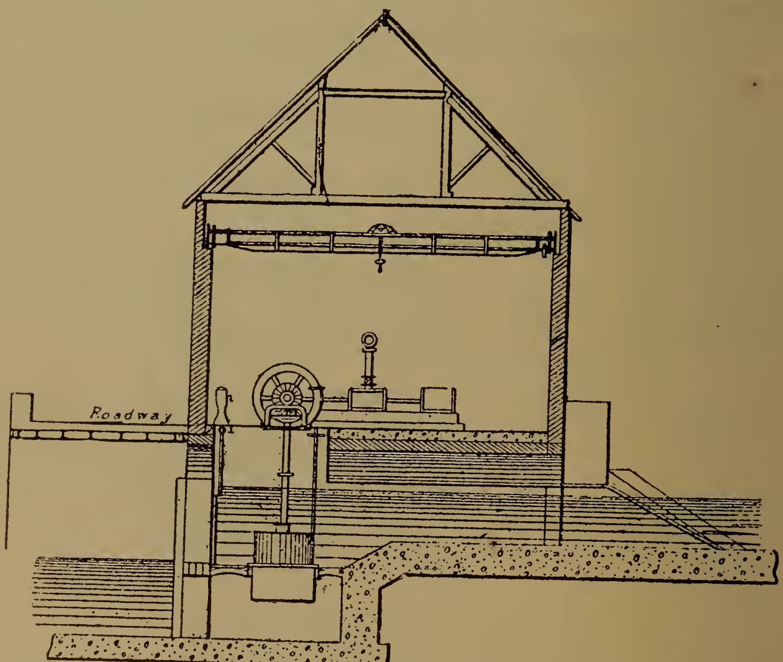

FIG. 261.

along Riverside avenue, under Foundry Bridge, along Prince of Wales street, Rosslane and Mountergate street, and finally debouches into the main outfall sewer in King street. All the sewage from the Thorpe district is discharged into this syphon through the sewers in Bishop's road, Gas Hill, Rosary road and Thorpe road. These four roads rise steeply from Duke of York street and Riverside avenue, and four cast iron branches from the syphon pipes are carried up the roads to a manhole situated above the hydraulic gradient of the syphon pipe. The population of the gravitation area discharging into this syphon is 4780, and of the ejector area 5735 inhabitants. Ejector station No. 4 discharges into a second syphon, which conveys the sewage from the northern part of the city, viz., the

Noncehold and Catton Wards, through three branches from St. Augustine street, Magdalen street and Bull Close street, meeting at Stump Cross in a 21-in. pipe, which is increased to 24-in. at the ejector station. This syphon pipe is flushed at frequent intervals from a flush tank of 3000 gallons capacity in Magdalen street, which receives the sewage from part of the Catton Ward, and discharges it through one of Shone and Ault's full-bore flushing syphons every time the tank is full, thus sending a powerful current through the syphon pipe day and night.

The population of the gravitation area draining to this syphon pipe is 25,180; that of the ejector district 12,026 inhabitants. The syphon pipe passes from Magdalen street, through Fye Bridge street, under the Fye Bridge, along

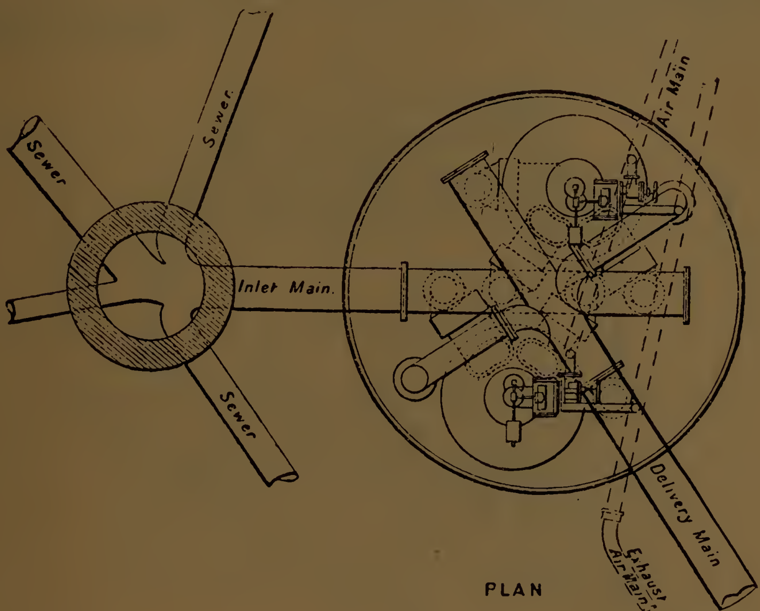

FIG. 262.

Wensum street and Tombland to the main outfall sewer in Prince's street. Ejector station No. 5 discharges direct into the outfall sewer in Benedict street, through an 18-in. main passing along Lower Westwick street and St. Margaret street. The total population of the area drained by the ejectors is thus 39,911 inhabitants, and an additional area with a population of 29,960 inhabitants is drained through the inverted syphon pipes. The whole of the sewage goes, as already stated, through the new outfall sewer to the Trowse pumping station, where it is lifted to the sewage farm by means of large beam pumping engines.

To ascertain the available water power at the New Mills, the water in the river Wensum was measured on May 9th, 1893, after a long period of dry weather. The mean sectional area of the river just above the Mills was found to be 0·80 per cent. of this, and the velocity 0·05256 ft. per second. The quantity of water per minute was therefore 57,700 gallons. The fall at the Mills is 6 ft. 6 in., and the total power of the water is therefore 113·6 horse power. The old wheels barely gave out 10 per cent. of this power, and the engineers therefore proposed to have them removed, and to put down a pair of 48-in. Victor turbines. These turbines have been used extensively in the United States and Canada, and they have recently been used for a large electric installation at Worcester, where they have given excellent results.

The Victor turbine is very simple in construction, strong and easily regulated. It gives nearly as high an efficiency with a greatly reduced gate opening as when working full power, and all the various parts are made to standard gauges, so as to be interchangeable and easily replaced.

Each turbine drives a set of horizontal air-compressing engines, each set having two air cylinders 15-in. diameter, 18-in. stroke, and able to compress 650

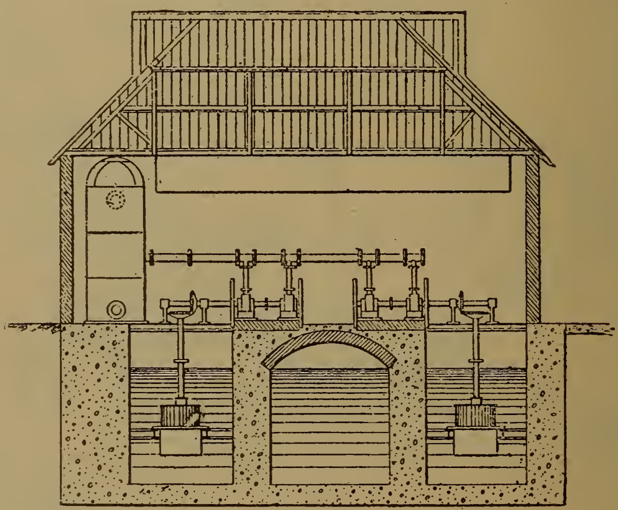

FIG. 263.

cubic feet of free air per minute to a pressure of 18 lb. per square inch, when the turbine is using 30,000 gallons of water per minute.

During heavy floods in the river, the total water below the mill rises to the level of the ordinary head water above, and then all the sluices must be opened to avoid the flooding of the upper parts of the town and the western suburbs. On such occasions there is no available water head for working the turbines. Provision has therefore been made for driving the air compressors by steam by attaching compound steam cylinders to the tail rods of the air-compressing cylinders. The steam cylinders are 9½ in. and 14½ in. diameter, and arranged in such a manner that they can be readily connected up when a flood occurs. Steam is supplied to work the compressors from a Babcock and Wilcox boiler, heated with town refuse burnt in two furnaces constructed by the Horsfall Refuse Furnace Syndicate. These works adjoin the air-compressing station, and form part of the New Mills property. Before the Victor turbine was substituted for the old water wheel, nine sluices were provided, the largest being 6 ft. by 4 ft. 6 in. deep, with a combined area of 182.5 square feet. They were, however, very difficult to open, and when heavy floods occurred some of the smaller openings became choked by *debris*. Sir John Hawkshaw recommended, in 1879, that they should be enlarged, and in the new works connected with the Victor turbines care was taken to provide large sluices of modern design. The waste water sluice is of the well-known Stoney type, 14 ft. 3 in. wide, 8 ft. deep, and in addition to this two sluices have been provided behind each of the turbines, 12 ft. 6 in.

FIG. 264.

wide by 5 ft. high, giving a total sluice area of 239 square feet, without reckoning the port area of the turbines themselves.

As the new buildings fronting the direction of the flow of the river are narrower in their width than the old buildings, there remains ample room for further extension of the sluices hereafter, if those now provided should prove to be inadequate during periods of heavy floods.

The compressed air is conveyed from the compressors in the air-compressing station to Lower Westwick street through a 9-in. cast iron socket pipe, and from that point the air pipes are gradually reduced in size to correspond to the volumes of air to be conveyed by them to the various ejector stations.

Two air receivers, 7 ft. diameter, 20 ft. high, are provided in the engine-house, and all the compressed air passes through these, being thereby cooled and dried before it enters the air mains. It is estimated that the cost of the whole scheme will be £164,000, and the works are being carried out by Mr. A. E. Collins, the city engineer, Messrs. Shone and Ault, of Westminster, being the consulting engineers for the Shone ejectors and machinery in connection therewith. The contractors for the Shone ejectors, air-compressing machinery and turbines, air and sealed sewage mains, were Messrs. Hughes and Lancaster, of Westminster and Ruabon. Contracts for the sewers in the various districts have been placed with Messrs. Monk and Newell, of Liverpool, and Messrs. B. Cooke & Co., of London.

TABLE 66.

Tabular Statement Showing Detailed Particulars Relating to Ejector Stations, Norwich Sewerage.

Ejector Station.	No. 2. Foundry Bridge.	No. 3. Bishops Bridge.	No. 3a. Barrack Street	No. 4. Fye Bridge.	No. Westwick Street, near New Mills.	No. 7. Carrow Bridge, Colemans' Works.	Total.
a. Population of district, present	2910	1425	1400	12,026	18,150	4000	39,911
b. Population of district, future	4110	2165	2160	12,026	23,550	8000	52,011
c. Number and size of ejectors	Two of 250 gals.	Two of 150 gals.	Two of 150 gals.	Two of 500 gals.	Two of 1000 gals.	Two of 300 gals.	—
d. Quantity of sewage discharged per minute, present	196 gals.	89 gals.	88 gals.	780 gals.	1184 gals.	250 gals.	2587 gals.
e. Quantity of sewage discharged per minute, future	271 gals.	136 gals.	135 gals.	780 gals.	1521 gals.	500 gals.	3243 gals.
f. Ground level at ejector stations	9·00	10·19	9·00	10·00	12·40	14·7	—
g. Invert of lowest sewer at station manhole	—5·50	—2·60	—4·00	—4·25	—4·86	—12·16	—
h. Delivery levels of sewage mains (centre of pipe)	+5·75	+5·75	+5·75	+8·00	+10·92	0·91	—
i. Total dead lift	15·77	11·27	12·67	18·00	21·53	18·26	—
k Total pipe friction in feet	2·91	11·26	17·54	1·38	1·97	0·93	—
l. Total dynamic head	18 68	22·53	30·19	19·38	23·50	19·19	—
m. Air pressure required	9·00	10·00	14·00	9·00	11·00	9·00	—

The particulars of the various ejector stations, with the population of the ejector districts, are shown in the table above.

Our illustrations, taken with the preceding article, are self-explanatory.—*The Engineer.*

PNEUMATIC CESSPOOL EXCAVATOR.

A pneumatic apparatus for emptying cesspools has been invented by English manufacturers and is now in use at Pokesdown, England. It consists of a tank for sewage and a dome and connecting pipe for producing a vacuum in the tank. The tank is mounted upon an ordinary four-wheel truck and can be drawn by a horse. A smaller portable truck supports a vacuum pump. Two men can work it and produce enough power to create a vacuum in the tank. The pump is connected to the dome by means of flexible pipe, and the gases arising by the exhaust of the air are forced to an upright boiler shaped stove and burned. The vacuum, of course, causes the material to rise from the cesspool and the tank is filled and carried away. None of the material is brought to view or comes in contact with any of the machinery.

HANDLING WATER BALLAST IN SHIPS BY COMPRESSED AIR.

Among the recently discovered uses for compressed air is that of handling the water ballast of ships. As is well known, modern vessels are provided with an inner water tight floor or bottom, usually placed four or five feet above the keel, forming with the shell a double bottom which strengthens the vessel, and makes it safer against leaks.

The space between the bottoms is divided into a number of compartments, into which water is flowed for use as ballast.

In order to trim ship it is necessary to vary the amount of water ballast or to shift it from one compartment to another. This has hitherto been done by means

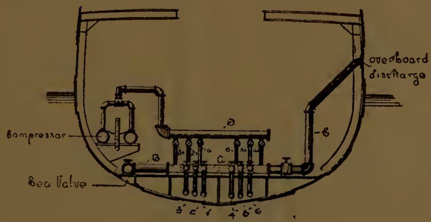

FIG. 265.

of ponderous ballast pumps attached to a reservoir or "header" and connected by pipes with the various tanks.

In Figs. 265, 266 and 267 we illustrate a system of ballast handling that dispenses with the pumps and controls the ballast entirely by compressed air. This system is the pioneer of its kind, and is described in a patent issued Nov. 20, 1900,

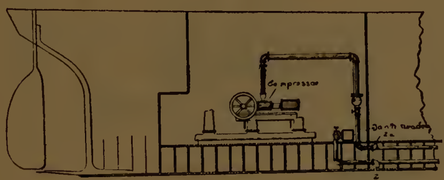

FIG. 266.

to George B. Wilcox, of Bay City, Mich. The system consists in omitting the ordinary ballast pump by which the water ballast is usually controlled, and using an air compressor to force air into the tank to be emptied, thus displacing the water, which flows out into the water header and thence either into another tank or overboard, as desired.

A compressed air reservoir or header similar to the water ballast header is provided, and each tank is connected to the air header by means of an air pipe. Suitable valves permit the discharge of air into the tanks in any desired combination. Owing to the high velocity of the air a large volume of water can be displaced by means of a small air pipe.

The advantages of this system are that the water ballast can be shifted at will from one tank to another without pumping any water overboard and without taking in harbor water. The location of the air compressor is not confined to the line of the discharge pipe as ballast pumps must be. With this system the ballast water does not pass through pump valves, but has a free flow and the frictional

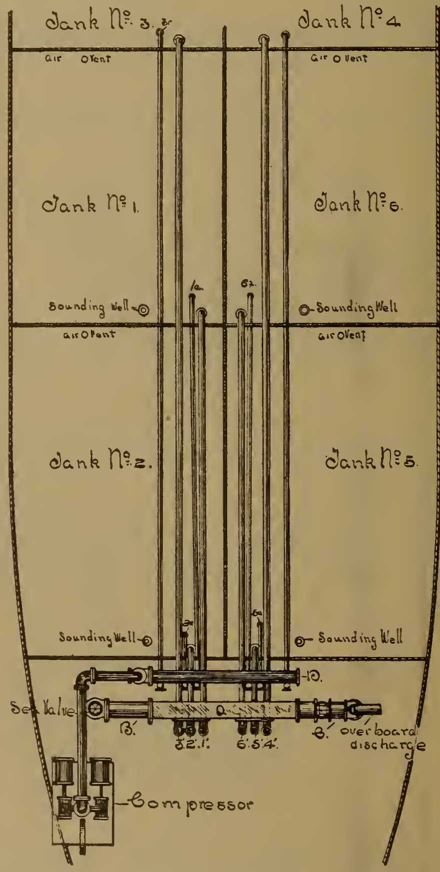

FIG. 267.

resistance of valves and the danger of blocking them by refuse is eliminated. An air compressor is very much lighter for a given capacity than the ordinary ballast pump, and will work with about ten times the economy of the ballast pump, besides being available for operating deck hoists, capstans, ash hoists, repair tools, etc., when it is not being used for handling the water ballast. This system is the subject of the first patent ever granted for a pneumatic ballast handling system, and will doubtless soon come into general use.

PUMPS VS. COMPRESSORS FOR SHOP USE.

We had thought that everybody was convinced of the fact that air for shop use cannot be economically compressed in air-brake pumps, but if the May meeting of the Central Railroad Club is correctly reported in the Buffalo papers (and these reports are usually official), a committee submitted a report on air-brake testing plants in which they advocated the use of pumps instead of compressors, on the score of economy, and in the discussion that followed, Mr. Higgins, of the Lehigh Valley, and Mr. McKenzie, of the Nickel Plate, were the only dissenting parties.

Unfortunately for the committee, if their opinions are correctly quoted, it can easily be proven that it is economy to replace even a single pump with a compressor, and, in testing plants adjacent to shops where air can be used for other purposes also, thus requiring the capacity of several pumps, their use instead of compressors is extremely wasteful.

Comparisons between the large steam-air compressors and pumps have been made in the past, but we are not aware that any attempt has been made to show the relative economy of pumps and small steam or belt compressors. For that reason it may be well to inquire into the matter. Two years ago the writer made some tests of 8-inch brake pumps in which it was found that for every pound of steam passing through the pumps there was on the average about 2.25 cubic feet of free air compressed to 70 pounds pressure. For every 1,000 cubic feet of air compressed there is therefore required 445 pounds of water, and if the evaporation of the boiler supplying the steam is taken at 8, the coal required is 55.6 pounds. The capacity of one 8-inch pump with 80 pounds of steam is about 1,000 cubic feet per hour, and if we assumed that the pump ran the equivalent of 10 hours per day for 300 days in a year, the annual coal consumption is $55.6 \times 10 \times 300$, or 83 tons. As it is seldom that a single pump is of sufficient capacity for a yard or shop, and as even the smallest belt compressors are usually of the capacity of two such pumps, we will first make a comparison on the basis of 2,000 cubic feet of free air compressed per hour, requiring two pumps consuming 166 tons of coal per year. It might here be remarked that as the speed of pumps vary considerably with slight differences of pressure, it may reasonably be urged that one pump might be made to do this work if higher steam pressure were used; but if this is done the coal consumption is not altered materially, nearly the same amount of steam passing through one pump instead of two.

In considering compressors of small capacity, those driven by belts must not be overlooked. We find by investigation that in this type about 2.8 horse power is required at the belt for each 1,000 cubic feet of air compressed per hour. If the shop engine consumes 3½ pounds of coal per horse power per hour and the loss in transmission by shafting, belts, etc., is 40 per cent., the coal per horse power at the compressor becomes $3.5 \div .6 = 5.8$ pounds, and for compressing 2,000 cubic feet of air it is $2.8 \times 2 \times 5.8 = 32.4$ pounds. For a year of the same number of hours as before, the consumption is $32.4 \times 10 \times 300 = 48\frac{1}{2}$ tons.

In a steam compressor the horse power per 1,000 cubic feet of air compressed, including the internal friction of the engine, we will take as 3.2, though it will vary somewhat with the construction of the compressor. In one having only 2,000 cubic feet capacity per hour, a horse power cannot be expected on less than 4½ pounds of coal with the evaporation we have assumed, and it might easily be more. Taking it at that figure, the annual consumption would be $3.2 \times 2 \times 4.5 \times 10 \times 300 = 43$ tons.

Now a belt compressor of 2,000 cubic feet capacity per hour and provided with an automatic regulator or governor, can be bought for from $200 to $250, and a steam compressor of that capacity will cost in the neighborhood of $350. Two brake pumps, even if they are not new, will represent an investment of from $100 to $200, according to their age. The comparison between the two types of compressors and the pumps might be summarized in tabular form thus:

TABLE 67.

	Value of investment.	Coal consumed in tons, per annum.	Cost of fuel, per annum, at $1 per ton.	Saving per annum.	Saving capitalized at 6 per cent.
Two second-hand pumps	$100	166 tons	$166 50	....	....
One belt compressor	225	48½ "	48 50	$117	$1,958
One steam compressor	350	43 "	43 00	123	2,050

From the columns showing the annual saving and the same capitalized at 6 per cent., it will be seen that if the air-brake pumps were to be had for nothing it would still pay to buy the compressors if they cost less than $2,000. Perhaps a more striking way to view it is that if a road were offered two pumps and a bonus of $1,500 with them, their use to be confined to pumping air for shop use, it would be wise to refuse the offer and to purchase a compressor at market prices. If only one pump were needed it would still pay to buy a compressor of the size mentioned above, and the saving per year in fuel would still be more than $50.

We think the above figures are fair and not in the least exaggerated. If anyone is disposed to quibble over some of the items, let him consider what the comparison would become according to his own figures if coal were at the same time taken at, say, $2.00 per ton, a price which many pay for it.

The figures seem to prove conclusively that though the air-brake pump is admirably adapted for the service which it was designed and is almost beyond criticism when on an engine, it is in the wrong place when compressing air for shop uses. If managers, purchasing agents and others who wield the blue pencils that occasionally disfigure requisitions, could be made to realize these facts, there would be more compressors purchased, for many officials in the mechanical departments who know the wastefulness of pumps cannot induce their managements to purchase compressors.

Before closing, we might make a brief comparison between a compressor, with a capacity of about 18,000 cubic feet of free air per hour (a favorite size with some roads), and pumps of the same capacity. On the same basis as the previous comparisons, but assuming that the compressor can furnish a horse power on four pounds of coal, the annual fuel bill for the compressor would be $346, and of the pumps $1,500. This is not an ideal case, for we know of one company that had ten air pumps in its shops and now has in their place one large duplex compressor. The latter almost pays for itself in one year, with coal at only $1 per ton.—*American Engineer.*

COMPRESSED AIR IN THE FOUNDRY.

PAPER READ AT THE FOUNDRYMEN'S CONVENTION, HELD IN PHILADELPHIA, MAY 12, 1896, BY CURTIS W. SHIELDS.

Compressed air has long been known as an ideal medium for power transmission, but its introduction into the arts has been slow, because of the general lack of knowledge of the subject, due in a measure to the limited experience had with it.

It has been looked upon as being an expensive power at best—too much of a mystery and something to be avoided rather than encountered and mastered.

In many cases cheap and badly designed air compressors are put in use, and where such machines have been designed to occupy a small space or to be

FIG. 268.

light in weight, compressed air is sure to cost a great deal to produce, and this has stood in the way of the general introduction of compressed air more than anything else.

Only recently inventive genius has been turned toward the development of labor-saving machines which would use compressed air as a motive power.

Since compressed air is now produced economically, owing to the many recent improvements made in the design and construction of compressing machinery, the up-to-date plant without its air compressor in the power house is the exception. Devices for using air are being placed upon the market in rapid succession, and its field of usefulness has broadened until now it is practically indispensable in a great many operations, and its economic value is recognized.

Under the ordinary conditions existing in foundries a belt-driven compressor is usually more favorably considered than one driven by steam.

The ordinary shop engine of a good type gives better results for the amount of steam used than if the steam was used to drive a small compressor direct.

A belt compressor fitted with a proper regulator absorbs only enough power to meet the demands of the work performed, and being run in connection with other machinery, its effect on the coal consumption is not noticeable.

However, in many cases a steam-driven compressor is preferable, because a high class steam-actuated compressor uses steam almost if not quite as economically as a shop engine, and whatever loss there may be is more than made up for by the advantages of a steam-driven compressor. With them all shafting and belting are avoided, and the machine can be located in the engine room, where it can be under the care of the engineer. If installed in the foundry the dust and sand have a very appreciable effect upon the bearings and moving parts, and no matter how carefully housed, your compressor cannot be as well taken care of as though it were in the engine room. Frequently, when a foundry has no steam power, the compressor can be located in a neighbor's engine room, and

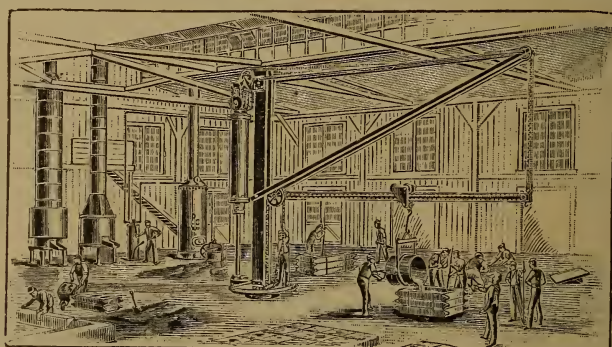

FIG. 269.

power rented to operate it, as the air pipe can be run any desired distance quite readily and at small expense.

Transmission of power by compressed air has the advantages of certainty and regularity in action; simplicity in machinery, freedom from the possibility of fatal accidents, and the assistance given to ventilation and in cooling the shop —these last being considerations of much importance in many cases. Works employing this method do not require the supervision of a specially qualified expert, and the chances of interruption by accident through negligence are certainly less than in any other form of power transmission.

When we come to the question of laying out the piping for a foundry, it is well to keep this simple rule in mind. The head necessary to drive the air through the pipe is as the square of the velocity, and to obtain the best results the flow of air through the pipe should not exceed 20 ft. per second. If this is borne in mind, air can be conveyed almost any distance with little or no loss.

The receiver should be placed in any convenient place, and should be of not less capacity than the rating of the compressor in cubic ft. of free air per minute.

It is preferable to have the inlet pipe from the compressor enter the receiver near the top and the outlet near the bottom, and at right angles to the inlet. A drain cock at the lowest point should be provided, and a pressure gauge safety valve on the top is a great convenience.

Too frequently no attention is given to leaks in the air pipes, as the air is not visible and causes no discomfort in its escape. Leaks, however small, should receive prompt attention if anything like economical results are desired.

Leaks in air pipes are fortunately easy to find, because of the hissing noise caused by the escaping air. This point is an important one in comparing pneumatic with electric transmission of power.

Leaks in electric wires are hard to discover, and are usually found after some damage has been done. The current may be led away through the crossing of other wires, moisture, or frame of building if of iron, and occasions an unseen, though none the less undesirable, loss.

A little thought and attention given to the elimination of turns and angles in the pipe mains will amply repay for the trouble. It is a great economy to lead the air mains centrally and then run smaller connections to points adjacent and convenient to place air is to be used.

If this is done, short lengths of hose pipe can be attached wherever most convenient for connection to hoists, sand-sifter, or other apparatus, or the air can be used for the same purposes that the bellows and brush are employed.

The application of the air hoist to cranes may be made in an almost endless variety of ways to meet the requirements of foundries. The most common types are simple cylinder hoists either vertical or horizontal, or in combination with a low pressure hydraulic system. In many instances direct acting hoists may be readily applied to hand-power cranes already in use, without in the least interfering with the gearing, and at a very small expense.

In an air-hoist the power and load are brought together in the most simple manner. A boy, with this aid, can lift a given load a dozen times while a gang of several men are operating a chain block or windlass. There is no noise, no jar, and the load is always balanced. In foundries where an overhead traveler cannot be installed, air hoists suspended from trolleys running on an overhead track answer very satisfactorily; and if hose couplings similar to those used in connection with the ordinary air brake are provided, by simply detaching the hose connection after load is raised, the hoist may be run on the overhead track to any desired part of the establishment.

This is especially valuable in conveying flasks outside of foundry to storage sheds, patterns to pattern shop, or finished castings to machine shop.

Nearly every foundryman is conversant with the value of air-hoists in the foundry for lifting flasks and copes, drawing patterns and conveying cores to ovens.

Few of us realize how cheap an air-hoist is to operate, apart from its convenience and speed in handling loads. It has been estimated by Mr. Frank Richards that at 100 lbs. gauge pressure compressed air costs 5 cents per 1,000 cubic ft. of free air.

In a very interesting article recently published, this gentleman figures the cost of operating a hoist as follows: "Suppose we have a hoisting cylinder 6 inches in diameter, with a piston rod or hoisting rod 1 inch in diameter and capable of lifting 4 feet or more. Then, using air in the cylinder at an effective pressure of 90 lbs., the lift of the hoist will be $(6^2-1^2) \times .7854 \times 90 = 2475$ lbs.

"If this weight is lifted, say 4 feet, the volume of air used will be: $(6^2-1^2) \times .7854 \times 4 \div 144 = .7636$ cubic ft. To this we add 30 per cent. to cover all possible contingencies: $.7636 \times .229 = .9926$, and we will call this 1 cubic ft. The one loss that seems to be inevitable, and which is included in our 30 per cent. allowance, is in taking up the slack of the hoisting chain, or other means of attaching to the load, before the hoisting actually commences, so that a certain portion of the cylinder must be filled with the compressed air, besides the actual 4 feet of travel for the lift. As the air in the cylinder is up to a pressure of 90 lbs. or 7 atmospheres, the volume of free air used will be seven cubic ft., and the cost of this will therefore be 7/1000, or $.007 \times .05 = \$0.00035$, and this is all we have to pay for lifting more than a ton a height of 4 ft. A hundred of such hoists will be made, of course, for $0.035, or 3½ cents. The accompanying table, which might be greatly extended and still not cover all the actual conditions of service, will be found of interest especially in the idea that it conveys of the cost of air hoisting. It is probable that many persons will be surprised at the low figures."

In connection with the low cost of air, it is to be remembered that the hoists are also simple and cheap.

TABLE 68.—AIR HOIST TABLE.

A Table of the lifting capacities of direct acting air hoists, with volume of free air per lift, and cost of air per single lift and per 100 lifts, with a maximum lift of 4 feet, and a minimum pressure of 90 lbs. air furnished at 5 cents per 1,000 cubic feet of free air.

Diameter of Cylinder.	Effective Area of Piston.	Maximum W'ght Lifted.	Cub. Ft. Free Air for 4 Ft. of Lift.	Cost of Air per Lift.	Cost of Air per 100 Lifts.
2	3.05	274	74	$0.000037	$0.0037
3	6.87	618	1.67	.000084	.0084
4	12.22	1099	2.97	.000149	.0149
5	19.09	1718	4.64	.000232	.0232
6	27.49	2474	6.68	.000334	.0334
7	37.42	3367	9.09	.000455	.0455
8	48.87	4398	11.88	.000594	.0594
9	61.85	5566	15.03	.000752	.0752
10	76.36	6872	18.56	.000928	.0928
11	92.39	8315	22.46	.001123	.1123
12	109.96	9896	26.73	.001337	.1337

FRANK RICHARDS.

Air used in combination with a low pressure hydraulic system gives the best results for heavy loads. By interposing the water between the elastic medium air and the load, we eliminate that element of danger which otherwise would be present in handling vessels of molten metal, as in foundry practice, and also obtain a sort of elastic positiveness which is so essential and desirable. In the actual work of molding, as in lifting copes and molds, drawing patterns and moving cores, the men are enabled to do about 50 per cent. more work and do it easier and better, when equipped with a hydro-pneumatic hoist. Included in this percentage is the saving in repairs and the danger of losing castings. These hoists more nearly approach the old-fashioned hemp rope cranes in their elasticity, as the compressed air behind the water seems to impart this peculiar quality. All danger of the liquid freezing is overcome by using a non-congealing compound or a little glycerine, wood alcohol or chloride of magnesium added to the water.

In addition to operating movable hoists, air has proven its value for conveying pig iron to the top of the cupola, and for breaking up scrap by lifting a heavy weight which is dropped some 15 or 18 ft. This pig-breaker broke three

FIG. 270.

half pigs into three pieces each in one minute, and can easily break twenty tons of pig while a man is breaking up one ton by the old sledge method. A portable pneumatic drilling machine for boring holes to weaken stiff castings is used to advantage in connection with this breaker.

The product of a molding machine can be greatly increased if the handling of the sand in shovels is done away with. This is accomplished by an air jet which at 60 lbs. pressure will lift 100 lbs. of sand per minute 20 ft. high. A quarter-inch nozzle will use 90 cubic ft. of free air per minute doing this duty. By elevating the sand to a bin overhead and then conveying it in a chute or pipe directly over the molding machine, much time and labor can be saved.

A simple slide in the pipe forms a ready means of regulating the amount of sand served to the machine for each mold.

In a foundry where the air pipes have been led as previously indicated, and hose connections located at convenient points, the portable pneumatic sand-sifter is indispensable. In this machine a small amount of air operates a rotary motor which drives gearing connected to the sieve. Air admitted through an 1/8 inch opening at a pressure of 70 lbs., developes sufficient power to do the heaviest work.

Recent observation of a molding machine in operation at the foundry of the Ingersoll-Sergeant Drill Company of Easton, Pa., gave the following figures:

On rock drill cylinders, three helpers operating a duplex machine can turn out 22 per day. It formerly took four molders to make this output.

In other words, to do the work by hand now being turned out with the aid of the molding machine operated by compressed air, would cost 100 per cent. more than is being paid now.

On rock drill steam chests, same machine, operated by two helpers, produces 66 molds per day. Formerly it required three molders to equal this number.

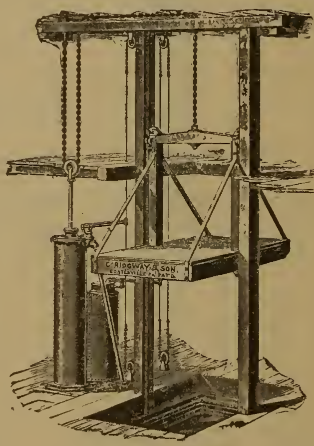

FIG. 271.

In this case it would cost 125 per cent. more to turn out the same product by old method.

The economy of the sand blast for cleaning castings was quite as marked as that of the molding machine. On a flask 30″ x 14″ x 5″, made without using any facing, no difficulty was experienced in cleaning 6 sq. ft. of surface per minute. A box bed plate, weighing 1,700 lbs., was cleaned in one hour by the blast, while another bed plate made from the same pattern, took three hours to clean by hand. With the blast the casting was cleaned so that the chipper did not have to do any cleaning as he had to do when blast was not used. Neither brushes nor files will get around fins and risers as the blast does.

A very difficult casting with cores that are almost impossible to get out by hand, was cleaned in 45 minutes by the blast, as against 2 hours and 40 minutes by hand.

In this same foundry they formerly melted about 5 tons of iron per day and employed 14 molders, 8 core makers, and a cleaning and chipping gang of 7.

They have practically doubled their plant and now pour 10 to 12 tons per day and employ 27 molders, 12 core makers and a number of labor-saving devices to increase their output, but the same cleaning gang of 7 men, with the addition of a sand blast, take care of the product, and the cleaning is done in a much better manner than previously.

The sand blast not only effects a great saving in the actual cost of the castings, but a further saving through the removal of the oxide which is so destructive to tools in the machine shop.

This saving on tools is most apparent where the work is milled, as cutters can be run at an increased speed. The sand blast applied to the tumbling barrel is an improvement worthy of notice.

Aside from the economical features connected with the use of the sand blast, it cleans the castings far better than by hand, and where a casting has in-

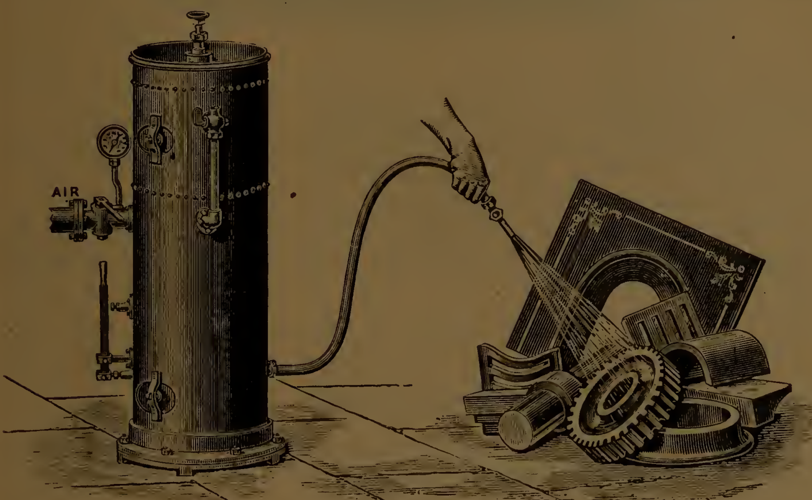

FIG. 272.

tricate steam or air passages, it is of the greatest importance to be able to thoroughly clean these inaccessible parts.

Associated with the sand blast the pneumatic chipper shows to good advantage.

These tools were formerly too delicate and complicated for foundry uses, but recent improvements have so simplified their construction that they now have only three pieces in their entire make-up, and but one of these is a moving part.

Dark foundries have found the Wells, Lucigen, or some simliar light of great use where a cheap intermittent light was needed. In these lamps compressed air forces oil through a nozzle forming a spray, which when ignited gives a flame about 5 inches in diameter and 30 inches long, and of about 1,000 candle power.

The air is used at a pressure of from 10 to 30 lbs., and one gallon of oil and 60 cubic ft. of free air per hour suffice to operate the lamp.

These hydro-carbon burners are very useful for skin-drying large molds as well as for lighting.

Breaking test bars from each cast is another use to which air has been applied.

A comparatively small air compressor of proper construction and design will furnish sufficient air for all the needs of a foundry of ordinary size.

An illustration in point is a foundry running 4 cranes of 20, 10, 8 and 1

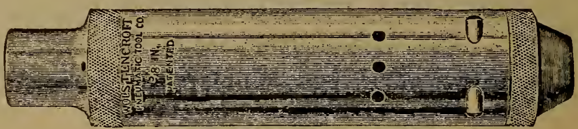

FIG. 273.—WOLSTENCROFT PNEUMATIC CHIPPER.

ton capacity respectively; a sand blast, 2 pneumatic chippers, 1 duplex molding machine and for blowing out and dusting molds in process of construction.

In addition, the machine shop uses air for testing small engines and blowing out cylinder ports and inaccessible parts after machining, to get rid of oil and chips, and for bench dusting and copying letters in the office.

Air at 60 lbs. pressure for all these uses was supplied by a 14 x 16 x 18 compressor, running at 120 revolutions per minute and furnishing about 500 cubic feet of free air per minute.

COMPRESSED AIR AND ITS ECONOMIES IN THE FOUNDRY.

Perhaps in no other operation in the foundry is air used to such good advantage as in hoists and cranes. By using direct acting hoists suspended from trolley tracks and using detachable air hose couplings, a casting or other weight can be readily conveyed to any part of the foundry, or carried outside the foundry building to the machine or pattern shop, or in fact to any point around the establishment that may be desired, thus covering a field vastly wider than is possible with a traveller alone.

The great economy of an air hoist is well illustrated in the following record of actual work performed in the foundry of Messrs. Russell & Co., of Massillon, Ohio.

In making wheels for their traction engines, a molder and helper formerly made one mold per day of a wheel 16 inches face by 66 inches diameter. During the entire operation of molding and pouring, 104 hoists and lowers were necessary. With the old crane it took these two men from five to six minutes to turn a flask when assisted by a laborer on the windlass. Now, with the air hoist, the laborer is done away with, and they turn a flask in two minutes. This saves in time alone 52 times 3½ minutes, or *three hours per day*, and the molder and helper make two 58-inch by 12-inch wheels in addition to the large wheel, which formerly constituted a day's work, in the time saved in moving by the air hoist.

In this same foundry a test of one of their jib cranes gave the following:

Area of piston, 452.39 square inches (24 inches diameter).

Height of lift, 6 feet.

Hoist, 2 feet to 1 foot of piston travel.

Weights lifted, 2,000, 4,000, and 5,000 pounds.

Main air receiver gauge, 100 feet from crane, registered 63 pounds pressure.

Gauge on hoisting cylinder, 30, 40 and 45 pounds for the respective hoists.

It was found that it took ten pounds pressure on hoisting cylinder gauge to overcome all the friction of the chains wrapping around the sheaves, as well as the packing in the stuffing box of piston rod and the frictional resistance of the piston against the cylinder walls.

Weight lifted 6 feet.	Pressure on Piston.	Deducting 4523.9 lbs. as being amount required to overcome all resistance except load, we get
2,000 lbs.	6785.85 lbs.	2261.55 lbs.
4,000 "	9047.80 "	4523.9 "
5,000 "	10178.77 "	5654.87 "

The excess of 261.55, 523.9, and 654.87 lbs. in the respective cases, is, no doubt, due to the fact that the chains are hugging the sheaves tighter under the loads than when empty; and this increased friction must be overcome at the expense of pressure. The ten pounds required to overcome the load and frictional resistance of the chain, chain block, etc., in the crane itself, is not altogether wasted, for the space in the cylinder between the piston and the head on the lifting side being once supplied with this amount, is then ready to do useful work. A 24-inch cylinder with piston moved 3 feet, would contain 28,275 cubic feet of free air if the gauge on the cylinder showed 30 pounds, or two atmospheres pressure, and ten such hoists would use 282¾ cubic feet of free air. This amount of air would not cost over one and one-half cents. With compressed air at five cents or less per 1,000 cubic feet of free air delivered at 100 pounds pressure, this is vastly cheaper than a gang of men, on a windlass, with the molders standing idle an indefinite time. The frictional loss in direct air hoists has been shown by tests made by the Whiting Foundry Equipment Co. not to exceed 15 per cent. A lot of 12 hoists taken at random showed a varying loss of from 9.2 to 23 per cent., average 12.9 per cent. loss. Another lot of ten averaged 14.65 per cent. loss.

Mr. Chas. O. Heggem, the well-known compressed air expert, uses compressed air for breaking test bars, and at the same time automatically recording the shrinkage and deflection. The pattern for the test bars is 24⅛ inches long, and in the case of a bar tested, the register showed a shrinkage of 9-64 in. to the foot; deflection, ½ in. in 24 inches; and the bar, which was 1 in. square, broke under a pressure of 1,375 pounds.

In view of the great variety of ways (more or less unsatisfactory) of testing the qualities of iron as expressed last May at the meeting of the foundrymen in Philadelphia, Pa., it would appear that the majority of foundries using air could adopt Mr. Heggem's idea with advantage.

Compressed air cranes have many advantages over those electrically driven for foundry work, as the dust and heat which materially affect the efficiency of electric motors have no appreciable effect on the air motors.

Few if any of the compressed air driven machines that have been introduced for foundry work serves a better end than the sand blast. By its aid, castings that were hitherto cleaned with the greatest difficulty can now be cleaned in a remarkably short time, and with a tithe of the exertion formerly necessary. For instance, a casting which was made with a core that was almost impossible to get out satisfactorily, and which took 45 minutes to clean by hand, was cleaned by the sand blast in 16 minutes. Six and one-half minutes of this time was occupied by chipping out a fin to allow the blast to reach the core.

The waste sand from a sand blast can be used to advantage in making cores when mixed with the core sand in proportion of about 1 to 4.

Another important use of compressed air is in connection with the molding machine.

By its use the expense of stripping plates is entirely done away with, and by using an air jet to blow sand from the pattern instead of using a bellows and brush, much time is saved. The use of air permits the molding machine to be moved to any part of the foundry, and it is decidedly cheaper to bring the molding machine to the sand pile rather than wheel the tons of sand to the machine.

A deeper draft is possible using air than can be obtained with a steam-actuated machine. In general, a molding machine operated by compressed air is portable, independent of any foundation, and can be connected to the air main by a hose and used in any part of the foundry, which is not possible when using steam. It makes molds without the use of stripping plates, in fact uses ordinary split-wood or metal patterns fastened by wood screws to the pattern plate. This is accomplished by the use of an automatic rapping attachment which frees the pattern from the sand, without any amplitude of motion in the pattern, while it is being drawn. This compressed air molding machine weighs and costs but little more than a hand machine, and has all the advantages in point of output and size of flasks of power machines. Observation of an air-actuated molding machine operated by two helpers at $1.50 per day each, showed that on certain work, containing 12 small cores per mold, they put up 50 molds per day. Formerly it took four helpers, at the same wages, to make 50 molds by hand per day, thus gaining a saving in wages of 50 per cent.

In another case, on new work, the first day two helpers at $1.50 each per day, turned out 35 molds. The best record on this work for a molder working by the piece was 7 molds per day.

The product of a molding machine can be greatly increased if the handling of the sand in shovels is done away with. This is accomplished by an air jet which at 60 lbs. pressure will lift 100 lbs. of sand per minute 20 feet high. A quarter-inch nozzle will use 90 cubic feet of free air per minute doing this duty. By elevating the sand to a bin overhead and then conveying it in a chute or pipe directly over the molding machine, much time and labor can be saved.

A simple slide in the pipe forms a ready means of regulating the amount of sand served to the machine for each mold.

After deciding to adopt compressed air as a labor-saving aid in the foundry, the most important points for consideration are the type or style of compressor to install, and its size or capacity. Only too frequently, confined space, together with a disinclination to expend more than will barely suffice for present needs, act as a handicap and incline the founder to decide upon a plant that "will do somehow," rather than one that his cold, unbiased judgment would dictate as being best suited to his needs. It is the exception to find a plant too large even for present needs, for while starting out with the best intentions to allow for a reserve, the ingenious foundrymen originate so many little labor-saving shop kinks that before long there is a demand for more air, and the engineer is told to "speed her up a few turns."

When it is decided to use air hoists, cranes, molding machines and other air-actuated machinery, it is imperative to bear in mind that if the air supply stops through breakdown or insufficient capacity, the whole foundry is practically at a standstill. If there is no air to operate the hoists, the men cannot handle their work, and great loss ensues.

It is clearly of the utmost importance that the source of air supply must be adequate to all reasonable demands and must be of such staunch and durable design and construction as will insure its ability to easily meet the increased duty when called upon to "speed up a few turns." These "few turns" usually mean about 20 per cent. increase, and it is only the very best high duty compressors that will survive such a test.

It is an open question, which must be largely decided by the individual conditions in each foundry, whether a steam driven or belt compressor is most desirable. When there is shafting already in the foundry and a good dust-tight room can be provided, it is perhaps cheaper to put in the belt driven type. The steam compressor has its advantages, however, as it can be located in the engine room under the supervision of the engineer, and the necessity for shafting and belting obviated. As the best steam-actuated compressors now use steam very nearly if not quite as economically as the majority of shop engines, low efficiency cannot be urged against their use with the same force as formerly.

The steam machine can be run at a speed to suit the requirements of the foundry by regulating the throttle. CURTIS W. SHIELDS.

A MODEL COMPRESSED AIR FOUNDRY PLANT.

The value of compressed air for operating small motors on isolated and moving apparatus, especially when power is used for perhaps a minute or so in every ten, is beginning to be appreciated in this country as it should be, and hardly a week passes that does not record some valuable addition to the list of new applications of this nature.

This progress would be much faster but for the fact that usually a change to air power involves a considerable outlay for new machinery and the discarding of the old type, which may be in good or perfect condition.

A neat avoidance of this objection is shown in Fig. 274, which illustrates a foundry crane in the works of John J. Radley & Co., structural iron manufacturers, New York City. This was originally made to be operated by hand, but to it has been attached an air motor without changing the original gearing in the least, so it may at any time be operated either by hand or air.

The motor is reversible and of the direct acting piston type. Its economy in the use of air is best illustrated by stating that the air compressor is stopped at the end of the day's work, with the air receiver (which is in this case a large boiler) fully charged, and sufficient air is thus stored to draw all their castings in the evening without running the compressor.

These progressive Founders are, we believe, the first to successfully apply this method to every-day shop practice; and the fact that they have proven this

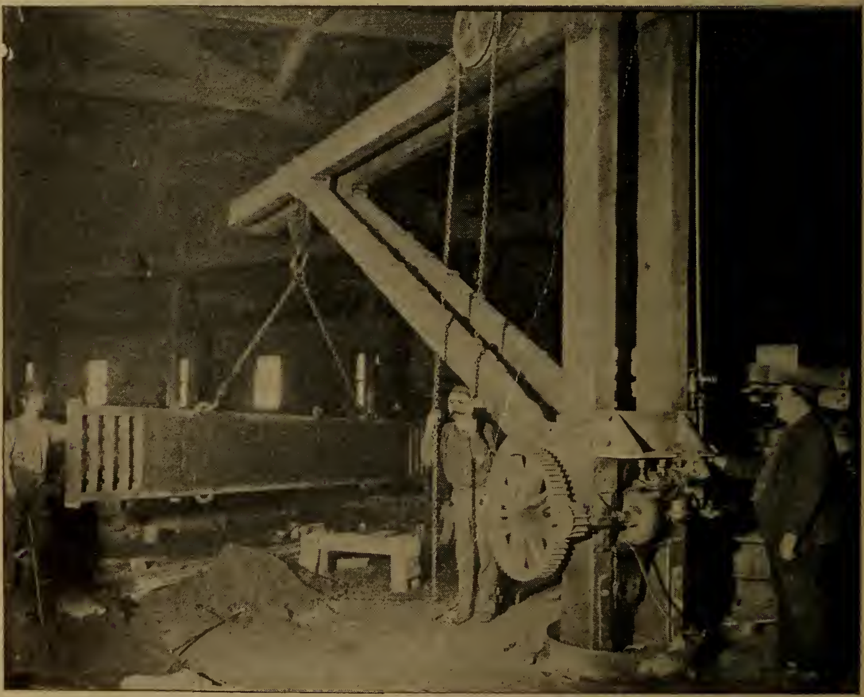

FIG. 274.—COMPRESSED AIR MOTOR ATTACHED TO FOUNDRY CRANE.

possible should effectively remove the objection that has sometimes been raised, that it is "so hard to keep air from leaking away." If they do not use any air in the evening, they find nearly the same pressure on the gauge in the morning as when the compressor was stopped, which shows that joints can be made tight and that compressed air is favorable to keeping them so.

This little motor, which weighs less than 200 pounds, easily lifts 8,000 pounds ten feet per minute, and by changes in the gearing can be made to lift almost any load. In use it is protected by a sheet-iron case to keep out dust.

These motors are used on traveling cranes for lifting the load and for moving the traveler along the track, and are well adapted to any light derrick work. For many purposes they are preferable to straight lift hoists, because they are not limited in the height of lift; use air only in proportion to distance load is lifted; hold load in constant position; do not jump up when part of load is

FIG. 275.—CYLINDER HOIST ON FOUNDRY CRANE.

removed, as in pouring molten metals; will do delicate mould work safely, and can be placed in close quarters where a cylinder hoist could not be used at all. For operating any light machine where it is inconvenient to get a belt, they should be very useful.

Fig. 275 shows another air crane in this same foundry, which embodies some original ideas of the owners, the chief one being the method of connecting the ropes; one end of the hoisting ropes is connected to a Whiting Foundry and Equipment Co.'s Cylinder Hoist, carried out to the lifting sheave and back to a hand windlass on the mast. This windlass works on one end of the rope, or the air cylinder on the other end; so this, too, is either a hand or air crane at will. The ladle suspended on this crane is also of the improved Whiting make.

These people also use a Haeseler Portable Compressed Air Breast Drill for boring test holes in cast iron columns.

Ample power for all these appliances is furnished by 10-inch belt-driven air compressor, which when air is not being used, automatically unloads itself, taking power only in proportion to the work being done in the foundry.

This entire compressed air equipment was furnished by the Ingersoll-Sergeant Drill Co., Havemeyer Building, New York City. H. M. PERRY.

THE USE OF COMPRESSED AIR AT A BLAST FURNACE PLANT.

When "A" Furnace of the Maryland Steel Co., Sparrow's Point, Md., was blown in for its second blast (November, 1895), a compressed air plant was put in, and has been used with much success during the past year. Compressed air is used for the tap-hole drill, the tap-hole "gun," the transfer-table at the scales, the turn-table on top of the furnace, and for lifting the rails of the turn-table in running off the empty cars.

The compressor (a Rand direct-acting steam air compressor) and the receiver are set up in the pump-house, and are cared for by the pump man. The air-pipe from the receiver to the furnace is about 500 feet long; there the pipe branches to the different machines. Last winter the air first passed through a coiled pipe heated by a coke fire near the scales, in order to keep the moisture in the condensed air from freezing. The piping at the furnace is so arranged that steam can be used for all the machines in case the compressor breaks down, and on the transfer-table hydraulic pressure also can be used. The pipes and valves are so arranged that air or steam can be used on any or all the machines, and so that all the pressure can be put on any one machine.

The tap-hole drill is a Little Giant rock drill so mounted as to swing into place and drill out the tap-hole without any hard manual labor. This arrangement is the device of Superintendent David Baker, and is described by him in Trans. Amer. Inst. Min. Eng., vol. xxi. The supporting crane has been much changed since that description was written, and now consists of the simple and light crane shown in the photograph. The crane is fastened to one of the columns at the side of the tap-hole so that the drill can be swung back out of the way when not in use. The air-pipe is connected by swing joints and an expansion sleeve, which can be seen in the photograph (the drill is in place ready to open the hole, the "gun" is loaded and ready to swing into place).

Formerly steam was used to run the drill, but it has several disadvantages which air has not. Great care had to be taken to prevent the condensed steam from dripping into the iron trough and perhaps causing a "boil." The escaping steam would make it hot for the men, and the clouds of vapor would often prevent them from watching the work well. A hose for the exhaust was necessary, and this made another part to care for, and it was sometimes burned. In cold weather there would be much condensing and loss of power. Compressed air does away with all these difficulties.

The tap-hole "gun" is Mr. S. W. Vaughen's patent device for shutting the tap-hole by power, thus saving much hard, hot work for the men, and doing away with the necessity of taking the blast off the furnace after each cast to shut the tap-hole.

An illustrated description of an early form of this gun is given in the *Iron Age,* Nov. 21, 1895. The gun shown in Figs. 276 and 277 has a "breech" for loading, a compact valve, and a simple and adjustable mounting. It is made of cast iron and consists of two cylinders and a piston rod with a piston on each end. The air end of the gun is an ordinary air-cylinder operated by a hand valve. The clay "barrel" is open at the "nose" end, and has a "breech" at the other end (see Fig. 277). The gun is suspended on a crane fastened to the column opposite the

FIG. 276.

drill. The crane is similar to the drill crane, and the air-pipe has swing joints and a rubber hose connection to allow freedom of motion.

The gun is loaded with about 35 clay balls before the cast, and when the iron is all out of the furnace the gun is swung around and clamped into place and the whole charge shot into the tap-hole at once. By reversing the valve the piston is brought back; the breech is opened, the clay barrel loaded up again and more clay shot into the hole till it is completely shut up.

Here the air has the same advantages over steam as in the drill. About 65 to 70 pounds air pressure is needed for the drill and gun. If at any time there is not enough pressure to run the drill well, a signal is given from the furnace to the pumpman, and he sets the escape valve of the receiver for higher pressure.

In order to have rapid handling of the ore, limestone, and coke, buggies which have four wheels, run on tracks, and hold from 1,500 to 2,300 lbs. of stock, at the scales, a transfer table is placed between the scales and the elevator. When the empties come down they are run off from the elevator onto the transfer which is run to one side; then the loaded cars on the scales are pushed across the transfer, which is provided with seven sets of rails running crosswise, onto the cage of the elevator. This transfer is operated by compressed air, and is provided with water cushions at either end to permit rapid running and to take up the shock. At present the compressed air is obtained from the regular blast main of the furnace, which averages 10 or 12 lbs. pressure. When the blast is off the furnace, hydraulic pressure of 26 lbs. is used in the same cylinder, but it is too slow for regular work. At first the transfer was run by air at 60 to 70 lbs. pressure from the compressor, using a smaller cylinder which can now be used in case of any break-down of other parts.

The turn-table on top is a part of the filling arrangement necessary to give an even distribution of the stock as it is dumped into the furnace. It has a track on each side holding two buggies at once, so that two buggies are dumped on one side, and the next two buggies on the other side. On every other "charge" the turn-table with the loaded buggies on it is turned about 75 degrees, and then the

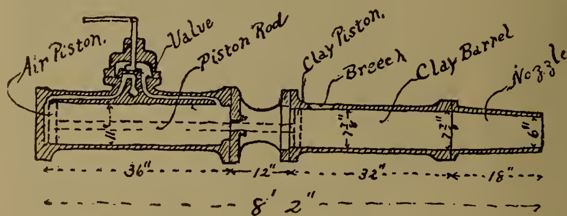

FIG. 277.

stock is dumped. Air from the compressor is used for this table, and has proved more suitable than steam, especially in cold weather.

The two tracks which extend across the turn-table are arranged so that the back ends can be raised by pistons working in compressed air cylinders. When the ore is dumped the rails are raised, and the empty buggies run back onto the cage with a little help from the men. Air from the compressor runs these lifts also.

The blacksmith's forge, in a shop near the pump-house, is ordinarily run by blast from the furnace blowing engine; but if the furnace is stopped for any reason, blast for the forge can be taken from the receiver of the air-plant.

Thus the air compressor has become a valuable machine at the furnace.

The trouble from condensed moisture in the different machines was largely due, I think, from the fact that the compressor takes its air directly from the pump-room which is always warm and moist. I here suggest that much better work would be done if the air were taken directly from outdoors.

RALPH H. SWEETSER.

BRIEF HISTORY OF LIQUID AIR.

As the subject of liquid air and low temperature is receiving so large an amount of attention and thought in the scientific world to-day, a brief history of its production may be considered timely. Prior to 1877 air was thought to be a permanent or incondensable gas, but it was liquefied simultaneously by Messrs. Pictet and Cailletet at that time though at an enormous expense. About 200 years ago the lowest temperature thought to be obtainable was produced by a mixture of snow and ice and was used by Fahrenheit in establishing a zero for his thermometric scale. Since that time scientists have reached a temperature some 400 degrees below the lowest point ever reached by Fahrenheit. Of the three known methods for producing cold, the first, i. e., by the rapid solution of a solid, was used entirely up to 1820 and yielded a temperature of 50 degrees below zero centigrade. The other two methods are the rapid evaporation of a volatile liquid and the rapid expansion of a cooled and compressed gas. By a combination of pressure and refrigeration, Faraday in 1823 liquefied all except six of the existing gases, but it was not until 1869 that it was discovered that these gases must first be cooled to a critical temperature. By subjecting hydrogen to an enormous pressure and at the same time lowering its temperature it was found possible to liquefy it. Hydrogen has a critical temperature only 33 degrees c. above the absolute zero of temperature. From the experiments performed, the conclusion was drawn that solids, liquids and gases were but different forms of matter through which any substance could be made to pass by the addition or withdrawal of heat and pressure. The liquefaction of air economically and in large quantity has only recently been accomplished.—*The Engineer.*

LIQUID AIR.

The subject of liquid air has of late attracted considerable attention, and in view of some erroneous statements which have become widely circulated, a few remarks in correction of such errors would seem timely.

Ordinary atmospheric air is nothing more or less than the super-heated vapor of a liquid, and the boiling point of air at about this liquid, is 312° F. This is probably the most reliable temperature of the boiling point of liquid air, being that obtained by Wroblewski, and quoted in Prof. De Volson Wood's thermodynamics. Much lower temperature can be obtained by evaporating liquid air in vacuum.

It should be noted that the boiling point of liquid air is lower than the boiling points of either of its principal constituents. Although some very creditable work of investigation in the subject of liquid air has been done in Europe by Dewar, Wroblewski, Olszewski, Pictet, Cailletet and others, comparatively little is definitely known of the chemical and physical properties and effects.

The physical effects of the low temperature of liquid air vary, but in general makes all substances very hard and brittle. While in the case of some metals the tensile strength is increased, the elasticity seems to have been destroyed. Heavy sheet iron becomes so brittle that it may be readily mapped in pieces with the fingers, and the fracture exhibits a finely crystaline structure. Gum rubber, meats, vegetables and other substances become hard and brittle enough to be broken in fragments by the hand. Ice, at this low temperature, crumbles into small pieces, and resin under slight pressure falls down in the form of a powder. Oils are readily solidified.

It would seem that some substances are brought almost to the point of disintegration, and the above examples are merely cited to give a slight idea of the various effects which this low temperature has upon the physical properties of matter.

Chemical affinity at this low temperature is apparently destroyed, and substances which combine violently at ordinary temperature have no effect upon each other in liquid air. From the laws of electricity, we know that if a conductor were immersed in liquid air the low temperature would cause it to have practically no resistance.

It has been stated that the flesh, if immersed in liquid air long enough to come in contact with it, would be burned, the same as if it were exposed to a high temperature. This is erroneous, for while the nervous sensations are the same, the two effects are quite different, the high temperature producing a burn and the low temperature a freeze, which when produced by such a low temperature, is much more painful than a burn.

It has been stated that "a handkerchief of silk, linen or cotton, saturated with liquid air, will be charred and destroyed just the same as if it were put in an oven and browned, though no change of color is apparent." This is also erroneous, as the fibre is merely frozen by the low temperature, and if allowed to remain undisturbed and return to the normal temperature again, is not harmed in the least. But, if when in the frozen condition it is crumpled up and crushed, the fibre will be broken and destroyed. The statement that the vapor of liquid air when mixed with atmospheric air in certain proportions can be used for illuminating purposes seems to have been given considerable credence. The vapor of liquid air is nothing more or less than cool atmospheric air, and how two quantities of air mixed together will produce illuminating gas, is not plain to the writer.

In all the articles that have been written concerning liquid air, the work of Charles E. Tripler, of New York, has been entirely ignored, and this is surprising, in view of the fact that he has devoted his entire time for the last twenty years to this line of investigation, and has brought the apparatus to a greater state of perfection than any one else, and developed the subject to the point of commercial practicability.

During the past summer Mr. Tripler took a can of liquid air from New York to both Washington and Boston, starting with about four gallons in each instance. After being in transit eight or nine hours, not over twenty-five per cent. was lost in either case.

The apparatus accredited to Prof. Linde and described in the August number of COMPRESSED AIR, is identical with an apparatus patented by Mr. Tripler five years ago. But, while with this apparatus of Prof. Linde's it takes five hours to obtain liquid, with Mr. Tripler's apparatus liquid air can be obtained in less than an hour from the time of starting. In a subsequent article the writer hopes to be able to give data concerning the properties of liquid air.

W. H. DICKERSON.

LIQUID AIR.*

By Walter H. Dickerson, M. E., '96.

Through the kindness of Mr. Charles E. Tripler, of New York, the Alumni Association was afforded an opportunity at the mid-winter meeting of witnessing some experiments with liquid air. It has been the good fortune of the writer to have been associated with Mr. Tripler for nearly a year past, and as a member of the Alumni Association, it was with pleasure that he came before them as Mr. Tripler's representative, and endeavored in the limited time available to give them some account as to the production of liquid air, its principal characteristics, and some idea of the great possibilities attending its practical application on a commercial scale.

A few remarks at this point upon the conditions necessary for reducing gases to the liquid state, will probably aid the reader to more clearly understand the matter that follows.

All matter is capable of existing in three states, gaseous, liquid and solid, due to its temperature, pressure and volume. If we compress a gas, we increase its density, but as long as the temperature is above a certain point, it will not liquefy. If, however, we reduce the temperature of a gas to a certain point, it will liquefy at a certain pressure and at a less pressure if the temperature is carried lower. This temperature, at which a gas begins to liquefy, is known as its critical temperature, or point. All gases possess a definite fixed critical temperature, at or below which they will liquefy, and above which, they cannot be liquefied, regardless of the pressure applied. Air at the ordinary temperature, has been compressed under fully 4,000 atmospheres of pressure per square inch, without liquefying. Oxygen gas, at 17 degrees centigrade compressed by 4,000 atmospheres per square inch, reaches a density of 1.25, but is still in the form of a gas. The following is a table prepared by Prof. Dewar in the *London Engineer*, giving the density of some gases, at the temperature of 15 degrees centigrade, and at a pressure of 3,000 atmospheres per square inch:

	Density of gas at 3000 atmospheres per square inch.	Density of liquid at boiling point.
Oxygen	1.1034	1.124
Nitrogen	0.8259	0.885
Air	0.8820	.94
Hydrogen	0.0879	

Thus, we see that it is possible to have a gas denser than its liquid. The limiting density of hydrogen is 0.12. The existence of "critical temperatures" was discovered by Dr. Andrews, of Scotland. All liquids possess, below their

* Reprinted from *The Stevens Indicator.*

TABLE 69.

Number of line.	SUBSTANCE.	Symbol.	Critical Temperatures Deg's. Cent.	Critical Temperatures Deg's. Fahr.	Critical Pressure. Atmos.	Tem. of Saturated Vapor at atmospheric pressure. Deg's. Cent.	Tem. of Saturated Vapor at atmospheric pressure. Deg's. Fahr.	Freezing Point. Deg's. Cent.	Freezing Point. Deg's. Fahr.	Pressure at which freezing point was determ'd mm.	Density of Gas.	Density of liquid at Temperature given.	Color of Liquid.
		PHYSICAL CONSTANTS.											
1	Water	H_2O	365	689	200	100	212	0	32	760	.....	1 at .4°C.	Colorless.
2	Hyd. Selenide.	H_2Se	185	365	91	— 41	— 41.8	— 68	— 90.4	....	40	....	"
3	Ammonia	NH_4	130	266	115	— 33	— 27	— 77	—107	....	8.5	0.6364 at 0°C.	"
4	Propane......	C_3H_6	97	206.6	44	— 45	— 49	Still liq —151	uid at ° C.	....	20.95	....	"
5	Acetylene	C_2H_2	37	98.6	....	— 85	—121	— 81	—113.8	950	12.97	....	"
6	Nitrous oxide.	N_2O	35	96	75	— 89	—128	—115	—175	760	21.99	....	"
7	Ethane.......	C_2H_6	34	93.2	50.2	— 93	—135.4	Still liq —151	uid at ° C.	....	19.97	....	"
8	Carb. dioxide.	CO_2	31	88	75	— 80	—112	— 56	— 69	760	21.94	0.83 at 0°C.	"
9	Ozone	O_3	....	....	....	— 93	—135.4	....	....	....	23.89	....	Dark blue, easily exploded.
10	Ethylene.....	C_2H_4	10	50	51.7	—102	—150	—169	—272	....	13.97	....	Colorless.
11	Methane	CH_4	— 81.8	—115.2	54.9	—164	—263.4	—185.8	—302.4	80	7.98	0.415 at—164°C.	"
12	Nitric oxide..	NO	— 93.5	—135	71.2	—153.6	—254	—167	—369	138	14.98	....	"
13	Oxygen......	O_2	—118.8	—182	50.8	—181.4	—294.5	....	....	....	15.96	1.124 at—181.4°C.	Blue.
14	Argon	A	—121	—185.8	50.6	—187	—304.6	—189.6	—309.3	....	19.9	about 1.5 at—187°C.	Colorless.
15	Car. monoxide	CO	—139.5	—219.1	35.5	—190	—310	—207	—340.6	100	13.96	....	"
16	Air..........	..	—140	—220	39	—191.4	—312.6	....	....	....	.....	0.933 at—191.4°C.	Light blue.
17	Nitrogen	N_2	—146	—231	35	—194.4	—318	—214	—353.2	60	14.01	0.885 at—194.4°C.	Colorless.
18	Hydrogen....	H_2	—234	—389	20	—243	—405	....	....	....	1	....	"
19	Helium	He	....	....	....	Below —264	—443.2	....	....	....	2.02	....	

Reference for data in this table will be found on the next page.

critical temperatures, definite fixed boiling points, for definite fixed pressures. In the case of air the boiling point under atmospheric pressure is—191° Centigrade or 312° Fahrenheit. At this point, gaseous air liquefies and remains in the liquid state at ordinary atmospheric pressure, so that air can be changed into a liquid form by cold alone. A glass of liquid air, exposed to the atmospheric air, will receive heat from the warm atmosphere, which will tend to evaporate it, but the portion that evaporates, by absorption of heat energy, keeps the remaining liquid cool; consequently, a jar of liquid air will take a considerable time to evaporate.

Mr. Tripler has been engaged in researches in high pressures for the liquefying of gases, for a number of years, having spent all his time and a great deal of money in this work. During his researches, he devised a simple and economical apparatus for the liquefaction of gases. Although Mr. Tripler's name has not been before the public until very recently, outside of a limited circle interested in his work, his investigations have developed many important results.

The work of the European scientists, in the practical liquefaction of gases, has been chiefly in the following direction:

Starting with a very easily liquefiable gas, as carbon dioxide, the cold produced by the evaporation of its liquid, was used to refrigerate and liquefy a less easily liquefiable gas, under high pressure (such as ethylene for example) and the evaporation of the liquid ethylene, was in turn used to refrigerate and liquefy one of the so-called permanent gases such as oxygen. As the reader can readily conceive, it was an elaborate and necessarily expensive plan, as all these gases had to be compressed to a high pressure.

But, with the apparatus devised by Mr. Tripler, all that is necessary to produce liquid air is gaseous air, under a pressure from 2,000 to 2,500 pounds pressure to the square inch. The liquefying apparatus proper consists simply of a series of coils of pipe arranged in several concentric cylindrical compartments in two large "liquefiers." The coils of pipe, which are capable of withstanding high pressures, terminate in a specially designed expansion valve and an orifice. The high pressure air entering the liquefier, passes through the coils until it reaches the expansion valve and orifice. Here, the air is expanded in the expansion chamber to very nearly atmospheric pressure. The air in expanding from the high pressure of 2,500 lbs., is reduced in temperature, and this cold expanded air in passing over the coils from which it has just issued reduces the air under high pressure therein contained to so low

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REFERENCES FOR DATA GIVEN IN TABLE 69.

Lines 2, 4, 7, 9, 10, 11, 12, 13, 15, 16 and 17 are given by Olszewski in *Philosophical Magazine,* February, 1895.

Lines 1, 3, 6 and 8 are given by Prof. Linde in *London Engineer,* Nov 13, 1896.

Line 18 is given by Olszewski in *Philosophical Magazine,* 1895. Calculated.

Line 19 is given by Olszewski in *Annalen der Physik und Chemie,* 1896. Calculated.

Line 5, Critical temperature, given by Ansdell in *Proceedings Royal Society,* Vol. 29, p. 209, 1879. Other data on this line given by P. Villard, *Comptes Rendus,* Vol. 120, p. 1262, June 10, 1895.

a temperature that it is in part liquefied. With this apparatus, liquid can be drawn off within fifteen minutes from the time of opening the expansion valve. The method of continuously cooling the incoming air by passing the cool expanded air back over it, as above described, was discovered by Mr. Tripler, in the winter of 1889 and 1890.

Within the last year or two, certain men in Europe have claimed this apparatus as original with them, but their claims as inventors of this apparatus are easily disposed of by the fact that the apparatus, which they are at present using, is almost identical with that which was patented in England by Mr. Tripler over five years ago, and also by the fact that the patent examiners have given him a priority of three years over all others in the use and application of apparatus involving the principles referred to.

It is a significant fact that, with the apparatus first brought out by these claimants, it required 17 hours to produce liquid air, but the time has recently been reduced by them to two or three hours. Another significant fact is that these same claimants did not bring out their apparatus until after Mr. Tripler had filed his applications for patents in England.

Mr. Tripler was assured a few years ago by certain scientists, that it would be impossible to produce liquid air according to his idea. Notwithstanding these discouragements, he has by patient persistence, accomplished it, and demonstrated that his method was effective.

The power plant for the production of high pressure air, in Mr. Tripler's laboratory, consists of an ordinary tubular boiler, and a three stage straight line Norwalk compressor. The principal dimensions of the compressor are as follows:

Diameter of steam cylinder	16	inches.
Diameter of piston rod	2½	"
Stroke of piston	16	"
Diameter of intake air cylinder	10½	"
Diameter of piston rod, head end	2½	"
Diameter of piston rod, crank end	$1\frac{13}{16}$	"
Diameter of intermediate cylinder	$6\frac{3}{8}$	"
Diameter of piston rod	$1\frac{13}{16}$	"
Diameter of high or 3rd stage air cylinder	2⅝	"
Stroke of all air pistons	16	"

Steam pressure carried is from 85 to 90 pounds per square inch.

The cylinders are arranged in tandem, all on the same bed, and are in the following order: Steam cylinder, intake air cylinder, intermediate air cylinder and high or third stage air cylinder. The steam end is a simple steam engine, with adjustable cut-off Meyer valves.

The air is led to the compressor through a pipe, which extends above the roof of the building, in order to get clean air free from dust. Before entering the compressor, the air passes through a washer, which washes it free of dust and saturates it with water. The air enters the intake cylinder, which is double acting, where it is compressed to about 65 lbs. pressure to the square inch. It then passes through an inter-cooler, and is reduced to the ordinary atmospheric temperature, by means of water circulated through the pipes in the inter-cooler. It then enters the intermediate cylinder, which is single acting, and is compressed to about 400 pounds pressure. From here, the air is discharged into the second inter-cooler, where it is again cooled by means of the water circulation to the ordinary atmospheric temperature. It then enters the high pressure or third stage air cylinder, where it is compressed to the discharge pressure of from 2,000 to 2,500 pounds pressure per square inch. After passing through an after-cooler, to reduce its temperature again to that of the atmosphere, the air passes through a separator, where all the moisture, oil, dirt, etc., are removed from it, and from there passes to the storage tubes.

From the storage tubes the air under high pressure passes to the liquefying apparatus and in from twelve to fifteen minutes from the time of starting, liquid air can be drawn off from the apparatus through a discharge pipe at the bottom.

The present apparatus will produce from two to three gallons of liquid air per hour.

The facility with which the liquid is handled and transported is rather remarkable, considering the temperature condition necessary to maintain it in its liquid form. It has been transported in three and four gallon quantities to Lynn, Mass.; Philadelphia, Baltimore and Washington, with a loss, from evaporation, of from 25 to 30 per cent. The receptacle in which the air is carried is nothing more or less than a large tin or copper can insulated with about three inches of hair felt.

As noted in Table 69, the critical temperature of air is—140 degrees Centigrade and the corresponding pressure is 39 atmospheres. The boiling point at atmospheric pressure is—191.4 degrees Centigrade. Its density is .94. The specific heat and latent heat of evaporization of liquid air are unknown. The liquid is perfectly transparent and slightly tinged with blue. Both the oxygen and nitrogen of air liquefy simultaneously, but do not evaporate in the same relative proportions. The nitrogen, having a lower boiling point than the oxygen, evaporates more quickly, so that the liquid after a time becomes substantially liquid oxygen.

There are three methods in measuring these low temperatures—namely, the hydrogen thermometer, the thermo-pile or thermo-electric couple, and the platinum thermometer. The correct reading of these thermometers all depend on the assumption that the laws which govern their actions at ordinary temperatures, hold good at these extremely low temperatures; consequently, the temperature determinations based on these assumptions can only be taken as approximately correct.

In using the hydrogen thermometer to measure temperature as low as that of liquid air, it is open to the criticism that such temperatures approach the critical point of hydrogen, and this introduces a great chance of error. In using the thermo-pile or thermo-electric couple, it is calibrated at ordinary temperatures, and a calibration curve plotted. Assuming that the curve conforms to the same laws throughout a wide range of temperature, the curve is exterpolated to cover low temperature readings. The instrument readings are taken at the low temperature and plotted back upon the exterpolated portion of the curve and the temperature then determined. The platinum thermometer is probably the most reliable of the three, and has been used by most of the European investigators in the greater part of their researches in low temperatures. It consists of simply a fine pure platinum wire, sometimes bare, and sometimes sealed in a small glass bulb, and intended to be placed in the liquid, the temperature of which is to be measured. In using it, its resistance-temperature curve is plotted, a given resistance corresponding to a definite temperature. The resistance-temperature curve of pure platinum, for ordinary and high temperatures, is very nearly a straight line, and produced, passes through the origin of co-ordinates, a point corresponding to zero resistance and zero temperatures. The resistance of the thermometer being determined, it is plotted on the curve and the temperature deduced. The temperatures thus deduced, depending as they do on an assumption, are always expressed as platinum-Centigrade, or platinum Fahrenheit, degrees. When the liquid air is dipped up in an ordinary glass tumbler, it boils at first very violently, but, after the tumbler has given up its heat and has had its temperature reduced to that of the liquid, the liquid air boils gently.

TABLE 70.

Specific heats of air calculated by Prof. Linde. Published in *London Engineer*, November 20, 1896.

	PRESSURE IN ATMOSPHERES.					
	1	10	20	40	70	100
Temperature +100° C..........	.2372	.2389	.2408	.2446	.2512	.2583
" 0° C..........	.2375	.2419	.2465	.2512	.2773	.2986
" — 50° C..........	.2380	.2455	.2572	.2785	.3319	.4124
" —100° C..........	.2389	.2585	.2844	.3697	.8461	....
" —150° C..........	.2424	.3105	.5048	....	....	....
" —170° C..........	.2467	.4147	....	....	....	....

The production of liquid air and oxygen at the Royal Institution of London, was a very expensive process, and Prof. Dewar, in searching for a vessel suitable for holding the liquid gases and preventing their rapid evaporation, devised the vacuum bulb. This consists simply of two bulbs, or vessels of glass, one within the other, having an annular space between the walls, and joined in a common neck at the top. In this annular space, a very high vacuum is formed, which prevents the heat from being conducted from the outer to the inner wall. If the wall of the inner bulb or vessel is silvered with mercury, nearly all of the radiant heat will be reflected, and the amount of heat that will enter the liquid contained in the inner bulb, will be reduced to a minimum. It has been suggested by Mr. Tripler, that this bulb, out of courtesy to Prof. Dewar, should be called the Dewar bulb or globe. Liquid air when placed in a Dewar bulb, remains in a quiet state, evaporating very slowly, a tumblerful requiring about four or five hours to entirely evaporate. If the Dewar globe is unsilvered, the perfect transparency of the liquid is shown, as is also its bluish tinge. As the evaporation progresses, the liquid becomes richer in oxygen and the bluish color becomes deeper. The change of the relative proportions of oxygen and nitrogen in the liquid, due to evaporation, and the consequent change in density, is very nicely shown by the following experiment:

If, in a large glass jar or flask, filled nearly full of water, a dipper of liquid air is poured, the liquid at first will float on top of the water, because the specific gravity of pure liquid air is less than that of water. The liquid coming in contact with the water, causes rapid evaporation of the air, and in a moment or two, the air becoming very rich in oxygen, its density becomes greater than that of water, and it dives down into the water in the form of large globules.

Some idea of the very low temperature of liquid air, may be gathered from the experiments showing the ease with which all liquids, having a low freezing point, are solidified.

Both absolute and 95-per cent. alcohol are easily frozen and form a white transparent solid. Absolute alcohol solidifies at between —202° and —203° Fahr. and just before reaching the solid state, becomes very viscous, reminding one of a heavy oil. Whiskey is easily solidified, and when frozen, looks like brown sugar.

FIG. 278.—TUBES EXPLODED BY MEANS OF COTTON WASTE SATURATED BY LIQUID AIR.

All the organic liquid reagents and the acids are readily reduced to a solid state by means of liquid air. Prof. Dewar has discovered that, if reduced low enough in temperature by means of the vacuum pump, liquid air is apparently reduced to a solid, but when the solid mass is placed in a strong magnetic field, the oxygen is sucked out towards the poles in the form of a liquid, leaving little doubt that the apparently solid mass is but a magma of solid nitrogen, containing liquid oxygen. Liquid oxygen has never been solidified.

Some idea of the low temperature that can be obtained by evaporating liquid air in a vacuum, is shown by the following experiment: A large test tube filled with liquid air is connected at the top with the vacuum pump. When a vacuum of about fifteen inches has been reached, the atmospheric air commences to liquefy on the exterior of the tube, and trickles from the bottom in a small stream. After this condensation has progressed for a few moments, the liquid in the interior of the tube is reduced by evaporation to almost pure liquid oxygen, and when the vacuum has been raised to 28 or 29 inches, the liquid air on the exterior of the tube is reduced to a solid state.

The effects of very low temperatures upon the physical properties of metals are very striking, and open up a wide field of investigation for scientists.

Metallic mercury solidifies at—39° Fahr. If a proper mould is made, a hammer head of mercury can be cast on to a handle by means of liquid air, forming a hammer with which nails can be driven into boards. Solid mercury when hammered is affected very much the same as ordinary lead. It has also been found that a bar of solid mercury possesses considerable tensile strength. Pure mercury exhibits a fibrous structure, the fibres extending in vertical unbroken lines from the bottom of the mould to the top. When amalgamated with a slight percentage of tin, the structure becomes granular.

Sheet iron and steel, which at ordinary temperatures are pliable, become so brittle when reduced to the temperature of liquid air, that they are as easily broken as is thin china-ware. Seamless steel tubing, when reduced to this low temperature, slivers into long fragments when struck with a hammer. Tin, with slight impurities, also become brittle and may be easily broken.

If the fracture of these metals is examined, it is found to be very granular. While the pliability of iron and steel is greatly reduced at low temperatures, the tensile strength is greatly increased. Copper, aluminum, pure tin, cadmium, silver, platinum and gold, are all apparently unaffected, and are as pliable at the low temperatures as at the ordinary temperatures.

The following table contains some approximate results regarding this subject, obtained by Professor Dewar:

	Tension in tons per sq. inch for a temp. of		Percentage of elongation for a temp. of	
	15 C.	–180 C.	15 C.	–180 C.
Copper	22.3	30.0	6.8	13.4
Iron	34.0	62.7	8.2	4.7
Brass	25.1	31.4	35.5	32.2
German Silver......	38.3	47.0	10.7	20.4
Steel	35.4	60.0	29.4	19.5

The effects on other substances at low temperatures, are as remarkable as those upon metals. Resin and paraffin, when frozen in liquid air, are easily reduced to a fine powder, by the pressure of the fingers. Rubber tubing and sheet rubber become so brittle, that a light blow will shatter them into fragments. Common ice, if placed in the liquid, becomes very granular, and is reduced to small fragments by pressure of the hands. Bread, soaked in the liquid, becomes hard, and can be crushed like a piece of dry toast. Meat becomes as hard as a stone, and has a ring, when struck, like porcelain. An onion, after being frozen in the liquid air, shells off in pieces, which, when shaken up in the hand, sound like broken china.

Pictet discovered that chloroform, when treated with liquid air becomes a more powerful anæsthetic and also that a patient after being under the influence ot chloroform so treated, experiences no bad after-effects upon reviving, as is the case when the ordinary chloroform is used.

With liquid air, it is possible to perform some very interesting experiments in combustion, as in the liquid, we have oxygen in a very concentrated form. If a piece of smouldering wood is held over a glass of liquid air, that has become richly oxygenized by the partial evaporation of the nitrogen, it will burst into a flame instantly. A newspaper, soaked in the liquid and ignited, burns vigorously. Hair, felt and wool, which will burn only when held directly in a flame, will blaze violently, when saturated with the liquid. Cotton waste or cotton batting, treated in a similar manner burns with almost explosive violence, and in a manner similar to gun-cotton. If the cotton waste is partially saturated with oil and then treated as above, the burning is still more violent. In experimenting with cotton waste, a small piece which could be easily enclosed in the hand, was soaked in turpentine and then saturated with liquid air and placed unconfinedly on the floor, upon being ignited it produced a surprisingly heavy detonation, breaking all the glassware on a table that stood several feet away. Another experiment will serve to show still further, the violently explosive nature of this substance when saturated with liquid air. About one-half ounce of cotton waste saturated with oil and with liquid air, was placed in the end of a ¾-inch wrought iron pipe which was 20 inches long, and open at both ends. On igniting the cotton waste a violent explosion took place, bursting and curling the heavy pipe as if it were so much paper, for a distance of ten inches.

Steel and iron may also be burned in the richly oxygenized liquid. The following experiment will afford a striking illustration: If a steel writing pen be securely fastened to a match, and the match ignited and then held over the liquid air, it will burn so intensely that the pen will also become ignited and burn violently with a beautiful scintillation, throwing off globules of the molten metal which, as they fall, will be fused into the glass vessel containing the liquid. If an ordinary electric light carbon is heated on the end with a blow-pipe until it glows, and then immersed in the liquid, it will burn and be consumed very much as the carbon in the arc lamp, giving out a brilliant light and generating a large quantity of ozone. By means of liquid air, steel may be fused into ice; this is shown by the following beautiful experiment:

A glass beaker is partially filled with liquid air, and immersed in a vessel of water; in a few minutes, a thick coating of ice is formed on the exterior. If the glass beaker is then emptied of the liquid, and warmed by pouring water in it, the coating of ice can be slipped off and you have an ice-tumbler. Filling this partially full of liquid air, and burning a thin strip of steel, as in a former experiment, the steel will be fused into the walls of the ice-tumbler in the same manner as it was fused into the glass.

The expansive properties of liquid air are very nicely illustrated by the three following experiments: Fill a large test tube with the liquid, and close up the end with a cork, through which projects a long glass tube. A very small amount of heat, even the heat of the hand will drive the liquid up through the tube, to a considerable height in the air, giving a good illustration of a geyser. If a heavy piece of copper pipe, closed at one end, is clamped in a vise, and two or three spoonfuls of liquid air poured in, and a wooden plug is driven tightly in the open end, the expansion of the air from the liquid to the gaseous state, will almost instantly force the plug from the pipe, with a loud report.

An ordinary tea kettle, filled with liquid air, boils in the same manner in the atmosphere, as though it were filled with water and placed over a hot fire; placing on a hot stove increases the ebullition very slightly, but pour a tumbler of cold water in it, and it boils furiously, and the water in a few minutes will be reduced to ice. This experiment has suggested itself as being the 20th Century revision of "Watt and his Tea Kettle" in an open fireplace.

The property of certain bodies to phosphoresce and the cause of phosphorescence, is a subject about which very little is known. Liquid air enables us to gain some information regarding this subject. Such substances as ivory, celluloid, kid leather, feathers, blotting paper, etc., will not phosphoresce at ordinary temperatures, but upon being immersed in liquid air, and reduced to its low temperature, and then exposed to a strong calcium, or arc light, will phosphoresce in a beautiful manner, as long as they remain at the low temperature. Tungstate of calcium, which is used for coating the fluorescent screens in the fluorescope, when reduced to temperature of liquid air, loses its fluorescent property entirely. A set of phosphorescing tubes, such as are used in physical laboratories to show phosphorescence, lose their phosphorescent properties entirely when reduced to the temperature of liquid air. A vacuum, or "Dewar" bulb, filled with filtered liquid air, can, in connection with the electric lantern, be used as a lens to focus the heat rays and with this lens paper may be burned.

Another series of very interesting experiments, are those which show the destruction of chemical affinity at low temperatures. Metallic sodium combines instantly with water at ordinary temperatures, but if the metal is first cooled in liquid air, and then thrown on the water, it will float for several seconds until warmed up before combining. Nitric acid and metallic sodium may also be mixed at the temperature of liquid air without combining. A battery consisting of sodium and carbon with a concentrated caustic soda solution between them, was placed in liquid oxygen. The spot of light on the scale of the galvanometer, to which the battery was attached, came to rest at zero, showing that there was no chemical action taking place between the elements of the couple. Liquid oxygen has been reduced to such a low temperature by evaporating under the vacuum pump that a splinter of wood, with a glowing spark on the end, will not burst into a flame when immersed in the liquid. The above experiments in the destruction of chemical affinity, with the exception of sodium and water, were all performed by Prof. Dewar.

Atmospheric air is a very good electric insulator, and in the liquid state is proportionately more so. The same amount of energy will produce a spark in liquid air of only one-sixth the length that would be produced in the atmosphere.

With liquid air in connection with a strong electro-magnet the magnetic properties of liquid oxygen can be shown. If the pole pieces are brought comparatively close together and liquid air poured over them, the liquid nitrogen will run off, while the liquid oxygen will cling to and form a bridge between the poles. An electric conductor, when at a low temperature, will offer less resistance to the passage of electric current than when at a high temperature. Professor Dewar has found that with pure metal conductors the resistance varies almost directly as the temperature. But with conductors made of alloys the resistance is very little affected by a reduction in temperatures. It was also found that the strength of a magnet was much increased when reduced in temperature.

Another interesting electric fact is that when liquid air is poured into a warm metal can, the can becomes charged, acting like a Leyden jar, and from which a good-sized spark can be drawn.

In the foregoing matter the production of liquid air has been briefly outlined, and some experiments described which show its characteristics.

As an agent in scientific research it opens up a wide field of investigation. In this direction valuable data has been obtained by the European investigators. Profs. Dewar and Fleming, in particular, have obtained a large amount of data relating to the physical properties of matter at low temperatures, and especially the electrical properties.

As a refrigerant, liquid air is almost perfect, being pure, clean and harmless; from it any desired temperature may be obtained.

For motive power purposes it offers a very desirable agent, the amount of power obtained being governed by the amount of atmospheric heat admitted to it.

While possessing no power in itself, except as heat is applied, yet, when mixed with certain substances, an explosive is formed, which has been said by one of the most eminent authorities on high explosives to be more powerful than dynamite or gun-cotton.

Results of much importance may be looked for from the application of liquid air in the practical electrical field, because of its properties of lowering the resistance of a conductor, and increasing magnetic strength of a magnet, and also because of its perfect insulating qualities.

The Pictet chloroform experiment offers a suggestion of what may be expected from its application in industrial chemical work.

In concluding this article no more fitting sentiments could be expressed than those uttered by Mr. Tripler during a recent demonstration of this subject.

"Can it be possible that a power so manifest, fully a hundred times more powerful than that of steam, shall lie dormant, as steam did for centuries, without an effort to utilize it?

"Shall we allow the rays of the sun to pass by us without an effort to utilize them, when we have here shown a manifestation of power from those rays, more abundant than Watt had with his tea kettle boiling on the fire?

"It has been my privilege to bring this problem one step further toward its ultimate success, and I can now see clearly its solution. It requires only the mechanical appliances to place in the hands of the present generation the greatest force of the age."

St. Paul, Minn., Jan. 16, 1899.

Editor Compressed Air:

On page 713 of this cyclopædia on "Liquid Air," reference is made to Prof. Dewar's table of the density of some gases at a temperature of 15° Centigrade, and at a pressure of 3,000 atmospheres per square inch.

Will you please have the kindness to explain how these very high pressures are obtained, and what materials are used for this purpose?

Thanking you in advance for your information, and always thankful for the useful information to be found in your Compressed Air. Frederick Thede.

Such pressures as 3,000 atmospheres pressure per square inch could be obtained by multiple or stage compression, just the same as 3,000 lbs. per square inch is obtained, only the compressor would need to be of special construction to suit that high pressure. Or it could be obtained by compressing the gas, say to 5,000 lbs. pressure per square inch, and then connect the storage tube or flask to hydraulic pump and pump in water until the gas had been compressed to required pressure. Either steel or bronze tubes or flasks made the proper thickness of wall to withstand such pressures would answer perfectly well. Care should be taken, though, that the metal is of dense enough grain to prevent escape of gas through metal itself.

LIQUID AIR.

We have been asked from time to time to express our opinion on liquid air, its usefulness, its commercial value, and whether or not we recommend persons taking stock in the several liquid air companies which have been organized. The province of this paper has been to publish in its columns descriptions of liquid air generating apparatus and various interesting experiments made with this extraordinary substance. We have also published opinions, ideas and theories on the subject, because we believe that liquid air being now an accomplished fact should be understood and the various ideas and suggestions agitated so that out of so many things we may be directed to something practical. Thus far we simply know that liquid air may be produced in large quantities by an air compressor and an expansion installation, and that the cost of producing it has been considerably reduced during the past year or two. When produced its properties establish its identity, and through its extremely low temperature we have been able to perform certain interesting experiments, which are in some cases valuable, from a scientific point of view; but it does not follow that liquid air is going to do what its promoters have proclaimed.

We are by no means sure that it is going to make money in the present generation, and yet we would not be surprised to learn that some one has found a practical application in its use. Such application, in fact, as may yet give it a commercial value.

Things that are new and of great value to mankind are slow in reaching practical results. A period of 75 years elapsed after the discovery of the electric arc before electric lighting reached a point when it became commercially valuable. Magneto electricity was brought to a point of great interest in science, and yet it was not until 50 years afterwards that dynamos and electric motors were used. The industry of refrigeration is now a large one, made commercially useful because of the liquefaction of ammonia gas, and yet ice was first made artificially in 1851 at Apalachicola, Florida, by Dr. Gorrie, and by means of compressed air.

We may say at present that liquid air is simply a substance of great scientific interest, yet it would be quite unwise to prophesy what the future may or may not bring forth. This very uncertainty has unfortunately been worked upon by promoters of schemes to sell stock. The fact that some remarkable results are being accomplished with this substance and its great novelty, are used for building up an easy foundation for the smart promoter who has issued stock and sold it on nothing but possibilities. The promoter is always attracted to things theatrical, and wins greater success in such a field than on lines of common, safe business practices. It is simply necessary to make a demonstration of liquid air, and prepare some wonderful experiments to make it pay, because the public is not scientific or technical and falls readily into surprise and error in the great possibility of a thing, which is so new and mysterious. It is a "get rich quick crowd" which falls into such a trap as this, and we are glad to say that in our judgment such schemes can only flourish in a short period of time. The reaction will surely come, and liquid air will remain as it is, simply a scientific experiment of great interest and value. Over all this there is a possibility of some good coming out of it. There are so many men at work upon it seeking to grind something out of it, that it is but natural to expect results if it be within the limits of possibility.

THE LIQUEFACTION OF AIR.

ITS COMMERCIAL VALUE.

An interesting demonstration of the liquefaction of air was given in University College, Dundee, Scotland, recently. The proceedings took place in the chemistry lecture room, and there was a large attendance of members of the society and friends. Professor Waymouth Reid, who presided, said it was a tradition of the society that as soon as any important scientific discovery was made it was practically demonstrated to the public of Dundee. In conformity with this time-honored practice this lecture had been arranged to show how air could be reduced to a liquid form. Professor Kuenen would give the necessary explanations. Unfortunately the college could not supply him with the apparatus, but they had been able to secure the services of Mr. W. Hampson, London, one of the experts of the Brins Oxygen Company, who had brought the apparatus he had himself invented to Dundee. The apparatus to be used had been made for Dr. W. R. Lang, of Glasgow University, who was also present, and who had kindly consented to it being employed that evening. (Applause.)

AN INTERESTING IMAGINATION.

Professor Kuenen said the subject of liquid air had been brought prominently before the public of late, chiefly in connection with magazine articles, originating largely from a country which, among its qualifications, was celebrated for an enterprising imagination that scorned to be hampered even by truth or by probability. (Laughter.) Apart from the attractiveness of the subject of the lecture, he was supported by the chairman, who with his usual generosity had offered himself as an object of experiment without imposing any limiting conditions. (Laughter.) That afternoon he offered to drink liquid air, but he would not be asked to do that . (Laughter.) He was also supported by Mr. Hampson, whose ingenuity as an inventor was equal to his skill as a demonstrator. (Applause.) While Mr. Hampson was preparing his apparatus, he (the Professor) would make a few remarks on the principle on which the production of liquid air was carried out. If a quantity of air at an ordinary temperature was compressed into about 800 times as small a volume there would be produced a very dense gas, so dense that it would resemble ordinary liquid in regard to the way in which it acted on light—it would refract light as a liquid; and it would be acted on by electric and magnetic forces in the same way. At the same time it would not be liquid air, because they would not have that condition in which the lighter portion was separated from the heavier portion by means of a liquid surface. If carbon dioxide was pressed into a cylinder it separated into two layers—there was a liquid and a vapor part. It was more than a century ago since the first gas—ammonia—was liquefied in that way, and in the course of this century—he meant the nineteenth century—(laughter)—all the other known gases had been liquefied, and two important facts had been discovered in the process—first, that the lower the temperature the more easy would the gas be liquefied by compression, and, second, that gases which resisted liquefaction by pressure might be liquefied by a sufficient lowering of the temperature. Carbon dioxide at 20 degrees C. required a pressure equal to 50 atmospheres to liquefy it; but if the temperature was reduced to freezing point (32 degrees Fahr.) it would only require 35 atmospheres to liquefy it. There were seven gases—called the permanent gases—which could not be liquefied by compression, but they could be liquefied by reducing the temperature. The temperature which they must get below before gases could be liquefied was called the critical temperature. Air could be liquefied if the temperature was reduced below 220 degrees Fahr. The boiling point of a substance was the temperature at which one atmosphere was sufficient pressure to keep the substance in a liquid state in an open vessel, and the boiling point of air was—314 Fahr., or 346 degrees below ordinary freezing joint. The next question was—How to reduce the temperature of air to that low degree? It could either be done by cooling it from the outside or by making it cool itself. People thought that by taking exercise or doing work they could get warm, but it had been shown that heating was only a secondary effect of doing work, and they could make the gas cool itself by making it work. It had been shown by Joule and Lord Kelvin that when air was allowed to fall from a high to a low pressure it cooled itself. But that would not be sufficient to bring it down to —192 degrees C., which was the boiling point of air, and Mr. Hampson had combined that principle with the principle of cooling by expansion. The general working of the system was that the air was first compressed into a cylinder at 150 atmospheres, and by means of a copper tube it passed into an exhaust cylinder, in which by expansion it cooled 40 or 50 degrees. In the exhaust cylinder there were over 100 yards of stout copper tubing, through which the compressed air passed, and as it flowed into the cylinder and expanded and cooled the temperature got lower and lower by the successive action of each quantity of incoming compressed air, till it reached —192 degrees C., when the air passed into a liquid form. It was then drawn off from the apparatus by means of a Dewar vacuum tube and placed in an open vessel for experimental purposes. The nitrogen in the air was more difficult to liquefy than the oxygen, and by exposure to the ordinary air the nitrogen returned more rapidly to its original state than the oxygen; so that after a short time the liquid was almost wholly pure oxygen. The liquid air now produced was the first that had ever been seen in Scotland, and they might be proud that it had been first produced in Dundee. (Applause.) As matter of fact, there had never before been such intense cold in Scotland, even in the glacial period. (Laughter.)

Mr. Hampson then carried out a number of experiments by means of the liquid air, such as have beeen referred to frequently in this journal.

LATENT HEAT OF EVAPORATION OF LIQUID AIR.

BY WALTER H. DICKERSON, M. E., '96.

During May, 1898, the writer, in connection with Professor D. S. Jacobus,* made some determination of the latent heat of evaporation of liquid air at the Stevens Institute of Technology.

As a result of the investigation the latent heat of evaporation at atmospheric pressure was found to be 123.0 British thermal units per pound.

The method of determination was as follows:

A large mercury mirror Dewar vacuum bulb was employed to contain the liquid air. The vacuum bulb consisted simply of two glass bulbs, one within the other, and joined in a short neck.

These bulbs have, between the walls, an annular space of about one-half inch, which is exhausted to a very high vacuum. If a drop of metallic mercury is originally introduced into this vacuum space, it will be changed into vapor when the vacuum is formed. On filling the inner bulb with liquid air, the mercury vapor in the vacuum space will be condensed on the surface of the inner bulb and a mercury mirror formed. The vacuum space prevents ingress of heat to the liquid air by direct convection and the mercury mirror intercepts the radiant heat so that the rate of evaporation in this form of containing vessel is very low.

The vacuum bulb was filled with liquid air and weighed, and the rate of constant evaporation due to the heat of the atmosphere determined. A small bar of metal of known weight and temperature was then introduced into the liquid air and after it had acquired the temperature of the liquid, it was withdrawn and the bulb weighed again, the length of time the metal bar was in the liquid air being noted. Then, knowing the initial and final temperatures, specific heat, and weight of metal bar, and also the weight of the liquid air evaporated, the latent heat of evaporation of the liquid air could be calculated.

No means were at hand to determine the temperature of the liquid air and it was therefore taken as the boiling point at atmospheric pressure and temperature, given by Prof. Dewar and others as — 312° F., or — 181.4° C. Although the liquid air used was slightly richer in oxygen than the ordinary atmospheric air, the error due to the difference of temperature from this cause was considered well within the error of other observations and was therefore disregarded.

There were three determinations made, with a different metal in each instance. The three metals used were iron, copper and aluminum, each in the

* It is very generous of Mr. Dickerson to mention my name as I did not assist him, except in placing apparatus at his disposal.—D. S. J.

form of a small cylindrical bar. The specific heats of these particular bars had previously been determined for a range of temperature from the atmosphere to the boiling point of liquid air with the following results:

TABLE 71.

Metal.	Weight of Bar in grammes.	Specific Heats.
Iron...........	51.925	.0914 for range of temperature of from + 13° C. to— 181.4° C.;
		.1162 for above + 13° C.
Copper........	63.49	.0868 from + 11° C. to—181.4° C.
		.094 for above + 11° C.
Aluminum.....	19.865	.1833 from + 14.5° C. to—181.4° C.
		.2173 for above + 14.5° C.

During the tests the following observations were noted:

FIRST EXPERIMENT WITH IRON BAR.

Temperature of atmosphere, 23.9° C.

Temperature of iron bar, 23.6° C.

Total weight of vacuum bulb and liquid air before immersing iron bar, 338 grammes.

Total weight after iron bar had acquired temperature of liquid air and been withdrawn, 319 grammes.

Time between weighing, 10.5 seconds.

Rate of constant evaporation per minute due to heat of atmosphere, .4286 grammes.

Total constant evaporation, 4.500 grammes.

Net evaporation due to iron bar, 14.5 grammes.

Heat units in iron per gramme.

+ 13° C. to — 181.4° C. = 17.768
+ 23.6° C. to + 13° C. = 1.232

Total heat units per gramme................... 19.000

Total heat units in iron bar in grammes-calories, + 23.6° to — 181.4° = 986.57.

Latent heat, by iron bar, 68.03 calories.

SECOND EXPERIMENT WITH COPPER BAR.

Temperature of copper bar, before immersing, 23.2° C.

Weight of bar, 63.49 grammes.

Weight of vacuum bulb and liquid air before immersing copper bar, 312 grammes.

Weight of vacuum bulb after bar had acquired temperature of liquid air and been withdrawn, 291 grammes.

Time between weighings, 10.92 minutes.

Rate of constant evaporation per minute due to heat of atmosphere, .4342 grammes.

Total constant evaporation, 4.741 grammes.

Total evaporation, 21 grammes.

Net evaporation due to copper bar (21 — 4.741), 16.26 grammes.

Heat units in one gramme copper,

+ 11° C. to — 181.4° C. = 16.70
+ 23.2° C. to + 11° C. = 1.15

Total, + 23.2° C. to — 181.4° C. 17.85

Total heat of copper bar in gramme-calories, 1126.948.

Latent heat of evaporation of liquid air by means of copper bar, 69.31 calories.

THIRD EXPERIMENT WIITH ALUMINUM BAR.

Temperature of aluminum bar before immersing, 23° C.

Weight of bar, 19.865 grammes.

Weight of vacuum bulb and liquid air before immersing aluminum bar, 284 grammes.

Weight of vacuum bulb after bar had acquired temperature of liquid air and been withdrawn, 269 grammes.

Time between weighings, 9.4165 minutes.

Rate per minute of constant evoporation due to heat of atmosphere, .4166 grammes.

Total constant evaporation, 3.9229 grammes.

Total evaporation, 15 grammes.

Net evaporation due to heat of aluminum bar, 11.077 grammes.

Heat units per gramme of aluminum,

+ 14.5° C. to — 181.4° C. = 35.908
+ 23.° C. to + 14.5° C. = 1.847

Total 37.755

Total heat in aluminum bar used, 750.1 calories.

Latent heat by aluminum bar, 67.72 calories.

Average latent heat by iron, copper and aluminum bars, 68.35 calories.

Latent heat expressed in B. T. U. per pound, 123.03.

The writer wishes to express his thanks to Mr. Chas. E. Tripler for so kindly furnishing the liquid air with which to make the investigation; also to Prof. Trowbridge, Columbia University, for loaning the metal bars and furnishing the data of the respective specific heats.—*Stevens Institute Indicator.*

OTTAWA, CANADA, Dec. 13, 1899.

Editor COMPRESSED AIR:

Permit me to point out one or two circumstances in connection with Mr. Dickerson's method, set forth in his article in the current number of your interesting periodical, for measuring the latent heat of liquid air, which seems to me to depart further than should be permitted from accurate measurement.

Mr. Dickerson mentions that the liquid experimented on contained a greater proportion of oxygen than does air and that he nevertheless disregarded the higher boiling point which this circumstance would naturally involve in view of its comparative negligibility. He was undoubtedly justified in doing so as, unless the oxygen was very much out of proportion, the rise in temperature could not be more than about a single Celsius degree. I must point out, however, that, although he states the boiling point of liquid air correctly in terms of Fahrenheit degrees as —312 degrees, he has taken the temperature of boiling oxygen instead of that for boiling air when stating the thing in Celsius degrees. That is to say, he has taken —181.4 degrees C. instead of —191.4 degrees. This is an error to start with of no less than 18 degrees F. His results are stated in Fahrenheit units. If he had worked from the Fahrenheit temperature, which he took correctly, he would have been all right but, instead, he used the French units and then worked them back into English.

This error, however, while regrettable and one which vitiates his results clear through, can readily be corrected for and the experiment recalculated without repeating any of the work. The chief points which I wish to criticise are fundamental in the method.

What occurred when the metal pieces were immersed in the liquid air was not at all a boiling off of air, but of an atmosphere containing but a few per cent. of oxygen, and the heat rendered latent by this occurrence was the sum of the latent heat absorbed by the two constituents, which was quite different from the latent heat of the same weight of air. One might as well endeavor to estimate the latent heat of a mixture of water and alcohol by a method which caused a volatilization only of a fraction of the whole mass and which, in consequence, caused a vaporation of the alcohol out of all proportion to the ratio of its presence in the original mixture.

This serious error would throw out the result or not depending on whether or not the latent heat of nitrogen deviates much from that of oxygen. I am not aware whether it does so or not, but, as Dewar's figure for the latent of oxygen is 144 B. T. U., and as Mr. Dickerson's, when corrected for the error above pointed out in connection with the boiling point of air, becomes, for the latent heat of a mixture of oxygen and nitrogen of indeterminate composition, 129 B. T. U., it will be obvious that there is a probability of a pretty considerable divergence.

Of course, what he should have done was to arrange a method in which the whole of the liquid would be evaporated or else to measure the amount of heat rendered latent in evaporating any weight of a mixture which could thereafter be analyzed and working the result by algebra against another result from the gasification of a mixture of oxygen and nitrogen of widely different (and known) composition.

Respectfully yours,

Ernest A. Le Sueur.

ON THE SEPARATION OF THE CONSTITUENT GASES OF LIQUID AIR—DISTILLATION OF THE GASES—WORK OF COMPRESSION—COST OF POWER.*

BY PROF. RAOUL PICTET AND MORITZ BURGER.

It will be our effort in this paper to impress our hearers with the true value of the process by which liquid air has been produced. To make the subject clear, we will give a brief description of the process and the original primitive apparatus.

The present process for liquefying air in quantity and at low cost presents many valuable features for consideration, and is the one along the lines of which past efforts have been principally directed.

It consists, in brief, of compression of the air, cooling after compression by water coolers, and expansion of this compressed and cooled air in a countercurrent, or self-intensifying, apparatus, wherein the cold expanded air flows back over the incoming stream of compressed air and serves to refrigerate or intensify itself down to the critical temperature of liquefaction.

All previous apparatus constructed upon this principle have lacked in one essential feature, namely, insulation against atmospheric heat. The importance of this feature does not seem to have been appreciated, as it has been customary to coil up the tubes forming the apparatus in any convenient or compact form, without regard to protection of the point of critical temperature.

Obviously, when we are dealing with great extremes of temperature, insulation becomes of vital importance, viewed from the point of efficiency or economy. In past practice this lack of insulation has been overcome by the application of increased refrigeration, secured by greater expenditure of power, resulting, in all instances, in excessive cost of production of the necessary low temperature for the liquefaction of air.

In this primitive condition the art languished, until it was conceived that the point of critical temperature could effectually be protected, or insulated, from atmospheric heat by its isolation within the surrounding coils, and by the outrunning refrigerating streams of cold expanded air, whereby the radiant atmospheric heat would be intercepted and carried outward.

The direct or immediate application commercially of this new process of producing low temperatures lies in its value for the separation of the several gases or components of atmospheric air and making them available commercially.

First, it is necessary to consider the laws of nature, which dominate all gases and vapors. The exactness and value of these laws are comparable with those of astronomy. In our case, we simply apply them to atmospheric air. All vapors, compressed at a certain temperature, rise in pressure to a certain limit, which cannot be exceeded. This limit represents the maximum tension of the vapor. Beyond this limit any change of volume is accompanied by a condensation of the vapors or an evaporation of the gas previously condensed.

The phenomenon of the transformation of the nature of two mixed and compressed gases shows a special character if the liquid obtained out of every

* From address delivered before Franklin Institute.

one of the gases dissolves itself in the liquid obtained from the other. The main character of this transformation is the following:

It can be said that, in a liquid which represents a solution of two soluble liquids which can be mixed in all proportions, the liquids and the vapors derived from them will never, at any temperature, show the same proportion of weight of their constituents. Always, and without exception, the more volatile constituents of the liquid mixture will create a vapor richer in weight than that of the corresponding constituents, whatever may be their proportions in the liquid which produces the vapors. Thus we obtain out of a liquid mixture composed of 10 per cent. alcohol and 90 per cent. water, at a temperature of 32° F., vapors which contain 64 per cent. of alcohol and 36 per cent. of water in weight. This law is the basis of all processes of distillation and refining of mixed liquids.

It is entirely applicable to liquid oxygen and nitrogen. Both gases become vapors when being cooled to a temperature of 292° F. below zero, but the temperature of liquefaction of one of the gases, the oxygen, under atmospheric pressure lies 25° above the temperature of evaporation of the nitrogen at the same pressure. These two liquids dissolve in any proportion. It may be remembered that the latent heat of evaporation decreases with an increase of the temperature. According to this, liquid air evaporates at a temperature of 317° F. below zero, whereby one pound of liquid air will absorb about 325 B. T. U., while at a temperature of 292° F. below zero, it only absorbs about 305 B. T. U. This reduction allows us to explain, without difficulty, the theory of our process, consisting in the separation of oxygen and nitrogen.

LIQUEFACTION OF AIR.

The atmospheric air consists mainly of four constituents, only three of which have industrial value. The atmospheric air is composed, at a temperature of 60° F., of nitrogen, 79 to 80 per cent. in volume; oxygen, 21 to 20 per cent. in volume; carbonic acid, from 3 to 50 per 10,000; and watery vapor, about 29 per 1,000 in volume. The problem of the separation consists of the following parts:

First—Perfect extraction of the watery vapors before further operation. The same would offer many obstacles to the successful operation by its liquefaction and its freezing.

Second—Extraction of the carbonic acid, which freezes in form of white snow at a low temperature of the gases.

Third—Liquefaction of the snow purifies quantity of air.

Fourth.—Distillation and refining the liquid atmospheric air, collecting the oxygen and the nitrogen in different separate gas holders.

Here is may be mentioned with special emphasis that there exists a fundamental difference between distilling, in our sense of the word, and the general conception of that term. If we distill alcohol, in industry, we introduce it in a liquid form into the apparatus, and after the process we regain it again in liquid form, in which state it is used for commercial purposes. During the process we introduce heat, thereby converting the liquid to vapors, which are afterward liquefied by condensation.

In our process it is the exact reverse. We take air in a gaseous state and reduce it to a liquid and again evaporate it, in the form of separated constituents, into different gas holders, from where they may be taken for the numerous industrial applications. During the process we cool the gases instead of heating them. This is, so to say, a reversed distillation, but the functions follow the same laws.

The atmospheric air enters first a filter wherein all dust or foreign matter is removed. This filter purifies the air and delivers it to the compressor, which can be driven by any available source of power. The compressed air then enters a cooler under a pressure of from thirty to 150 pounds per square inch. There it is cooled to about 40° F. below zero. This cooler contains a solution of calcium chloride, which condenses the entire amount of moisture out of the air. After leaving this cooler, the compressed air enters the heat interchanger. This is a very important part of the system. In the interchanger the compressed air is cooled to the temperature of the liquid air by interchanging the temperature of the cold gases of evaporation with the temperature of the incoming stream of new air. The heat interchanger consists of three divisions. It is a tubular apparatus, in which a counter-current of the gases is produced. In the first part, the cold nitrogen, arriving from the separator, flows through a system of parallel tubes, on the outside of which compressed air circulates. In the second part, the nitrogen of the first series is replaced by a mixture of oxygen and nitrogen, which does the cooling of the compressed gases in this part.. Finally, in the third part, we have pure or industrial oxygen in the tubes, for interchanging the heat.

The quantity of the separated gases coming from the separator is in weight equal to the quantity of the mixed and compressed gases before entering the separator. By giving the heat interchanger enough cooling area a perfect interchange of heat can be secured, provided the losses through radiation and conduction of heat are a minimum.

SEPARATING THE GASES.

The compressed and cooled gases enter the separator at a temperature of about 310° below zero. This apparatus consists of a series of parallel and horizontal trays. Each tray is provided with a flat spiral coil. All these coils are connected between one another, and form, thus, an enormous coil, starting at the top and ending at the bottom of the apparatus.

The liquefier or separator can have any number of these trays—ten, fifteen, twenty, or even more, if a great purity of the separated gases is required. Each tray of the apparatus is connected with the next lower one by means of an overflow. All trays are filled with liquid air. The compressed and cooled air in the tubes lying on the trays, and bathed in liquid air, will liquefy. This liquid air has a milky appearance, as it contains carbonic acid in the solid state. We purify it with filters located at the top of the apparatus. This liquid, as it emerges from the liquefying coil, is purified by filtration, on its way to the trays of the separator. The filtered liquid air then falls by its own weight from the top downward, from tray to tray, to the bottom of the apparatus.

During the passage of the liquid air from the top to the bottom, the entire separation of its constituents, oxygen and nitrogen, is effected. At the same time the necessary supply of liquid air for maintaining the process is continually replaced, and even increased, by an additional amount of work. In effect, the compressed atmospheric air liquefies in the coil under a pressure of from thirty to

150 pounds per square inch, at a perceptibly higher temperature than that of the liquid air which surrounds the coil, and which boils under atmospheric pressure.

As formerly explained, the latent heat of evaporation of the liquid air is smaller under higher pressure than under atmospheric pressure. The higher, therefore, the pressure in the coils, the greater will be the amount of air liquefied, with a correspondingly great amount of liquid air evaporating on the outside, under atmospheric pressure. Under all conditions, the amounts liquefied and the amount evaporated will at least be equal. The constant precipitation of liquid air from the coil into the upper part of the apparatus maintains a continuous supply upon all the trays, equaling the already evaporated quantity of liquid air. The process is automatically regulated by the pressure.

The gases evaporated on the first upper tray will be pure nitrogen, because the nitrogen is a great deal more volatile than the oxygen, and the ratio of its weight to that of oxygen is as four is to one. It may be interesting to note that the nitrogen evaporating on the upper trays of the separator has a purity of from 99 to 99½ per cent. In order to collect this gas, it suffices to connect the upper trays with the heat interchanger, and to lead the nitrogen gas from there to the gas holder.

If the amount of the evaporated nitrogen is great enough to diminish the ratio of the gases in the remaining liquid, the proportion of oxygen to nitrogen will be such that the gases evaporated on the next lower trays will begin to show some traces of oxygen.

In the central trays, and especially nearer to the bottom, the evaporated gases will become richer in oxygen. If four-fifths of the original liquid air is evaporated, the remaining oxygen will have a purity of 85 per cent. If nine-tenths of the original liquid air is evaporated, the oxygen evaporating from the last trays will be of 90 per cent. purity. The last twentieth of the original liquid can be considered to be chemically pure oxygen, and may be applied to all purposes to which chemically pure oxygen, hitherto produced in laboratories only, is applicable.

It is obvious that the gases, which, after leaving the separator represent a mixture of oxygen and nitrogen, not applicable industrially, have to be led to the heat interchanger, in order to give up the quantity of energy represented by their low temperature, from whence they may be allowed to escape. However, as soon as the gases evaporating from the last trays are rich enough in oxygen, they will be collected in the gas holder, from where they may be distributed for general use.

It is possible to manufacture this gas in two different qualities, namely, industrial oxygen and pure oxygen. Pure oxygen will always be derived from the final evaporation of the last twentieth of the total liquid. Industrial oxygen can be accumulated after the evaporation of the first two-thirds of the total quantity of the liquid.

The apparatus is constructed so that any particular tray may be connected with any particular gas holder by means of the mere application of simple clapper valves, governing the connection between the trays and gas holders, and between the different trays themselves.

We start with the collection of nitrogen almost perfectly pure; then we will find in the evaporated gas of each successive tray certain quantities of oxygen, which will increase continually toward the bottom. Up to the evaporation of the first half of the original liquid, the total loss of oxygen will not exceed one-fifteenth of its total weight. After the evaporation of the first two-thirds of the original liquid, the evaporation of the oxygen will increase constantly, and with remarkable rapidity.

It is easy to increase the quantity of the chemically pure oxygen obtained in this apparatus, if desired. For this purpose, it suffices to lead the gases evaporated on the trays back to the compressor as soon as they contain over 21 per cent. oxygen. The ensuing liquid is thus much richer in oxygen, as it again enters the separator. To accomplish this, it is only necessary to connect the gasometer, containing industrial oxygen, with the suction inlets of the air compressors. This we call a compound process, which can, of course, be applied for the manufacture of chemically pure nitrogen.

The carbonic acid is collected in duplicate filters, which may be interchanged at intervals during the operation, without interference. Their construction is quite peculiar, and would require too much time to describe in detail. It need only be mentioned that they extract all the carbonic acid out of the air.

If it is desired to increase the quantity of the carbonic acid thus collected, this can be accomplished to an extent amounting to 1 per cent. of all the air treated, by pipe connection from the inlet of the compressors to the chimney of the power plant, or any other chimney under which coal is burned. The ascending gases in chimneys are very rich in carbonic acid, and mix freely with the outer atmospheric air, and the percentage can, in this manner, be materially increased. This fact is of great importance, as carbonic acid is a product of enormous commercial value.

It is possible to connect any number of trays with one single gasometer during the operation, and control, in this manner, the quality of the collected gases. An arrangement of electric lamps and windows in each tray will permit of regulation by observation. This apparatus for the separation of the gas mixtures can be made of any material, and in different forms, particularly in connection with a system designed to effectually exclude the radiation of heat from the surrounding atmosphere.

COST OF MANUFACTURE OF THE GASES.

The many experiments which have been made up to the present time permit us to state that air can easily be liquefied in all quantities in an apparatus built according to the foregoing principle, under a pressure of fifteen pounds per square inch. If we consider the results of experiments made as a basis, and take into consideration the friction, the clearance and all imperfection of valves, and all other losses unavoidable in gas compressors, we can accept that we may compress our air to twenty-five pounds, instead of fifteen, which, as before mentioned, would suffice.

Under these conditions, the work necessary for the compression of one cubic foot amounts to exactly 2,038 foot-pounds. Although this work is accepted as excessive, we can calculate that the minimum volume of compressed and liquefied air in a 500-horse power plant will be 8,000 cubic feet per minute.

This will result, in an operation of twenty-four hours, in the liquefaction and distillation of air of 11,500,000 cubic feet. The distillation of this quantity of atmospheric air will result, according to previous experiments in 5,300,000 cubic feet of industrial nitrogen, and 3,550,000 cubic feet of industrial oxygen. The quantity of carbonic acid varies, according to the topographical conditions, and to the desire of the manager, between 520 and 5,200 pounds in twenty-four hours.

COST OF POWER PRODUCTION.

Experience in the electric industry indicates that plants of 500 horse power are of satisfactory efficiency. The statistics show that the work of steam plants in the vicinity of seaports and large industrial centers in general costs one-third of a cent per horse power hour. In this cost are included all expenses of the power plant, such as depreciation, operation, coal, wages, illumination, oils and small details. This cost of one-third of a cent per horse power hour is in many cases high, especially if triple expansion engines are applied. We accept this cost, however, in order to be conservative. The operation of a 500-horse power steam plant would, therefore, cost in twenty-four hours, $24 \times 1 \times \frac{500}{3} = \$40$. To this cost of operation we have to add the special expenses caused by the operation of the separating apparatus and manufacture of carbonic acid. These are:

First.—Wages of the necessary attendants. Two men suffice, if continually present, for the whole operation. One mechanic, day and night, $6. One laborer, $4.

Second.—Maintenance of coolers, small details, and necessary repairs, $6.

Third.—Depreciation. The initial cost of construction of the complete apparatus for separation of the oxygen and nitrogen will amount to $25,000. Depreciation of 10 per cent. per year will amount daily to $8.

Fourth.—Incidentals, $10; or a total of $74.

Seventy-four dollars will, therefore, cover the cost of production, operation and depreciation of all materials. With this daily expenditure we can produce, then, 3,550,000 cubic feet of industrial oxygen, 5,300,000 cubic feet of industrial nitrogen, and 3,000 pounds of carbonic acid.

ON THE LIQUEFACTION OF AIR BY DYNAMICAL ACTION.

BY PROF. J. E. DENTON, M. E., '75.*

It is now known, through the labors of several European physicists, that air as it exists in the earth's atmosphere is a superheated vapor of a liquid, whose boiling point under atmospheric pressure is 312 degrees below the Fahrenheit zero of temperature.

Thus if *Ao* (Fig. 279) represents the cubic feet occupied by a pound of liquid air at atmospheric pressure, in order to put the substance in the condition of natural air at, say, 60 degrees Fahr., the liquid must be conceived to be evaporated as a saturated vapor until it occupies the volume *Ag*, at the constant temperature

Stevens' Indicator.

of—312 degrees, and to then be further expended to the volume *AD* by superheating the vapor to 60 degrees. To generate the vapor, or to produce the increase of volume *Og*, would require heat to be supplied equal to the "latent heat" of evaporation, which rough experiments shows to be about 160 British thermal units. To produce the increase of volume *gD* would require an amount of heat equal to 0.238 [60—(—312)]=89 British thermal units, if the mean specific heat of the air over a range of temperature so low was the same as for its natural conditions. The mean specific heat may be greater than 0.238, so that 89 units may be less than the heat necessary to affect the superheating effect.

If the pound of liquid air is put under a pressure of 10 atmospheres, and then heated, it will not begin to vaporize until some higher temperature than—312 degrees is created, as, say,—275 degrees. This may be conceived to increase the volume of the liquid, as in the case of other substances. Then if the liquid was all vaporized its volume would be increased by o_1g_1, and the latent heat to affect this would be less than that for atmospheric pressure vaporization in the proportion of o_1g_1 to $o\ g$. As the pressure under which the vaporization occurs increases, the liquid volume becomes greater, and the vapor volume less, so that finally there is no difference between them. We do not know the relation of the temperatures and volumes of the vapor and liquid below 39 atmospheres, but physical investigation has determined that the vapor and liquid volumes become identical at 39 atmospheres, and that the temperature is then—220 degrees.

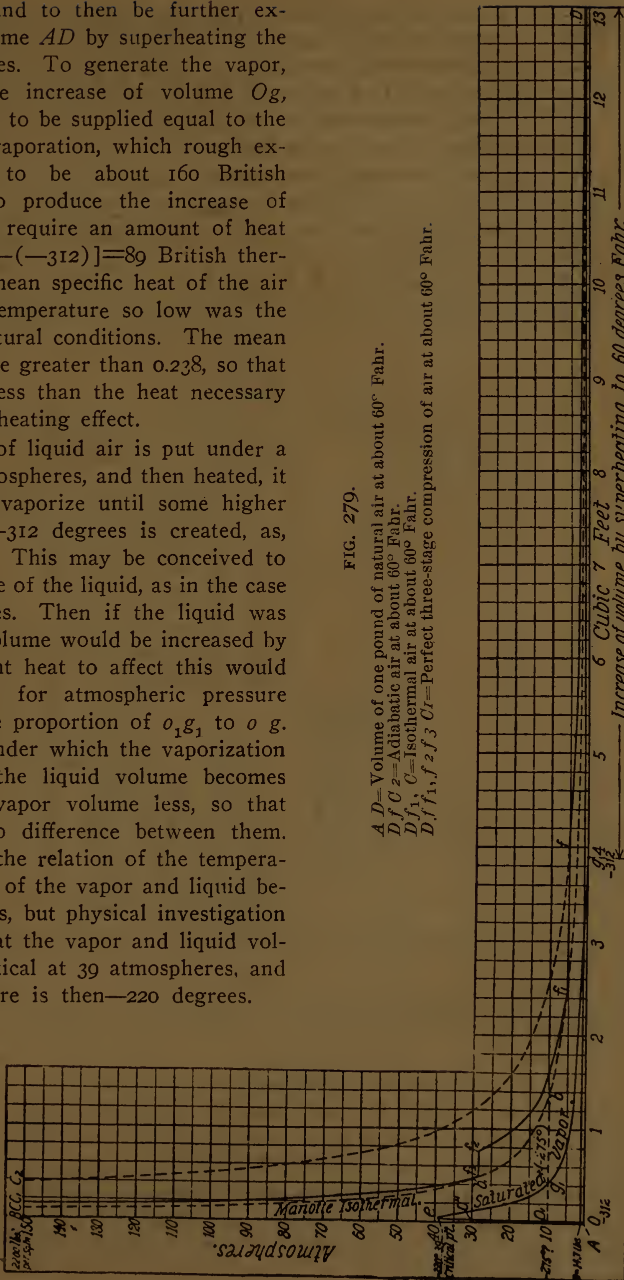

FIG. 279.

A D=Volume of one pound of natural air at about 60° Fahr.
D f C 2=Adiabatic air at about 60° Fahr.
*D f*1, *C*=Isothermal air at about 60° Fahr.
*D f f*1, *f* 2 *f* 3 *C*1=Perfect three-stage compression of air at about 60° Fahr.

At this temperature air must occupy the volume at *e* if its pressuee is 39 atmospheres or greater, and it may then be considered to exist either as a gas or a liquid. The slightest addition of heat will make it a super-heated vapor, and the slightest abstraction of heat will make it a liquid. This temperature is therefore called the "critical temperature" of the substance.

If, therefore, natural air is compressed from the volume *AD* to, say, 150 atmospheres, and then stored in a reservoir at 60 degrees, so that its volume will be *BC,* and if then the pressure is maintained constant, and sufficient heat is abstracted to more than cool the air to — 220 degrees, it will pass into the liquid condition.

Experiments by Mr. C. E. Tripler in New York, and Dr. Linde in Munich, have shown that the necessary abstraction of heat to cool highly compressed air

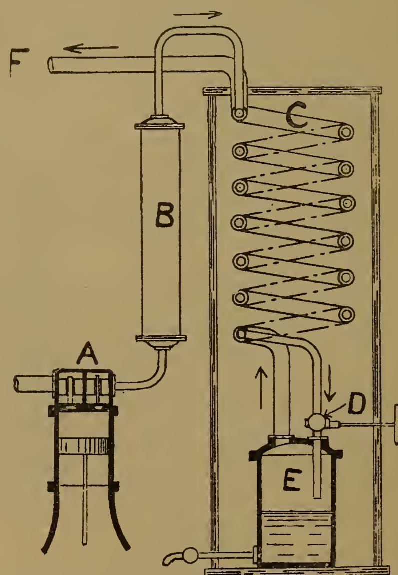

FIG. 280.—DR. LINDE'S APPARATUS FOR OBTAINING LIQUID AIR.

from ordinary temperatures to its critical point or possibly lower, can be accomplished by the dynamical effect resulting from the flow of air through a small orifice connecting a reservoir at high pressure with one at a much lower pressure.

Dr. Linde,* and his collaborator, Prof. Schroeter,† of Munich, have published sufficient details of their work to enable the results to be scientifically studied. Linde's apparatus is outlined in Fig. 280. A compressor *A* delivers air from the atmosphere to a reservoir *B,* where it is cooled to ordinary atmospheric temperature The air also fills the inner of the two coils *C,* and is maintained at a constant pressure therein, while flow occurs through a throttling cock *D* to the chamber *E,* which is maintained at a lower pressure by allowing the expanded

**London Engineer*, *1896*.
†*Zeitschrift des Vereines deutscher Ingenieure*, Vol. XXXIX.

air to escape through the outer of the coils *C*. In an experiment in which the higher and lower pressures were 220 atmospheres and 1 atmosphere, respectively, the temperatures were distributed as shown in Fig. 281. Curve No. 1 shows the temperature of the air leaving *B*. Curves No. 2 and No. 3 show its temperature at the high and low sides of the throttle *D*, respectively, and No. 4 shows the temperature of the gas leaving the apparatus at *F*. Liquefaction commenced at about the fifth hour of operation.

It is evident from the curves of Fig. 281 that the flow of the air through the expansion cock causes a permanent cooling of the air greater than the radiation and friction losses of the apparatus, and that this cooling effect being applied to reduce the temperature of the air flowing to the throttling cock continually *increases* the permanent fall of temperature due to the flow through the cock. The second column in Table 1 shows the cooling effect due to the flow in Linde's experiment.

TABLE 72.

Temperature approaching cock. Degrees Fahrenheit.	Fall of temperature by flow through cock. Degrees Fahrenheit.	
	Experiment.	$\delta=0.5\,(p_1-p_2)\left(\frac{461}{\tau_1}\right)^2$
+30	35	97
0	65	110
— 30	80	125
— 60	96	132
—100	112	179
—150 Liquefaction commenced	135	240

The proportions of the coil *C* show that the air escaped with a velocity of about 40 feet per second, which is neglectable in its influence upon the temperature of the air after expansion. The permanent cooling effect is, therefore, attributable to the imperfectly gaseous nature of air, which causes some of the fall of temperature due to the adiabatic expansion governing the flow, to be absorbed in internal work. This cannot be reconverted into temperature like the external work of the expansion, when the velocity of the gas subsides. The possibility of permanent cooling due to the imperfect gaseous nature of air, for flow through a throttling cock, was shown by Thomson and Joule, in 1854. They gave as its measure in degrees Fahrenheit:

$$\delta=0.5\,(p_1-p_2)\left(\frac{461}{\tau_1}\right)^2$$

p_1 and p_2 are given in atmospheres.

τ_1 = absolute temperature of air at high pressure side of the expansion cock.

This formula is the empirical expression of experiments in which $p_1 - p_2$ did not exceed seven atmospheres, and τ_1 was not less than the equivalent of 32 degrees Fahr. The amount of permanent cooling which it would give for the Linde experiment is shown in the third column of Table 72. The formula can hardly be expected to hold true quantitatively for such abnormal pressures and

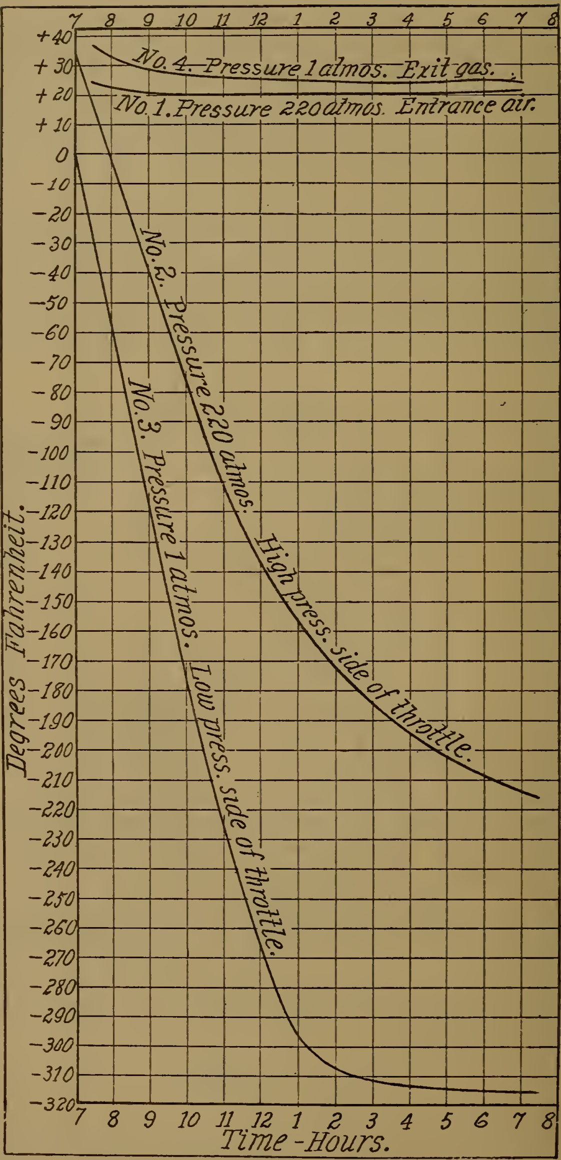

FIG. 281.—DISTRIBUTION OF TEMPERATURES.

temperatures as are concerned with the liquefaction of air, but it suffices to account for the existence of a tangible amount of permanent cooling effect due to the flow of the air through the throttling cock in Linde's apparatus, and for the increase in this cooling effect as the temperature of the air at the high side of the throttle was reduced. It appears that the actual cooling effect as the temperature approached the critical point was about 55 per cent. of the value of δ given by the original formula. This would make $\delta = 0.27\ (p_1 - p_2)\ \left(\frac{461}{\tau^1}\right)^2.$

The continuous operation of the apparatus finally results in cooling the air at the high side of the cock to some temperature t_1 which is, say, above the critical temperature t_c when liquefaction commences. Then if the substance remain homogeneous the process of liquefaction might be as follows:

Adiabatic cooling by the flow through the cock reduces the temperature to the critical point, without reducing the pressure to the critical point, and all the air is liquefied. Then as the pressure continues to fall in the jet the temperatur of the liquid follows saturated vapor laws, and consequently the release of heat from the liquid causes vaporization, and since at the critical temperature the heat of the liquid is equal to the total heat of vaporization, and the latter may be supposed to increase slightly with pressure—the whole of the liquid will be vaporized to the saturated condition of the lower pressure, and then superheated to the amount of the difference between the total heat of evaporation for the critical temperature and the lower pressure, respectively. There will also be some superheating effect due to the actual energy of the initial adiabatic flow before the air is reduced to its critical temperature.

Now if the cooling effect δ due to the flow, acts, and is more than sufficient to annul the superheating effect, some of the superheated vapor will be liquefied and the resulting mixture will be at — 312 degrees, the boiling point for atmospheric pressure. This mixture can now act on the air above the throttling cock and cool it to the critical temperature, thus liquefying it before it flows through the cock. Then the release of heat from the liquid will vaporize and superheat as before, but the δ cooling effect will possibly condense a greater proportion of the air to liquid, as the lower temperature at the high pressure side of the throttle may have increased δ.

By the continued action of these conditions liquid can either be drawn off from the chamber E, or made to liquefy other air confined in a separate vessel lodged in E, or located in the midst of the coils C so as to share with them the effect of the return current from E. The separate liquefying vessel may theoretically be at any pressure, and the liquid in it be cooled so nearly to — 312 degrees that it can be collected in a receptacle under atmospheric pressure without practical loss from vaporization. Theoretically, also, the temperature t_1 at the high side of the throttling cock might be reduced so far below the critical temperature by the return action of the mixture of vapor and liquid from E, that the evaporative action from the release of heat from the liquid in flowing through the throttling cock would be exactly neutralized by the cooling effect δ. All of the air would then arrive in E as a liquid, but the portion of this which could be withdrawn, or used to liquefy other air, would be due to the cooling effect δ, the remaining portion being re-evaporated in the return action to effect the cooling of the liquid above the throttle below the critical temperature t_c. In the German experiments the temperature above the throttling cock appears to have not been reduced below t_c.

The amount of liquid permanently producible being dependent upon the cooling effect δ, the algebraic expression of thermal relations according to above hypothesis would be as follows:

Assuming steady liquefaction to be attained,

t_o = temperature of air entering apparatus.
t_1 = temperature of air on high pressure side of throttle.
t_c = critical temperature.
t_2 = temperature of air on low pressure side of throttle.
p_1 = high pressure, atmospheres.
p_2 = low pressure, atmospheres.
r_3 = latent heat of liquid air at p_2. B. T. U. per lb.
λ_1 = total heat of liquid air at p_1. B. T. U. per lb.
λ_2 = total heat of liquid air at p_2. B. T. U. per lb.
a = Superheating due velocity of flow before t_1 becomes reduced to t_c. B. T. U. per lb.
R = losses by radiation, friction and escape of air at less than t_o. B. T. U. per hour
W = weight of air compressed per hour.
w = weight of air liquefied per hour.
C_1 = specific heat of air between t_o and t_1.
C_2 = specific heat of air between t_1 and t_c.
C_3 = specific heat of air between t_1 and t_2.

Then the whole cooling effect available is $WC_3\delta - R$, which must cover:

1. The cooling of all the air from t_o to t_1 or $WC_1\ (t_o - t_1)$ B. T. U.
2. The cooling of the whole air from t_1 to t_c or $WC_2\ (t_1 - t_c)$ B. T. U.
3. The condensation of w pounds of vapor superheated, $\lambda_1 - \lambda_2 + a$ thermal units above saturated condition at t_2, or $w\ [a + (\lambda_1 - \lambda_2)] + wr_3$ B. T. U.

Hence, $WC_3\delta - R = WC_1\ (t_o - t_1)] + WC_2\ (t_1 - t_c) + w\ (a + \lambda_1 - \lambda_2 + r_3)$

$$\frac{w}{W} = \frac{C_3\delta - C_1\ (t_o - t_1) - C_2\ (t_1 - t_c) - R}{a + \lambda_1 - \lambda_2 + r_3}$$

Let $p_1 = 220$, $p_o = 1$, $t_o = 32$, $t_1 = -200$.

$$\text{Then } \delta = 0.27 \times 220 \left(\frac{461}{461 - 200}\right)^2 = 185° \text{ Fahr.}$$

$$\frac{w}{W} = \frac{185\ C_3 - 232\ C_1 - 20\ C_2 - R}{a + \lambda_1 - \lambda_2 + r_3}$$

If $C_1 = 0.33$, $C_2 = 0.4$, $C_3 = 0.5$, $r_3 = 160$, and $a + \lambda_1 - \lambda_2 = 10$. Then $\frac{w}{W} = \frac{7 - R}{170}$.

If $R = 3$, or about 3 per cent. of the cooling effect $WC_3\delta$, then $\frac{w}{W} = \frac{1}{42}$.

This was the ratio of weight of liquid to weight of air compressed in the experiment to which Fig. 281 refers. The air to be liquefied was in this case confined in a separate vessel in the chamber E at about three atmospheres. The weight of air compressed per hour was about 85 pounds.

In another experiment about 65 pounds of air were compressed per hour to 190 atmospheres, and one-thirty-fifth of it liquefied and withdrawn directly from E. Liquefaction commenced in two hours, the weight of the coils being only about one-ninth of those used in the other experiment, so that less time had to be devoted to cooling the weight of the apparatus.

Analysis of the liquid product showed it to contain an excess of oxygen in both cases. Therefore the air does not remain a homogeneous substance, and this fact, together with the absence of any exact knowledge of the specific heats, and of the true value of the peculiar cooling influence δ, makes any attempt to calculate $\frac{w}{W}$ from thermodynamic laws a very rough approximation.

LIQUID AIR AS A MEANS FOR THE MANUFACTURE OF OXYGEN.*

BY HENRY MORTON, PH. D., SC. D., LL. D.

Readers of the *Indicator* may remember that in the numbers for April and July of 1899, beginning on pages 113 and 239, there were published two articles by the present writer in which the extravagant claims which had been brought before the public for "Liquid Air" as a source of energy, were discussed and disposed of.

Since that time, until recently, those interested in the promotion of companies which propose to establish a business on the manufacture and use of liquid air as a foundation, have not been prominently before the public.

Quite recently, however, extensive advertisements and circulars have brought the subject into notice along new lines.

Though the language of these is largely indefinite or ambiguous, yet it does not seem that the former fallacies have been definitely repeated, though they are in a way hinted at, but the merits of the scheme are now proclaimed in relation to a possible use of the liquid air process as a means for the production of cheap oxygen gas.

Air, as of course all know, is substantially a mixture of four parts of nitrogen with one part of oxygen, and when liquefied in the usual way this proportion is substantially maintained in the liquid. As the liquid evaporates, however, the nitrogen escapes much faster than the oxygen, and thus after a time what is left will be mainly oxygen, the nitrogen having escaped or been driven off, or, as we might say, distilled. If then we pass a stream of liquid air continuously into a vessel in which evaporation is allowed to take place, we will in time find said vessel to be filled with substantially pure oxygen.

If this was all and no effort was made to utilize the cold of the evaporation of the liquid air such a process would be very costly. Mr. Tripler's figure for the cost of liquid air, it will be remembered, was 20 cents a gallon, and five gallons of "liquid air" would be needed to produce one gallon of oxygen, or in other words, each gallon of liquid oxygen would cost one dollar.

This gallon of liquid oxygen would on expanding to atmospheric tempera-

* *Stevens Institute Indicator.*

ture and pressure, give about 104 cubic feet, or roughly, each cubic foot of oxygen would cost one cent, or, a thousand cubic feet would cost $10.

It is, of course, obvious that by employing "regenerative processes" by means of which the cold from the escaping nitrogen and also that from the vaporizing oxygen was transferred to the air which was being liquefied, the cost of manufacture could be greatly reduced.

What that reduction would be there are, as yet, I believe, no data for computation, but it would without doubt be considerable, so that it would seem probable that as compared with the chemical methods heretofore in use for the production of oxygen, this new one would be decidedly cheaper.

The question which next presents itself is what shall we do with the cheap oxygen when we get it? This question is more difficult to answer. The present uses for oxygen are very limited, being chiefly for lime lights used in theatres and for stereopticon exhibitions and in some refined processes in metallurgy, such as the working of platinum the amounts used for these purposes would obviously be quite inadequate to support a large business.

In view of this the "promoters" have naturally turned to the suggestion that oxygen might be used as a substitute for air in ordinary processes of combustion, as under steam boilers, in iron furnaces and the like. In this case the quantities required would be amply great, but here another difficulty presents itself. The cheap oxygen will here encounter the yet cheaper "free" atmosphere as a competitor, and in that connection the cost of storage and transportation would be prohibitory.

For example, it has been suggested that if coal burning under the boiler of a steamship was supplied with oxygen in place of air there would be a saving due to the fact that the heat carried up the funnel by the nitrogen of the air would be retained if oxygen only was fed to the fuel. This saving has been, we think, incorrectly estimated at so high a figure as 40 per cent.

The most conclusive way to test the value of such a suggestion is to reduce it to a concrete case with actually calculated proportions of parts, volumes and weights, as for example, in one of our Atlantic steamers.

To begin with, every ton of such coal as is used on our ocean steamers would require 2½ tons of oxygen for its combustion,* and if this was carried along like the coal supply, the cargo capacity would be fatally reduced, as regards weight, even neglecting the strong steel cylinders in which the gas would need to be stored, and which would weigh much more than the gas.

As regards bulk also, even if the oxygen gas was carried under a pressure

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* 1 lb. of carbon requires 2.66 lbs. oxygen for its combustion, and 1 lb. of hydrogen requires 8 lbs. of oxygen.

English steamer coal contains about 80 per cent. carbon and 5 per cent. hydrogen; American steamer coal, about 75 per cent. carbon and 5 per cent. hydrogen. Average for both coals, say, 77 per cent. carbon and 5 per cent. hydrogen.

Oxygen for pounds of coal—

For carbon........................	$.77 \times 2.66 =$	2.05
For hydrogen........................	$.05 \times 8 =$	.40
		2.45

or, say, 2½ lbs. oxygen for combustion of each pound of coal.

of 2,000 pounds to the square inch, each ton of coal would require about 500 cubic feet of compressed gas, and as 2,000 tons is a fair allowance of coal to carry one of our large steamers across the Atlantic,† this would mean that about 1,000,000 cubic feet of compressed gas in cylinders would need to be loaded into such a steamer. This volume of gas alone, not allowing for any lost space between the cylinders, would be more than 10 times that of the "bunker" capacity for the 2,000 tons of coal.‡

If the gas was not compressed then each ton of coal would require about 66,000 cubic feet of gas, or for as much coal as would carry a steamer across the Atlantic, 132,000,000 cubic feet. Now as the capacity of the huge gas-holder which is such a conspicuous object in New York City as seen from the Hudson River, is 3,500,000 cubic feet, it follows that no less than 38 such gas holders, or, if one prefers, balloons of equal capacity would need to be towed along by a steamer to furnish it with a full supply of oxygen. This, it is true, does not allow for the assumed 40 per cent. saving of fuel, and with that included only 22 balloons would be required.

To meet the above, it might be suggested that the oxygen should be manufactured as needed on board of the vessel. This, however, would require machinery comparable in bulk and weight with the engines driving the vessel, and, therefore, this suggestion also fails to relieve the difficulty.

Another practical difficulty which at once suggests itself to any one familiar with the combustion of fuels of any sort in oxygen, is the enormous intensity of the temperature produced. A furnace fed with oxygen in place of air would melt down or burn up in short order, not because a pound of coal would yield a greater quantity of heat if burned with oxygen, but because it would develop this quantity with a more intense combustion and so produce a greater and practically destructive intensity of temperature.

The above simple calculations show how utterly impracticable, not to say absurd, is the suggestion that oxygen might be used with advantage in the furnace of a steamer.

We have selected the case of a steamer from those referred to by the "promoters" of the new oxygen process, as involving data easily secured; but it goes without saying that the conditions with a locomotive or any other traveling motor would be substantially the same, and that even with stationary engines the bulk and mass of the oxygen gas to be handled would render its cost prohibitory by reason of the first cost and operating expense of the machines required to produce and manipulate it.

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†Tons of coal required for steamer across the Atlantic. Table in London *Engineering*, 1893, Vol. I., p. 469, gives for the Umbria 1,900 tons. The estimate of coal for the Campania from the same table is 2,900 tons. The St. Louis has bunker capacity for 2,500 tons, *Engineering*, 1895.

‡Space required to store a ton of coal, Kent's Mechanical Engineer's Pocket-Book, p. 170. To store ton of coal, 2,240 lbs. Bituminous coal, 41 to 45 cubic feet. Anthracite coal, 34 to 41 cubic feet.

LIQUID AIR AND ITS USES.

Air is the vapor of a liquid and acts in its properties like the vapor of other liquids; for it liquefies at a pressure of 573 pounds per square inch with the temperature reduced to—220° Fah., and upon gradual release of pressure commences to boil at 294 lbs. pressure with a falling temperature reaching—312° Fah. when the pressure is entirely released, at which temperature it will maintain its stability exposed to the atmosphere for some little time, according to the quantity under trial, and holding its intensely low temperature by its own evaporation until the whole is evaporated.

The critical point for air, or the temperature above which it will not liquefy by increased pressure, has been stated by Prof. Dewar to be —220° Fah. It has been compressed to over 14,000 lbs. per square inch without signs of liquefying at ordinary temperatures, and has been used for blasting rock and coal at 9,000 lbs. pressure.

Its use in physical experiments has been a most important one in developing the action of intense cold on the tenacity of metals, in chemical reaction and magnetic effect under temperatures approaching that of inter-planetary space.

The lowest temperatures as yet artificially produced was obtained in the experiments of Professors Dewar and Wroblewski by the evaporation of liquid air by which a temperature of—346° Fah. was reached, or within 115° of the reputed absolute zero; beyond which, it is claimed, molecular vibration ceases and the chemical action between all substances are in abeyance.

In physical investigation the convenience for obtaining and maintaining intensely low temperatures for a considerable time or sufficient for the manipulation of experiments in physical phenomena is only of recent date, and this has opened the way for the most noted expansion in the paths of physical research.

The action of extreme cold on the tenacity of metals has become a most interesting inquiry, with results greatly contrasting with former theories and tending to show a critical temperature in the tenacity of metals not uniform, but widely varying with their crystalline structure.

Thus with steel, iron, copper, brass, German silver, gold, silver, tin and lead, the tenacity has been found to be largely increased from 60° Fah. to—295° Fah., mostly equal to 50 per cent., and in the case of iron to more than 100 per cent.; while the highly crystalline metals, zinc, bismuth and antimony, lose half their strength at the lowest temperature.

A singular incident is the increase in the tensile strength of the fusible alloy of tin, lead and bismuth of 300 per cent. at this low temperature.

The behavior of a magnet at the temperature of boiling liquid air has been found to be somewhat erratic, owing probably to the difficulties attending such experiments; but with final results of an increase of from 30 to 50 per cent. of its magnetic strength by the extreme cooling process.

In chemical research the field of operation at extreme low temperatures is so new that but few results of a positive character have been reached, owing to the chemical inertness of all the active elements, as with acids and alkalies.

At the lowest temperature yet reached, nitric acid has no action upon metals, and acids and alkalies may be mixed without evolution.

A most curious physical phenomenon is shown in the condition of meats at the extremely low temperature derived from the evaporation of liquid air; mutton becomes so exceedingly hard that it rings like porcelain when struck with an iron rod, and may be crushed into a fine dry powder with a hammer, in which muscle, fat and bone are undistinguishable, but mingled as dry sand.

Prof. McKendrick, in England, has found that microbic life in flesh is so tenacious that it cannot be frozen out, even after exposure to—133° Fah. for four days; that on thawing and raising to normal temperature and moisture, activity of life is at once manifested.

The commercial production of liquid air is a very important discovery, and the future question of economy in motive power may be intimately associated with this liquid. Compressed air, at pressures ranging from 1,000 lbs. upward, is conducted from an air receiver through a small pipe, is refrigerated to expel its moisture, and is then conducted into the apparatus which liquefies it completely, without the use of chemicals of any kind, and it flows from this apparatus in a stream about the size of a lead pencil (in the apparatus of Linde) into a glass insulated receptacle, containing about two gallons. This receptacle was filled in a very short time. Of course, being in an open vessel, liquid air has no pressure, but its temperature is approximately—385° Fahr., or 445 degrees below the atmosphere at 60° Fahr. Inasmuch as it boils rapidly on the surface, owing to its absorption of heat from the atmosphere, it looks like carbonated milk on the surface, but upon dipping some of it out in a glass and observing its color through the glass, it has very much the appearance of ordinary water, and about the same weight. Its temperature is very deceptive, for as it runs from the condenser one may allow it to trickle over the fingers for a short space of time, and it appears to have the atmospheric temperature. The truth, however, of the matter is that it does not come in contact with the fingers at all; the hand being something like 480 degrees warmer than the liquid, it throws the liquid into a spheroidal state and interposes between it and the finger a film of atmospheric air. The sensation is very much like pushing one's hand into a bag of feathers or into a mercury bath, allowing, of course, for the difference in weight between the mercury and the liquid air. If, however, you immerse your hand in the liquid a sufficient time to establish a contact, the flesh would be burned, the same as if it were exposed to 440 degrees of heat, measured above the atmospheric temperature. If a test tube of 1½ inches diameter, having a couple of pounds of mercury in the bottom, is immersed in liquid air, the mercury will be frozen solid in a few seconds, and may be hammered out and otherwise manipulated the same as lead. An alcohol thermometer of large size will be frozen instantly upon being immersed in the liquid.

An idea of the tremendously low range of temperature may be gathered from the fact that it will take several minutes to thaw out the small bulb of this thermometer by covering it with the palm of the hand. It is one of the peculiarities of these substances at these low temperatures, that the surfaces were not sufficiently large to absorb heat fast enough to restore their condition, excepting after a considerable length of time.

A tablespoonful of liquid air poured on about a fluid ounce of whiskey will freeze it at once into flat scales, giving the whole the appearance and color of cyanide of potassium. This may be emptied out on a table, and will remain frozen in that condition for fully five minutes.

One thing that impresses one is that while all molecular motion is practically arrested at this temperature, the odor is perfectly distinct, showing that these particles which stimulate the sense of smell are active and independent of the temperature.

A teacupful of liquid air poured on top of a tank of cold water goes into its spheroidal state instantly, in globules of about half the size of an ordinary marble, which fly around on the surface, leaving a trail of white vapor behind them.

A handkerchief of either silk, linen or cotton, saturated with the liquid, will be charred and destroyed just the same as if it were put in an oven and browned, though no change of color is apparent. Its evaporation is quite slow and it may be carried about for a number of hours in an open vessel without entirely disappearing. It probably represents a compression of about seven hundred atmospheres, and would, therefore, in a confined space, and at 60 degrees temperature, represent a pressure of somewhere from ten to twelve thousand pounds to the square inch.

Liquefying air is not a new thing; it has been performed by exerting enormous pressure or by freezing air to an unusual degree, or by a combination of pressure with refrigeration. There are so many uses to which liquefied air can be put that scientists hardly know where its usefulness will end if it can be produced at a low rate of cost in commercial quantities.

Among other advantages, air in the portable, cheap form of a liquid, as it passes back to its ordinary state, can be used for illuminating purposes by mixing its escaping gases with atmospheric air in certain definite proportions. Moreover, as a driving force in the way of detonators, or explosive material to drive engines, liquid air is obviously a power that can be, under given conditions, profitably applied.

Hitherto the classic example of a method to liquefy air and obtain oxygen has been that invented by Beatty and Cailletet in 1877. With their machine, one began with carbonic acid gas. By means of a pump this gas was condensed in a tube, round which lay water at 10 deg. to keep the tube cool. The carbonic acid gas, being reduced to a very low temperature, passed from the first tube into another chamber with a tube in it, and in so doing fell to a lower temperature. Into this second tube was pumped at high pressure ethylene gas, which, in turn, fell to a low temperature, owing to the coldness of the carbonic acid gas bathing the tube. The ethylene gas was then passed from the second tube into a third compartment and fell further in temperature in so doing. The third compartment had likewise a tube with an air pump attached. Into this third tube was pumped oxygen gas and from the ethylene gas bathing it the oxygen gas reached a temperature of 192 deg. below zero. Finally, the oxygen was let out into a fourth compartment, in which was a fourth tube. The air pump attached to this fourth tube having filled it with condensed atmospheric air, the latter was so reduced in temperature that when it in turn was released from the tube, its cold was 273 deg. below zero, and it appeared in the form of drops like water.

This product, which is called liquid or fluid air, has a milky appearance from the presence of some carbonic acid gas, bubbles constantly, and from its enormous cold emits a smoke or cloud like the top of a very high mountain, and will only gradually resolve itself again into air when exposed to the ordinary atmosphere.

Fluid air costs about 10 marks (say $2.25) for 5 cubic meters reduced. The new method is the invention of Professor Linde, of Munich. It produces the liquid for 10 pfennigs (say 2¼ cents) for 5 cubic meters, and it yields the product either as a gas or fluid, as one wishes. This is one of the most ingenious pieces of mechanism recently known; its chief feature is its economy of

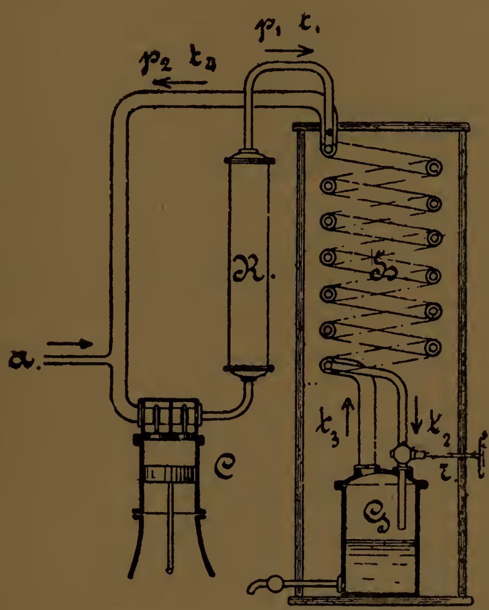

FIG. 282.—THE LINDE METHOD OF LIQUEFYING AIR.

working, for it uses air to refrigerate air. After the pump has worked for a certain time, one turns a cock and the liquid air runs out at a temperature of 273 deg. below zero.

In Professor Linde's method, an air pump of 5 H. P. condenses air to a pressure of 200 atmospheres; this air passes down a spiral tube and is let out in a chamber, causing great cold; then it rises and passes on the outside of the spiral tube, bathing it and thus cooling the new air that has been pumped into the tube to take its place. This cooled air follows on into the chamber, expands and again lowers its temperature, then passes on up around the same spiral tube; but as its temperature has become much lower, the new air in the tube is still further refrigerated. This circulating process goes on, until the new air pumped into the tube reaches the expansion chamber at a temperature of 273 deg. below zero, when it drops into the chamber in the form of liquid. Thus the air, steadily cooled, is made to refrigerate the newly pumped air more and more, until the necessary degree of cold is attained.

Another idea, which may or may not be an improvement, is to have the pump and all parts of the machine kept very low in temperature.

Air in the cheap, portable form of a liquid rich in oxygen can be used for many purposes in manufactures and the trades. The discovery of a cheap method may be of importance to American manufacturers.

We illustrate the ingenious and simple apparatus used by Prof. Linde in Germany for liquefying air by a continuous process in which a recompression of the cold expanded air is carried in a cycle of continually depressing temperature with an inlet of cold fresh air under pressure to compensate for contraction by compression and cold, until a temperature and pressure is reached by which a portion of the air liquefies and is held in the expansion chamber, from which it may be drawn off in a continuous stream, or as wanted.

In the Linde apparatus, as shown in our illustration, cold compressed air at 324 lbs. per square inch is furnished to the apparatus at (a), which establishes through the suction pipe and outer coil, a back pressure in the liquefying flask (G) of about 325 lbs. per square inch.

The compressor (C) is of the kind used for liquefying carbonic acid gas; it raises the pressure from the suction side of 324 lbs. to 955 lbs. on its force side, from which the expansion is obtained for producing the low temperature required in the flask (G).

In subsequent experiments a pressure of 3,000 lbs. per square inch has been used.

The high pressure air pipe enters the refrigerator (R) into a coil immersed in a circulating current of cold brine at about 10° Fah., which reduces the temperature of the high pressure air to about 15° Fah. The high pressure pipe then enters and is enclosed in the exhaust pipe of the apparatus in a coil containing 260 feet of 1½-inch pipe, the internal pipe size not stated, but probably ¾-inch pipe. The small pipe emerging from the large coil at the bottom, enters the liquefying flask with a regulating cock, as shown in the cut. The regenerating coil and flask being enclosed in a thoroughly insulated chamber, the operation may be as follows:

Taking the air from the primary compressor at 324 lbs. pressure and at normal temperature or less by artificial cooling, say to 30° Fah., the high pressure compressor carries the pressure with a third of its previous volume to, say 972 lbs., which will raise the theoretical temperature to, say 520° Fah.

This temperature should be so much absorbed by the refrigerator (R) as to allow at the start of the machine, of a temperature below the normal at the expansion nozzle in the flask. The expansion of the air from 972 lbs. to 324 lbs., say 3 volumes, or 43 atmospheres, reduces the temperature by expansion, theoretically, to about 400° below zero, Fah.; but in consideration that the material of the apparatus is at normal temperature and the specific heat of air being of low degree, a large part of this excessive cold must be absorbed in the material of the apparatus and its insulation, in order to bring the whole apparatus down to a productive temperature. This can only be done by operating the air in a cycle by which the cold produced by expansion in the flask is utilized in the outer coil for reducing the temperature of the air in the inner coil. The time required for cooling the insulated apparatus to the temperature for producing liquid air in the flask was found to be 5 hours; when the machine became a constant producer of liquid air at the rate of six pounds per hour. G. D. HISCOX.

PENN YAN, N. Y., Oct. 6, 1897.

EDITOR COMPRESSED AIR:

I have been intensely interested in the paper "Liquid Air and Its Uses," and also in the account recently published in your columns of experiment with air at high pressures.

I have done some experimental work with air at moderate pressures, but I am not one of the lucky few who can have the liquid article on tap.

Mr. Hiscox's admirable article gives us a great amount of valuable information, but still suggests a great many questions to be asked by a worker who sought to use *liquid air as condensed power.*

First, and probably most important, would be the question, would any development so far met with along this line indicate that natural laws make it possible or practical for us to realize returns in work for efforts expended in producing cold to any such extent as is done with the same amount of effort in producing heat?

Suppose, after having been able to produce or purchase a flask of liquid air I wish to realize upon my investment in work? Naturally one might suppose that if I inject homœopathic doses of it into a closed receiver it would endeavor therein to return to its original volume, and would exert a pressure in accordance with the space allowed it. Does it really accomplish this with sufficient rapidity to generate any considerable pressure? Or will its effort be exactly measured by its ability to absorb or extract heat from its surroundings? This last would seem to be inevitable, and the question will seem to have been unnecessary to those who have the opportunity for investigation. But I believe there are many readers who would like to know something about the action of liquid air in the process of re-conversion backward *under pressure* to the point where it is air again. Very truly yours,

FRANK CAREY.

LIQUID AIR AND LOW TEMPERATURES.*

Probably no other discovery of the last quarter of a century has created such widespread interest and astonishment as the simultaneous liquefaction, by Messrs. Pictet and Cailletet in 1877, of air hitherto considered as a permanent or incondensable gas. This discovery was of little value commercially, however, because of the enormous expense of the product, and therefore, outside of its value as a scientific achievement it was practically worthless. With the recent

*Yale Scientific Monthly.

announcement, however, by Mr. Tripler, of New York, that he can produce this substance in practically unlimited quantities, the value of this product assumes more tangible proportions, as the uses to which this inconceivably cold and extremely volatile liquid can be put are almost innumerable.

The evolution of the production of low temperatures has been gradual yet wonderful in its development. Two hundred years ago when Fahrenheit was striving to produce cold by artificial means for the sake of establishing a zero for his new thermometric scale he boasted that no one could obtain a lower temperature than that which he had produced by a mixture of snow and ice. Since Fahrenheit's day scientists have been gradually probing the depths of temperature. until to-day a point over 400 degrees below the lowest point ever reached by Fahrenheit, has been obtained.

Three methods for producing low temperatures are known. 1st: By the rapid solution of a solid. 2d: By the rapid evaporation of a volatile liquid. 3d: By the rapid expansion of a cooled and compressed gas.

Up to 1820 the first method, that is, a freezing mixture, was used entirely, and in this manner a temperature of 50 degrees below zero centigrade was obtained.

In 1823, Faraday, by combining pressure with refrigeration, succeeded in liquifying all except six of the existing gases, namely, by heating in one limb of a sealed siphon a mixture which evolved the desired gas, and immersing the other limb in a freezing mixture. The gas was thus liquefied in the cold limb by pressure proceeding from its own expansion. Faraday reached a limit, however, in oxygen, hydrogen, nitrogen, nitric oxide, carbon monoxide, and marsh gas. He subjected them to a pressure of 1,000 pounds per square inch, subsequently increased by others to 4,000 pounds, without affecting their liquefaction. Hence these gases were termed permanent, or incondensable gases, because it was supposed that they would remain gaseous under any conditions.

It was not until 1869 when Dr. Andrews, of Belfast, discovered the important fact that unless these gases be cooled to a certain temperature, known as the critical temperature, and varying in different gases as the following table will show, no amount of pressure will liquefy them.

CRITICAL CONSTANTS.

	Temperature in Degrees Centigrade.	* Pressure in Atmospheres.
Hydrogen	—240	13.3
Nitrogen	—146	33.
Carbon monoxide	—140	39.
Oxygen	—119	50.
Methane	—100	50.
Nitric oxide	— 93	71.
Tthylene	+ 10	51.
Carbon dioxide	+ 32	77.
Nitrous oxide	+ 53	75.
Acetylene	+ 57	68.

* The above equals the amount of pressure required to liquefy a gas when cooled to the critical temperature and is known as the critical pressure.

This important discovery created quite a sensation in the "scientific world" and gave a new impulse to the workers in this field of physical research. Chief among these were Pictet, a Swiss chemist, and a French chemist, Cailletet. These two men although working and investigating entirely independent and ignorant of each other, simultaneously announced to the Academy of Sciences on December 24th, 1877, their success in liquefying air. The incredulousness of this discovery to the public may be compared to that of a skeptical African chief, who, having accepted the many reports as related to him by his white visitor, absolutely refused to believe him, when he was told that owing to the intense cold in some countries, the rivers became so solid that people actually walked over them.

Pictet cooled carbon dioxide by surrounding it with liquid sulphurous acid until a temperature was reached at which it liquefied. (Although at atmospheric pressure the boiling point of sulphurous acid is relatively high at reduced pressure it is very much lower.) He then obtained a still greater degree of cold, by allowing the liquid carbon dioxide to evaporate rapidly in an exhausted space. The oxygen was generated in the usual way from potassium chlorate, by heating it in a strong iron retort. In this way a pressure of several hundred atmospheres was obtained. The retort was then surrounded by this liquid carbon dioxide, boiling in a vacuum, and a temperature finally resulted, which liquefied the oxygen.

Cailletet's process was practically the same as the one in use at present. His method consisted in exposing the oxygen, or whatever gas he wished to liquefy to enormous pressure produced by means of a hydraulic press, while at the same time the temperature was lowered, by suddenly allowing the gas to expand. In this manner a sudden disappearance of heat energy occurred, it being absorbed and transformed into mechanical motion. By this method Cailletet succeeded in liquefying hydrogen, a gas whose critical temperature is but 33 degrees centigrade above the absolute zero of temperature, that is, the point where a gas, if it did not liquefy would have zero volume, but as matter is indestructible, it is evident that every gas must liquefy before the absolute zero of temperature is reached. He was unable to collect any of the liquid hydrogen, however, it merely appearing as a mist on the inside of his tube, when the great pressure of 300 atmospheres, to which the gas was subjected, was suddenly relieved. The explanation of this method is that the gas first of all cooled, on account of its quick expansion, because of the transformation of the heat energy into mechanical motion, in temperature below its critical point and then becomes liquefied under the enormous pressure to which it is subjected.

These results by Cailletet and Pictet, and a few years later Dewar, led to the inevitable conclusion that solids, liquids, and gases were but different forms of matter through which any substance could be made to pass by the addition or withdrawal of heat and pressure. It was held that every known substance, that is any of the elements, would behave similarly if heated or cooled sufficiently.

Professor Dewar, of Glasgow, working in the same laboratory in which Faraday so successfully experimented, succeeded in 1883 in liquefying all known gases except hydrogen and fluorine. His method involved practically the same process as that employed by Pictet in 1877, except that he cooled and liquefied ethylene gas, instead of carbon dioxide gas, with sulphur dioxide. Then by means of the liquid ethylene, boiling in a vacuum, he cooled air and other gases below their critical temperatures and liquefied them by pressure, due to their own expansion. To him belongs the credit of first liquefying air in quantity.

Liquefied air and nitrogen were first collected in any desirable quantity by Olzewski, in 1885. Later, by using oxygen as a cooling agent, he cooled a tube containing hydrogen under a compression of 150 atmospheres, to 211 degrees below zero centigrade, and then by further cooling the hydrogen, by allowing the confined gas to suddenly expand to a pressure of only 20 atmospheres, he obtained liquid hydrogen. By boiling liquid oxygen in a vacuum he obtained a temperature of 225 degrees below zero centigrade. By boiling the liquid hydrogen, which he subsequently obtained, in a vacuum, a temperature of —264 degrees C. was obtained, but 9 degrees from that coveted absolute zero of temperature, which scientists have sought for as eagerly as have explorers the North Pole. Olzewski's process was, however, very complex and expensive.

The economical liquefaction of air has only very recently been accomplished by Mr. Tripler, of New York, who has for many years been experimenting and striving to reach this end. His method is what is known as the "self intensifaction of cold," or the method of the expansion of air under pressure. In short, he produces liquid air simply by the expansion of compressed and cooled air, without employing any other substance than liquefied air to bring this about. Mr. Tripler first produced liquid air in 1890 by the same method used by him to-day, only of course with very crude apparatus. His aparatus consisted of a compressor connected by a tube to a coil, containing an inner tube which has a valve at the top. This coil is in turn surrounded by a glass tube 12 in. by 1 3-16 in. diameter open at the bottom. Air under a compression of 2,000 pounds is forced from the compressor through the coil, up through an inner tube, and out a valve at the top. By the expansion of the escaping air, the coil and the inner tube were so cooled, that liquid air trickled down the pipes and dropped out at the bottom of the tube. The plant as it to-day, after eight years of experimenting and testing, consists of a triple air compressor, a cooler and a liquefier. The compressor is of the ordinary form having three pumps upon one piston shaft, working in a line. The first pump compresses the air to 60 pounds per square inch; the second raises this to 750, while the third brings the air under a compression of 2,000 pounds per square inch. After each compression the air is forced through jacketed pipes, in which it is cooled by city water to about 50 degrees Fahrenheit. After the third compression (40 H. P. is used for this compression) it flows through a purifier and thence into what is termed a liquefier. This apparatus consists of a felt and canvas-covered tube, 15 feet long and 1½ feet in diameter, placed about 5 feet above the floor. The interior is full of pipes and coils. These are in two sets, the first of which contains compressed air to be liquefied while the second is filled with compressed air which is to do the liquefying. By means of a valve this air is allowed to escape through a small hole when it rapidly expands and rushes over the first set of pipes greedily licking up all the heat contained in them. Finally after about five minutes, so much heat has been extracted from the first set of pipes that the air in them is cooled way below the critical temperature, and owing to the intense cold and the enormous pressure, this air becomes liquefied. Oftentimes such a cold prevails in the apparatus at this stage, that even the air used to do the liquefying is liquefied and sometimes even frozen. If now the valve in the first set of pipes be turned, liquid air rushes out in the form of a dense white chilly mist as on exposure to the normal air, which is 390 degrees F. hotter than the liquid air, it instantly vaporizes.

Thus Mr. Tripler makes liquid air at a cost of about 20 cents a gallon. It is this fact wherein the value of Mr. Tripler's method lies. The production of liquid air by Dewar in 1885 at a cost of $500 a pint, was hailed by scientists as a very creditable achievement. From this fact a slight idea of the greatness of Mr. Tripler's accomplishment may be seen.

With some of this liquid air produced by Mr. Tripler, Professor Barker, of the University of Pennsylvania, recently performed before the students a very interesting series of experiments. By means of this extremely cold liquid, he froze mercury and alcohol, the thermometric substances. When iron, tin, steel or rubber were dipped in this liquid they became extremely brittle. The tensile strength of metals was found to be vastly greater after immersion in this liquefied air, and in the case of iron this increase reached 88 per cent. In the same manner the electric resistance decreased after immersion, and it is claimed after numerous experiments and profuse calculations, that all metals would become perfect conductors at absolute zero. It is by their practical application of this phenomenon that these extremely low temperatures are measured; namely, by measuring the resistance of a platinum wire before, and after, immersion in the liquid whose temperature is to be measured. Then from these resistances the temperature of the liquid can be calculated.

Perhaps the most startling experiment performed by Professor Barker was the placing by Professor Barker was the placing of an ordinary tea kettle containing liquid over an intensely hot flame. This caused the liquid to boil terrifically and it shot from the spout in straight columns three or four feet into the air. The carbon dioxide generated by the flame froze in a solid layer on the bottom of the kettle which was but a few inches from the flame. When a glass of water was poured into this seething liquid it was frozen solid, although the liquid was at a temperature of 191 degrees below zero centigrade, when the hand was dipped into it a sensation indistinguishable from that of a severe scald was experienced. If, however, the hand were withdrawn immediately, no injury resulted, because the moisture on the hand evaporating, formed a sort of non-conducting cushion. When, however, the hand was not immediately withdrawn it was soon robbed of its protecting cushion, and severely scarred. When this liquid air was poured from the kettle and filtered, to free it from the frozen particles floating in it, the liquid was seen to be of a pale blue color. This liquid was almost pure liquid oxygen as in the previous boiling most of the nitrogen—the other constituent of liquid air—was distilled off, for its boiling point is 13 degrees C. below that of oxygen. From the pale blue color of this diluted oxygen, as it still contains liquid nitrogen, which is colorless, and from the indigo blue color of ozone, that is, condensed oxygen, a theory has been advanced, attributing the blueness of the sky to the oxygen in the air. When phosphorus, for which oxygen at ordinary temperature has a great affinity, is brought in contact with liquid oxygen, no combination and vigorous combustion results, as takes place at ordinary temperature. Should the liquid air be confined in a vessel a terrific explosion would result, as one volume of this liquid air will expand to 748 volumes of gaseous air. If placed in an ordinary open glass flask, or bulb, the liquid air will rapidly volatilize and the moisture in the surrounding air will be condensed and frozen in the form of a shaggy white coating on the outside of the flask. A very suitable receptacle for this liquid was devised by Professor Dewar. This is merely a double globe with a vacuum between, which being a non-conductor of heat prevents the passage of it by convection. Heat is conveyed in another manner, however, namely, by radiation. To prevent this the inside of the outer globe was silvered. It was found that liquid air would last 10 times as long in a silvered Dewar bulb as in an unsilvered one. Another very excellent apparatus for storing liquid air consists of four globes, one within the other. In the first or outer space, between the first two globes, is inserted a mixture of liquid carbon dioxide and ether, which is at a temperature of —110 degrees C. In the second space liquid ethylene is placed, at —160 degrees C. In the third space liquid oxygen or air at —190 degrees, and in the fourth space the liquid air to be stored, also at a temperature of —190 degrees. With this receptacle, although there is considerable loss by evaporation, it is possible to store the liquid air for a reasonable length of time. The uses to which this condensed gas can be put are innumerable. Probably its greatest future use will be as a source of power. It will be extremely valuable for medicinal purposes and surgery. For refrigerating purposes it will be almost indispensable. As an explosive it will rival, and even surpass, nitro-glycerine and dynamite. W. H. SWENARTON.

LIQUID AIR AS A NEW SOURCE OF POWER. ANOTHER ENGINEERING FALLACY.

By President Henry Morton, Ph. D., LL. D., Sc. D.*

During 1894-5 the present writer prepared two articles under the title of "Engineering Fallacies" which were published in this journal, Vol. XI., pp. 273-294, and Vol. XII., p. 125.

Since that time, though several new forms of what might be termed in a general way "Perpetual Motion Schemes" have appeared, none of them has seemed of sufficient importance to warrant any special notice, but in the March number of *McClure's Magazine* there is published an article entitled "Liquid Air —a new substance that promises to do the work of coal and ice and gunpowder, at next to no cost," which is so eminently calculated to mislead the general reader, and even to become the basis of financial frauds, like that of the Keely motor, that it would seem a duty to draw attention to the fundamental errors in scientific principles and in statement of facts which this article contains.

This *McClure* article may be fairly considered as made up of two prominent elements or parts, one of which is the statement of certain things as facts which, as I shall presently show, connot possibly exist and are inconsistent with other facts stated in the same article and known from other sources to exist as so stated; while the other main element consists of rather vague statements concerning general principles which, though in a general sense true, yet as here used are calculated to cover up or befog the too obvious inconsistencies of the statements of facts, with the established principles of science.

* *Stevens' Indicator.*

As an example of the first element, we find on p. 400 as follows: "I have actually made about ten gallons of liquid air in my liquifier by the use of three gallons in my engine." This I shall presently show is simply impossible and inconsistent with data given elsewhere in this article and known to be substantially correct.

A sample of the other element is found in the following: "That is perpetual motion you object. 'No,' says Mr. Tripler, sharply; 'no perpetual motion about it. The heat of the atmosphere is boiling the liquid air in my engine and producing power exactly as the heat of coal boils water and drives off steam. I simply use another form of heat. I get my power from the heat of the sun; so does every other producer of power.' "

This, while true as a general statement of what might be done on an impractical scale, is not correct as here used to imply that in his experiments Mr. Tripler actually derives or can derive any adequate amount of energy from the heat of the atmosphere or in that sense directly from the sun. This I shall show later, but will first take up the statement that three gallons of liquid air have supplied or can supply the power to liquify ten gallons.

On pp. 402 and 403 of the *McClure* article we are told that Mr. Tripler uses to make his liquid air a steam engine of 50 horse-power and that with this he can make liquid air at the rate of 50 gallons a day. This I know from other sources is substantially correct, and means that *each horse-power in a day (say 10 hours) makes one gallon of liquid air.* In other words, one gallon for 10 horse-power hours.

It is again stated in this article on p. 405 that a cubic foot of liquid air contains 800 cubic feet of air at ordinary atmospheric temperature and pressure, or in other words, any volume of liquid air if adequately heated, will expand 800 times in reaching atmospheric temperature and pressure. This also is substantially correct. We may remark in passing that this is nothing wonderful for water when expanded into steam at atmospheric pressure increases about 1,700 times in volume, or more than twice as much as liquid air. If we apply to the above data the well-known and universally accepted formula for the maximum work done by air when expanded at constant temperature,

$$W = p_2 \, v_2 \text{ hyp log} \frac{v_2}{v_1}$$

We find that a pound of liquid air in expanding 800 times would develop about 190,000 foot-pounds of work. As a gallon of liquid air weighs about 8 pounds this would give eight times as many foot-pounds, or 1,520,000. If this work were accomplished in an hour it would represent almost exactly ¾ of a horse-power, because one horse-power means 1,980,000 foot-pounds of work per hour, and 1,520,000 is only a trifle over ¾ of this. From the above, it follows as a matter of *absolute certainty* that the maximum power which liquid air could develop in an *ideally perfect engine* without any loss from friction or other cause would be *¾ of a horse-power for an hour for each gallon of liquid air expended.*

We have seen, however, that with his 50 horse-power plant, which on account of its size, should operate with considerable efficiency, Mr. Tripler *makes only one gallon* of liquid air with 10 *horse-power-hours.* In other words, he requires to make a gallon of liquid air 12 *times as much power* as a gallon of liquid air could *possibly develop* in an *ideally perfect* engine.

In face of this, how supremely absurd is the statement that with a little engine such as the pictures and descriptions in the *McClure* article show, lacking all conditions for efficient working, Mr. Tripler can make 10 gallons of liquid air by the use of three.

Turning next to the statement about using the heat of the atmosphere to develop mechanical energy or work, let us put this to the test of a quantitative example.

Assume the temperature of Mr. Tripler's laboratory to be 70° F. and that he has an abundant supply of water at 50° F. These will be of necessity the limits of work he can get out of the atmosphere, because any lower temperature is only secured by doing work and so expending energy which will be at least equal to the power obtainable from the use of such lower temperature. All the work that can be obtained *for nothing* is that which nature will freely give in the warm air and cool water, supposing both to be supplied freely without charge.

The 20° F. which we may assume as being possibly taken out of the air by the cool water will represent the maximum gift of nature in this shape of "power costing nothing." Now 42 British thermal units, or pounds of water changed 1° F. per minute, will represent one horse-power, and as the specific heat of air is about ¼ that of water, we would need four times as many pounds of air to produce the same effect. This would call for 168 pounds of air changed 1° F. If, however, the air is changed 10° F. in place of 1° F., we need but $\frac{1}{20}$ or 8.4 pounds of air parting with 20° F. each minute, to give us one horse-power at 70° F. For "round numbers" let us say 8 pounds. Now a pound of air has a volume of about 13.3 cubic feet. Call this also "for round numbers" 13 cubic feet, then 8 pounds of air would be about 104 cubic feet, and this volume of air would have to part with its 20° F. heat each minute to the apparatus, in order to develop *one* horse-power. For a 50 horse-power engine 50 times as much air would be required, or 5,200 cubic feet each minute; this would be the contents of a room 26 x 20 feet on the floor and 10 feet high, which would have to be drawn through the apparatus each minute in such a way as to completely yield its 20° F. between 70° F. and 50° F. What sort of a boiler or heat-absorbing apparatus can we imagine which would absorb from air, at 70° F. 20° F. of its temperature while the said air was passing through it at the rate of 5,200 cubic feet a minute? It would surely need to be "as big as a house," to use a familiar phrase.

This also, be it remembered, makes no allowance for loss by friction, eddy currents, and the like which would be enormous, nor for the power to put this air in motion.

Obviously such a machine would be simply huge in size, and indeed the friction involved in it would probably use up a large part of the power it could develop.

Suppose, however, that it could be built and operated in place of Mr. Tripler's 50 horse-power steam plant. Its entire output would be 50 gallons of liquid air a day, and this as we have seen, could only develop in an ideally perfect engine ¾ horse-power for an hour for each gallon or 3¾ *horse-power for a day of ten hours.* This does not look as if heat obtained from the atmosphere and operating an engine by aid of liquid air, was likely to become a dangerous rival to the coal mine.

On p. 402 of the *McClure* article it is stated that Mr. Tripler makes his liquid air at a cost of 20 cents a gallon.

We have shown above that the maximum power obtainable from this liquid air, by heating it to ordinary atmospheric temperature, is ¾ of a horse-power-hour. This at 20 cents would be vastly more expensive than power derived from an ordinary steam engine, whose cost ranges from less than 1 cent per horse-power-hour under the best conditions to 3 or 4 cents, where a profit is included, or the conditions are less favorable.

The really difficult thing to explain in connection with this *McClure* article on Mr. Tripler and his liquid air, is how those concerned in its publication (being as I do not doubt honest men) can be deceived or have so deceived themselves as to make and repeat such obviously impossible statements. In this connection, however, I will make a suggestion founded on experience.

Some years ago I was called upon to examine an engine operated with liquid carbonic acid, which was said to have ten times the efficiency of an ordinary steam engine.

I, of course, told the applicant that such a thing was physically impossible and did not deserve investigation, but finding that a number of substantial people had been so impressed by what had been shown them that they would not be satisfied without an investigation, I consented to make one. This proved an easy piece of work. I found that the promoters and others were under the impression that a horse-power was measured by the raising of 33,000 pounds one foot high *irrespective of time,* and in their demonstrations were contented with showing that their engine did this amount of work in *ten minutes.* As, however, a horse-power involves the raising 33,000 pounds one foot high in *one* minute, it was obvious that the power shown by the carbonic acid engine, was 1-10 of a horse-power and not *one* horse-power, as those exhibiting the engine claimed. This, of course, explained the situation. An engine developing 1-10 of a horse-power might easily require only 1-10 as much fuel as an ordinary steam engine developing 1 horse-power, without violating any of the established laws bearing on this subject. The curious thing was that such people as were concerned in this matter, should have been misled on such a simple and elementary subject; but if they were, as I personally know, so misled, why may not Mr. Tripler and his friends be in a similar case?

I could give from my own personal experience many like examples, but have said enough for the present, to make it evident that what is claimed in this *McClure* article for liquid air as a new source of "power which costs nothing," is not founded on fact, but is probably the result of some oversight in observation or calculation not inconsistent with honesty of intention.

THE POSSIBILITIES OF LIQUID AIR.*

At the outset it must be understood that in dealing with the present subject the writer does not wish it to be inferred that what he calls possibilities are in his

* *Engineering Magazine.*

judgment probabilities of the near future, or, that we are upon the eve of any great revolution in engineering methods as the outcome of the recent laboratory studies of liquid air. Much further study and much additional data are required before anything more than mere suggestion can be made in this fascinating field; for, say what we may, the subject possesses an attraction for those who are accustomed to look ahead, remembering that the laboratory experiments of one day and generation have often in the past become the foundations of great industries. It took three-quarters of a century for Davy's electric arc to develop into the beginnings of commercial arc lighting and nearly fifty years elapsed after Faraday's brilliant researches in magneto-electricity before dynamos became a part of engineering. Yet Faraday had built a primitive dynamo and its reversed form was known in primitive types of electric motor.

Who would have supposed, when ammonia gas was first liquefied by pressure, that before the close of the century companies would be doing business by sending it about in pipes for refrigeration? Yet such is the fact.

The splendid studies in liquid air and other gases carried on by Professors Dewar and Fleming, on the very spot where Faraday had made his memorable researches in the liquefaction of gases, form a fitting sequel to the work of that great pioneer.

The object of the present article will be to suggest rather than predict directions in which, under certain conditions, liquid air may possibly become a factor in engineering. And in the absence of favorable conditions need it be said that such possibilities will not be capable of realization?

Let us assume the availibility of some innocuous gas liquefiable at about one hundred atmospheres pressure, at temperatures easily and cheaply attained, and at no cost for the gas itself. In such a case there can be no doubt of its soon finding enormous application in the storage and recovery of energy. Cheap power would be used to compress and liquefy it, after which it would be stored in quantity, either at atmospheric pressure or at some selected higher pressure. Such a liquefied gas would be stable, or remain in the liquid state, if heat were prevented from reaching it. This could be done, not perfectly of course, by surrounding the containing vessel with a liberal thickness of some good non-conductor of heat. That part of the gas which would inevitably escape on account of the lack of perfect heat-insulation would be cold and would be made to traverse the non-conducting covering in successive layers from within outward, and thus assist in cooling the covering and in preventing access of heat to the liquid; or, the escaping gas might even be made available for power in an engine, if the liquid were kept under a proper working pressure. In this case further heating of the gas, analogous to superheating of steam, could be employed before sending it to the engine. But little of the energy of the heat so added would be lost, and a considerable part of it could be supplied by the surrounding air or by water.

With such a liquefied gas produced at one place by cheap power and carried to another for evaporation and recovery of power, ice could be made as a by-product.

In many plants used for the development of power on a large scale, a twenty-four hours' output is not called for, but could be attained at but slight additional expense. The excess power from such a plant needs some means of ultilization. This excess power, as during periods of otherwise light load, could be employed to liquify the assumed gas. On a large scale this procedure would not be costly, supposing the use of highly developed machinery. The liquid product could then be transported in tanks provided with heavy lagging and special arrangements to prevent access of heat from the outside. Perhaps it could be distributed by a well-covered pipe-line. The unavoidable evaporation which would be involved in the pipe-line transportation might not be altogether a loss, for if the line be under a pressure suitable for engines the escaping gas might possibly be tapped out at intervals, heated, and used for power along the line of way.

But the foregoing considerations are based upon the existence of a gas at no cost, with desirable properties rendering its liquefaction easy. Such a gas does not in fact exist. There then arises the question whether we can render available any of the gases known to us. Carbonic-acid gas is cheap, but still far too costly for use in the way proposed. It would not pay to send it back long distances for recompression and reliquefaction. It costs too much to be thrown away after it has been once used.

The air itself meets the condition of no cost for material in the case. We owe much the larger part of our present knowledge of the properties of liquid air to a brilliant series of investigations undertaken some years ago by Professor Dewar at the Royal Institution in London, and continued later by Professors Dewar and Fleming conjointly. The effects of the exceedingly low temperature attained by the evaporation of liquid air, upon electric conductors, dielectrics, electrolytes, etc., have been carefully studied by them. Few are able to appreciate the labor and painstaking effort that must have been expended in these researches.

In culmination, Professor Dewar has indeed lately succeeded in reducing even hydrogen to a liquid and in collecting quantities of it. Temperatures not far removed from absolute zero (—273 degrees C.) are obtained by the evaporation of liquid hydrogen. But the absolute zero, like the dynamo of 100 per cent. efficiency, may by each advance be more and more closely approximated but never reached. This low-temperature research has shown that at temperatures as low as —200 degrees C., attainable by evaporation of liquid air, conducting metals, as copper, platinum, silver, etc., when in a very pure state, have their conductivities so much enhanced that electric currents flow with but a fraction of the resistance experienced at ordinary temperatures. Research has shown that at absolute zero they would become perfect conductors. Professors Dewar and Fleming also found that liquid air is a very perfect insulator, and that ice and many frozen electrolytes even become excellent insulators at the temperatures of liquid air; and in general that intense cold in insulators improves the insulation, just as it improves the conductivity of conducting-metals when they are pure.

Unfortunately, however, the liquefaction of air requires rather extreme conditions, and in the early work of Dewar was an exceedingly costly process.

The discovery of the fact that air compressed, cooled and collected in a reservoir at from 100 to 150 atmospheres might be made to liquefy a portion of its own volume, rendered possible the procuring of liquid air by a more direct and simple means. This discovery is claimed by several persons, the merits of whose claims will not be here discussed. When highly compressed air escapes from a suitable orifice it is cooled by its own expansion. If the cooled air be now caused to circulate around a long coiled pipe, which brings the compressed air to the jet in such a way that the portion of pipe nearest the jet is the first to be met by the cooled air, and so back progressively from the jet; further, if the whole be thoroughly jacketed by a non-conducting covering, the temperature at the jet soon falls sufficiently low to cause liquefaction of a portion of the air even at ordinary atmospheric pressure. The operation itself is cumulative or self-intensifying, since the cooling due to expansion is employed, on the regenerator principle, to cool most effectively the compressed gas on its way to the jet and ready to expand.

If air be compressed to about 800 atmospheres it may be made to occupy the same space as it does when liquefied, but even at higher pressures it would remain gaseous. Ordinary temperatures of the surrounding air are far above the critical temperatures of the gases composing it. In order that it may liquefy, it must lose kinetic energy or be cooled; the velocity of the moving molecules must be brought down. The removal of heat is essential, and the process of liquefaction can only be carried on by cooling the gas during or after compression. Conversely, liquid air confined in a closed and filled receptacle, when allowed to regain the heat lost in being liquefied, would become gaseous and exert a pressure of about six tons per square inch.

That the processes for producing liquid air will be developed so as to reduce the cost to an extent such as to render it available in place of a more ideal gas would be a vain prediction to make at present.

Liquid air consists chiefly of a mixture of four parts of nitrogen to one of oxygen. The presence of the oxygen is a disadvantage, inasmuch as fierce combustion, if not explosion, may be occasioned by bringing liquid air into contact with combustibles in presence of a spark or fire. Fine cotton fibre and such like substances soaked in liquid oxygen are highly explosive. It is easy, however, to separate the oxygen from the nitrogen by fractional distillation at low temperatures, or methods may be employed to condense the oxygen separately from the nitrogen. Doubtless, oxygen gas so separated from its companion would have a value in chemical and metallurgical processes. The remaining nitrogen liquefied would be perfectly safe. Can it be transported?

The fact that a three-gallon milk-can of liquid air was brought by Mr. Tripler, of New York, from that city to Lynn, Mass., a journey occupying nine hours, and that not more than one-third of the liquefied gas was lost, although the only covering for heat-insulation was about 2½ inches of ordinary steam-pipe felting, goes far toward indicating the possibility of transportation. With a tank of 20 times the linear dimensions of the milk-can referred to, the surface for loss of heat would rise to 400 times while the capacity would have increased to 8,000 times, and with no better lagging it is easily seen that the daily loss would then be not over 5 per cent. Doubtless, however, improved means for heat-insulation would make the loss but a fraction of this amount. If the tank were kept under a pressure of, say, 200 pounds to the square inch, a suitable safety-valve being provided to prevent excess of pressure, the evaporated gas or air could be made to do work, especially if superheated. If the tank were in a train the motive power might, at least in part, be derived from the normal evaporation from the tanks. Further, let us imagine a pipe-line well insulated for heat, and it is easy to see that if the velocity of flow equalled the train-speed in the journey of the milk-can from New York to Lynn, the percentage loss in a pipe of the diameter of the milk-can with no better lagging than is possessed would be the same or even less.

Here again perfection of heat-insulation might make quite a saving, and the evaporated gas might, if the line were under pressure, be made available for power along the line of way.

Whether the liquefied gases of the air can be employed in this way, will, however, depend upon the development of efficient methods of extracting the heat and effecting condensation of the air. That liquid air possesses no advantage for refrigeration is without doubt true, unless the refrigerating effect be obtainable as a by-product, so to speak, of energy conveyance.

Liquid air represents air compressed to about 800 atmospheres, but existing without pressure. No heavy and excessively strong tanks are needed for storing it. If it be pumped into a closed receptacle, under regulated pressure it may be evaporated by the heat of the air, or that of surrounding objects, or it may receive heat from bodies undergoing refrigeration, as water being converted into ice; after which heating operation it may be further heated to the melting-point of lead by heat of combustion, and be finally used in a suitable engine where its expansion may develop power. During its expansion and delivery of power to the pistons of the engine it may become so cooled as to be discharged from the exhaust at nearly normal atmospheric temperature and pressure.

The power expended in compressing and liquefying air is, of course, converted into heat and thrown away. The product, liquid air, has no inherent power of energy in itself. It represents negativity, bearing somewhat the same relation that an exhausted globe does to the surrounding air. It may become the means for rendering the normal energy in the surrounding air available. Liquid air has capacity for taking up the ordinary heat pressure of surrounding objects and thus acquiring pressure. It can be superheated very efficiently, and so used in the form of compressed air in an engine. The superheating will, of course, tend to raise greatly the total efficiency. The inevitable losses in the compressing and liquefying processes would in part be made up in the added heat, the amount of which is small and efficiently employed. We have no reliable data of large-scale operations, and can as yet reach no certainty as to the efficiency attainable in compression and liquefaction or in recovery of power. It is possible that the separation of oxygen which would probably possess a value in metallurgy, might tend to diminish the cost of condensation. So also the refrigeration which is obtained during evaporation might help the recovery end. Where so much is "in the air" we must be content with suggestions only, and they may never be realized in practice. The power required to be expended in liquefying a given amount of air can be approximately estimated, and an assumed efficiency of plant may be made to do duty in place of exact figures where none are to be had, and if the conclusions based thereon are understood as tentative and subject to extensive modification in view of further advances in our knowledge, no harm is done.

In making an estimate of the cost of liquid air as produced on the large scale, the factors of plant-efficiency, maintenance, etc., come in to a greater or less extent. Assuming that air be compressed as nearly isothermally as possible, and that in a large plant a possible total efficiency of seventy per cent. might probably be realized, each horse-power hour might thus be expected to compress nearly 10 pounds of air to a pressure of 2,000 pounds to the square inch. If such compressed air, on being expanded in a very carefully arranged self-intensifying apparatus should condense 25 per cent. of the air admitted we would have about 2½ pounds of liquid air per horse-power hour. The assumed proportion, 25 per cent., seems not improbable in view of all the data—meagre enough, it is true—which have come to the writer's knowledge.

If the power cost be taken at $20 per year in large units and an additional charge of $10 be allowed for each horse-power of the compressing and condensing plant, its interest, maintenance, and operating expenses, the cost per pound of liquid air would be about one-sixth of a cent, assuming the plant to run 7,200 hours per year. This estimate, subject to modification from the very nature of the problem, would make the liquid air cost for production about 8 cents per cubic foot. If oxygen, separated by fractional distillation, possessed a value for equal amounts in excess of the cost of the air the remaining nitrogen would, of course, be producible at a lower figure.

It is probably within the possibilities that a cubic foot of liquid air or nitrogen, if allowed to heat from its surroundings and then be further heated to 200 degrees C., could, in a high-pressure engine, yield about five horse-power hours. If at the same time the vaporization of the air were attended by useful refrigeration, as in making ice, the cost of recovery would diminish. Need it be said here, however, that even if the cost of horse-power of recovered energy much exceeded that which is indicated in the foregoing estimates or assumptions, a demand may still exist for a source of power having great compactness, freedom from nuisance, no heated nor noxious exhaust, and of unequaled controllability? The horseless vehicle problem certainly presents us with an instance in point.

It would seem, however, that certain uses may be found for liquid air in which considerations of cost are not so important as is the ability to obtain the effects in view. In warfare, for example, the possession of highly concentrated energy-stores under control is very important. Liquid air can be rapidly converted into compressed air at six tons per square inch. This would probably be useful in the projection of high explosives. Compressed air is now used for propelling mobile torpedoes, or fish-torpedoes as they are called. Dirigible torpedoes either depend for power upon compressed air or the electric energy of a storage battery. Compressed air requires high pressures and very strong and heavy containing-vessels. Liquid air can be stored without pressure or at low pressures, and can be evaporated at any desired pressure, while its bulk represents that of air under 800 atmospheres. A storage battery would probably be from five to ten times as heavy as liquid air in a receptacle, for equal available energy. But no storage-battery could be discharged at an equivalent rate.

Submarine boats and flying machines may yet find use for liquid air. In the submarine boat it could be evaporated by the heat of the surrounding water, and after furnishing power it would ventilate the boat. Before its final discharge it could be burnt with oil in a fuel-engine for further power. We may find use for it in the flying machine. For emergency work it could in evaporating cool the cylinders of a fuel-engine and yield power as a result. Moreover, control of the submergence of a boat could be effected by the use of liquid air, so easily gasified, to add to the displacement.

The great feature of the application of such a power as liquid air would be its emergency value. By this is meant the ability to obtain at will a sudden output far beyond the normal. Animal power notably possesses this emergency value, and the success of electric trolley systems largely depends upon the fact that, when needed, the station can be called upon for a temporary delivery to any single car or train, of a power greatly in excess of the rated output of the motors.

Suggestions have already been made of the use of liquid air or oxygen, mixed with combustibles as a high explosive. Such an explosive can be made at the time of use, and if left unexploded, either by accident or design, soon loses its dangerous character by evaporation of the liquid gas.

Liquid air may also be used in the rapid production of high vacua. Let the bulb to be exhausted be filled with a gas such as carbonic acid, more condensible than air, and be provided with an extension that can at any time be sealed off. If now the extension-piece be immersed in liquid air the condensible gas will be taken from the bulb and deposited in the solid state in the extension-piece. This is now sealed off, leaving a high vacuum in the bulb, particularly if the same be heated during the process.

A fascinating speculation for the electrical engineer is the possibility of so cooling the conductors of electric lines or apparatus as to improve the conductivity many times, and so diminish the losses in any given length of conductor, and at the same time greatly improve the insulation. Professors Dewar and Fleming have shown, however, that it is a condition of this enormous improvement in conductivity that the metals be very pure, a very small percentage of impurity greatly lessening the result. As regards the insulation, they have shown that dielectrics and even electrolytes become insulators of excellent character when cooled to the temperature of liquid air. What effect such a lowering of temperature would have upon the dielectric strength or striking distance between conductors at great differences of potential is not as yet determined, so far as the writer is aware. The result to be expected from a consideration of the effect of heating upon dielectric strength or striking distance is that very low temperature will make it far more difficult to break down insulation by sparking through it.

That the electrical engineer covets just such agencies as will thus extend the range of possibilities in his art needs no proof. He would be apt to choose a pipe-line conveying liquid air as the very best location for his conductors, assumed to be made of as pure metal as possible, the high insulation probably attainable being the chief object. Whether his conductors were placed outside such a pipe or within the same, he could no doubt adapt himself to the conditions, provided he could get the benefit of the low temperature insulation, and possibly, to a certain extent, a gain in conduction.

It is indeed very questionable whether a pipe-line will ever be laid and kept filled with liquid air solely for its electrical benefits, but if such a line were also used to supply liquid air to a distant point and the normal evaporation utilized, the case would be somewhat modified, though the improbability of such a combination being put into service, at least within any reasonable period, still remains.

It will be the proper attitude for the conservative and at the same time progressive engineer to await the possession of full and accurate data before draw any conclusions as to future practice. Suggestions of possibilities are, of course, useful, even if only a fraction of them prove realizable, and no attempt is here made to do otherwise than call attention to matters which must from their nature possess more or less of interest.

ELIHU THOMSON.

LIQUID AIR FOR AUTOMOBILES.

We none of us know now as much as we will know a little later about the best methods of using liquid air, whether for power, for refrigeration or for other service, or of the practical value of the effects realized in proportion to the cost. As it has been suggested that liquid air may be made serviceable for the self-propulsion of road vehicles, it seems to be in order to offer some suggestions or to indulge in a little speculation, as to the way to do it and as to what would come out of it.

Liquid air represents, among other things, stored energy, and energy which may, partially at least, be reconverted and employed for our service. Liquid air is compressed air in an easily portable form. The advantage which it has over high-pressure, non-liquefied, compressed air is that it is not dangerous to convey or to hold, and that it does not require many and costly bottles to contain it. The liquid may be carried in a milk can, or in anything that will hold water, and which is merely strong enough for the weight of the water without any added pressure, although it is quite imperative to surround the vessel with large quantities of heat-insulating material. Even with abundant insulation provided, a given charge of compressed air in liquid form must weigh much less than the same charge under high pressure, and not liquefy but contained in the necessary steel bottles. The shape of the vessel in which the liquid may be conveyed may be made to conform to the conveniences of the vehicle, while high-pressure air insists upon its long cylindrical receivers, which must be disposed of as best they may.

In the previous article I spoke of using liquid air for maintaining supplies of compressed air in receivers of considerable capacity, and where the use of the air was slow or intermittent, the liquid air being occasionally inserted in charges sufficient to restore the fallen pressure in the receiver within certain predetermined limits. An entirely different system would have to be followed in the case of the automobile. All the liquid air for a trip, or for a run between charging stations, would be carried in the liquid state, and usually in a single receptacle, and there would be practically no compressed air reservoir, or any receptacle required for any considerable volume of compressed air after its re-evaporation. The liquid air would be pumped into the working compressed-air system just as it was wanted for use, and almost precisely as the feed water is pumped into a steam boiler. The boiler in this case would necessarily be of the tubular type, with the important difference from the steam boiler that the requirements for the evaporation of the air would not call for the assembling of the tubes in close proximity to each other and around or over the fire, for there would be no fire. The heat required would be obtained from the surrounding atmosphere, and the tubes, or the single continuous tube, would be so disposed as to get the best exposure to the air. In the automobile it would be most natural and proper to have the air traverse a coil spread out in front of the machine, so that the air would strike it with some velocity when the vehicle was in motion. After the air had by this means attained the temperature of the external atmosphere, its mechanical status and value would be precisely the same as that of compressed air which had been produced directly by compression in the usual way, except that the liquefied and re-evaporated air would be absolutely dry air, and would be entirely incapable of causing any trouble by freezing up in the passages of the motor. The air after attaining normal temperature might be passed through a reheater, heated by a little oil lamp or other means, and the consequent increase of volume would add considerably to the efficiency of the air as in other cases. If the air was used in a compound motor, it should certainly be passed through a reheater first, and also again before entering the low pressure cylinder. If the latter re-heating was not effected there would be little or no reason for compounding.

With this general scheme for using liquid air for an autocar motor, the vehicle that I have in mind just at present is a tricycle for a single person, and to be used for service similar to that of the present bicycle. Say that we have a receptacle that will hold 50 pounds of liquid air, or something over 6 gallons, and that 10 pounds of the liquid will be evaporated and lost during our trip through the park and up the boulevard, leaving 40 pounds of liquid air available for use. Our working pressure will be, say, 100 pounds to the inch. As a cubic foot of air at 100 pounds weighs, say, 6 pounds (see preceding article) we have available $40 \div 6 = 66$ cubic feet of air at 100 pounds. Our motor has a 1-inch diameter cylinder, 2 inches stroke, normal speed 300 revolutions per minute; connected to the driving wheels by differential gearing of wide range. Cutting off at quarter stroke, the mean effective pressure will be 44 (see Richards' "Compressed Air"), and the theoretical power developed will be: $1^2 \times .7854 \times 44 \times 100$ feet piston speed $\div 33{,}000 = .1047$ horse-power, and the air consumption per minute will be $1^2 \times .7854 \times 4'' \times \frac{1}{4} \times 300 \div 1{,}728 = .1363$ cubic feet, to which we should add 10 per cent., making the consumption .15 cubic feet per minute. As we have 66 cubic feet available, the charge should last $66 \div .15 = 440$ minutes, or say 7 hours, which, at 8 miles an hour, should be as far as any one should want to ride at one time, and it would only be necessary to pour in the liquid air again to be all ready for a ride as far again. With liquid air in sight as low as 2 cents per pound, this riding is distinctly cheaper than the maintenance of a horse. In the few figures here given nothing is said about the gain that might be accomplished by reheating. This it would be very proper to go into for larger vehicles, and also the compounding of the motor. With air at an initial pressure of 200 pounds, and reheated both before entering the first cylinder and also intermediately, it should be easily possible to show results 50 per cent. better than here indicated.

FRANK RICHARDS.

LIQUEFYING HYDROGEN.

LONDON, May 11.—Prof. Dewar has succeeded in liquefying hydrogen, which is an unprecedented feat, despite the successes claimed by some theorists. Prof. Dewar produced half a wine glass full of the liquid in five minutes. The process is applicable to any quantity. The boiling point of the liquid is 240° below zero, Centigrade. Scientific men regard the feat as being of immense importance, apart from its enormous scientific interest. By use of liquid hydrogen, Prof. Dewar has also liquefied helium.—*N. Y. Sun.*

LIQUID AIR AS A CURE. IT WILL STOP SKIN DISEASES, BUT WILL NOT KILL BACILLI.

Dr. A. Campbell White has been experimenting with liquid air in its effect on disease and disease germs. Dr. White first experimented with cancer at the Vanderbilt Clinic. He found that liquid air not only had a curative effect on cancer, but on erysipelas, abscesses, sciatica, carbuncles, neuralgia and blood tumors. Dr. White will not declare the cancer and lumpus patients permanent cures, because sufficient time has not elapsed to demonstrate that the poison is out of the system. He hopes for the best, however.

Dr. White operates on his patients in a simple way. His liquid air flask is so arranged that the vapor issues from a small aperture. As liquid air evaporates its volume increases 800 times. Consequently there is plenty of pressure within the flask. Dr. White directs the vapor against the sore. As the vapor strikes the mark it congeals and coats the sore with frost, which dissipates, however, in two or three seconds, as the stream of vapor is turned off. Abscesses, boils and carbuncles succumb to one application of liquid air vapor. A quarter of an hour is ample time for ordinary cures, though, as the doctor says, whenever pus has formed in large quantity it is well to anaesthetize with liquid air, incise and evacuate. In all cases the application of liquid air relieves the pain instantly. Sloughing does not follow except in the case of fairly well advanced carbuncles, and in some abscesses when the overlying skin has lost its life by tension and inflammation. But in these cases the slough is only superficial, and the ulcer left heals rapidly.

Dr. White praises liquid air as an anaesthetic, and says that it has the advantage over every other. Its greatest benefit is that it prevents hemorrhage.

Dr. White also has been experimenting with liquid air to kill germs, but this, he is satisfied, it will not do. It is known that 160 degrees of heat will destroy all forms of germ life, but liquid air, 312 degrees below zero, has no effect so far as he can find. He has experimented with typhoid, anthrax and diphtheria bacilli. The doctor says:

"These experiments show that liquid air is not an antiseptic, and that germs can resist a temperature of 312 degrees below zero, even though exposed to it for a long time. I hope to make experiment before long by exposing bacilli to liquid hydrogen. I think intense cold may hinder the activity of germs temporarily without destroying their life.

"By the means of liquid air we may be able before long to distribute cold throughout our houses in the summer as we now distribute heat in winter. Cold is stimulating and invigorating."—*Cold Storage.*

LIQUID AIR AS A BLASTING AGENT.

Although a reaction has promptly set in against the exaggerated opinions on the prospects of liquid air, in which the press indulged, the difficulties which the application of condensed gases of so low boiling points involves do not appear to be well understood. Some experiments, conducted by the Vienna Crystal Ice

Co., in the presence of representatives of the Austrian Technical Military Committee may, therefore, be of interest. We do not regard the experiments as by any means decisive, since they were certainly not made under favorable circumstances; but they are instructive. The liquid air was obtained from the Linde Company in Munich, and was transported in open flasks provided with a Dewar vacuum jacket. The flasks were packed with felt and cotton; over the open neck, which projected through the lid of the wooden case, a cap of felt was loosely fitted. When despatched, the liquid contained a mixture of oxygen and nitrogen in the ratio of 75 : 25. During the 72 hours which elapsed before actual use, the greater part of this time being spent on transport, half of the liquid had evaporated, and the remaining liquid contained 85 per cent. of oxygen; nitrogen is more volatile than oxygen. Two kinds of cartridges were made of kieselguhr, mineral oil (solar oil) and the liquid. In the first case, the kieselguhr and oil were mixed in a wooden basin, the liquid added gradually, and the paste ladled into paper cartridges clothed with asbestos. In the second case, the earth and oil were charged into the cartridge, which rested in a double sheet-metal cylinder with a separating layer of felt, and the liquid air gradually poured into the cartridge until the mass was thoroughly impregnated. In both cases the formation of mist and of hoar frost sufficiently indicated how much of the oxygen escaped during the preparation. The cartridges could be handled, but the men did not care to squeeze them in firing the primers and detonators; as a consequence one cartridge missed fire. Holes, 30 inches deep, were bored in rock. It resulted that these so-called oxylignit cartridges were hardly strong enough, as too much oxygen had evaporated. The cartridges of the second type did not prove so powerful as the others, probably because the lead cases furthered evaporation, especially from the bottom of the cartridge. On the results, Artillery-General-Engineer Hess has commented to the following effect: The preparation of the cartridge is wasteful and dangerous to the eyes, etc., and, owing to the rapid evaporation, it is further impossible to guarantee the strength of the cartridge, even in the roughest way. Kieselguhr and oil seem to be suitable absorbents, and oxylignit an effective blasting agent, though comparative tests have not been made yet. The cartridges must be used within, say, 15 minutes of their preparation. There is no danger, hence, from missing fire. But, on the other hand, it will be difficult to fire many cartridges simultaneously, and, strictly speaking, the cartridges should be made on the spot, and be in a very hard condition. That would scarcely be possible below ground; the spurting liquid might break the the glasses of the hot safety lamps, and it remains to be investigated whether the large volumes of oxygen might not lead to spontaneous ignition of marsh gas or coal dust. The evaporating oxygen would, on the other hand, improve the air, and the blasting would not contaminate it. Some of these objections are very serious, especially the unreliability of the power of the cartridge, and the short period during which it remains active. The cartridge cannot, of course, be sealed, nor can the vessels in which the liquid air is transported. For military operations oxylignit would certainly not appear to be suitable. But the whole question is only in its experimental stage, and better methods of making cartridges could probably be divesed.—London *Engineering*.

LIQUID AIR AS AN EXPLOSIVE.

Experiments which have just been made in Austria with liquid air as an explosive are reported to have brought forth sensational results. The liquid air was mixed with a siliceous marl, making a substance which is unsusceptible to shock, and will only act under direct ignition. This gives it an important advantage over dynamite. One-twentieth of a pint of the mixture was placed in a crevice in a quarry two feet deep and ignited by electricity. The effect of the resulting explosion is reported to have been equal to the work of twenty times the same quantity of dynamite. Tests were also made with the liquid air as an explosive of heavy ordnance, which showed that the gun was not heated and that the explosive will considerably increase the range of projectiles.

LIQUID AIR AS AN EXPLOSIVE.

Among other peculiar properties of liquid air, says Mr. A. Larsen, in a paper read before the Institution of Mining Engineers, it has been found that in combination with carbonaceous substances it forms an explosive compound, and numerous experiments have been made in different countries with the view of applying it to blasting. The first practical trials were made in a colliery in Germany about three years ago. They do not appear to have been very successful, and were soon abandoned. Since then trials have been made at different places, but the most important of these have been made, and are still being continued, in one of the largest explosive works on the Continent, the carbonate factory at Schlebusch.

Many different mixtures were studied, both as regards explosive strength and safety of manipulation, while Professor Linde endeavored to turn the results so obtained to practical account by getting the system introduced in the Simplon Tunnel. One of the problems to be studied was to find a suitable carbon carrier. A number of these have been tried, but most of them involve a considerable amount of danger; not only are they highly inflammable after being soaked with liquid air, but when ignited they often detonate immediately and with great violence.

Very good results have lately been obtained with a mixture of equal parts of paraffin and of charcoal. Several modes of preparing the cartridges have been adopted. Either a wrapper was first filled with the carbonaceous material and bodily dipped in liquid air until completely soaked, or the liquid air was poured into the filled wrapper. The liquid air would be taken down into the mine in large "ammunition boxes," the latter preferably on a wheel base, and sent into the different working places, like ordinary empty tubs. Square-shaped wire baskets filled with cartridges would be taken down at the same time, placed in the liquid in due course, and left there. By the time the boxes had arrived at the shot-firing points all the cartridges would be soaked full, but they would, of course, remain in the liquid until immediately before being placed in the shot-holes.

A carriage 8-in. in length by 2¾-in. in diameter, when filled with a mixture of kieselguhr, tar and tar oil, weighs 11¾ ozs. The same absorbed 24¾ ozs. of liquid air, thus showing a total weight of 2 lbs. 4½ ozs. The time occupied for fully soaking the cartridges was about 10 minutes. The life of a liquid-air cartridge is unfortunately but ephemeral when once it has been removed from its vital fluid. A cartridge of the above-mentioned dimensions would have to be fired within 15 minutes to avoid a missfire.

A larger cartridge would, of course, have a better chance, but a thinner one much less. Liquid-air cartridges are best detonated with a small gun-cotton primer and detonator. Dynamite primers such as are used for blasting gelatine are useless, as they would immediately freeze. The explosive effect to be derived from liquid-air cartridges depends, therefore, (1) on the "freshness" of the liquid; (2) on the selection of carbonaceous material; and (3) on the time of exposure. This last is, without doubt, the most important consideration, and, besides, the most difficult to adapt to the requirements of practice.

Cartridges of small diameter, such as are met with in ordinary mining, would appear to require quite exceptional working conditions to enable their use with advantage. Even cartridges of large diameters—say, 3-in. to 4-in.—require very quick handling. The rapid surface evaporation soon creates a coating of inert material around the cartridge which, acting like an empty space, causes a considerable loss of pressure. Again, the absorptive power of the carbon carrier, as well as the amount of carbon contained therein, are important factors to consider. A carrier rich in carbon, but of inferior absorbent capacity, will, if the cartridge be exposed too long, leave too much carbon monoxide in the fumes to make it safe for underground work.

Broadly speaking, it may be said that with certain admixtures, notably of the petroleum variety, and by using highly-oxygenated air, it is possible to obtain an explosive compound of greater strength than blasting gelatine. But these mixtures are, as already mentioned, highly inflammable, and therefore dangerous to use. The safer mixtures are less strong. Owing to the rapid evaporation, however, a reliable standard of strength is not obtainable in any case.

MICROBES THRIVE ON LIQUID AIR.

At the meeting of the Royal Society, at Burlington House, a paper was read describing some of the results of a remarkable investigation which has been undertaken by Professor Dewar, Sir James Critchton-Browne, and Professor Macfadyen. These gentlemen have submitted a large number of disease-causing microbes—those responsible for typhoid fever, diphtheria, cholera and others—for prolonged periods to the temperature of liquid air, which is 190 Centigrade, and have found that they are not a bit the worse. After 20 hours of this frigid regimen these lively bacteria proved as lively as ever, and set up with punctuality and precision their appropriate maladies. The microbes are to have a dose of liquid hydrogen shortly, and it is said if they can stand that they will stand anything.

LIQUID AIR IN MEDICINE AND SURGERY.

Dr. A. Campbell White, writing for the *Medical Record,* says:

"I think there is reason to hope that we have in liquid air a therapeutic agent which will remove many otherwise obstinate superficial lesions of the body and cure some lesions which have heretofore resisted all measures of treatment at our disposal, including the knife. I am firmly convinced, with the experience already had with its use, that it is a specific in the treatment of such diseases as herpes zoster (painful neuralgia, accompanied by an eruption), sciatica and intercostal and facial neuralgia, affording instant and continued relief after one application over the spinal end of the affected nerve. The use of liquid air in medicine, i. e., in pulmonary diseases, in the reduction of fever, etc., opens a large field, one which presents many obstacles at the very start, but much hope for the future."

Dr. White, who is known as the first New York physician to use anti-toxin, became interested. Mr. Tripler gave him the use of his laboratory, and Health Commissioner Jenkins gave him the privileges of the department's hospital laboratory to test the effects of liquid air on germ life.

Dr. White began treatment of the human skin by curing ulcers of the leg. The doctor put himself on record as saying: "So many of these cases have been successfully treated with liquid air that it can be positively said that we have nothing at our disposal to-day which will cure ulcers so quickly, thoroughly and with as little pain."

Dr. White accounts for the phenomenal quality of liquid air in this way: He says in liquid air we have pure cold without moisture. The danger in getting one's feet frozen is not long exposure to cold, but to cold and moisture combined; moisture preventing evaporation.

LIQUID AIR IN GAS MAKING.

In the *Chemische Industrie* Professor W. Hempel, of Dresden, has an article on the use in gasmaking of the mixture of half oxygen and half nitrogen, which is obtained by liquefying air in a Linde machine and allowing the liquid air to evaporate its nitrogen partly away. The half-and-half mixture can be made at a working cost of 4d. per thousand cubic feet by evaporating the remaining liquid, and it can be applied in two ways, for making oxygen producer gas and for making oxygen water gas. Both in producer gas and in water gas the great advantages of internal heating are secured; but in both cases there is too much nitrogen in the product, and the heating values are relatively low.

PRODUCER GAS.

In making this gas, as used in regenerative heating, we pass air through glowing coke so as to form carbonic oxide and nitrogen. But if Linde 50 per cent. oxygen be used the results alter considerably, in the manner illustrated by the following table, which refers to gas made from brown coal:

	Ordinary Producer Gas, Volumes=Percentages.	Oxygen Producer Gas.	
		Volumes.	Percentages.
CO_2	3.4	3.4	6.1
Heavy hydrocarbons	0.8	0.8	1.4
Oxygen	0.3	0.3	0.5
CO	25.4	25.4	45.9
CH_4	5.3	5.3	10.7
H	6.8	6.8	12.3
N	57.4	12.7	23.0
	99.4	54.7	99.9

These results are approximate, and would be affected by the nitrogen taken in along with the production of CO_2; but, on the other hand, the production of CO_2 would be diminished, on account of the higher temperatures which would be obtained in the producer. For manufacture of such a gas as that in the last column it is only necessary to use the 50 per cent. Linde oxygen in the producer.

COMPRESSED AIR AND LIQUID AIR AS USED IN THE SIMPLON TUNNEL CONSTRUCTION.

Mr. Axel Larsen, M. Inst. M. E., in *Cassiers* for January, 1900, has an interesting article illustrating and describing the progress of work on the Simplon tunnel.

Among the ordinary uses of compressed air on this work we also find some extraordinary uses. To clear away the debris Mr. Brandt, of the firm of contractors who are building the tunnel, proposes to use a gigantic air gun 300 feet long, and with a calibre of 6½ inches. This gun is charged with compressed air at a pressure of 100 atmospheres and fires a projectile of 900 gallons of water. When the cannon has been placed in position the powder fuses will be abandoned and the shot firing will be done by electricity. In this manner it will be possible to fire the explosive in the bore holes and gun simultaneously. Thus at the same moment as the solid rock is splintered into a heap of fragments by the blasting charges a huge volume of water is hurled against the debris which is instantaneously washed away from the working face and left against the wall some 50 yards further down the tunnel.

It is at this tunnel that the use of liquid air as an explosive was first tried, and much is expected of it. The cost of it is comparatively low, as liquid air could be made on the spot where ample water power is available. The minor difficulties with it have been overcome and it is now possible to keep liquid air in specially constructed vessels for fourteen days and longer. Cartridges of 6 inches diameter would have a life of over a quarter of an hour, which would be sufficient for loading and firing. But one great drawback remains. It is the danger of premature explosion of the cartridges when accidentally brought into contact with fire, and as naked lights of the oldest type are used everywhere in the Simplon tunnel, such an accident would seem extremely probable.

A liquid air cartridge is made as follows: A cylindrical paper or cardboard wrapper is filled with the powdered material intended to support combustion, the liquid air being, of course, the oxidizing agent. The cartridge is then bodily immersed in liquid air. In from 15 to 20 minutes it is soaked through and is ready for use. Several mixtures of carbonaceous bodies have been tried as substances supporting the combustion, and it has been found that not all of them involve the same degree of danger. Some of the cartridges made as above described burn away more or less violently when ignited by flame, while others explode almost immediately. Unfortunately, the mixtures which have proved comparatively safe are also the least effective. It, therefore, remains to be seen whether a mixture will be found which combines sufficient explosive strength with safety of handling. Meanwhile, it may be said with a fair degree of certainty that liquid air mixtures will never be generally introduced as a blasting agent, for apart from the difficulty of preparing the cartridges under ordinary mining conditions, it is an exceptional thing to meet with 6¼-inch cartridges in ordinary mining (1 to 2 inches being the usual sizes), and a thinner cartridge does not retain the liquid air long enough to be relied upon for shot-firing purposes.

With the work in the Simplon tunnel it is, of course, a different matter. The conditions there are different. It is altogether an exceptional case, and if the experiments with liquid air should ultimately prove successful, the advantages achieved may mean the completion of the tunnel in 1903 or even earlier.

Professor Linde, of Munich, who has done so much to render the liquefaction of the atmospheric air an industrial success, personally conducts these experiments at his laboratory near Brig, and his thorough knowledge of the subject promises a successful issue, if it is to be attained at all.

COMBUSTION IN LIQUID AIR.

When air is liquefied, nitrogen and oxygen condense simultaneously, so that the liquid has the composition of the gas mixture in the air. As soon, however, as evaporation recommences, the composition begins to change. At first the escaping gas is essentially nitrogen. After a while the vapors again contain the two gases in the proportions in which they are found in the atmosphere. That point occurs when about 70 per cent. of the liquid has evaporated, and 81 per cent. of the original nitrogen, and 35 per cent. of the oxygen have escaped; the remaining liquid contains the two bodies in equal proportions, afterward oxygen begins to predominate in the vapors. These numbers concern evaporation at atmospheric pressure. In vacuo, the evaporation of the two gases proceeds more rapidly; at increased pressure, more slowly. The changes may be observed with the help of a glowing chip of wood. At first the wood will be extinguished, when held over the liquid; then it will brighten up, and when dipped into the liquid burn intensely. Powdered carbon, soaked with liquid air, puffs away like gunpowder on ignition, and explodes when a detonator cap is employed. This seems very strange when we think of the exceedingly low temperature of the liquid, —180 degrees C.; and in a paper brought before the Bavarian Academy of Science, Carl Linde expresses the opinion that we may have to modify our views on the nature of explosions. Petroleum, absorbed by kieselguhr or powdered cork coal, can be saturated with liquid oxygen. Such a mixture explodes even when not confined. Cartridges filled with it cause others, placed at a distance of 25 centimetres (10 in.) from them to explode, while with the highest explosive so far known, blasting gelatine, cartridges 15 centimetres away from the detonating cartridge remain inactive. Linde has tested this preparation at Schlebnoch. Within a steel bomb of 20 litres capacity blasting agents are exploded by means of fulminate of mercury. The gas pressure is registered by a piston on a drum which has a circumferential velocity of 330 centimetres (10 ft.) per second. The petroleum-liquid air preparation gives a curve which demonstrates that the maximum pressure surpasses that obtained with blasting gelatine, and is reached in a shorter period of time. The preparation was simply wrapped in paper. It is singular that such a mixture should burn more rapidly, in spite of its low temperature, than any solid or liquid compound we know at ordinary temperatures.—*Engineering.*

A PLANT FOR THE COMMERCIAL MANUFACTURE OF LIQUID AIR.

The announcement that within a short time there will be in operation in New York City a commercial liquid air producing plant, with an estimated capacity of some 1,500 gallons of liquid air per day, is certainly a remarkable one, and especially so when it is remembered how short a time has elapsed since the liquefaction of air was first effected, and that up to a couple of years ago or so the lequefaction had only been accomplished on a minute scale in one or two laboratories, and at an expense which made the product almost as costly as a precious metal.

In the issue of *Engineering News* for April 14, 1898, was given the first technical description of the laboratory and apparatus of Mr. Charles E. Tripler, of New York City, who was unquestionably the first to produce liquid air on anything like a commercial scale.

Since then, descriptions of this laboratory, and statements concerning Mr. Tripler's work of all degrees of accuracy and inaccuracy have run the rounds of the newspapers and the popular magazines, so that the general public has become quite conversant with liquid air, at least, from the spectacular standpoint.

In our article above referred to, and in an editorial discussion of the possibilities of liquid air, published in the same issue, some of the uses and the limitations of liquid air were pointed out. These prospective uses and the great popular interest in the subject, have set a large number of investors and scientists at work in this field, both in this country and abroad.

By all odds, the most extensive work, however, to the best of our knowledge, has been done by the General Liquid Air & Refrigerating Co., of New York City, whose offices are in the same building as those of *Engineering News*. This company has been organized to control the inventions of Messrs. O. P. Ostergren and Moriz Burger, relating to the liquefaction of air. It has secured

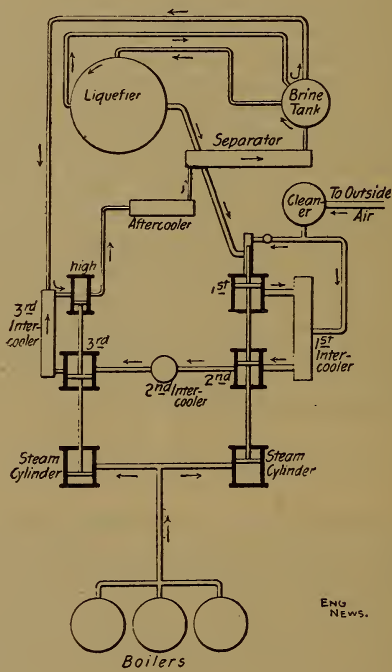

FIG. 283—SKETCH DIAGRAM OF AIR LIQUEFYING PLANT, SHOWING PRINCIPAL APPARATUS AND PIPING.

patents in the United States, and in a large number of foreign countries, and it has built and has now ready for operation a plant for the commercial production of liquid air on a scale sufficiently large to demonstrate the efficiency and value of its process.

In the accompanying diagram, Fig. 283, we have represented in symbol the various parts of the apparatus, and by reference to this, the operation of the plant will be readily made clear to the reader. It may be said in the first place that in principle the plant is merely a steam-power refrigerating plant, utilizing the expansion of compressed air to produce a low temperature, and causing this cold air to react upon itself, utilizing a different principle, as they claim, from that of the Tripler or the Hampson apparatus, until a temperature is reached so low that liquefaction occurs.

The steam is furnished by three vertical fire tube boilers, of 75 nominal H. P. each. These deliver steam at 150 lbs. pressure to two independent, two-stage horizontal straight line air compressors, built by the Ingersoll-Sergeant Drill Co., of New York City. The one at the left, which may properly be termed the low-pressure compressor, has a 16 x 18-in. steam cylinder, an 18¼-in. low pressure cylinder, and a 12-in. intermediate air cylinder. These are connected by the first intercooler. The large low pressure cylinder is in reality a vacuum cylinder, whose function will be explained later, and in this the maximum pressure is never more than the atmosphere, or 15 lbs. The air leaves the second cylinder at 60 lbs. gauge pressure, and passes through the second intercooler to the low pressure cylinder of the second or righthand compressor. This has a 22 x 24-in. steam cylinder, low and high pressure cylinders 7¾ and 7 ins., respectively, in diameter.

The third compressing cylinder delivers the air into the third intercooler at a pressure of 300 lbs., and from it the air enters the high pressure cylinder and is raised to 1,200 lbs. pressure. The air then passes to the aftercooler. In this, as well as in the intercoolers, the operation is simply to extract the heat which has been generated by the compression of the air by passing the air over water-cooled tubes.

So far, the operation is identical with that of any ordinary four-stage air compressing plant. It is from this point on that the special apparatus for purifying and refrigerating the compressed air comes into play. Continuing the circuit from the aftercooler, the air enters at the base of a tall separator, whose purpose is to remove all moisture, oil, dust or other impurities from the compressed air, an operation quite essential to prevent the liquefier becoming clogged with ice and grease. As it enters the separator the compressed air meets a perforated disc, which breaks the incoming current up into a large number of fine jets. These bubble up through a column of water which washes the air and extracts from it all grease or other impurities which it may have accumulated in its journey through the compressors, intercoolers and piping. Breaking from the water surface, the level of which can be maintained by means of the blow-off or regulating pipe, the air rises towards the top of the separator and strikes a series of conical baffle plates, between which it zig-zags, as shown by the arrows, until the top of the separator is reached. It will be noticed that the alternate plates with open tops have a series of holes in the inner casing which supports all the plates. This arrangement permits the entrained moisture to run back to the water chamber without coming into contact with the rising current of air.

Just beyond the outlet end of the separator is a pressure regulating valve, whose duty is to let the compressed air pass by at a constant pressure, so that it will enter the liquefier in a constant and steady stream. From the far side of this valve a small pipe is carried to the automatic governor of the steam end of the high pressure compressor to insure its proper action.

Passing on the air enters the header of the brine or cooling tank, Fig. 284. The header has an inner tube, which is small enough to considerably increase the velocity of the entering air, and at its lower end is provided with a small inverted conical, nozzle-closing receptacle, known as the "supplementary moisture collector." The air passing through the small tube, with increased velocity projects into the nozzle any moisture which may have passed the separator, and then passes up between the small tube and the header. Radiating from this header and winding spirally inward towards the centre of the tank, Fig. 285, is a series of flat coils, all of which terminate in a second header, from which the air pipe leads to the liquefier. Beginning at the centre of the tank and winding outward in the reverse direction, is a similar and duplicate set of spiral tubes which terminate in an outside header. This second set contain the expanded air returning from the liquefier. The principle of this apparatus is seen by referring to Fig. 285, in which it will be seen that the cold expanded air in passing through its coils is in close proximity to the entering compressed and warm air.

Before considering the liquefier it is perhaps well to trace the course of what has just been called the expanded air. In reality, this is only partially ex-

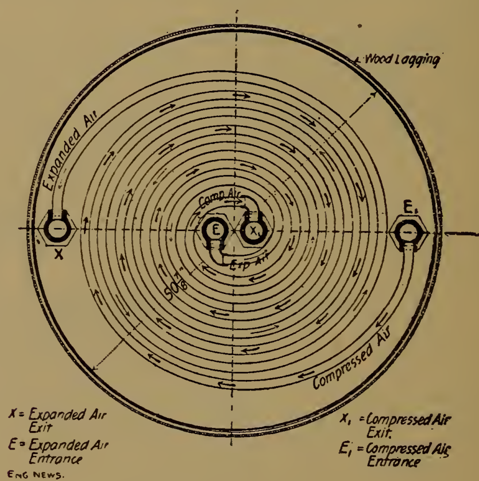

FIG. 284—PLAN OF THE BRINE TANK, SHOWING ONE LAYER OF COILS.

panded, for it reaches the exit end of the brine tank coil at a pressure of about 300 lbs. per square inch. Referring again to Fig. 283 it will be noticed that a pipe leads to the third intercooler, which has also a pressure of 300 lbs. This arrangement, it will be observed, starts the cleaned and cooled air which has not been liquefied on the circuit again at a point where only a single compression is necessary to put it into condition for supplying to the liquefier.

The principal part of the system and, of course, the one to which the most interest attaches, is this liquefier. For the present let us consider the apparatus without air, as it stands when inoperative.

The liquefier consists of two portions, Fig. 286, the upper and larger of the liquefier proper, and the smaller and lower portion called the aftercooler which contains the reservoir for the liquid air and plays a very important part in the proper working of the system.

Referring now to the liquefier, the upper portion is filled with two sets of coils of small copper pipes which, as in the case of the brine tank, are wound in flat spirals in reverse directions, that is, those for the entering air spirally inward to the central of the header, shown in Fig. 286, and the other set starting from the outer section of the breaker and spiralling outward to an outside header. However, a fundamental difference exists between the brine tank and the liquefier in the fact that the tubes of the latter are soldered

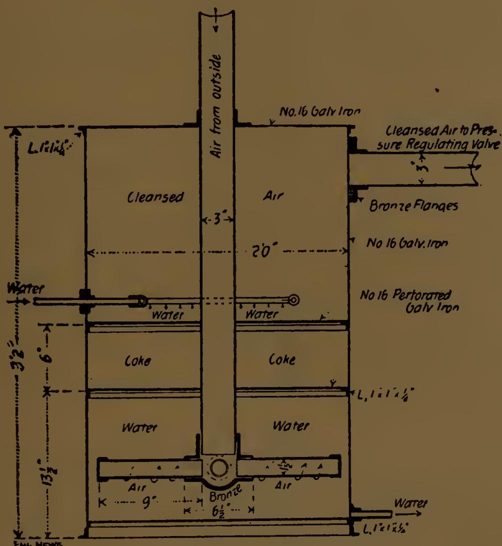

FIG. 285—SECTION OF THE CLEANSER FOR REMOVING DUST FROM AIR PREVIOUS TO COMPRESSION.

together in vertical rows, thus forming a spiral space from the outside to the inside, or vice versa. In other words, it is as if a solid flat strip of 40 tubes were wound in a spiral. Connected with the space which surrounds both sets of tubes is a large exhaust pipe leading to the suction end of the first cylinder of the low pressure compressor, already mentioned, whose function it is to exhaust the air from this space and the interior of the aftercooler, as will be explained later.

The aftercooler, shown in detail in Fig. 286, consists of a central chamber closed by a heavy cast-iron inverted cup, resting on a knife-edge turned on the top of the reservoir, and a siphon tube dipping to the bottom of the reservoir, and winding around the cup and cover, and finally emerging to the outside of the supporting casing of the apparatus. This is all enclosed in an air-tight casing which connected to the spiral space of the liquefier, and hence to the vacuum pump.

At the lower extremity of the central header of the liquefier, and at the top of the aftercooler, are two similar valves, shown in detail in Fig. 286, and operated by separate valve handles from the outside of the apparatus.

Having now an idea of the mechanical construction of the apparatus, let us start with the compressed air entering the liquefier, and follow the operation of the several parts. The air, at a pressure of about 1,200 lbs., and a temperature equal to that of the brine tank, say 50 or 60° F., flows into the outside header, and round and round through the spiral tubes towards the central chamber, and finally through the expansion valve into the small space below. This valve is so adjusted as to throttle the flow and keep the difference of pressure between the two sides of the valve at approximately 900 lbs. This drop in pressure, and consequent expansion cools the air a certain amount. This cooled air now passes upward in the outer portion of the central header and starts in its spiral course outward, the tubes in which it is confined being in close metallic contact with the entering air tubes. No matter how small the difference in temperature may be, the entering air will in consequence lose some of its heat to the outgoing cooler air, and will thus arrive at the expansion valve at a slightly reduced temperature only to expand and produce a further drop in temperature, which, in its turn, still further cools the entering air. This accumulative cooling continues until eventually the critical temperature of air is reached. Then, and then only, a portion of the air passing through the expansion valve liquefies and collects in the small chamber over the second or aftercooler or reservoir valve. That portion which does not liquefy, which is, however, intensely cold, of course passes into the cooling tubes as before.

From what has been said, it will be seen that the air once taken into the system is used over and over. There is, of course, need for new air to take the place of that liquefied, and this is drawn in from outside through the cleanser, shown in Fig. 285, and a suitable automatic valve. This cleanser consists of an inlet tube coming from the roof of the building, and extending down to the bottom of the containing tank. From the bottom of the four arms, the air bubbles out and up through water to a coke filter, where it is thoroughly scrubbed. It is also subjected to a water spray, after which it remains in the upper portion of the tank until needed by the system, when it is drawn into the vacuum cylinder.

Returning to the liquefier again, it will be seen that opening the aftercooler valve allows the liquid air to pass into the reservoir below, where at first it will immediately volatilize, owing to this portion of the apparatus being warm. This will produce in the reservoir sufficient pressure to lift the heavy inverted cup and permit the intensely cold air to flow out into the vacuum space of the aftercooler, and thence through the spiral space of the liquefier. At the same time a portion of the cold air will pass through the coiled siphon tube and out the draw-off valve. Soon the parts of the aftercooler become sufficiently chilled, and the liquid air passing through the lower valve, remains in a liquid state. The heavy cap is so proportioned that there is a pressure of about 6 lbs. per sq. in. on the liquid surface, and this is sufficient to force the liquid air through the siphon tube and out of the faucet. We then have the following condition of affairs:

The reservoir is partially filled with liquid air, as is also the coils of the aftercooler, and the space surrounding the tubes is constantly being exhausted, so that whatever liquid air or vapor may spill over when the inverted cap lifts is instantly evaporated in and around these filled tubes, thus further reducing the

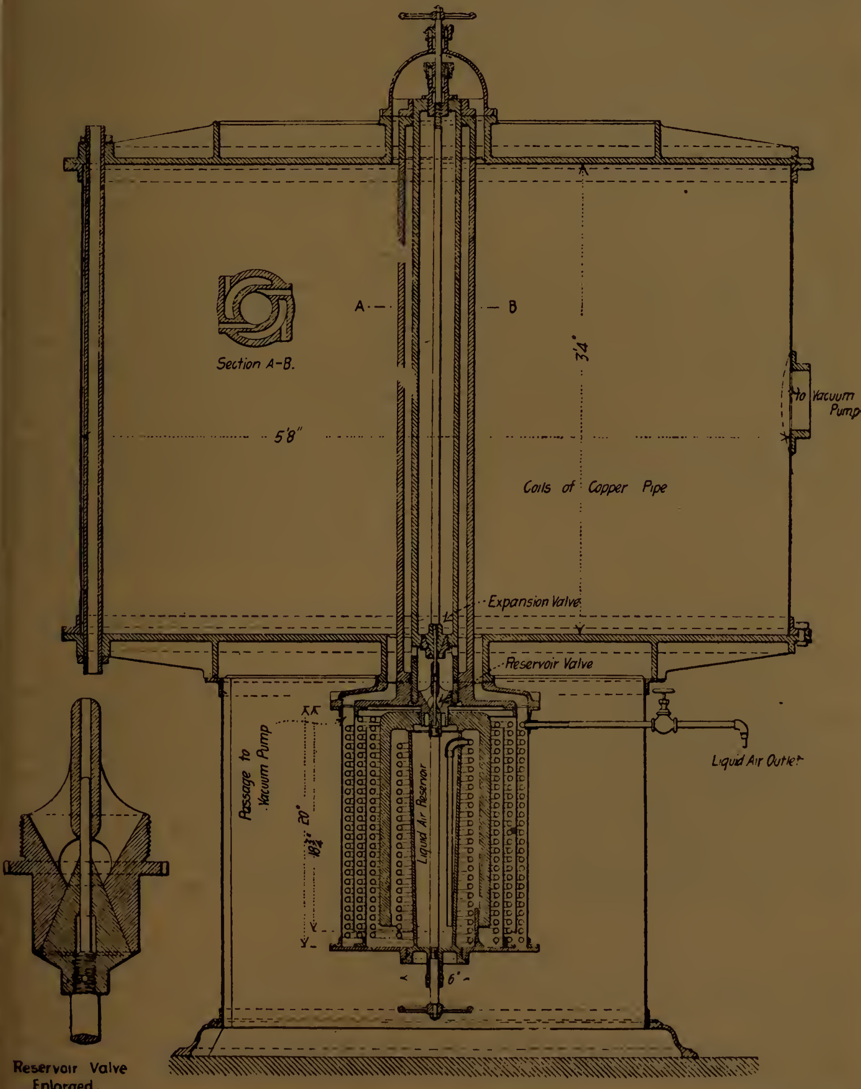

FIG. 286—SECTIONAL ELEVATION OF LIQUEFIER AND AFTERCOOLER, SHOWING DETAILS OF VALVES. LIQUEFIER COILS ARE NOT SHOWN.

temperature of the air about to be drawn off; the vacuum spiral space surrounding the tubes of the liquefier is constantly having the intensely cold evaporated air passing through it and the temperature of the whole apparatus is therefore being gradually reduced toward some minimum which, so far as present indications go, is remarkably near absolute zero. In fact, judging from results obtained the first time the plant was operated to test the compressors, etc., it may be expected that air will be actually solidified.

The same test seemed to indicate that the brine tank is superfluous, and it was found that the entering and leaving air and the liquefier casing were at practically the same temperature.

One of the problems to be solved before liquid air can be of any great commercial value is some method of carrying and storing the material so that it can be retained in a liquid form. The company has endeavored to perfect this feature in a practical and business-like way. The results of its efforts is a double tank consisting of an outer and inner tank. The inner metal vessel is closed, except for a small offset pressure gauge tube, and the larger opening constituting at the same time the filling tube and the relief valve. Surrounding this is a second vessel, in its turn surrounded by some non-conducting material such as corn pith, excelsior, granulated cork or the like, contained in a wicker basket. The inner tank being filled with liquid air the relief valve automatically opens slightly from time to time, as the pressure exceeds about 6 lbs., and permits the escape of the cold air into the space between the two metallic tanks. This forces the warmer air out through the bottom of the tank and maintains a very cold blanket of air between the liquid air and the exterior insulating casing; smaller and cheaper forms are made by using an open inner vessel made of wood pulp similar to the well-known one-piece water buckets. These are surrounded by wire netting held away by small wooden strips.

The vessel is then put in a wicker basket, packed about with some insulating material as in the former case, and is provided with a wooden cover which rests on the wire netting and forms an air space.

Still another form consists of two metallic spheres, between which is a third molded cork sphere held away from the others.

Both the inner and outer spheres are provided with separate relief valves, so that when the pressure exceeds a certain set amount the inner valve lifts and, one might say, exhales into the space between the inner and the cork spheres. The cold air gradually works outward through the cork, becoming warmer as it progresses. Finally it reaches the space between the cork shell and the outer metal casing and accumulates until the pressure is sufficient to lift the second valve when it passes into the surrounding atmosphere.

While the company has devoted its chief endeavors to the process of liquid air manufacture and transportation, it has also paid some attention to the possible applications of liquid air. One which is of especial interest in these summer days is the operation of a cooling fan by compressed air obtained from volatilizing liquid air. The liquid is held in a suitable receptacle, while a coil connected with this receptacle constitutes a vaporizer and heater utilizing the heat of the atmosphere. The fan is revolved by a small turbine driven by the air under pressure, which, as it escapes from the motor, is caught by the fan blades and whirled forward in the current of air. In this way not only is the air in a room kept in constant motion, but it is continually cooled and freshened by the addition of the cold exhaust air of the motor.

To our readers who have followed the above description of the air liquefying process, it will be apparent that its efficiency, or the quantity of liquid air produced for a given expenditure of power, depends primarily upon the amount of refrigeration which is effected in the expansion of the air through the contracted orifice of the expansion valve from a pressure of 1,200 lbs. to a pressure of 300 lbs. The cooling which is effected in such an expansion from ordinary atmospheric temperatures, when the expansion takes place in a cylinder against a piston, is, of course, known with fair accuracy; but what the cooling may be when the expansion occurs through a nozzle and the jet of air at high velocity, performs more or less internal work which tends to restore its original heat, is something as yet unknown, and which can only be determined by careful experiment.

Such preliminary tests as have been made with the above apparatus, however, indicate that the refrigeration due to the expansion under the conditions existing in this apparatus, is much greater than such empirical formulas as have been heretofore relied upon have indicated. The results of complete and accurate tests to determine the product of liquid air per horse-power hour in this apparatus, will therefore be awaited with interest.

For the material from which this description and the accompanying illustrations have been prepared, we are indebted to Messrs. O. P. Ostergren, President and Engineer of the General Liquid Air Co., and S. M. Gardenhire, Esq., its Secretary.—*Engineering News.*

MECHANICAL APPLICATION OF COMPRESSED AIR.

We have had this week a significant illustration of the scientific interest which is taken in the utilization of this force. There is, perhaps, no institute in the United States which has more speedily recognized new commercial tendencies and utilizations due to scientific discovery than the Franklin Institute of Philadelphia. This institution set apart one evening recently for the discussion of the various uses to which compressed air is now put for commercial ends and for a discussion as to the range in the future which the utilization of this force may find in commerce and in manufacturing. Men of high scientific authority of New York, Chicago, Philadelphia and other centers in scientific study, took part in this discussion.

USE IN MINOR INDUSTRIES.

There was agreement that for a thousand and one industries, many of them of delicate and intricate character, compressed air is to furnish the most satisfactory and economical of all power-producing agents. In fact, it seems to cover the whole range of minor industrial vocations, especially some that hitherto have been presumed to be adapted only to hand power. When, the other day, workmen painted the whole substructure of the Washington Bridge by means of compressed air apparatus and did it satisfactorily, there was amazement expressed here that this force could be put to such use.

The master mechanic of the Erie Railroad laughed contemptuously when he was told that an air apparatus would tamp his railroad tracks more speedily and more cheaply than it could be done by hand power. This is something which master mechanics have always believed no apparatus excepting the tamping iron and the brawny arms of the laborer could satisfactorily do. Now, the president of the Erie tells his friends that compressed air apparatus will do this better than hand power. These are only illustrations of the wide range of the mechanical use mentioned at the Franklin Institute meeting. It was also said that compressed air would solve the problem of perfect food refrigeration in the tropics, and it is hinted that before very long there are to be established not only in Cuba and in Porto Rico, but in Manila, American apparatus designed to do this work.

No one believes that compressed air is to be such a competitor of electric current as to supplant that. There are many things that electricity can do cheaper and better than any compressed air apparatus yet invented is able to do. It is more likely to supplement the electric current.

It is true that compressed air force may be seriously threatened, by and by, by liquid air, the possibilities in which seem to be so great as to suggest complete revolution in the production and utilization of power. But that day is remote, although Mr. Tripler has demonstrated to the scientists of authority here that he is no quack, no maker of ingenious, interesting, but commercially useless philosophical experiments, but is carrying on a line of investigation worthy of the approval and encouragement of all scientists and of the commercial world as well.

From 1881 to the present day we were in what may be called the era of the commercial development of electricity for other than telegraphic purposes. This year we seem to be entering into an era to be characterized by the commercial utilization of compressed air, not so much in competition with electricity, but in sympathy with and supplemental to it.—"Holland," in the Philadelphia *Press.*

COMPRESSED AIR IN MACHINE SHOPS AND FOUNDRIES.

In *Cassier's Magazine* for August, 1895, Mr. C. O. Heggem writes instructively on the utility of compressed air for the transmission of power to out-of-the-way places and for use in lifts and hoists in machine shops, and also describes the various machines that are operated by air power.

In machine shops compressed air serves as a helper for the machine hand in a far more efficient and economical manner than that rendered by the manual help, which in some shops require an order from the foreman and a great deal of time lost.

All the attendant annoyances may be overcome by putting in air lifts over all lathes above 20 inches swing and over all planers, shapers, drilling machines, and drill presses working on pieces too heavy for one man to lift, and so quick and satisfactory are they in their action as to leave out of comparison all chain blocks or chain rigs of any kind. A very cheap form of air lift is a plain cylinder, suspended from a trolley traveling on a swinging arm, the cylinder being about four feet long, and for all lathes below 36 inch swing, or planers 30x30 inches, it need not be more than 6 inches in diameter, and yet will lift about 2,000 pounds with an air pressure of 80 pounds per square inch.

Chucks, face plates and steady rests can be lifted from the floor and placed in position by the aid of the compressed air hoist in less time than by hand, and work can be lifted and placed against the face plate or in the chuck with more satisfaction and in less time than by any manner of "blocking up" in vogue with the old helper system.

Very convenient little presses can be fixed up for driving mandrels, pressing in seats for valves, linings in piston rod glands, etc. The presses are made with a cylinder 16 inches in diameter, which at 80 pounds pressure is equal to about 16,000 pounds pressure on the ram. This compressed air press will at once commend itself for accuracy and avoidance of many accidents.

In turning soft steel shafting it is customary to use water to which a certain percentage of sal soda has been added in order that the water may not rust the finished work.

As the tool is being crowded away it crowds more over the harder portion of the steel than softer ones, and the result is, in addition to a tapering shaft one is also produced that is not round.

By using a small air jet—that is, air issuing from an orifice of about 1-16 inch in diameter, the work can be finished very much the same as if water is used. A smooth surface will be produced with this important difference, that the tool will not crowd, and, consequently, the shaft will be nearer true and straight when using compressed air than when using water.

The same size of air jet may be used to advantage at different places around the shop. It is excellent for cleaning off benches and machines, and is much to be preferred to the common dust brush for this purpose.

Punching may be done by having a small cylinder at the back end or arm, suitably pivoted, at the other end of which the attachment is made to the head carrying the punch. Such an arrangement is especially well adapted for quick work in the construction of smokestacks, breechings, tanks, and all work not requiring heavier than ⅛ inch, or, say, No. 8 gauge of iron or steel. With these presses arranged so as to be operated by a foot tripping device and equipped with jigs, it is surprising how much more can be done than by any other system of laying out.

A number of special tools have been on the market for some time, made for compressed air caulking. Some of these tools do the work very effectively, and with a minimum amount of discomfort to the man running it, in the shape of reduced jar.

It is an incontrovertible fact that caulking is done better and can be done very much cheaper by air pressure than by hand.

From the machine shop and boiler shop Mr. Heggem goes to the foundry, and there on every side he hears the blasts of escaping air. Here are direct lifts or suspended cylinders of five tons capacity. Copes are lifted off without any jar. Patterns are lifted out just as slowly as you please until they are clear of the mould. Large green cores are placed in position to dry, without jar or shock of any kind.

Compressed air for lifting and other purposes in the foundry will commend itself to any practical foundryman without using any argument whatever in its favor.

In the same article the writer gives practical advice to those contemplating compressed air. He says: "Put in a compressor two or three times as large as you think you will actually need, and a belted compressor is to be preferred to a steam-driven one where the main engine running the shop machinery is sufficiently large to carry this addition. It is preferable because it is more economically run, no matter from what standpoint the economy is viewed."

IN AND ABOUT RAILROAD MACHINE SHOPS.

The sand blast is the most efficient means of cleaning paint scale and rust from tanks. No other way cleans out the pitting and around the rivets as satisfactorily.

A tender which had been repainted several times can be cleaned bright at the rate of a square foot in 7 minutes. A tank which had never been painted may be cleaned of rust at the rate of a square foot in 3 minutes.

At the Susquehanna, Pa., shops of the Erie R. R. Co., a Baird stay-bolt breaker saves 50 per cent. in time and one man at $1.40 per day. Two men and the pneumatic breaker can break 300 to 325 stay-bolts in 7 hours.

Stay-bolt tapper run by air saves 50 per cent.

Stay-bolt pincher or cutter operated by 2 men cuts 1,000 per hour on inside work. By hand one man can cut 300 in 4 hours.

Caulking and beading tool beads 235 2-inch flues in two hours and ten minutes. By hand 200 flues can be beaded in ten hours.

Mud ring riveter and two helpers at $1.40 per day each will do as much as two boiler makers at $2.30 per day each and one helper used to do in two days.

Riveting bull saves one man's time at $1.40. Bull also used to punch out old stay bolts after same have been cut. One boiler maker at $2.30 per day by hand can punch out 100 per day. Bull and two helpers at $1.40 each punches 300 in five hours.

Tank frame pneumatic riveter operated at 100 pounds pressure saves 50 per cent. Flue swageing machine for reducing flue end 1-16 inch for ferrule saves 50 per cent. in time.

At the establishment of Russell & Co., Massillon, Ohio, oil stored in tanks buried in the ground is forced by air pressure to store room where it is drawn from a faucet as required. This is a great convenience and minimizes the fire risk.

Stay-bolt cutter cuts 100 ¾-inch bolts in one-half hour, by hand 100 to two hours is the average. When stay-bolt cutter was introduced a reduction of 60 per cent. was made in the pay of men doing this work and still they now make 6 per cent. more wages than before the reduction.

The cutter does not loosen the stay like chipping by hand is likely to do.

MANHATTAN ELEVATED RAILROAD SHOPS.

The power which is extending its range in railroad fields with a force and vigor of which we have no recorded precedent, is compressed air, which is becoming every day more and more closely linked with practical usefulness, and the reason therefor is not far to seek, and is a short tale soon told.

Compressed air and pneumatic apparatus of the highest types, are the embodiments of inventions made by mechanicians who grasped the compressed air proposition with one hand, and the requirements of industries with the other, incorporating them into the moulds that fashioned the compressors and tools

FIG. 287—BORING HOLES IN WOOD.

which are at work to-day in every part of the world. One of the most conspicuous features in the progress of compressed air apparatus and pneumatic tools is their rapidly extended use in railroad shops, under numerous novel conditions and forms. A notably well conceived and carried out installation of the latest type of compressed air service is that in the shops of the Manhattan Elevated Railroad Company, which covers two city blocks in the Borough of Manhattan, bounded by East 98th and 99th Streets and Third and Fourth Avenues.

The elevated roads comprised under the Manhattan management have been, for a quarter of a century, a great factor in the upbuilding of the new west and east sides of what are now the Boroughs of Manhattan and Bronx. In 1873, the then existing elevated road was a light structure, single track with sidings, extending from Rector to West 34th Street. The power was transmitted from stationary engines, to endless chains clutched by the cars. The system was crude, when measured from the standpoint of to-day, but nevertheless, the road sprang into immediate popularity, and its prosperity led to the great extension commenced in 1876, which stretched miles of tracks over territory in great part devoted to agriculture, and as sparsely settled as counties of the State bordering upon the Adirondack region. It is now 20 years since the roads were completed to

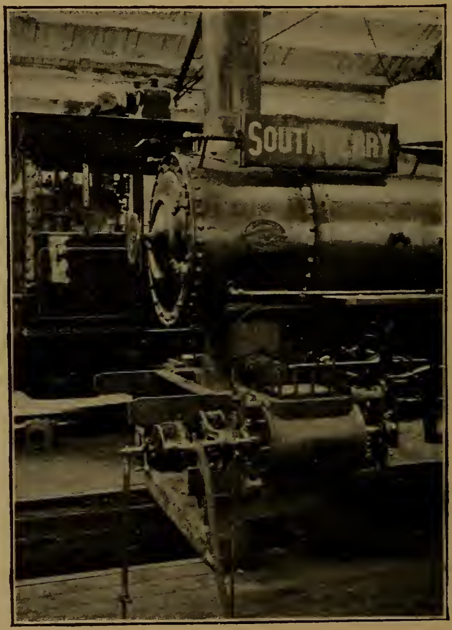

FIG. 288—BORING OUT A CYLINDER.

the Harlem river and beyond, and the strongest evidence of the road's success in building up the city is the indisputable evidence that since 1876, there has been built upon land from 59th Street to 176th Street, and from river to river, homes, shops, factories and institutions which house a larger population than is enumerated in the combined populations of Boston and Baltimore.

The Manhattan elevated system holds the world's record for frequency of trains, and passenger traffic, per mile of track. As an illustration of the volume of traffic, it may be said, that the system conveys more passengers than all the railroads which ply between the Potomac and Rio Grande rivers.

The following figures show the enormous traffic of one year.

Train, Car and Engine Mileage and Passengers Carried, Fiscal Year ending June 30th, 1897.

	Train Miles.	Car Miles.	Eng. Miles.
Branches	120,130.78	184,558.36	120,130.78
Main Lines	9,790,834.60	42,996,973.42	10,548,448.28
Total	9.910,965.38	43,181,531.78	10,668,579.06

Total number of Passengers—All lines 182,964,851

The need of improved appliances suitable for handling expeditiously the vast equipment of the road was quickly appreciated by Mr. W. J. Fransioli,

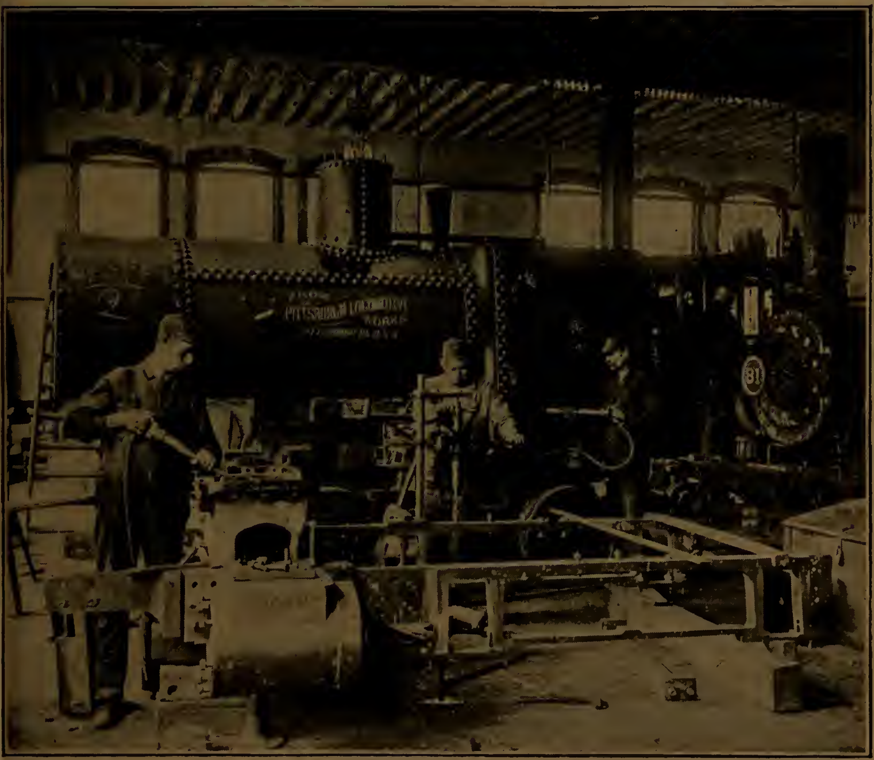

FIG. 289—CHIPPING AND DRILLING WITH HAESELER DRILLS AND BOYER TOOLS.

General Manager of the Manhattan Elevated Railroad, and one of his earliest acts on assuming management was to take up the compressed air feature. Previous to that time it had not been used at all. By his kind permission we recently had the pleasure of visiting the Manhattan shops for the purpose shown herein.

For the information relative to the plant we are indebted to Mr. M. McNally, Master Mechanic.

The air compressor is situated in the boiler and engine room, a separate building, adjacent to the blacksmith, boiler and machine shops. The type is an Ingersoll-Sergeant.

From the reservoir the air is conveyed in 600 feet of three inch, and 900 feet of two inch mains, to the various shops. In one line of main pipe the extension is underground in a public street, and then overhead for distribution in a shop 400 feet from the compressor, but there is no drop in potentialty in any of the smaller supply pipes deflected from that main. In each shop there are either batteries or single air tanks conveniently placed for access and distribution to the best advantage. A great many air hoists are used, and one is in course of construction

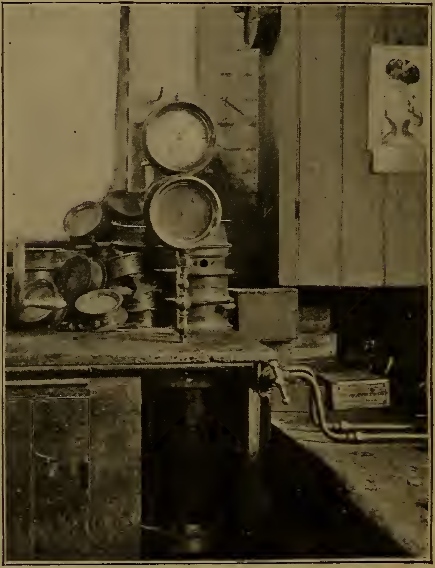

FIG. 290—GAUGE TESTING APPARATUS.

for hoisting lumber from the yard to the upper stories of the wood working shops. which will hoist about 3,000 pounds or less, 26 feet.

Several pneumatic cranes are in use; one recently installed, enables one man in one minute, to perform work that formerly required two men four minutes. In the boiler shop pneumatic tapping, screwing and drilling machines, perform varied operations with high velocity and accuracy. In form the machine is a rotary miniature engine, with a short cylinder fitted with a circular piston, internally tangent to the cylinder; the axis of the piston being parallel with the cylinder. A sliding diaphragm of brass divides the cylinder into two equal parts, air admitted behind the diaphragm, causes it to revolve until the exhaust passage is reached. The speed of the piston is controlled by gearing. This ingenious machine is used for tapping and screwing staybolts, reaming and drilling out boiler tubes, and drilling of several descriptions. With this machine a good mechanic can roll out 200 boiler tubes on both ends in four hours.

Several riveters are in use, and in them is noticeable the striking superiority of pneumatic over hydraulic riveters, in that the pneumatic riveter makes an initial stroke that is quick and powerful, bonding the rivet and plate into homogeneity, following with a secondary blow which upsets the rivet, so that the rivet and orifice are fixed in a perfect unit. The pneumatic staybolt cutter has a capacity for cutting off from 1,200 to 1,500 staybolts an hour, according to the diameter of the bolts.

Under the chisel and hammer method which obtains in shops not equipped with compressed air, staybolts are invariably loosened in the sheets, whereas with pneumatic tools, the work is flawless. All caulking performed in this establishment is done with pneumatic tools of especial design for the requirements.

REBORING OF CYLINDERS WHILE IN SHOP FOR ORDINARY PURPOSES.

The hoists for axle lathes and wheel borers are also of designs adapted to the requirements of the work, and are provided with ingeniously constructed grip-

FIG. 291—CLEANING RATTAN CAR SEATS.

ping, and overhead trolley attachment. One man can lift a wheel to the lathe in two seconds. All the air hoists were made in the establishment; the material being wrought iron pipe, the ends being set with ordinary caps and couplings. The pistons work well, notwithstanding the fact, that in several patterns, the cylinders were not bored out, as is done with hydraulic jacks and hoists, and arrangements are being made for a further extension of work in the direction of hammers, jacks and portable cranes for use in the yards. All cylinders are blown out with air, replacing the steam process, so hot and uncomfortable for the hands. All air is delivered at uniform pressure of eighty pounds, wheresoever required in and out of shops. Other uses besides the foregoing are seen in the air brake bonding and testing processes, the testing of Pintsch gas tanks and pipes to eighteen atmospheres, the boring and cutting of wood, the mixing of paints, and the conveyance of sawdust from the shops through pipes to the sawdust furnace near the boiler house.

All the seats and backs of the car seats are of cane work, and are soon soiled and begrimed with smut and dust in the almost incessant use to which they are subjected. These are cleansed from dirt and dust wholly by means of compressed air admitted through an ⅛″ nozzle secured to flexible connections.

All castings are cleansed by substantially the same process. A short time ago, when preparations were being made for painting the interior of the shops, Mr. McNally decided to free the walls and ceilings from dust by the use of compressed air forced through ⅛″ nozzles secured to hose connections. The result of the operations has firmly established the process for future use. This in brief recounts the application of compressed air and pneumatic tools in an extensive plant, which in every respect is in alignment with every progressive movement in mechanic arts that is founded upon correct principles, having for its purpose the production, conservation and practical use of the highest available type of power applied through the best tools.

Ere long further additions will be made to the use of compressed air apparatus at this plant, where it is recognized as a mighty power, swift and sure, pulsating with energy that can both push and pull.

IN THE SHOPS.

Boiler and Firebox-Sheet and Staybolt Work at the Union Pacific Shops.

The boiler shop is one of the most interesting departments of the manufacturing and repair plant of the Union Pacific at Omaha, and, as usual, the firebox work embraces some of the best features of this department. It is perhaps unnecessary to say that compressed air is used to a very great extent. With the air plant installed and in operation in such a variety of operations, it is difficult to imagine the possibility of a substitution of power or of accomplishing the work without its assistance with any degree of economy.

All firebox ends of boilers are made from sheets as large as can be obtained from the manufacturers; that is to say, sheets are never spliced when single sheets of sufficient size can be obtained. The largest now used are for the firebox boiler sheets, and the sizes are 109½ by 235½ inches and 114 by 176 inches for different classes of boilers. The work to be done is laid out on the flat sheets before bending, and the punching for staybolts, rivets, etc., is done upon the press shown in an accompanying illustration. The press is a home-made affair, located out of doors. It is built up of columns firmly anchored in the ground and braced, and the thrust is taken by heavy I-beams secured to the top of the columns. The "anvil" is a part of a driving axle supported by a driving wheel centre as a base. The opening between the uprights is about 12 feet. The sheets are handled during the punching process by a crane, also partially shown in the illustration. This punch is operated wholly by air. After punching, the sheets are bent to shape in ordinary bending rolls.

An ingenious device is used for holding firebox ends while flanging. The bed consists of a thick cast-iron plate of the form which the inside of the sheet is to be after flanging. This is supported near the ground level of the shop. Above this is a plate of similar shape, but smaller, which is attached to the piston of a long air cylinder anchored above. The sheet being laid upon this base, the upper plate is brought down and held by the air pressure while the flanging is done with hammers. The pressure is sufficient to hold the plate firmly in place, the base plate serves as a former to give an accurate curvature, and the piston rod being in the middle of the plate is entirely out of the way of the workmen.

The staybolt practice in this department is an especially interesting feature of the work. The holes are tapped by the use of an air-operated tool, and the

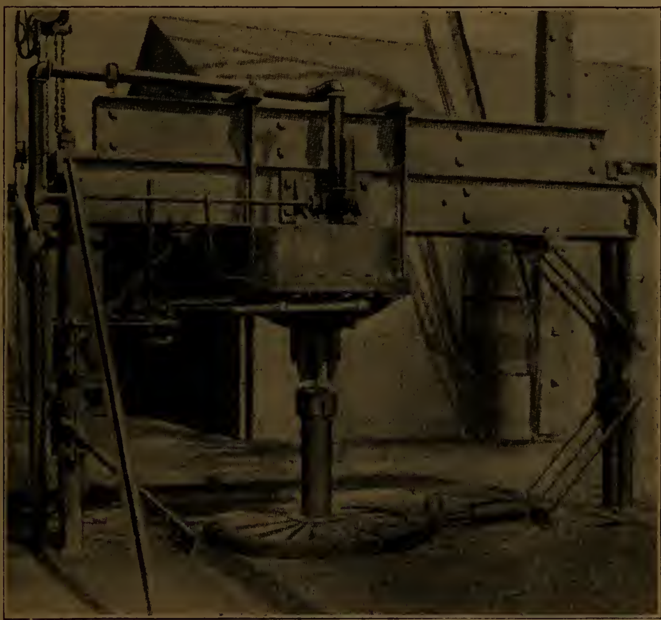

FIG. 292—PUNCH FOR LARGE BOILER SHEETS.

staybolts are screwed in in the same manner. All staybolts are screwed in from the inside and cut off inside. To do away with the necessity of forming a square head upon each staybolt, an ingenious and simple tool has been devised. This is shown in two forms in one of the accompanying engravings, one in a form adapted for handwork and the other the chuck which is used with the air engines. The clutch consists simply of a disc having an opening to receive the end of a bolt eccentrically mounted upon a pin, which is cut away so as to form about one-fourth the wall of the opening. The pin forms the means of attachment to the engine or to the handle when used in hand work. It is clear that the turning of the pin in the disc will cause the edges of the part of the pin forming the walls of the opening to grip the bolt firmly between itself and the other wall of the opening and the result is the same in whichever direction the tool is turned. It is said that the threads of the bolt are not injured by the use of the tool, and the saving of the work of forming a square end is an obvious economy.

It is the practice of the Union Pacific to drill all staybolts for 1½ inches from the outer end, as a precautionary measure to secure a sure indication of bolts partially broken near the outer sheet. The work is done before the bolts are inserted, contrary to the practice in many shops. This method is made possible by the practice before mentioned of screwing in and cutting off staybolts on the inside of the firebox, since if it was necessary to cut them off outside, the drilled holes would be partially or wholly closed in the process of cutting. A special machine has been designed for the purpose of drilling, which is substantially automatic except in so far as it is necessary to turn air off and on. A general view of this machine is shown herewith. Both ends are the same as the one shown, the machine being fitted up double, though the work at present requires the work of one part of the machine and one man only. The air is regulated by the handles at the front of the machine. In operation, the bolt to be drilled is automatically gripped and presented to the drill, withdrawn at intervals to clear the drill, while constantly fed at a uniform rate. When the gauge indicating the proper depth of hole is reached, the bolt is withdrawn from the drill and automatically released from the clutches. Each of the two cylinders shown represents a separate working part of the machine, three hand levers being necessary for controlling the operations of each cylinder. The rate of drilling is about 140 staybolts per hour, one man operating two drills.—*Railway Age.*

PNEUMATIC EQUIPMENT FOR BOILER SHOPS.

It is not enough that a modern boiler shop should be equipped with a power punch, shears and rolls, which have until recently seemed to constitute enough of an equipment to satisfy the ordinary boiler builder that he is doing justice to his business, his customers and to himself. While these machines are labor-savers of the first order, the proportion of work which they contribute in the manufacture of a boiler is small in comparison to the balance.

To overlook any opportunity to cheapen the production of standard commodities is a positive step towards a business failure, and a number of apparently insignificant savings amount to perhaps just enough to keep the business afloat.

To depend upon the sentiment of the consumer for a higher priced home product is folly, for when the home consumer recognizes the fact that the local manufacturer does not take advantage of recent appliances for cheapening the cost of production, he does them an injustice which they repay by trading elsewhere.

In return for the patronage of a community a manufacturer, in order to establish himself on firm ground, must never permit his patrons to pay out their money for the loss of time entailed by the use of antiquated or inadequate tools or machines.

The pneumatic chipping, caulking and light riveting tools, probably broke the ice, as it were, of the old methods, and took boiler making methods out of the realm of main strength and awkwardness and placed it alongside of machine shop practice. Plate steel may now be machined into boilers as legitimately as cast steel may be machined into engines. The pneumatic hammers have been a great help to boiler makers. In actual test, an operator with the pneumatic hammer cut off a 2½-in. tube in 36 seconds as against 2½ minutes by hand, and 46 tubes were cut off, turned over and beaded with the same tool, in an hour and three-quarters as against five hours doing the same work in the ordinary manner.

Horizontal boiler seams may be caulked and trimmed in one-third of the time required by hand labor, and another great advantage is, that in using the pneumatic tool the quality of the blow is the same, consequently the caulking should be perfect; whereas, in hand caulking, unless done by a very skilled mechanic, the quality of the blows varies considerably. The caulking is, therefore, not homogeneous, the heavier blows tending to reduce the effectiveness of the caulking done in a lighter manner.

For re-caulking an old boiler or re-caulking seams that have been imperfectly done, the pneumatic hammer is a most advantageous tool. A fresh cut can be made on the sheet in a very short time and in a perfect manner, and the boiler be re-caulked with the tool so as to leave the seam in as good shape as if it had been recently manufactured.

It is only necessary to watch the operation of one of these tools in chipping cast iron in cutting off heavy angles and beams or plates in awkward places and positions, to realize what a labor-saving device it is. There are many places where chipping and caulking have to be done where it is almost impossible to swing a hammer or to properly guide a chisel or caulking tool. Here is where the pneumatic tool shows to its greatest advantage. It weighs but a few pounds and does not occupy a space more than 12 ins. long, and any place into which the arm can be thrust this tool can be pushed and good work be performed.

These tools are especially valuable in light riveting. Not only do they save a great deal of time in ordinary open riveting, but in riveting up pipe they prove themselves money makers on every occasion. It is an expensive proposition to lay pipe and rivet up the joints in the ordinary manner. Holes have to be provided for passing into the pipe the hot rivets, which have to be pushed up through the holes and the men have to hold against the riveting from the outside. During all this operation light rivets are becoming cold and the difficulty and annoyance and hard work during the whole task make it expensive and the results inferior to riveting under ordinary conditions. With the pneumatic tool the rivets can be pushed in from the outside; the workmen on the inside of the pipe using the pneumatic tool to rivet it up on the inside. The holding is done on the outside. The workman inside is furnished with good air to breathe and merely has to handle the light tool. No expensive digging out under the pipe has to be undertaken in order to rivet the seams next the ground. In short, it is entirely probable that riveting in this manner can be done for at least one-third the cost and in a very much better manner than by hand.

The riveting up of gasometer rivets, stand pipes and tanks, which are set up outside, can be done much better and in a great deal less time by the use of these labor-saving devices.

These pneumatic hammers are not the only pneumatic tools which are used in modern boiler shops. There are many other appliances; for instance, pneumatic drill and tap combined, for drilling and tapping out the numerous holes required to be made for the stay bolts of fire boxes.

There is also the pneumatic drill, for drilling holes using ordinary twist drills. These machines are extremely easy to handle and they do good work.

There are pneumatic machines also for expanding tubes into place.

Every good boiler shop should also have, in addition to a large pneumatic crane, small pneumatic lifts for handling heads and sheets and pieces of boilers so they can be rapidly placed in position and without the pulling and hauling which would be necessitated by hand labor. A pneumatic crane properly installed in a boiler shop is a valuable acquisition and should be made powerful enough to pick up an ordinary boiler and move it from place to place as required, or for final transportation. The entire surface of the shop in this manner would be made to yield working space, while with no means of lifting and transporting boilers over each other a large portion of the ordinary shop space has to be left open for gang way, and the annoyance and inconvenience of pushing boilers past each other for exit, and the moving of work and tools which are frequently in the way, causes a loss of time and annoyance which amounts to considerable.

In the testing of boilers much time and expense could be saved by having a water tank on the shop floor in in any convenient place, at sufficient height to readily fill any of the boilers for testing. After testing, the water may be expelled from the boiler by compressed air, which will shoot the water back into the tank in a very small fraction of the time necessary to empty a boiler under ordinary circumstances; in fact, emptying a boiler after testing is one of the slow jobs and generally loses a day in shipment, whereas, with the use of compressed air, after a boiler has been tested it can be emptied and shipped inside of an hour. The water is also saved, which in many localities is a considerable item.

Besides the pneumatic tools, a well equipped boiler shop should have a gang shell driller, for drilling holes in the shell, as required for Government boilers, and if the shop is of any considerable size, a head spinning machine and furnace would pay for itself in a short time. The ease and rapidity with which ordinary boiler heads can be spun into shape and the certainty of turning out a first-class job, and the economy with which it can be done, should make it a desirable adjunct for any first-class boiler shop. All reasonable sized scraps about the shop can be heated in the same furnace, and with the addition to the plant of two or three forms of inexpensive hydraulic presses, these scraps could be made into manhole crow feet, manhole plates themselves, compressed steel or iron flanges, eyes, angle plates and many other pieces which go to furnish up a first-class boiler, which in cheap work are generally made out of cast iron. All this work, which consists of scarcely more than operating a lever connected to a machine and putting the heated raw material in place, can be done by boys as well as by the most experienced men.

For a large boiler shop the equipment would be incomplete without proper pneumatic or hydraulic riveters for heavy work, and finally when boilers are finished they can be painted more effectively and in one-third the usual time by the use of pneumatic spray painting machines which are now in use amongst most of the large car shops in America.

A compressed air plant to do all this work for an ordinary shop would be a very small one. A 15-h. p. engine, driving a small compressor, could, with sufficient receiver capacity, handle all the business of an ordinary shop, unless the boiler testing was done with compressed air, which, by the way, is, to the mind of the writer, a better method than cold water, for with the use of soap, water and a brush to paint the seams, the smallest leak can be instantly detected by the bubbles blown, and the rapidity with which the pressure can be introduced and released and the absence of water and leakage, makes the whole operation more desirable.

A valuable addition of any boiler shop would be a portable pneumatic plant with the proper tools for doing work away from the shop, such as erecting gasometers, stand pipes, putting in riveted water mains and doing any sheet iron work where the use of these tools saves in both expense and time. These plants could be small and easily portable and would certainly pay handsomely to the shop that possessed them.

The writer is glad to note that most of our principal shops here in San Francisco have, during the last twelve months, been gradually improving their equipments and installing many of the tools described above, with the most satisfactory results. Never has the output of boilers been so great in San Francisco as during the past six or eight months. While our manufacturers here are handicapped by a limited field and therefore not enjoying the advantages of manufacturing considerable numbers at a time, still the differences between the freight on raw material and the finished product in this community, acts as a protective tariff which partially does away with the disadvantage above mentioned and our boiler makers feel that with modern tools and methods, they can hold their own in the competition which is everywhere the life of trade.—E. A. Rix, in *The Boiler Maker.*

COMPRESSED AIR IN A ROLLING MILL.

Most of the more successful iron-working establishments now use "air"—a little—some a great deal, and among the foremost of the latter class is the Passaic Rolling Mill Co. at Paterson, N. J., not only because of their extensive use of compressed air, but particularly by reason of the variety of operations performed by it, several of which are of more than ordinary interest and we believe originality. These works cover about 25 acres of ground, employ about 1,200 men, and have a monthly output of about 5,000 tons, chiefly structural steel, a considerable portion of which is manufactured into bridge trusses, columns, etc., at the works, so it will be seen that compressed air has there a good field in which to demonstrate its value.

The accompanying illustration shows partially the row of jib cranes; each equipped with independent air hoist, used for loading the finished material on cars for shipment. The air cylinders for this work are about 6 in. diameter by 6 ft. stroke, mounted on the mast, the air connection being made with a short piece of hose at the top of the crane.

Figure 294 illustrates one of the most interesting applications of compressed air; one in which work formerly requiring the services of thirteen men is now done by four, and with less danger. By it the capacity of the rolls has been

FIG. 293.—UNLOADING CARS WITH AIR HOISTS.

trebled. This apparatus is not operated entirely by compressed air, steam and air being assigned to the work for which each was considered best suited. It consists of two transfer tables, one on each side of the main rolls of the rolling mill, the duty of one of which is to deliver the heated billet to the first roll, move into position to receive it from the second, move and deliver it to the third, and so on till the billet comes out a finished beam. Of course the process described applies to the table on one side of the rolls only, the one on the opposite side operating in the same way with it. This transfer table consists of a heavy four-wheeled carriage A carrying a tilting platform or girder B (with fulcrum at C), the top of which consists of rollers operated in either direction by the level gears and shaft plainly shown in the cut. The carriage travels in the pit on rails parallel

FIG. 294—TRANSFER TABLE.

to the rolls in moving from one roll to the next, and the end of the tilting table next the rolls is raised and lowered to position for the upper and lower rolls by an 18 in. air cylinder located in the yoke D. The crossbend E is connected at its center to the piston of this air cylinder and moves the tilting platform by means of the side rods fastened to its ends. The action of this cylinder is controlled by a special valve F, operated from the engineer's platform at P. The men shown in the cut were engaged in changing rolls at the time the photo was taken and are in no way connected with the operation of the table, one engineer and a roll tender being all that is required for the apparatus shown in the cut, and the same number for the other table (not shown) on the opposite side.

After the beam leaves the rolls it passes to the hot saw shown in Fig. 295 where it is trimmed and cut to length. The rollers A, Fig. 295, receive it from the rollers on the table, Fig. 294, without any handling or even a pause in its motion, so that a few seconds after it has received its last squeeze in the rolls it is being cut by the saw. This saw is fed through the beam by the compressed air cylinder

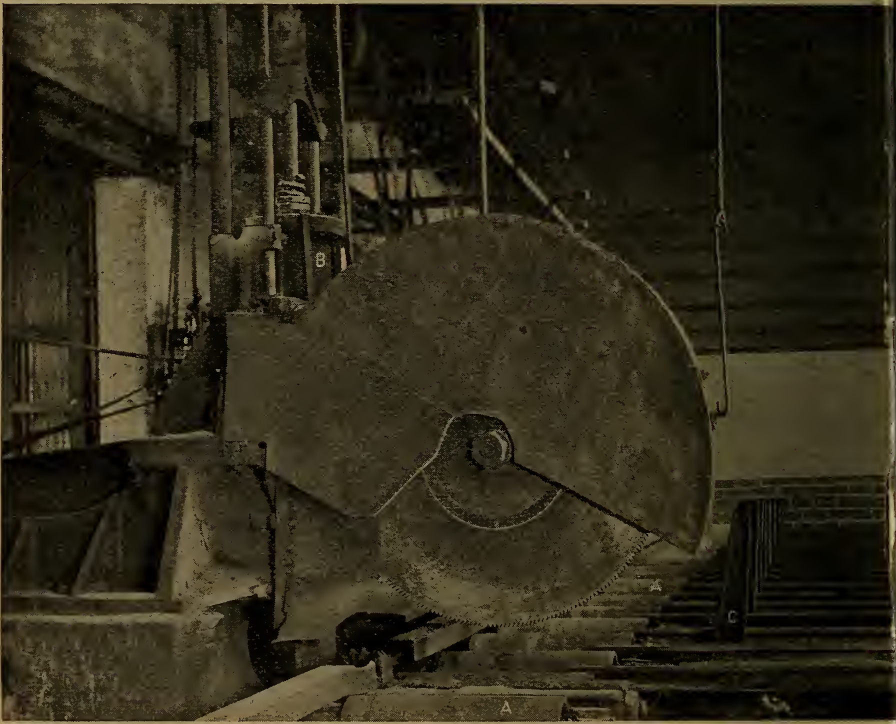

FIG. 295—AIR CYLINDER FOR LIFTING HOT SAW AND DEVICE FOR PLACING BEAMS ON EDGE, OPERATED BY AIR.

B, which is 12 in. diameter by 20 in. stroke; the elastic yet persistent nature of the feed given the saw by compressed air is found much better than any other method.

Compressed air performs the next operation on the beam, which is to remove it from the rollers (making room for the next) and set it on edge to cool. When the beam lays on the rollers after being cut to length the fingers (C) are in a horizontal position under it between the rollers, and an air cylinder, 15x36 in., located under the rollers pulls the fingers to a vertical position, bringing the beam with it, at the same time carrying it sideways far enough to clear the rollers.

The rest of the work done by air in these works is being done in many places elsewhere, and is consequently of but passing interest. Fig. 296 shows a busy corner in the bridge shop—a group of three riveters, two reamers, a chipping tool and hoist, all being operated by compressed air. The total pneumatic equipment of the works, outside of the special apparatus described consists of about 40

FIG. 296—AIR HOIST, AIR DRILLS, AIR HAMMER AND AIR RIVETERS.

cylinder hoists, 12 riveters, 5 drills and reamers, and 2 chipping tools. They now have nearly completed a very interesting device for charging the heating furnace, which we hope to describe in a future article. This equipment is being constantly increased, especially the number of hoists, which vary from 4 in. to 12 in. diameter and up to 6 or 8 foot lift, used for handling material throughout the works.

Fig. 297 is a ground plan showing the approximate location of these compressed air appliances.

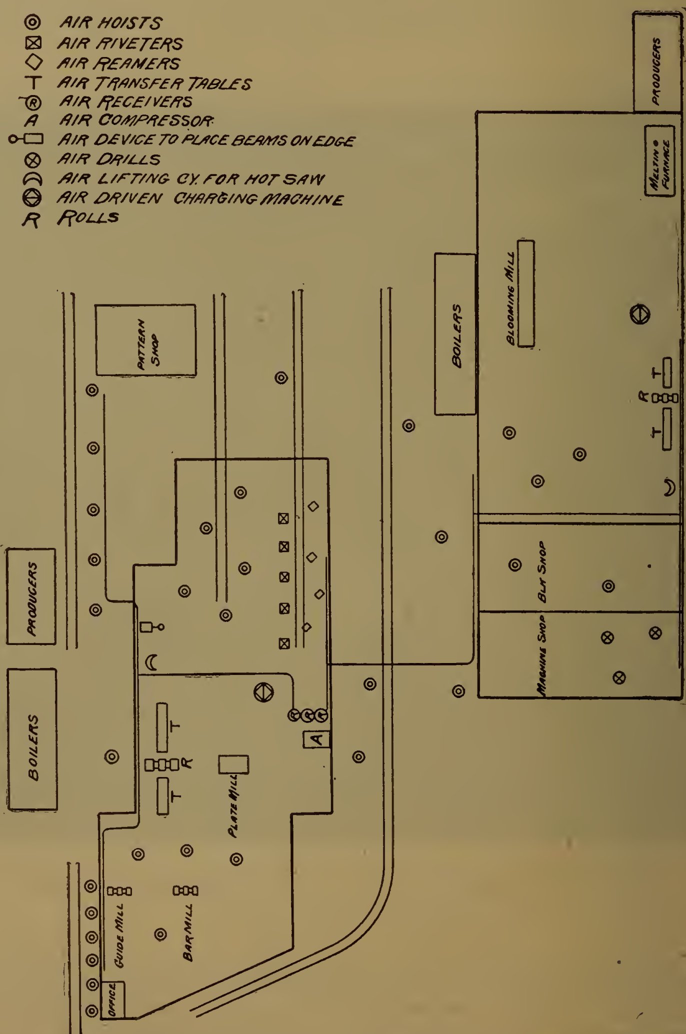

FIG. 297—PLAN OF THE PASSAIC ROLLING MILL, PATERSON, N. J., SHOWING THE DISTRIBUTION OF COMPRESSED AIR APPLIANCES.

Great credit is due their master mechanic, Mr. J. E. Jones, to whose energy and inventive ability is largely due the successful installation of this aggregation of pneumatic appliances, the value of which it is difficult to even estimate, and the cost of which was comparatively very low. The officers of the company (all of whom are great advocates of the use of compressed air) are: Mr. Watts Cooke, President; Mr. W. O. Fayerweather, Vice-President and Treasurer; Mr. A. C. Fairchild, Secretary; Mr. John K. Cooke, Superintendent, and Mr. G. H. Blakeley, Chief Engineer.

Ample compressed air for this plant is furnished by one Class A Straight Line Piston Inlet Ingersoll-Sergeant Air Compressor, which is controlled by an automatic device, so that steam is used only in proportion to air used in the works, which naturally varies within wide limits.

These works seem to be more favorably situated than would at first thought appear; they have in their yards the tracks of the Delaware, Lackawanna & Western and Erie Railroads and are very convenient to the New York market.

HARRY M. PERRY.

COMPRESSED AIR IN SHOPS.

Compressed Air has from time to time published illustrations and descriptions of compressed air appliances in railroad shops. We have endeavored to exercise care in dissociating patented and theoretical designs from those which have been put into practical operation and which have established themselves in a field of usefulness. We illustrate herewith some of the successful cessful applications of compressed air in railroad shops, the cuts being made from photographs taken by our representative.

In no class of work has compressed air such a varied usefulness as in shops, and it is much to the credit of the mechanical engineers connected with railroad shops that they should have assumed the initiative in this important industrial use of air and that they have developed it to so large an extent. We understand that Mr. Gordon, Master Mechanic of the P. W. & B. shops at Wilmington, Del., about the year 1882, and Mr. Dolbeer at the Renovo shops of the P. R. R. about the same time, were pioneers in the application of compressed air to railroad shops. We will be glad to have the names of persons who may have applied air to the shops prior to the date given. The first application was, we believe, to a hoist. Those who are familiar with railroad shops know the importance of a small, portable and powerful hoist, and we are quite safe in saying that prior to the introduction of the air hoist there had been nothing which met the requirements so well. Next in importance to the hoist is the application of air to portable motors, such as drills, reamers, taps, riveters, chipping tools, etc. Such uses can hardly be called exclusive, as other powers have been applied with, we think, less economy and success. There are, however, certain exclusive applications of air, such as cleaning cars, painting and pumping, which have of late come into general use, and which invariably argue as a good reason why a compressed air plant should be installed in the shop. There are many things now done by compressed air which might be done by electricity, but there are few things which electricity can do in a shop which cannot be done equally as well by air. Air power has a more general application and has a greater field of usefulness in a shop. With the single exception of lighting, what is there about a shop which can be done by electricity for which compressed air is not just as applicable? The great advantage of electricity is in long distance transmission of large powers and in the ease with which it is subdivided and distributed. These advantages are not apparent in a shop equipment. The power distributed is usually small and easily transmitted throughout the limits of the shop with practically no loss by friction. Piping a shop is an easier operation than wiring; the tools are at hand, and the men, down to the most inexperienced, are capable of understanding and managing a pipe line. There is less liability to leakage, because when air leaks it whistles, while with electricity much loss might occur for months or years without discovery. There is always the element of danger by fire and otherwise in an electric installation, while air is so safe that it has been called the "humane power." We have no doubt that, when properly understood, insurance rates might be affected favorably to an air plant. It certainly seems desirable in a place where there is so much oil and so many combustible elements to use that power which, when generally distributed throughout the shop, is perfectly safe. As air and electricity are both secondary powers, it costs perhaps as much to produce one as the other; but in any system where the use of the power is variable and intermittent, air is more economical. Upon this point we can stand with much assurance. If the motor does not consume air, the generator is simply reduced in speed or stopped altogether by an automatic governor. But we have heard it said that the most important advantage in air over electricity is that air machines are easily understood by the men in the shop, and if anything happens repairs may be promptly made. Trouble in an electric plant calls for a telegram to the electrician, who is not always as available as he is expensive.

AIR FOR SHIP BUILDING.

Compressed air for ship building is being used extensively in the large ship yards of the country. Following is a record of its use at the Chicago Ship Building Company's yard:

They commenced to use compressed air in this plant about two years ago, putting in at that time a couple of pneumatic hammers for caulking and chipping in the machine shop and outside on ships under construction. This part of the plant has been in constant use ever since, and with very great success. Both edge caulking and butt caulking are done much more rapidly and cheaply than either can be done by hand, and make better work in every respect. About eighteen months ago they started to experiment with portable pneumatic compression riveters for use in driving rivets in ships on the stocks. The riveter was the ordinary form of bow riveter, and the only trouble had with it was in arranging to handle it quickly in the ship. After considerable experimenting, a rig was finally gotten up which enabled them to pass rapidly from one rivet to another, and they have used these riveters with much success ever since on a number of vessels.

Last summer it occurred to the company to experiment with the pneumatic hammers for driving rivets, and in connection with a pneumatic holder-on, which was devised by themselves, the result in that class of work has been very satisfactory.

The latest application made is in the form of a light wrought iron bow of about 4½ ft. gap, with a hammer fastened on one side and a pneumatic holder-on on the other side. This is suspended by a chain fall from a portable section of overhead tramway, and has been very successful in use. The whole arrangement weighs only about 400 lbs., against a weight of nearly a ton on a compression riveter of the same gap and capacity. Altogether they are driving now from 15 to 20 per cent. of all the rivets in the ships by these riveters.

Pneumatic reamers for fairing the rivet holes have been adopted, and a number of them are in use. Two men with one of these power reamers can do the work of six or eight men working by hand, and on some classes of work can ream as many as three thousand holes a day. Pneumatic hoists are also used to some extent in the shops, and the extension of the application of the air goes along at a rapid rate.

The first compressor put in had a capacity of about 200 cubic feet free air per minute, and the one now being used has about 800 cubic feet capacity. Air is used at a pressure of from 90 to 100 lbs. Compressed air machines of their own designing are used for painting and whitewashing the shops and for painting the iron work on ships. They find it works very well on a plain flat surface like the outside of the hull, but it has not been very successful on the inside work.

MONON RAILROAD SHOP.

When the "Monon" Railroad erected new shops at Lafayette, Indiana, about a year ago, they installed 10″ x 10¼″ x 12″ Piston Inlet Class "A" Air Compressor, which they considered would be ample to operate any compressed air appliance they might put in for some time to come.

The use of compressed air has grown so rapidly in this shop that an order was recently placed for a Duplex Ingersoll-Sergeant Compressor, with both steam and air cylinders compounded and of about four times the capacity of the original machine installed.

At present they are using, in connection with the small compressor, air appliances as follows, some of which we illustrate and describe in detail, the description being kindly furnished to us by Mr. Charles Coller, Master Car Builder of the road.

FIG. 298. HOSE PRESS.—A bench 30″ wide, 8′ long, set up against shop wall; at each end is an upright post, 9″ x 12″ x 8′, secured to bench and against wall. To each post is bolted one cylinder, 5″ in diameter, 10″ stroke. These are old engine steam brake cylinders taken from scrap pile. The one on the right hand is used for clamping hose, having cast dies of different sizes for the different

sized hose. These dies slip into the cast iron blocks, which are fulcrumed to piston rod on cylinder, and the lower one is bolted to top of bench. The cylinder on the left has piston rod connected to the long arm of the tongs, or clamp, which is pivoted to a fulcrum bolted to bench. This is used for clamping hose bands onto hose while bolt is being inserted; is also used for cutting old hose off couplings.

The 8″ x 12″ freight air cylinder shown is bolted on top of bench. There are a series of dies which fit into the end of the piston shank, which hold all patterns of steam and air hose couplings and nipples to proper position to be inserted into hose. Above this cylinder is a shelf set up on brackets, upon which, standing in an upright position, is an auxiliary reservoir. This is used for testing plain triple valves. On the upper side of the bench is bolted a

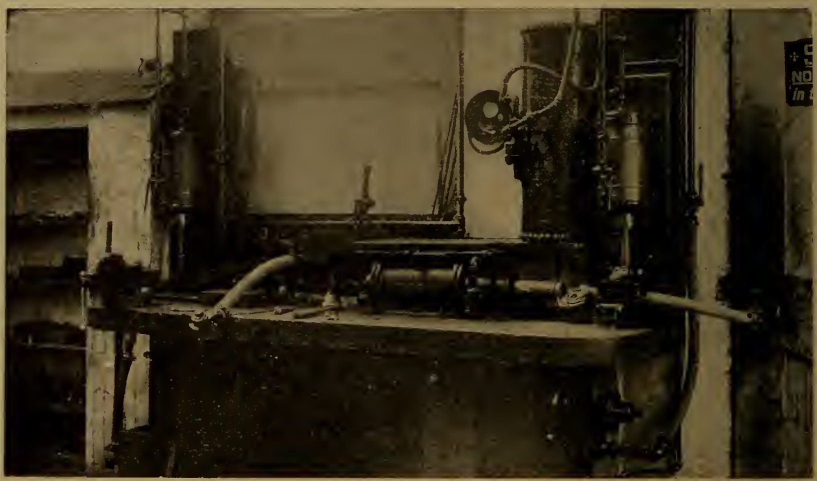

FIG. 298—HOSE PRESS.

freight car auxiliary and cylinder complete. This is used for testing quick-action triple valves. At the end of bench, to the left, is one air brake and one signal hose, which are attached to pipe leading from main reservoir. To these hose, all hose fitted up are coupled and a cap or plug put on the opposite end, and full pressure is turned on in order to be positive the hose leaves the shop in good condition with regard to leakage.

FIG. 299. CAR LIFTING JACK.—Used for lifting coaches. This jack has a piston 15″ diameter, with 26″ stroke; piston rod is constructed of a piece of pipe 6″ in diameter, 30″ long. There is a sleeve 5″ long on piston, which extends into lower end of pipe and is bolted to same. There is a cap with four lugs, 1½″ long, cast on under side, which drops on inside of upper end of pipe. The castings are all malleable iron.

The jack is bolted to a small truck of the warehouse type, being easily moved around shop or yard. Both jacks are operated by one man, the hose running in "Y" shape from jacks to main hose, which has a cock attached to it. There is a ¼" air cock attached to each jack, used for releasing air.

FIG. 300. CAR WHEEL HOIST.—Used for loading and unloading loose car wheels not on axles. There is a pit 3′ wide, 5′ long and 6′ deep in the ground, walled up with brick, and bottom of same laid with grout 6" deep. On top of this are three pieces of scrap "T" rail bolted to a piece of boiler plate, and to this plate are bolted two cylinders of 7" pipe, 5′ long. The plunger, or piston rod, is made of 6" pipe and fastened to piston at lower end, and a cast iron plate, 15" diameter with sleeve 5" long, inserted into the upper end. To these plates are bolted a platform of oak timber, 3′ wide by 5′ long, the cross pieces being sandwiched with iron plates. There are two posts, 6" x 6" x 20" long, framed into platform for wheels to rest against. There are four posts set suitable

FIG. 299—CAR LIFTING JACK.

distances between car to be loaded, or unloaded, and the air hoist. These are let into the ground about 3′, and boarded up on each side. The two forward posts nearest car have a piece of oak, 5" x 5", with ends rounded and pivoted to fit into slots in the posts; on this cross piece rests the stage plank. The end of stage next to hoist is hinged to platform of same. When air is applied this throws stage plank about 6" inside of car door, and when released it inclines same in a position that will clear car about one foot.

The hoist is operated, and all wheels loaded and unloaded by one man, he taking all numbers and defects, etc., of wheels. Time consumed to load one car of 80 to 100 wheels being 50 to 60 minutes; same being done piece-work.

FIG. 301. CAR WHEEL AND AXLE HOIST.—Overhead traveling hoist used for loading and unloading wheels on axles. This is constructed of two tripods, the legs of same being 3" gas pipe fitted to cast iron shoes at the bottom. The shoes

FIG. 300—CAR WHEEL HOIST.

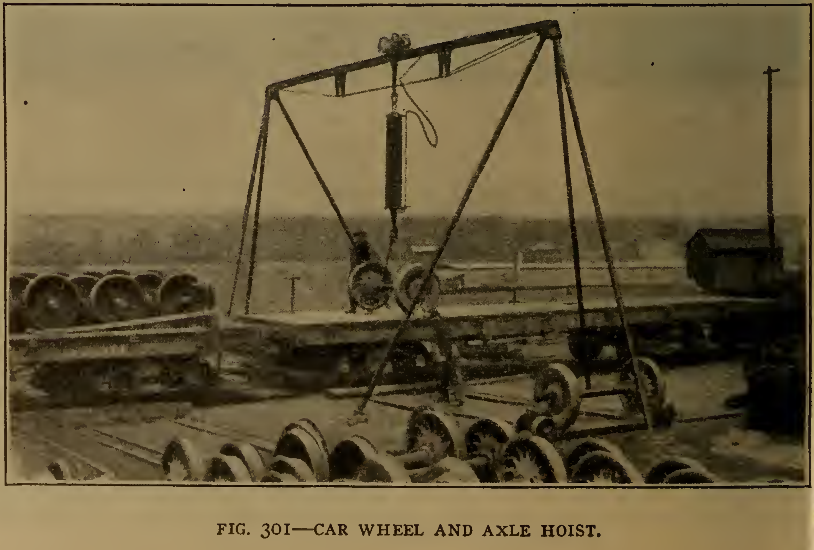

FIG. 301—CAR WHEEL AND AXLE HOIST.

rest on blocks of stone, 20" square, let into the ground and set in grout. Bolts which hold the shoes are let into stone and leaded. The top castings are made to take the three legs and the ends of the two "I" beams of 5" height and 30' long; these being trussed on under side with 1" rods. The trolley is constructed of four wheels, 12" diameter, with flanges on outside, and have axles of 1½" diameter. To this is suspended a hanger, made "V" shape, which is made of 1¼" x 4½" iron. Suspended to this, by a clevis, is a cylinder 10" diameter, 5' stroke. Alongside of car track, and running in opposite direction, is a series of tracks on which wheels are stored. Running parallel with car track, and about 20' from same, is a track of 20" gauge. This divides the series of tracks mentioned above; on one side are stored the wheels for shipment, and on the other side the old wheels unloaded. This track runs through the shop, alongside axle

FIG. 302—CARPET NOZZLE.

lathes and wheel press. On this track is a truck, the top of which is on a level with top of rails on cross track and top of platform of wheel press, making it easy work for one man to roll a pair of wheels on same from press platform, or any one of the cross tracks, running same out and rolling wheels off on track directly under hoist.

Usually two men operate this hoist loading and unloading—one man on the car, and the other on the car handling wheels. A car consisting of 14 to 18 pairs of wheels is loaded, or unloaded, in 20 to 30 minutes; same being done piece-work.

FIG. 302. CARPET NOZZLE.—Showing an air nozzle used for cleaning carpets, cushions, etc., and interior of coaches; this appliance being in use in most railroad shops employing compressed air.

FIG. 303. PNEUMATIC SCRAP SHEARS.—This is an old-time tool, being made of boiler plates by one of the veteran boiler makers in charge of this company's

boiler shop, some forty years ago. It was consigned to a resting place in the scrap yard, but when the "air" fever struck us we considered it economy to set this tool up again, attach a 14" car cylinder to it and operate same in our scrap shed, for cutting off old bolts, instead of trucking same into shop and then trucking the scrap cuttings out again to the pile. With one man and a pressure of 60 pounds, of air, this veteran tool is cutting off all old bolts 1¼", and under. in scrap shed, the only handling being to take them to the screw machine to be threaded, and our supply is kept up in good shape in the bolt room and a small stock carried in scrap pile.

Fig. 304. Pneumatic Punch.—This tool is a brother to the shears, as described and shown in photograph Fig. 7. It is made in the same manner, and about the same time, and, like the old shears, we took pity upon this tool in its old age and applied the elixir of life through a second-hand 10 x 12" car cylinder

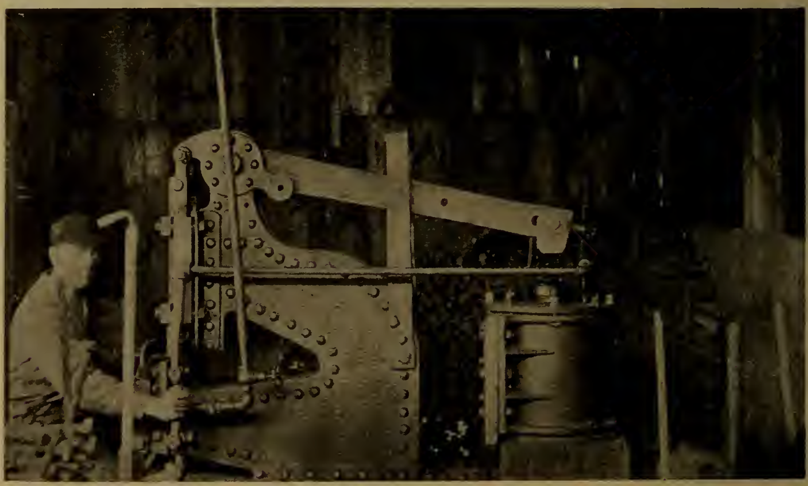

FIG. 303—PNEUMATIC SCRAP SHEARS.

and set it up in the shop, and at first trial punched a ⅜" hole through ½" iron with 50 pounds air pressure. We punch at the rate of six holes per minute in ¼" to ⅜" iron with punches of same diameter.

Fig. 305. Air Compressor.—This shows the small Piston Inlet Air Compressor now being used to operate the pneumatic tools. This machine will shortly be replaced by the Cross Compound Compressor of the following dimensions:

High pressure steam cylinder,	14"	in diam.
Low " " "	26"	"
Low pressure air cylinder,	22¼"	"
High " " "	14¼"	"

Stroke, 18".

This machine will be proportioned for a steam and air pressure of 125 pounds.

Overhead Trolley Timber Hoist.—(not illustrated.)—This is used in wood machine shop. There is a track leading from lumber yard through the shop; on one side of track is a heavy four-side timber dresser; on the other side

FIG. 304—PNEUMATIC PUNCH.

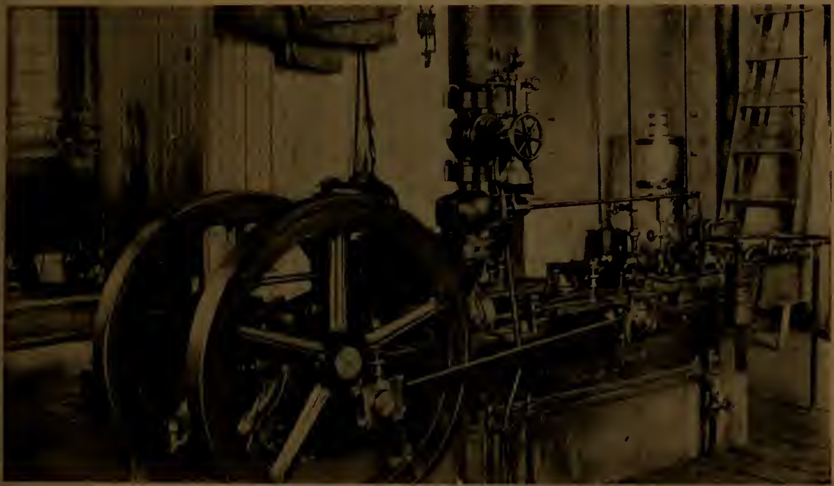

FIG. 305—AIR COMPRESSOR.

and adjoining track is a 40″ cut-off saw; 12′ back of this is a Fay Planer. Above these, running in opposite direction, is suspended a trolley track, 40′ long. Suspended from this is an air hoist, cylinder 5″ diameter with 4′ stroke. Attached to this is a half-inch hose running from distributing air pipe. There is a reducing valve between pipe and hose. On lower end of piston rod there is slipped a spiral spring to relieve any shock to trolley when the air is applied too suddenly. This, however, never occurs when the reducing valve is in good order.

A truck is loaded with heavy timber in the yard and run into the shop. The timber is then picked up by the hoist and conveyed to cut-off saw, and from saw to either side of track to planers.

There were formerly two men employed at this saw, cutting off and trucking timber; the work is now done by one man. There is a rope, with each end attached to hoist and passing over sheave at end of trolley. The operator stands at the saw and moves the timber to either side of the shop with little exertion. The timber suspended from hoist is of the following dimensions: 7½″ x 12½″ x 19″.

LIFTING JACK—(not illustrated.)—Used at wheel turning lathe. This is constructed of two cast-off 5″ x 10″ steam cylinders bolted to a block 9″ x 12″. There is a piece of boiler steel formed to fit the shape of the axle and fulcrumed to each piston rod, which is set in middle of lathe. Wheels are run into shop on track mentioned before as being used for transferring wheels; there are two pieces of timber laid across lathe pit and against truck.

Other air tools at present in operation in these shops are as follows:

MACHINE SHOP.

Three (3) Rotary Drilling and Tapping Machines.

BOILER SHOP.

One (1) Punch for sheet iron.
One (1) Punch for boiler plate.
One (1) 14″ Hoist.
Two (2) Caulking Tools.
One (1) Stay Bolt Breaker.
One (1) Stay Bolt Cutter.

BLACKSMITH SHOP.

One (1) Small Bulldozer.
Two (2) Babbitt Melting Furnaces.

CAR DEPARTMENT.

One (1) 10 x 12 Press for pressing oil out of waste.

Air is also used for cleaning lubricators, testing air brake pumps and testing air brakes.

COMPRESSED AIR IN A SAWMILL.

In the early part of 1898 a compressed air plant was installed in the sawmill of Wm. Engel & Co., Orono, Me., and all the appliances hitherto actuated by steam were made to run by compressed air. The chief object of adopting compressed air to operate sawmill appliances was to minimize the fire risk. Instead of dangerous belts, pipes now conduct the power and the details of the plant will prove interesting. An Ingersoll-Sergeant Class "B" Air Compressor is operated by a large water wheel. Air is compressed and stored in a receiver and dis-

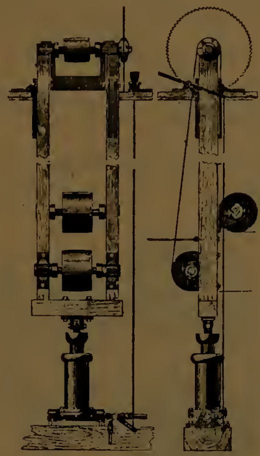

FIG. 306—STEAM FEED CUTTING-OFF SAW.

tributed through pipes to any part of the mill desired. The power generating plant, consequently, is so simple that any person of ordinary intelligence can

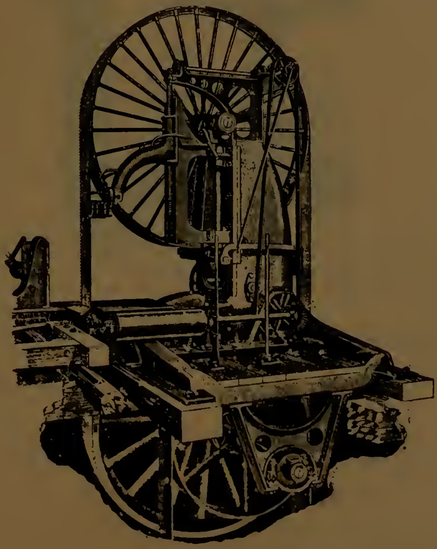

FIG. 307—THE NEW "ALLIS" BAND MILL.

easily superintend its operation. The machinery in use at the Wm. Engel mill is the same as that used in steam sawmills. Air at 90 to 100 lbs. pressure is carried in the receiver and pipe line to the different machines that air is used in. The following devices are necessary to operate modern sawmills, and combined with the use of compressed air the method of producing lumber may be fairly realized.

ALLIS JUMP SAW RIG.

Air is used to raise and lower an Allis Jump Saw Rig that is placed in the log slide to cut off the logs at the right length.

ALLIS LOG FLIPPER.

This machine throws the log out of the log slide on the log deck, where they are stopped by a

KLINE LOG ROLLER.

This appliance holds them in place until the sawyer wants the log on the carriage, when he does the same as he would in any steam mill, that is, step on

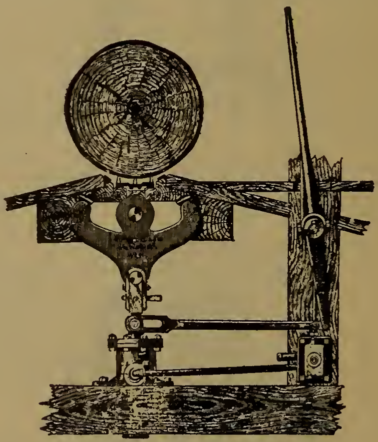

FIG. 308—DIRECT ACTING STEAM LOG FLIPPER FOR ROLLING LOGS OUT OF THE LOG SLIDE. OPERATED BY COMPRESSED AIR.

the treadle in the floor; the air does the rest. At the same time he has one hand on the

HILL STEAM NIGGER LEVER

and the other hand on the carriage lever; when the air gets in its work again with the nigger he places the log just right to saw and with

BECK'S TWIN ENGINE FEED

that runs the carriage back and forth to the

BAND SAW,

which puts the logs into lumber, which goes on down the mill on live rollers to some Allis Jump Saws that set in the roller casing to trim the lumber and timber work, also to cut up edgings and slabs. Besides the machines which have been spoken of which use the air successfully are a

STEAM PUMP

for fire protection, it is also used to blow a

LARGE WHISTLE

to start and stop the mill at meal times.

This mill is operated 11 hours per day and produced from 50,000 to 65,000 feet of lumber daily, and goes to show that compressed air does the work as well

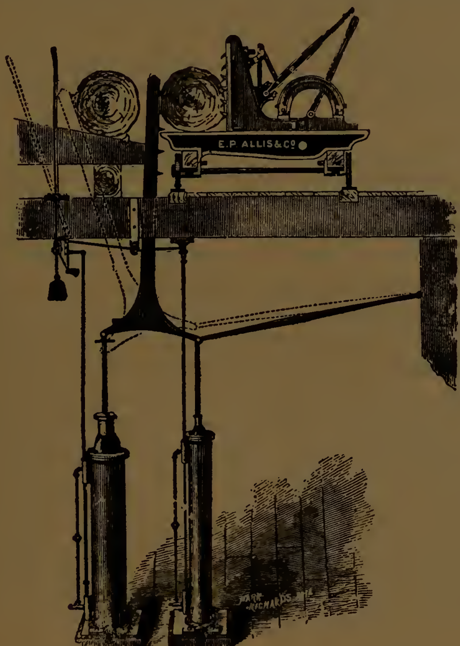

FIG. 309—HILL'S PATENT DOUBLE CYLINDER STEAM NIGGER. OPERATED BY COMPRESSED AIR.

as steam, with the advantages of lowering the rate of insurance, which is extremely high on sawmill plants, and the avoidance of disagreeable conditions that the use of steam entails.

APPLICATIONS OF COMPRESSED AIR IN RAILROAD SHOP PRACTICE.*

Wherever steam has gone to create the necessity and opportunity for it, there compressed air has followed, going often where steam could not go, rivalled only in its adaptability and convenience by electricity. In all branches of industry

* From an address before the St. Louis Railway Club.

and manufacture it has its hundreds of applications, and this is no mere figure of speech, for there lies before me a list of nearly four hundred different uses of compressed air, and this list is doubtless incomplete.

In case of transmission and of application, in adaptability, as well as in cost of installation and maintenance, air and electricity are on almost equal footing, and it is only when we consider the tools by which this power is applied that we find the advantages of the former over the latter. It is in the greater simplicity of the motors required for its local application that air may base its claim to distinction. In addition to the important difference in cost, due to the greater simplicity of construction, the air-driven tool possesses the advantage, so requisite for its proper use, of being readily understood by the operator—a claim which cannot be made for electricity for some time to come, for the confusion and dread, in the ordinary mechanic's mind, of all things electrical, are not soon dispelled.

The figures relating to saving in time and labor as given in this paper were, without exception, obtained from the master mechanics or general foremen, and in almost every case these estimates were verified by consultation with the shop foreman and the operators themselves. Care has been taken to insure that such figures represent ordinary conditions, and records made particularly for the purpose of showing a saving, or under unusually favorable circumstances, have been excluded or modified, so that the figures given may with reason be relied upon for the conditions mentioned and under which they were obtained. In one of the railroad shops, and one from which more than its share of this information has been drawn, the change from handwork to the use of air tools has been made within the last eighteen months, and many of the figures are derived from daily records, and all the information is fresh in the minds of those concerned. In all other cases where the figures given were not based on written records, the results, as intimated above, have been carefully scrutinized.

For riveting, the use of the pneumatic holder-on adds much to the tightness of the work. In one of the shops visited, in riveting the mud ring on a consolidation locomotive by the air hammer, the saving over riveting by hand was 67 per cent., and this class of work is typical of much that is done by the hammer.

One of the most interesting operations performed by the pneumatic hammer is the chipping of wrought iron and steel. In one instance, in work of this character, done on a "ten-wheeler," the work formerly requiring the labor of a boiler-maker and helper for two days is now done in one-quarter of that time.

In a particular piece of work on saddles, typical of many situations in which the pneumatic drill is used, a machinist and helper accomplished in three hours what would have required by means of the ratchet drill sixteen hours, and this saving of 70 per cent. is by no means extraordinary. . . . In one of our Chicago boiler shops the time required for work done by the pneumatic breast drill was to the time consumed on the same work when done by the hand-driven tool, in the ratio of one to ten or one to twelve. The various other uses to which the motors of all these air drills may be put present themselves at once, and by one of these applications—the grinding and facing of steam pipes—there is now accomplished in fifteen minutes what formerly, by tedious hand work, took an hour or more.

The facility with which compressed air may be made to meet particular needs has created in many shops, in addition to the regular pneumatic tools, a number of special devises, one of which is a press for the brasses of driving boxes. This machine drives the brasses for all the boxes that go through the busiest shop on one of the largest railroads in the West. With it two men and a helper now do all the work formerly done by eight men, and it has become as indispensable to its owners as the lathe beside which it works.

For chipping out defective stays on an ordinary American type locomotive, which had come into the shop with about the usual number to be replaced, three hours' work by an apprentice boy sufficed to do the cutting-out which it would otherwise have taken a boilermaker an entire day to do. In this case the boy can undertake, without risk of damaging the plate, work which would not ordinarily have been intrusted to him with the hammer and chisel. . . . The hammer used for flue beading effects about the same saving as it does in other classes of work. To bead 150 flues by hand cost $2.35, while the same work done with the aid of air amounted to 60 cents.

The portable riveting machine with fixed yokes can, of course, do better work than the hand hammer, and for a great variety of work will produce as good results as the stationary pneumatic riveter, besides being much more convenient. "With these riveters," to quote the foreman of one of the boiler shops, referred to above, "we can do with three men (two boilermakers and one helper) twice the amount of work formerly done by three boilermakers and one helper riveting by hand." These machines will operate successfully on plates up to about ⅞ in. in thickness, and for work of this class will compete in their results with hydraulic riveting. Indeed, the foreman in the same shop informed me with considerable satisfaction that work done by one of these riveters had been inspected and passed as hydraulic-riveted, a few days previous, by an inspector of one of our best known boiler-inspection companies, who was with difficulty convinced of his mistake.

One type of air-operated nippers cut off in one case all the stays in the firebox of a Brooks "ten-wheeler" in three hours where handled by two boys, a job which formerly occupied a boilermaker and helper nearly two days. This is a saving in cost of about 90 per cent., and the same work with this tool in another erecting shop results in a saving of 86 per cent. The nippers cutting off from both sides at once do not injure the sheet or loosen the thread, as may be done by chipping them off.

Passing now to the car shops, we may note the drill again at work, this time on wood—a drill, of course, adapted to this purpose, running at a higher rate of speed than the metal drill and weighing usually not more than twelve or fifteen pounds. One of these tools has a record of boring through 5 inches of oak a 2½-inch hole in less than twenty seconds—a statement which is particularly significant to any one who has ever tried to bore a 2½-inch hole in oak. This drill, in the car shop in rip-rap work, produces a saving of time even greater than that effected by the drill in machine shop operations.

The saving to be effected by the paint sprayer varies, of course, with the character of the work. In general, the larger the area to be covered the greater the economy in the use of the sprayer, although the intricacy of the work modifies this. The saving in painting trucks is about 85 per cent., while in the case of box car painting the records kept for several days show a decrease in cost of 90 per cent. . . . The paint burner is a compressed air and oil jet, and by its use four men have been found to do in ten hours what would by other methods usually require two days and a half. . . . In one shop inspected two boys were doing in ten hours with a sand blast what formerly occupied two men five or six days, and this saving of 80 per cent. does not represent the total economy; for by the sand blast the paint and rust are so thoroughly removed from even the smallest pit that the new paint lasts much longer and the tank is in the paint shop less frequently than when merely scraped. This same machine is used for sanding the roofs and ends of cars.

The car journal turner illustrates very forcibly one of the fundamental reasons for the general success of pneumatic tools—namely, the ability of local application and the avoidance of outlay of time and labor in transporting the work to the tool. We have here a machine-shop operation transferred out of doors, and a car journal being turned in nearly its original position. This tool takes two cuts and a finishing cut on a car axle in about an hour. The ordinary drill is its motor, which is detachable, and consequently available for other work.

The pneumatic fire kindler is an important piece of apparatus in the roundhouse. It is simply a compressed-air oil burner of the simplest construction, but of a usefulness entirely out of proportion to its simplicity. It is used above the coal and without any kindling material. Some of the results of tests conducted by the mechanical engineering department of the University of Illinois with this instrument may be of interest. The tests were made to determine the relative costs of kindling fires by wood and by crude petroleum, the latter being burned by means of a fire kindler. The boiler pressure raised in each case was the same; the time required to reach this pressure was one hour and ten minutes kindling by oil and one hour and forty-four minutes kindling by wood. The total cost, which in each case includes cost of labor, coal and the kindling material, amounts to 34 cents for oil and 61 cents for wood, on a basis of oil at 2¼ cents per gallon and coal 75 cents per ton—a gain in favor of the oil of about 45 per cent.

In the tables below are the averages of all the figures given in the foregoing. The conditions they represent are normal and such as exist in all shops. All extraordinary records or test cases have been excluded, and the results given may safely be applied in making deductions for conditions similar to those noted in the table.

I have confined my attention to the saving effected by the tools themselves, without regard to the outlay at the compressor, but the question naturally suggests itself: What does it cost to compress the air? This is a question easily enough answered in specific cases, but which must necessarily be differently answered in every case. In one shop, from which many of these figures were drawn, the decrease in the saving effected by the tools themselves, due to consideration of the cost of compression, amounts to about 15 per cent. at the most, which still leaves a net saving of from 50 to 60 per cent. These figures must be taken as representing only this one case, and further generalization would be fruitless. That the cost of compression, combined with the interest on the cost of installations and maintenance, would be prohibitive of the use of pneumatic tools in some cases, is entirely conceivable; but that this should be true in a railroad shop of any considerable size is hardly credible.

Among the various men who have supplied the foregoing information, the most enthusiastic advocate of compressed air was the general foreman of a plant where 1,800 cubic feet of air are used per minute, and where almost every one of

TABLE 73.

Tool and General Character of Work.	Saving.	
	Per cent. of Cost.	Per cent. of Time.
Pneumatic hammer, general foundry work—chipping	67 to 75	67 to 75
" riveting on mud ring and on firebox	67	—
" chipping flue sheet	84	75
" beading flues	75	75
" general boiler-shop work	60	—
" cutting out broken firebox stays	70	70
" cutting off staybolt heads	58	—
Riveter, boiler riveting	66	50
Drill, drilling saddles	70	70
" in general machine-shop work	75	75
" drilling for stays	50	50
" in general boiler-shop work	75	75
" facing steampipes	75	75
" tapping for stays	65	—
" reaming crown sheet	70	—
Breast drill, general work	90	90
Staybolt nippers, cutting off stays	73 to 90	75 to 90
Driving-box press, pressing brasses	68	—
Paint sprayer, painting box cars	67	67
" " car trucks	87	87
Paint burner, cleaning off passenger cars	67	67
Sand blast, cleaning tanks	90	83
Air jet, cleaning cushions	50	50

the devices mentioned in this paper are in daily operation. It can no longer be said that the use of compressed air is in its infancy, nor can the old charges of unreliability and uncertainty in its action and of great wastefulness in its transmission be substantiated. The use of compressed air in shops is no longer a subject of controversy. The field is already fairly well occupied and the possibilities are pretty clearly understood.

EDWARD C. SCHMIDT.

PNEUMATIC CYANIDE PROCESS.

Under various forms the mining papers of the West have been printing the account of what is called the Pneumatic Cyanide Process. It is claimed that it will revolutionize the treatment of ore.

The features of the "Pneumatic" process are so easily understood that it does not require an "expert" or a thorough chemist to appreciate them, for every mining man has had more or less experience with compressed air, and most of them know something about the cyanide process and understand that oxygen is absolutely necessary in a solution of cyanide of potassium in order to form a new compound called "Cyanogen," which is the true solvent of the gold. They know also that agitation hastens the process of dissolving and extracting the values during the leaching process, because agitation, or stirring, enables the oxygen of the air to reach the solution more rapidly to form "Cyanogen" and also to bring the ore and solution into more intimate contact, and does in a few hours what it takes days to do if the ore and solution remain unmoved in the leaching vats.

Many attempts have been made to stir or agitate the mass of leaching ore by machinery; but the great cost of power, expensive construction, breakage of

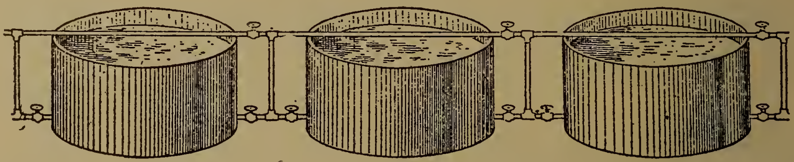

FIG. 310 SHOWS A SERIES OF LEACHING VATS, OR TANKS, FITTED WITH PIPES AND VALVES FOR THE INTRODUCTION AND CONTROL OF THE COMPRESSED AIR.

parts, etc., have caused them to be abandoned, and mill owners have gone back to the old slow process of letting the ore stand for days in the leaching vats because there was no practical and cheap way of agitating them, or of getting the oxygen through the solution, except by the slow absorption from the atmosphere.

Just at this time, when it seemed as if improvement in the cyanide process was at a standstill, the "Pneumatic" process comes forward with a method so simple and so effective that, as we said before, it is a wonder that it was not thought of sooner.

It is simply the introduction of strong currents of compressed air into the bottom of the leaching vats, which force their way upward bubbling and boiling

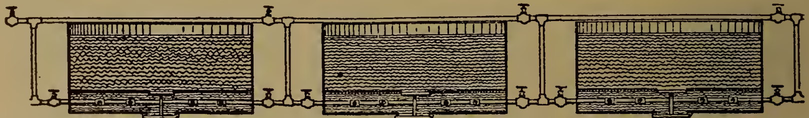

FIG. 311 IS A CROSS SECTION, CUT THROUGH THE MIDDLE OF FIG. 310, AND SHOWS THE AIR PIPES BETWEEN THE TRUE AND THE PERFORATED FALSE BOTTOMS OF THE VATS, AND THE TRAP DOOR IN THE BOTTOM FOR DISCHARGING THE LEACHED REFUSE.

through the mass of crushed ores and cyanide solution, and thus furnish both the oxygen and the agitation needed for the rapid and thorough extraction of the gold. This method of forcing the air through the leaching ores can be readily understood by means of the cuts shown.

Fig. 312 is a view of the bottom of a leaching vat, with a portion of the perforated false bottom cut away to show the coil of perforated air pipe, by which the compressed air is evenly distributed over the entire bottom of the vat.

It can be readily seen from these illustrations how fully this process solves the problem of leaching the ores rapidly and thoroughly—requiring only hours where old methods required days. It also drives all the slimes to the surface, where they cannot interfere with percolation, as they do when permitted to settle at the bottom of the vats.

Experience has proven that a hot solution of cyanide of potassium is more effective in dissolving gold than a cold one; but until this process was invented, no practical method of heating rows of large vats filled with solution and leaching ores was known. Now, however, by simply passing the compressed air through a small furnace before forcing it into the bottom of the vats, the solution is heated, the extraction hastened and increased, and all danger of freezing in cold weather obviated; an improvement which mill owners in high altitudes will certainly appreciate.

The method of precipitating the gold from the cyanide solution after the leaching process is completed is also an improvement over the present methods, and is covered and protected by a separate patent. It has all the good qualities of

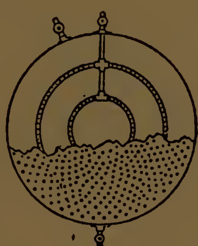

FIG. 312.

the old zinc box, with the addition of three new features which aid in rapid precipitation and leave the solution in better condition for using a second time.

The inventor of the process has been working quietly for nearly three years in perfecting it and securing his foreign patents, and it has been before the public for only a few weeks. The system is now being installed by the Pneumatic Cyanide Process Co., of Denver, Colo.

WORKING ROCK DRILLS BY ELECTRICALLY COMPRESSED AIR.

In some of the German collieries the drills are worked by compressed air, but the compression takes place within the mine, not far from the face, the air-compressor being driven by an electric motor, taking its current from the regular power service of the collieries. German mining engineers are stated to prefer this plan to either working the drills by compressed air, the air being compressed on the surface, as in England, or to driving the drills by electric motors, and it is stated to be more economical, though no figures are given. In Belgium rock-drilling by electricity has not been attempted.

ROCK CUTTING APPARATUS FOR MINING AND QUARRYING.

Under this heading come all forms of drills and rock boring apparatus, stone saws and other cutters, and it must be admitted that in this class of machinery American apparatus is superior to the foreign devices shown.

In the first place, with the exception of the various types of rock drills, foreign manufacturers exhibit absolutely no apparatus for quarrying.

Secondly, their rock drills range all the way from those operated by compressed air, through electricity and flexible shafts to hydraulic contrivances, with a preference for auger drills, electrically driven. On the other hand, with the exception of coal augers, American manufacturers adhere to compressed air and steam-driven drills of the reciprocating percussion type, except in the case of diamond drills for taking out rock cores for prospecting and other similar purposes, and extensive and expensive experience has shown the percussion drills to best meet the conditions of mining hard, medium or even soft rock; and, as a result, there are in operation in the United States over 35,000 rock drills operated by steam or compressed air. The American drills are extremely compact, substantial in construction and very simple in design.

Continental practice is not standardized, and the few manufacturers of drilling apparatus have such a small output that each machine is special, there being no attempt at interchangeability of parts.

The best-known American drills, on the other hand, are made in large quantities, and all parts are made with jigs, templates and dies, so that their dimensions are identical. This permits cheap and rapid repairs when parts wear or break.

Again, there are absolutely no delicate working parts, no insulation to be damaged by oil or water, no switches nor contacts to corrode or burn out, absolutely no danger from sparks igniting gas or explosives, and no danger to men.

American manufacturers have two forms of mountings—the tripod, and what is known as the shaft-bar, or a straight bar on which the drill is mounted. One is used for surface and cut work, the other for shafts and tunnels. Continental makers nearly always insist on a cumbersome carriage with a swinging arm, on the end of which are clamped one or more drills. Sometimes matters are complicated, and a tank, levers, wheels and other devices are added until the machine presents a formidable appearance.

The electric drills are generally of the auger type with twisted or gimlet bits rotated by a geared or belted motor and fed forward by a hand-screw. Usually water is forced down through a hole in the centre of the drill bit and flushes out the hole as the bit advances. These electrical augers may work here, but they never would under the conditions imposed in the United States, for the electrical parts are exposed, and moisture, grit, etc., would soon put an end to their usefulness.

The reciprocating electric drill finds some admirers, and this is shown by there being many manufactured. Extensive experiments with it in the United States have shown its absolute inferiority in efficiency, durability and simplicity, and its continued use, in face of troubles which it develops, can only be credited to a fad and the backing of an enterprising electrical company deserving to sell electrical machinery.

One form of electrical drill makes a very creditable showing in its exhibition colors, but we would prefer a history of three months' operation before saying much about it. It consists of a motor encased in a water-tight box, with a flexible shaft attached to a percussion drill mounted on either tripod or shaft bar. Gearing, a small crank and various springs inside produce the reciprocation and the blow.

Another strong reason for the use of compressed air drills is that the transmission of the air to the drills in pipes is economical. The pipes are easy to install and certain. Further, the introduction of the compressed air into the headings causes a decided current of air, which keeps the workings cool and fresh and incidentally blows out smoke and gases resulting from blasts.

Hydraulic drills mounted on enormously heavy carriages and complicated looking enough to worry a Yankee machinist, it must be admitted, have done good service in special cases, but it can hardly be seriously suggested that they are suited for more than a very few cases, and, indeed, even their friends could not recommend them for quarrying, general mining or rock excavation.

One concern, from the United States, exhibits two special quarrying machines which attract a good deal of attention. The purpose of both of these machines is the same, one of them only being considerably larger. The smaller machine consists of two round bars held parallel in a suitable frame, but mounted on four adjustable legs, so that the frame can be swung through all angles, from vertical to horizontal. On these bars is mounted a carriage, which can be moved back and forth along the bars by a small motor. This carriage forms the support for a powerful reciprocating drill, which may be operated either by steam or compressed air. The drill is equipped with a special cutter, and as it rapidly reciprocates and cuts the rock, it is moved back and forth, thus cutting a narrow slot the length of the machine and to a depth up to 7½ feet.

The other machine consists of a heavy four-wheeled truck supporting a vertical boiler and a powerful special drill, consisting of a cylinder, a heavy piston and rod, and a suitable guide for the cross-head of the piston, which, at the same time, constitutes the clamp for the cutting tools. The machine is also provided with a feeding mechanism which moves it back and forth along the track on which it runs. In this way, a vertical cut 12 feet deep and of indefinite length can be made.

If the types of apparatus signify anything, it may be stated quite conclusively that American methods and apparatus for general quarrying and mining purposes are in advance of continental practice. No doubt this can be attributed to cheapness of labor, conservatism, and, perhaps, a certain amount of self-satisfied feeling among continental mining concerns.—J. J. S., in London *Engineering Times.*

TUNNELING BY COMPRESSED AIR.

Compressed air is to be employed as the power to dig New York's great rapid transit tunnel. Within two weeks a compressor plant costing $60,000 will be in full blast at the north end of Union Square. This particular plant will operate the hoisters, drills, etc., used by Holbrook, Cabot & Daly, of Boston, who have the contract for section 3 of the tunnel, which begins at the middle of Great Jones street, in Lafayette Place, and runs along Lafayette Place to Astor Place, thence to Fourth avenue, to Park avenue, to Thirty-fourth street.

Workmen are engaged in laying five-inch steel pipe six inches below the surface and along the curb on the west side of Fourth avenue. This pipe line will be connected with the compressed air plant, and can be tapped for power at any point as readily as gas or water mains could be tapped.

Henry B. Seaman, engineer for Holbrook, Cabot & Daly, talked of the work, which may now be said to be really under way.

"At first," he said, "we considered the advisability of using electrical machines for power, but they proved impracticable. They are largely experimental as yet. What we sought was something that would prove applicable over the whole of the work, at the same time being as economical and as little of a nuisance as possible.

"The question arose as to whether steam or compressed air would be employed and the latter was selected. With steam it would be necessary to have separate boilers for each hoister and a set of drills, and this would necessitate having two or three boilers on each block. Soft coal would have to be used, too.

"So we decided to put in a $60,000 compressor plant in an enclosure at the north end of the park. Pipes from the plant will have three or four inlets to each block, and we can have power at any point. Escaping air will not be objectionable like steam, and there will be no offensive odors. There will be no danger of frightening horses.

"There will be five boilers in the plant. The first of these will arrive next Tuesday. The pressure will be from eighty to one hundred pounds to the square inch."

No especial machinery to be used on the work has yet been made, Mr. Seaman said, with the exception of a derrick designed to impede traffic as little as possible. As the work progresses, however, special devices will probably have to be employed, as in all such big undertakings.

"Just what devices we will have to use," said Mr. Seaman, "it is impossible to say at the present time. We will have to wait and see the condition of affairs under ground. We expect to strike considerable rock between Fourteenth and Twenty-second streets."

Excavations will be made for a short distance at a time, and photographs will be taken before the street has been torn up and after the section is complete, as the contractors desire to show that they will leave the pavement in as good condition as it was before they touched it.

THE USE OF COMPRESSED AIR IN MINES.

Of late years compressed air has gained greatly in prominence as a means for the transmission of power, and now occupies a broad field of usefulness. In addition to its value and convenience as a power transmitter for engineering purposes it possesses also characteristics which make it applicable to a great variety of uses in the manufacturing industries and mechanic arts, in which the element of actual transmission of power does not at all enter. A discussion of these, however, would not be appropriate here.

In connection with mining, tunneling, shaft sinking, and kindred operations, compressed air has found several of its most important applications. Here, for some purposes, it has made a place for itself in competition with steam, but it is in conjunction with steam, and other prime movers that compressed air, acting purely as an agency for transmitting power, has frequently become indispensable for underground work. As compared with steam the employment of compressed air for such purposes is particularly valuable and convenient for four reasons: First, its transmission loss is small; second, the troublesome question of the disposal of exhaust steam underground is avoided; third, the exhaust air is of direct assistance in the ventilation of the confined working places, and fourth, its capacity for storing power makes it well adapted for intermittent work. These points will be briefly considered.

The conveyance of steam long distances underground involves serious and unavoidable loss from radiation and consequent condensation. The loss due to friction is common to both steam and compressed air, and although not equal at the same pressure, on account of the greater density of compressed air, the one may be taken as approximately offsetting the other. In a steam pipe of proper diameter, under given conditions, the frictional loss should be not more than one-fifth the loss from radiation. Condensation may be reduced by carefully covering the piping with good non-conducting material, but even with the best covering the effective pressure at a distant underground engine is greatly diminished, and very uneconomical working is the result. In conveying steam a distance of several thousand feet, as is by no means uncommon in extensive collieries, the pressure may be reduced to half the boiler pressure, or even less. Take, for example, a pump situated 2,000 feet from the boiler and using 200 cubic feet of steam per minute at a boiler pressure of 75 pounds, with a mineral-wool covered pipe, 4 inches in diameter, the effective pressure at the pump would be only about 58 pounds, or, with a poor covering, like some of the asbestos lagging often used, it might easily be as low as 35 pounds. For compressed air transmission the reduction of pressure for the same volume of air, size of pipe, and initial pressure, would be 9.3 pounds, giving a terminal pressure of 65.7 pounds. But, as the speed of flow in pipes for economical transmission is greater for steam than for air, a comparison based on piping of the same diameter cannot justly be made. If, in the above example, the diameter of pipe were smaller the gain in reduced radiation would outweigh the increased frictional loss, and the net loss would be diminished. The frictional loss varies inversely, and the loss from radiation directly, with the diameter. Therefore, under given conditions, the diameter of the pipe can be so proportioned as to produce a minimum loss. With compressed air transmission, however, the case is different. For, if the diameter of the pipe in the above case be increased to 5 inches, the loss of pressure, or head required to overcome friction, is reduced to 2.8 pounds, and increasing the distance to one mile it would be only 7.4 pounds. Furthermore, the increased cost of the larger air-pipe would be offset by the expense of the non-conducting covering. No account has been taken here of the loss due to leakage. Attention may be called to the fact that little or no danger is to be apprehended from the rupture of a compressed air pipe, while the bursting of a steam pipe in a shaft or in the mine workings may be a serious matter.—*Western Mining World.*

COMPRESSED AIR IN UNDERGROUND WORK.

So much has been said regarding the use of compressed air in mining, that very little is left to be said. But I find that with all the information scattered from one end of the continent to another, there are a number of mining superintendents and foremen, in the Western mining country particularly, who are ready at all times to argue against its use. Their arguments are sometimes reasonable; for instance, when the question of expensive fuel comes up. But most of their arguments are unreasonable, and to prove this, we will commence with rock drills, and where they can be used economically; sinking shafts and winzes, driving drifts and upraising, and in a large majority of cases for stoping.

In sinking by hand, a good day's work for three men would be the drilling and blasting in medium hard rock of four holes three feet deep each. These four holes would just about make the sump two feet deep; the other two shifts' work, if working eight hours each, would hoist the debris and drill the holes to square the shaft, making in depth two feet in 24 hours. Had a compressed air rock drill been used for this work, all the holes necessary for blasting the bottom of a shaft 8 or 9 feet long by 5 feet wide, could be drilled in one shift of 8 hours; and instead of taking out a sump to square two feet, as done by hand, the machine in the time stated would drill the holes deep enough to take out a sump to square four feet—doubling the work at an extra cost of an engineer and the fuel; or, in other words, instead of sinking 45 to 50 feet per month by hand, 90 to 100 feet would be sunk with machine drills, and I think shows conclusively the economy of their use.

But with facts of this kind presented, we are told they are not economical, and the reasons given are that sinking by machine drills break out too much of the sides or walls of the shaft, requiring a great deal of filling and wedging behind the timber, and in blasting the debris was thrown so high up the shaft that it cut out the dividing timber, and the time lost in the filling and repairing the shaft would more than offset any time gained by using machine drills.

To disprove these statements we would ask, why should the holes drilled by a machine have a greater burden to remove than a hole drilled by hand? and with the same judgment used in planning or marking out the position of the hole to be drilled, the same results should be obtained and all the holes necessary to make the sump and stope holes to square the bottom would be done in one-third the time; showing a saving of not less than one-half the cost of drilling compared with hand labor. But experience shows that the holes should be drilled by a machine with a greater burden, for the reason that the diameter of the hole is much larger than a hole drilled by hand; and (as an illustration) where a hole is drilled by hand, say 4 feet deep and 1 inch diameter, and in the opinion of the miner charging the hole, he should insert powder enough to fill it up one foot to remove the burden and prevent the breaking out of the sides and cutting out the dividing timber. Now, if a machine hole be drilled with double the burden, the same depth and about 1 3-8 inch diameter at the bottom, one foot of powder would be about double the quantity there would be in the hand-drilled hole; and if the resistance is double in the machine-drilled hole, why or by what cause, providing the hole was practically pointed, should this hole break further into the walls of the shaft, or throw the debris up the shaft to cut down the timber? The only answer that suggests itself is: If any difference in results was shown, it was not because the hole was drilled by a machine, but for this reason: the hole or holes were improperly pointed, or the charge of powder was too great to remove the burden in a safe and economical manner.

If this is correct, is it not economical to use machines? Aside from this, you have the benefit of ventilation. The work done in one-half less time, the benefits derived from this in most cases is worth to the mining company one-half the actual cost of sinking the shaft.

No one questions the economy of the rock drill in drifting and raising and in stoping.

East of the Missouri River, in Africa and Great Britain shaft sinking is done successfully by machine drills operated by compressed air, and there is no reason why every shaft in the United States that requires drilling should not adopt the rock drill and use of compressed air.

Many advantages are also gained by compressed air for pumping; no condensation of steam, no change necessary in the pump for its application. Mine timbers are kept dry and preserved. It prevents arches and pillars in the mine from slacking and crumbling; can be applied to small hoists for hoisting the debris out of winzes, raising timber, etc.

Many mines have soft or what is termed running ground, very difficult to timber. If in drifting the breast has to be close timbered in sections, the advancement is very slow. A great deal of time can be saved by putting in an air lock and using 30 to 40 pounds pressure of air. This will in most cases allow the miners to advance very rapidly and far enough for a set of timber, and the set of timber put in in the ordinary way. The cost of a lock in a small tunnel would be no more than the extra cost required for timbering such ground as above described for the advancement of 6 feet of three sets of timber in the ordinary way.

WM. M. TREGLOWN.

CHARLESTOWN, MASS., Aug. 6th, 1897.

COMPRESSED AIR:

Some experiences in connection with the early use of compressed air at the Hoosac Tunnel may be amusing if not instructive.

It was clearly understood by those who were devising and building compressors and drills, that steam could not be used in Tunnel work.

The drills were simple and strong machines, the Burligh type being the first and, I think, the only ones there.

In the very beginning it was determined to put the drills in charge of the foreman of miners, instead of introducing a new element in the way of skilled or even common mechanics, with whom the other men would have no sympathy. It was thought more important to have men, who, through their experience, knew how to place holes which would do the most work, than to have men ignorant in this respect, though, familiar with the construction of the drills, which they could scarcely injure. This plan proved successful, and secured harmony all around.

But even while using compressed air, at the east end there were many who believed that steam would do just as well. In order to convince such, and secure uniform belief on this subject, it was determined to make the trial.

A point was selected which was as near out of doors as any thing on the work, the central shaft. This was an ellipse in form, its axis being 27 and 15 feet respectively.

It was then down 74 feet from the surface. There were no means of compressing air at this point, but there was an engine of 100 horse power for hoisting, and 3 boilers, set up and in working order. So a drilling machine intended to be used with air was set up on its tripod and the work begun. The escape steam was carried by a rubber hose into the water in the bottom of the shaft. The hose was shifted about from puddle to puddle, until all the water became boiling hot, and it became a very serious question where to find standing points. When the water under foot would take no more steam, it must of course take to the air, which soon became so thick that a man could not see his hands before his face, nor find air enough to breathe.

In addition to this, the drills of course could not be directed aright, and they also became so hot that they could not be handled.

So by this simple and inexpensive trial, everybody was convinced, and no more talk about it was heard.

As in much of this world's experience, "seeing is believing."

THOMAS DOANE.

VENTILATION OF THE ST. GOTHARD TUNNEL.

Up to the year 1890 the differences of air pressure in the two ends of this double line tunnel (length 9¼ miles), and the resulting through current of air, was sufficient to keep the atmosphere pure enough for platelayers to work comfortably in, but after that date the traffic increased so much that it became necessary to resort to artificial ventilation, and in March of 1899, a complete plant on Saccardo's system was set in operation to effect this object.

The installation, which is situated at the north end of the tunnel, consists of a locomotive driving two fans, each five metres (16.4 ft.) in diameter. These fans compress air into a chamber surrounding the face of the tunnel, from whence it issues through an annular aperture and in a southerly direction along the tunnel, dragging the mass of air in the body of the tunnel along with it, on the same principle as the steam injector.

Since the plant has been in operation the air in the tunnel has been pure and free from smoky smell, and besides facilitating the work of platelaying and inspection it is expected that the permanent way will have a longer life under the new conditions. The cost of the installation, exclusive of the locomotive, was about £7,200.

COMPRESSED AIR DREDGER FOR GOLD MINING.

In general, as shown above, these machines are iron caissons, which can be raised or lowered through the center of a boat or barge, the water being expelled

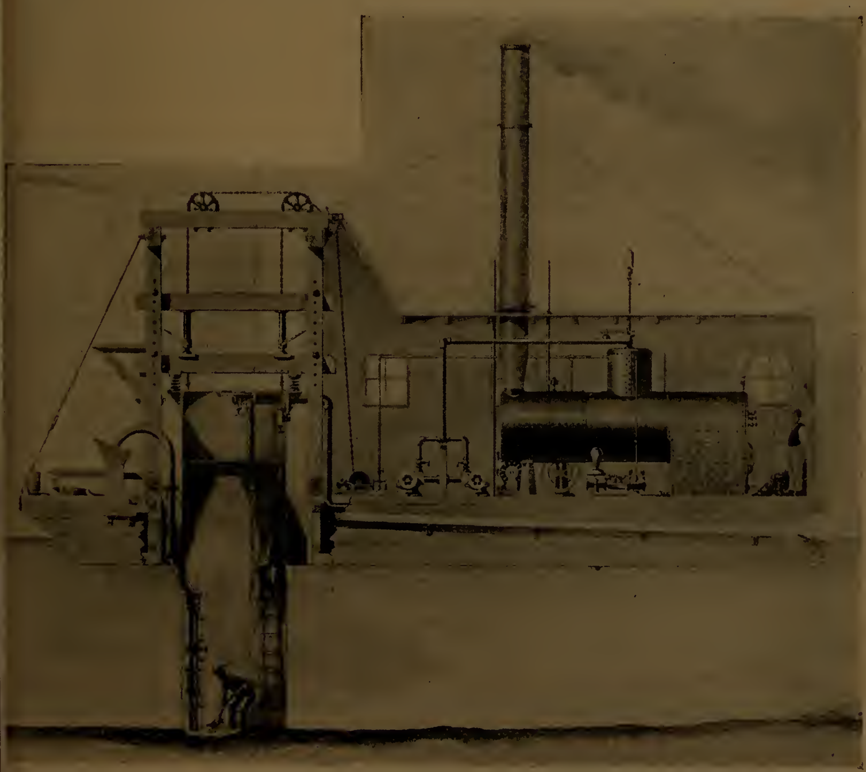

FIG. 313.—SUBMARINE GOLD MINING MACHINE.

by the proper pressure of compressed air. The bottom is thus exposed to the direct manipulation of the miner who is within the caisson, and he picks or otherwise loosens up the earth or gravel on the bottom and sends it to the surface through the small internal discharge pipe, either by direct air or water pressure as he desires.

This apparatus consists of an air compressor and appurtenances for operating it. The equipment being very complete with telephones, traps, pipes, ejectors, etc.

This machine does not interfere with the dredgers, the idea being to clean up the bedrock in the cracks and crevices wherein lie the heavy gold which no dredger of any kind has ever been able to lift. Dredgers working on rivers have to stop when they have cleared off the upper portion of the bed rock. They cannot go into the holes or crevices.

No bad effects upon the operator are produced as the pressure is moderate and invigorates rather than depresses the worker.

Men work in caissons at 25 to 30 pounds pressure per square inch, which corresponds to 60 and 70 of water pressure.

This machine is intended for such rivers as the Yukon and is manufactured by Rix & Donahoo, San Francisco.

ELECTRICITY IN MINING.*

It has already been pointed out that electric percussion drills have not so far been at all successful. Two principles have been made use of in these drills, some deriving their reciprocating action from the sucking power of solenoids, others striking a blow under the action of a spring, which is compressed by a cam, and, when released, allowed to shoot the drill forward, or else, actuating the drill by some form of crank; that is to say, the latter class convert the rotary motion of the motor into a reciprocating movement. Solenoid drills, of which the Van Depoele and the Mavin are examples, have not proved satisfactory, the main difficulties being the treating of the coils of the solenoid and want of power in the blow. Mavin drills have been used in one or two places, but no accurate data as to the results obtained are available. The solenoid drill made by the Union Electricitates Gesellschaft strikes 350 to 500 blows per minute, requires 4 h. p., and is said to drill about two inches per minute. The Bladray drill is one of the neatest forms of the second type, spoken of sometimes as electrical mechanical drills. In this drill the drill stem is encircled by a cylindrical cam which forms the continuation of the hollow armature of a small motor. The cam works against a scroll-shaped cylindrical tappet, which is a portion of the drill stem, and is pressed forward by a powerful spring. As the cam revolves the tappet is pressed back against the spring till it clears itself, when the spring shoots it forward, striking the blow. This drill strikes 700 3-inch blows per minute, and has been used in South Africa; but nothing is yet known of the results obtained by it. Messers. Siemens and Halske make a percussion drill very like the Ingersoll hand drill, fitted with a heavy flywheel, and worked by means of a separate motor, the cam of the drill and the motor being connected by a flexible shaft. This machine strikes 450 blows per minute, and is said to be

* By Henry Louis, M. A., A. R. S. M., F. G. S., etc., Professor Mining, Durham College of Science, Newcastle-on-Tyne.

capable of boring a 1½-inch hole into hard granite at the rate of 4 inches per minute with the consumption of 1 h. p. It need hardly be said that if these results can really be obtained in practical work it would be a most valuable machine, and far more efficient than any compressed air drill. It has hardly yet passed beyond the experimental stage, and is, moreover, a cumbersome and clumsy machine. A more modern type is the Bornet drill, which has been used in the south of France. This drill is actuated by a separate motor, the connection between the two being by means of a flexible shaft on a double Hooke joint; this works a crank shaft, the crank moving a solid piston backwards and forwards. The piston is enclosed in a cylinder, to the front cover of which the drill is attached; the action is thus precisely similar to that of the Scoll pneumatic stamp, the air compressed alternately in either end of the cylinder acting as a spring and giving the machine the required elasticity. As already said, electric percussion drilling is, as yet, very far from being a success.

Rotating electric drills have given excellent results wherever they are applicable, which is, of course, only in the softer rocks, such as ironstone, salt and coal. One of the best of these drills is that designed by Mr. A. A. Steavenson and made by Messrs. Easton, Anderson & Goolden (Limited), for use in the ironstone mines of the Cleveland district. It consists of a carriage supporting a standard capable of being turned in any direction, which carries an arm, on one end of which is supported a small direct current motor, whilst the other end carries a twist drill driven by means of bent gearing, the connection between the drill and its driving shaft being made by a Hooke joint, so as to allow the drill perfect freedom of motion. Such a drill works at 220 volts, and requires 20 amperes, or (say) 6 h. p. at the drill. It makes 100 revolutions per minute, and drills in ironstone at an average rate of 3 feet to 4 feet per minute; in a working shift of ten hours each drill will put in 100 holes, averaging 4 feet to 5 feet deep, in about eight different working places. Messrs. Siemens & Halske make a twist drill, worked from a separate motor by means of a flexible shaft. It is used in the salt mines of New Stassfurt, where it has given good results; its rate of advance is controlled by differential gear. The motor is of 1 to 1.5 h. p.; the drill makes 200 revolutions per minute, and drills about 1 foot in depth in from 1 to 2 minutes. The General Electric Company makes an electric twist drill connected directly with the motor. It absorbs 2 h. p., makes 300 revolutions per minute, and drills 1 foot in depth in 30 to 40 seconds. These machines are quite effective for boring in coal, for which purpose the Jeffrey drill is particularly well adapted on account of its lightness, portability and compactness. It works at 220, 350 or 500 volts, and will drill to a depth of 6 feet in about a minute.

Electric motors present quite special advantages for working diamond drills, and have been largely used for that purpose, both at surface and for explorations underground. A drill working a 2-inch hole and bringing up a 1⅜-inch core, capable of drilling easily to a depth of 600 feet, can be driven by a 2¾-h. p. motor, the whole arrangement being compact in the extreme and suitable for prospecting underground or in awkward situations where steam could hardly be used. The only rival that electricity has to compete with under such conditions is the oil engine, and it is obvious enough that the latter has many serious drawbacks, especially underground. The rapid rotation of the diamond drill renders it particularly suitable for electric drivage. Were it not for the prohibitive price of the diamonds required, it is probable that electrically driven diamond drills would have been used extensively before this for drilling shot holes, and, as already said, it needs only the discovery of a suitable substitute to place this mode of boring high amongst the most important of mining appliances.

Electric locomotives have been used a good deal in America, and also on the Continent of Europe. Some are worked by means of secondary batteries, but the majority take their power off wires running along the roof or sides of the drift. Except in fiery mines, no more convenient or economical method of haulage can be devised where large quantities of mineral have to be transported considerable distances, whether underground or on the surface. Electric locomotives have been built by the Jeffrey Company, the General Electric Company, Messrs. Siemens & Halske, and others. These locomotives usually run at from 200 to 400 yards per minute, and can ascend grades of 5 per cent. When this inclination is exceeded, rope haulage is generally preferable. In addition to the general advantages of electricity over steam underground, the electric locomotive has that of great compactness combined with ample power, electric mine locomotives capable of developing a drawbar pull of 10,000 lbs. having been built and worked successfully. Polyphase motors have been used, but most locomotives are worked with continuous current. The useful effect of an electric locomotive is usuallly 70 per cent. of the electric power in the conductors, expressed in terms of drawbar pull. Mine locomotives are usually of 10 to 15 h. p., the weight of the former being about 2½ tons; but in special cases much larger and heavier locomotives are employed. As has already been pointed out, underground traction by means of electric locomotives presents practically the same problems as does ordinary traction at the surface, and is, therefore, rather a matter for the electrician than for the mining engineer.

IMPROVED QUARRY PLANT.

During the past year the Washington Slate Co. has been quietly experimenting on the practical application of compressed air as the motive power for the operation of their quarry and factory plant, and it is claimed by the manager, Mr. A. P. Berlin, who designed and built the plant and conducted the experiment, that it has proven not alone successful, but has exceeded his highest expectations.

This plant is not only a novelty because it is the only successful one of the kind in the world to-day, but also on account of the general effect noticeable in the quarries and about the works by reason of its entire absence of condensed steam and smoke. Every quarry man will understand and fully appreciate the importance of having the quarries relieved of the heavy clouds of vapor and smoke which so often hang over the opening when the outside atmosphere is heavy.

The power plant is located on the Company's private siding connected with a branch of the Lehigh Valley Railroad and consists of one Return Tubular Boiler of 140 horse power, with a return draft and a nest of two reserved boilers of 90-horse power so connected with the main boiler and the machinery that either one or both can be used in running the plant.

The Air Compressor is an Ingersoll-Sergeant, Straight Line, Class "A" machine, with piston inlet valves and automatic unloading device and all the latest improvements. The steam cylinder is 18 inches in diameter and 24-inch stroke, and the air cylinder 20¼ inches in diameter and 24-inch stroke, capable of developing 127 horse power with 90 revolutions per minute and 60 lbs. air pressure. Total weight of compressor, 20,400 lbs.

The plant has all the necessary side equipments, consisting of air receivers, water tank, feed and supply pumps and a unique system of pipe and valve connections by which the steam direct from the boilers can be substituted for the compressed air and the compressor put out of service in case of emergency or accident, without closing down the operations.

The main supply of compressed air is delivered through a 5-inch pipe to the quarries 1,000 feet from the power plant. The quarry plant is operated solely by compressed air, and consists at the present time of two Double Drum Flory Hoisting Engines for three cable ways, and one small hoisting engine operating a swing derrick, one duplex pump, two air drills and one small stationary engine which supplies the power for two slate sawing benches and two sets of school slate saws.

Besides the quarry operations, this plant supplies the power for the running of two slate factories, with a 30-horse power stationary engine in each one located 75 feet from the compressor, and the other at a distance of 300 feet.—*Slate.*

THE POWER PLANT OF GOLDEN WAVE MINE, CONGRESS, ARIZ.

A most interesting installation of an air compressor, a gasoline engine and a mine hoist, is afforded by a plant installed at the Golden Wave Mine, Congress, Arizona, and as an example of the cost the following information is given:

The speed of the compressor is 175 revolutions per minute.

The size of heading, 10′ x 8′.

Elevation above the sea level, 6,000 feet.

Ten holes are put down to each round, 1⅜″ diameter x 5′ deep.

Two rounds of holes are drilled and blasted each shift of 10 hours, making 7′ progress per shift, or 14′ per day.

It requires 6 lbs., of No. 2 Giant powder for each round of holes, or 24 lbs. to 14′ of tunnel, or 1,714 lbs. powder per lineal foot of drift.

The following force is employed underground:

Four drillers per shift, making eight per day, with wages $3.50 per day each.

One mucker per shift, or two per day, at $3 each.

Number of cars hoisted per shift, 25.

Cars waste, 15.

Cars, ore, 10.

Weight of loaded car—ore	1,500 lbs.
" car	500 "
Total	2,000 lbs.

Total output per shift, 37,500 lbs.
" " " day, 37½ tons.
Gasoline, per shift, 9 gallons.
" " day, 18 "
Cost of gasoline per day, $2.70.
Number of men above ground; two each shift, four per day, at $3.50.
Drills operate about 2½ hours per shift, or five hours per day.
Time to drill one round of holes, 1¼ hours.
Ground hard and flinty, 1-3 harder than Chicago Tunnel work.
Hoisting, incline, 30%; 380′ to heading.
Time hoisting, 1½ minutes.
Feet tunnel per day, 14. Gasoline, $2.70. $0.1928 per foot.

Eight drillers, at $3.50	$28.00
Two muckers, at $3.00	6.00
Four men above ground, $3.50	14.00
	$48.00
$48.00 labor for 14′; per foot	$3.43
Gasoline, per foot	.1928
Cost of labor and fuel per ft. of drift	$3.6228

This is a practical demonstration of the cost of operating such a plant and those who are working small claims now by hand will find a plant of this kind one that can be installed with small outlay and at the same time obtain results possible only with machine mining.

We are enabled, through the courtesy of Messrs. Patterson, Gottfried & Hunter, of New York, the general Eastern agents of the Fairbanks-Morse Co., to give to our readers the following accurate description of the plant itself, which, when taken in connection with the foregoing data, should prove of interest.

The gasoline engine is a standard Fairbanks-Morse engine of 30 B.H.P., and is located between the air compressor and hoist. The shaft of the compressor is directly connected to the engine shaft by means of a friction clutch coupling which permits of the disconnection of the compressor at will. When the compressor is not required it may be totally uncoupled from the engine, thereby allowing the use of the available power for hoisting.

The compressor is fitted with a mechanical unloading device, which, when the desired pressure has been attained holds open the admission valve and prevents compression. When this unloading occurs the load on the engine is immediately reduced and the governor automatically cuts down the supply of fuel in proportion to the demand for power.

The usual forms of Fairbanks-Morse gas engine air compressors met with are either a direct connected outfit in which the air cylinder and engine cylinder are mounted on the same frame having a common shaft, and secondly the familiar belted unit. In the plant in question, however, the conditions were such that neither of the above combinations would answer, and it was found necessary to especially devise this direct driving arrangement with the intermediate clutch coupling so that they could be used intermittently.

The hoister employed is known as a flat faced friction hoist. On the opposite side from the compressor the engine shaft is extended to receive two flat friction rollers; these rollers bear on two iron surfaces which form the sides of the rope drum, the rollers thus acting on either side of the drum. The drum is carried on two eccentric boxes and its movement horizontally is controlled by a lever which works in a quadrant. When it is desired to operate the hoist the drum is shifted into contact with the friction rollers by manipulating the controling lever and the drum is made to revolve.

In connection with the hoisting part of the apparatus the engine is equipped with an automatic speed regulating device. A foot pedal is conveniently placed which communicates with the governor, and when no pressure is exerted upon it the engine runs at a minimum speed of approximately 70 revolutions per minute. This pedal being pressed down, however, immediately increases the speed of the engine to normal. The object of this speed variating device is two-fold; first, the chances of accident are greatly reduced, for, immediately the pressure on the pedal is removed the power and speed of the engine is cut down to a minimum and second, the speed being cut down when the hoist is not in use greatly reduces the consumption of fuel during the periods of idleness.

Another feature which may be of interest is the fact that power is used only in hoisting; while lowering, the power is cut off and the drum is controlled by means of a band brake.

The compressor is constructed with opening for air intake, so arranged as to connect with cold air outside of engine room, air arriving as cold as possible within the cylinder. The cylinder and head of the compressor are water jacketed, relieving the air of much of the heat due to compression. The air cylinder is single acting, doing away with stuffing box and having only one set of valves, which are easily removed together with their seats.

This plant tends strongly to confirm the many advantages of the gasoline engine for mining, and especially is the fact made clear that great economy may be expected from a gas engine air compressor combination, for, where other fuels are scarce gasoline is generally easily obtainable owing to its portability, and this fact coupled with the portability of the machine itself and its general compactness render the gasoline engine invaluable for many purposes.

THE USE OF COMPRESSED AIR IN BUILDING THE DELAWARE BREAKWATER.

Among recent appropriations made for river and harbor improvements by the United States Government was an appropriation of $4,665,000, which provided for the construction of a harbor of refuge for deep draft vessels in Delaware Bay, and is expected to be completed on or before December 31, 1901.

GENERAL PROJECT.

The plans submitted by the chief of engineers, January 29, 1892, which were adopted by Congress in the Act of June 3, 1896, are contained in the report of a commission of engineer officers, dated January 5, 1892, and published in Document No. 112, House of Representatives, 52d Congress, 1st Session. They provide for the construction of a stone breakwater located upon the line of least depth along the eastern branch of the shoals known as the Shears. This shoal is situated upon the west side of the main ship channel near the entrance of Delaware Bay. It is proposed to form the breakwater by the deposit of random stone to the level of low water, and by the construction of a superstructure

FIG. 314.—THE USE OF COMPRESSED AIR IN BUILDING THE DELAWARE BREAKWATER.

thereon, by the erection of outer and inner walls of very heavy stones, the interior space to be filled with rubble.

The total length of the breakwater at the level of mean low water will be about 8,000 feet, but this length may be increased if found practicable without increasing the quantity of stone estimated for the construction of the work.

The depth at mean low water along the site of the work varies from 13′ to 53′, the average depth being 28′.

It was assumed that each cu. yd. of enrockment will contain 1.25 gross tons of stone. Upon this assumption, the approximate amount of stone to be quarried for the construction of the breakwater, expressed in tons of 2,000 lbs. each, is as follows:

Substructure	1,210,665
Superstructure	173,745
Total	1,384,410

The site of the proposed breakwater is about 2¼ miles north of the Delaware breakwater harbor, about 3 miles from the Government pier at Lower Delaware, and about 10 miles from Cape May.

The contract for the complete work was let on Dec. 10th, '96, to Messrs.

FIG. 315.—MC MYLER DERRICKS.

Hughes Bros. & Bangs, of Syracuse, New York, and is one of a number of large contracts on public works now in hand by this firm.

The work of laying out a plant for this immense work was begun soon after the awarding of the contract, and at the present time the work is pretty well under way, the output at the present time being just about 50 per cent. of the proposed total capacity.

Suitable stone in sufficient quantity was found at Bellevue, Del., a station on the P. W. & B. R. R., and located on the Delaware River, about 5 miles from Wilmington, or a distance of 75 miles from breakwater. At this point a large dock has been constructed, and ample facilities are at hand for handling an output of 3,000 tons of stones per day.

Connecting the dock with the quarry is one mile of double track railroad, built of 60-lb. steel rail, and has stone ballast laid on a 2 per cent. grade. A number of cross-overs, or sidings, are provided, so that loaded and empty trains may pass each other.

Four Baldwin locomotives (Fig. 320), with cylinders 12 x 16, handle the various mixed trains of flat cars and gondolas. The train equipment consists

FIG. 316.—AIR COMPRESSOR.

of 300 flat cars, 15 tons capacity, and 60 gondolas, 10 tons capacity each (for earth and small rock).

When a train load of stone reaches the dock it is run on one of the sidings, the locomotive taking back the empties, and two derricks, provided each with Bull wheels, as shown on cover, unload the stone from cars to the barges; 2 hoisting engines operate the derricks, and each Bull wheel is controlled by a small rotary engine operated by compressed air.

The water-way equipment for this plant consists of 13 barges, each 180 feet long, with 40 feet beam; 7 of these barges have flat decks and are fitted with steam derricks, and the other 6 are known as open bottom dump scows. The capacity of each barge is 1,500 tons.

There are also 3 ocean tugs, 110 feet long, that tow the barges from Bellevue to the breakwater, each tow consisting of 2 barges, and takes about 6 days to make the round trip.

The quarry equipment proper consists of 9 McMyler Derricks; 20 Ingersoll-Sergeant Rock Drills, 3½" cylinder; 12 Lidgerwood Hoisting Engines for operating 22 derricks, and several small pumps for draining quarry.

The McMyler derricks, as shown in cut (Fig. 315), are fitted with steam cranes, run on 16 feet gauge track, and have a capacity of 15 tons at 30 feet radius, or 6 tons at 45 feet radius. The rock drills are of the standard Sergeant and Tappet make of the Ingersoll-Sergeant Drill Co.

The hoisting engines are 8¼" x 10" double cylinder, double drivers, so roped as to handle stones from 12 to 15 tons.

The question of operating so large a quarry plant as this in the most economical manner was thoroughly considered by the contractors. Estimates

FIG. 317.—POWER HOUSE.

were received for electric transmission, compressed air and steam transmission. A visit to Jerome Park, where similar work is being done from a compressed air central plant, soon convinced the contractors that for work of such variable nature as this the Central Compressed Air Power Plant gave the best assurance of economy, and it was therefore installed.

The compressor is one of the best type made by the Ingersoll-Sergeant

Drill Co., of New York, and has compound steam and air cylinders of the following dimensions:

High	pressure	steam	cylinder	......22" x 48"
Low	"	"	"	......40" x 48"
Low	"	air	"	......36¼" x 48"
High	"	"	"	......22¼" x 48"

The air cylinders are tied tandem to a Corliss Compound Condensing Engine, and are also connected by a vertical receiver intercooler, 48" diameter by 13' 6" high (Fig. 316). The air pressure is steadily maintained at 80 to 85 lbs. at power house, and Fig. 317 shows location of power house. The pond shown

FIG. 318.—COAL-BIN 600 TONS CAPACITY, AND FLAT DECK BARGE 1,500 TONS CAPACITY.

in cut has an average depth of 14 ft., and is of sufficient area to maintain a low temperature for the condensing water which is used over and over. The coal is first stored in a 600 ton bin at the dock (Fig. 318), and carried as required by dump cars upon inclined track to bin of 300 ton capacity at boiler house (Fig. 317).

The boiler plant consists of 3 Hogan water tube boilers (Fig. 319) of 125 horse power each, and furnish steam to the compressor at 125 lbs. per sq. in.

One fireman is all that is required at the boilers, and the compressor receives the attention of only one man, the engineer; so that aside from the old method of carting the coal to the various small boilers about work of this kind, and the expense thereof, there is quite a saving effected in labor for attendance, to say nothing about the difference in producing a given amount of power by an economical Corliss engine, situated convenient for water and coal, as compared with a number of small boilers carrying steam through long, uncovered pipes, and where the boilers are constantly in danger of being damaged by flying stones, thus making the question of repair account an important one when compared with the central power plant.

Aside from these questions of advantage, it will be well to bear in mind that the compressor is fitted with an automatic unloading device which unloads the air

FIG. 319.—THREE HOGAN BOILERS.

cylinders as soon as a maximum pressure of 85 lbs. has been reached, thus calling for only enough steam to overcome the friction of the compressor. When the pressure in pipe line falls to 80 lbs., the unloading device responds and the machine goes on with its regular work.

When rock drills use compressed air, the drill is capable of drilling more feet per day than with steam, due to higher pressure (because of no condensation), and the drills are easier handled by the operator on account of being cold. Again, a given quantity of oil will do more service in an air motor than in a steam motor, for there is less heat to destroy the useful effect.

The convenience of having air power on tap at this quarry is illustrated in its use in the various pumps which are set to work intermittently and at any place without the delay of changing boilers and keeping them partially fired. Drinking water of the finest quality is drawn from a well 200 ft. deep, by means of a Pohlé Air-lift Pump, a device calling for but 2 long pieces of pipe, and has no valves to get out of order.

Up to the present time there has been no trouble due to freezing of the moisture contained in the air. However, if trouble should arise from that source

FIG. 320.—LOADED TRAIN.

in winter, small reheaters will be placed near the various motors, which are quite inexpensive to maintain and have the good grace to add about 30% to the efficiency of the plant when used in the proper manner.

This is practically the second large plant of this kind in this country, and we venture to predict the establishment of more; for the results obtained are so far in advance of old practice, that it would be folly to go back.

F. C. Weber.

THE COMPRESSED AIR POWER PLANT AT JEROME PARK, N. Y.

The Aqueduct Commissioners of the City of New York have now in active progress of construction two important works to increase the water supply of New York City. One is the new Croton dam, designed to increase the size of the present Croton Lake and thereby impound a greatly increased water supply for the city at large.

From the present Croton Lake two aqueducts, the old one of 1840, the other the new one completed in 1890, run to the city, delivering their water directly into the reservoirs in Central Park. The city of New York has had one

FIG. 321.—THE POWER PLANT—JEROME PARK, N. Y.

policy as to its water supply; it has always worked on the lines of an increase of reservoir capacity by addition, the old reservoirs being preserved.

To provide for additional storage capacity for direct use in the city, construction operations are now in progress on what is known as Jerome Park reservoir, in Fordham, in the annexed district.

Here Jerome Park, with its famous old race course on which so many celebrated horses have been ridden to defeat or victory, with a quantity of adjacent territory, has been selected for a reservoir. The ground offers fair advantages in point of elevation and configuration; its vicinity to the city and its situation in the heart of the annexed district make it peculiarly available for the purpose. The area of about 5,800 feet long and 2,800 feet wide is to be surrounded by an embankment and the bottom is to be excavated until good surface is reached, so as to establish an available depth of 33 feet 6 inches. This will involve a very large amount of excavation; the engineers having estimated that there will be nearly seven million of cubic yards of excavation to be made, of which 3,165,000 will be in solid rock.

The reservoir will be bounded on the west by Sedgwick avenue, on the east by Jerome avenue, north by Van Cortlandt Park, and south by Kingsbridge Road.

Mr. John B. McDonald secured the contract for building the reservoir in August, 1894. He examined the various methods for facilitating the work and doing it economically. Being a man of practical methods, he went into the examination with great thoroughness, and finally decided that he would adopt the compressed air central plant system as the most efficient and economical.

The plan is to locate a compressor at a central point, compress the air into a large storage receiver and from thence conduct it in pipes to wherever it is needed. Consequently a plant of this kind was procured. An 8-inch pipe is laid from the storage tank and takes a straight course to the northeasterly corner of the work.

This pipe is tapped at various points, and each lateral supplies air to drills and other apparatus. These drills, hoists, pumps, etc., are located in

FIG. 322.—ONE OF THE QUARRIES.

various parts of the tract. They may all be in use at one time if occasion requires it, or only one machine need be in use. This distribution of air power on the "European plan" has effected some wonderful economies.

There are 14 rock drills, 14 hoisting engines, and 3 water pumps at work during the day. They are supplied by power from the central plant, which consists of one Ingersoll-Sergeant Duplex Corliss Condensing Air Compressor, steam cylinder 24 and 44 x 48; two air cylinders, 24¼ x 48, capable of producing 540 H. P. at a pressure of 80 pounds at the air receiver. Steam is made for this compressor by a Hogan Water Tube Boiler, manufactured by the Hogan Boiler Co. of Middletown, N. Y., the nominal rating of which is 240 horse power. The pipe leading from the receiver is 8 in. in diameter and carries the main supply of air to the individual machines. At a distance of 2,000 feet the air passes through a Sergeant Reheater. This reheater consists of two cast iron shells, which are bolted together. In appearance it resembles a truncated cone. It keeps the velocity of the air constant. The air being hot, it has greater volume, and would consequently increase the friction if there was no room for expansion. Tests have been made with this heater, and the results show that 340 cubic feet of free air per minute, at 40 lbs. pressure, can be reheated so that a gain of 35 per cent. is imparted to the energy of a pound of air.

The point where the economy is immediately effected is in the operation of the drills, hoists and pumps. Ordinarily these would be run by separate boilers requiring the attendance of an engineer and stoker, and the extra labor of hauling fuel and water to each boiler. This performance is dispensed with by the air power being transmitted from the central station.

Aside from the reduction in expense, the convenience of having a power that can be used at any moment and without the annoyances attending the care of individual boilers for each machine facilitate the work vastly.

The whole work of excavation is reduced to as small a use of human effort as can well be devised at this time.

With the use of steam for the operation of drills, considerable water—condensed steam—collects in the pipe, even in the short time consumed in chang-

FIG. 323.—RE-HEATING THE AIR.

ing bits or moving from one hole to another. This must be worked out through the exhaust before the drill can begin to do good work. If this water from the different drills and pumps could be collected, it would be found to amount to a great many barrels in the course of a day. Each cubic foot of water wasted by condensation represents one horse power. There is another and serious loss with steam—that of loss of capacity of the drills. With full pressure of dry elastic compressed air at the drills, more work will be done than by the wet steam, a less number of drills, drill runners and helpers are required for the same work, and these various reductions in the pay roll and coal bill may amount to the cost of the plant before it is worn out. It is a common expression of quarrymen who have adopted compressed air after using steam, that "two drills will do more work with air than three with steam."

There are several other items, representing in the aggregate a large amount, that would be difficult to name, that is saved by the Jerome Park plant. For instance, a cheaper grade of hose can be used with air, and will outwear several lengths of steam hose. As a matter of fact, quarrymen using compressed air find that the saving in hose alone equals the expense of keeping up the plant.

Less oil is required with air than steam. A little oil will last for hours in an air cylinder and will ease the working of the machine. Steam burns the oil out in a few minutes.

It is evident that greater economy will be realized by the use of one central plant placed where fuel and water are most accessible, removed from all danger from blasts, falling derricks, etc., not subject to constant removal, provided with an economical boiler plant, a compressing engine of high efficiency, fitted with an entirely automatic system of governing devices, using steam expansively, and requiring steam only in exact proportion to the amount of air being used. This disposes of all annoyance and expense incidental to supplying coal and water to a number of different boilers, and there is only one fire-

FIG. 324.—HOISTING A 3 TON ROCK BY AIR POWER.

man, and one boiler plant to keep in repair. All annoyance and expense from frozen pipes in cold weather, smoke, exhaust steam and ashes in the quarry are avoided.

PAINTING BY COMPRESSED AIR.

IMPORTANT DISCUSSION BY THE NEW ENGLAND RAILROAD CLUB.

At the February meeting of the New England Railroad Club the subject for discussion was: "Is it Economy to Use Compressed Air in Painting Railway Equipment?" The facts presented by the various speakers are of such a character that they have been widely published and favorable comment has been the rule. We reproduce the various interesting parts of the discussion. Following are the remarks of Mr. C. E. Copp, general foreman painter B. & M. R. R.:

"I saw and questioned a man who painted the equivalent of 29 standard 34-ft. coal cars in about five hours, which is an average of one every 10 minutes, and the air pressure was poor. Various speeds of from five to ten minutes per car were realized at this work. This was for the car body and attachments only. No more material was wasted than by the brush generally. By a test made at the Pittsburg & Lake Erie shops less was used by the spray method. But when computing the expense of painting by compressed air, the cost of the air should be reckoned in. Westinghouse air pumps will not answer for all these attachments that are being put on the shops; there must be compressors of more power employed.

"As to the practicability of this method, conditions will vary. As an open-air way of painting cars in yards in pleasant weather, I have no doubt of its utility, by having the yards, of course, piped with the air, with connections at proper intervals. But in very cold weather out of doors it is found that the condensation or dampness of the air in the hose congeals and stops the valves, rendering them inoperative. To remedy this trouble, some way of warming the air by passing it through a heated coil has been considered. My opinion is that it will require as much skill, if not more, to operate a spray successfully as by the brush method, especially if the machine is at all complicated. And then it must be adjusted rightly, held at the proper distance from the work, and not too long in one place; for, if it is, it will produce unsightly runs, requiring slicking up with a brush afterward.

"If lead dust from sandpapering is deadly to breathe into the system, what may lead mist be from spraying? And so green paint containing arsenic, or any other poison. But if cars are painted with an earth paint, as they should be, such as mineral brown, which most roads are doing, then no fears need be entertained of its poisonous effects. And in this connection I should recommend, if this method of painting were adopted, to do the car all over with it, top, body, trucks, iron-work and all, and afterward black no irons, as they would be much more durable that way than with the asphaltum black which is generally applied.

"As to the quality of work done by the spray method in comparison with brush work, it may be thought that the working of a heavy-bodied paint well into the pores of the wood by a patient and diligent spreading of the same by hand with a brush would be more durable, than the sprayed article, and doubtless it would be if it were done; but, as a matter of fact, freight cars are not painted that way in nine cases out of ten. We know that they are slopped over in the most hap-hazard way possible, especially at piece-work prices, the only object being to cover them with the paint and a brush, which is often of huge proportions, so that the paint runs down the beads and drips on the floor.

"To the credit of paint sprayed on, it may be truthfully said that it will go into places where, with great difficulty, if not impossibility, it is to be put with a brush.

"Regarding the immediate adoption of this method of work, I should recommend its postponement, except in the line of experiment, until its patentability is cleared up, and then only when its practicability was fully settled."

Mr. Worrall presented the following, which was prepared by Mr. W. O. Quest, foreman of painting, P. & L. E. R. R. Co.:

"We will further call your attention to the fact that a perfectly atomized sprayed on paint will almost instantaneously reach, cover up and consequently protect a car's most complicated structural parts. It penetrates the rough beaded work—the open joints through shrinkage of sheathing—the crevices and other disfigurements usually met with where painting the new and repainting the old railway freight car equipment. In refutation to existing doubts in circulation, we will ask you to accept the evidence of the close observation made by us, from time to time, of some sprayed freight and other large surface work done by the P. & L. E. R. R. Co., in the beginning, convincing us that the results from a standpoint of durability will not suffer on the score of fact that the paint was not applied with a brush.

"We will also advance the theory that we will be safe when we express the belief that the operation of a perfect atomized painting apparatus will not

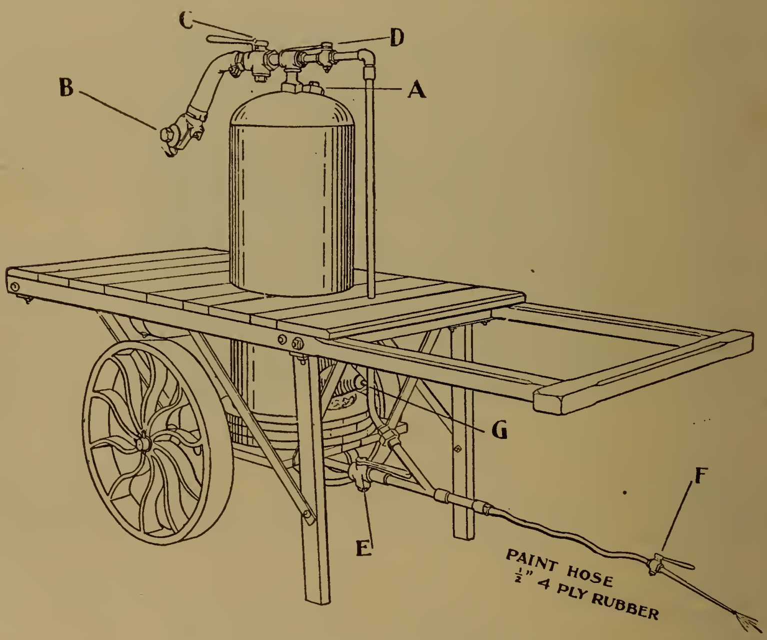

FIG. 325.—COMPRESSED AIR PAINTING MACHINE.

injure the health of the operator, if the proper precautionary measures are taken. The safe-guard we would suggest against this possibility is to use nothing but a perfect atomizing device, which should be worked to its full capacity with a sufficient generated air pressure to force the paint clear of nozzle on to work without dripping. The much-objected-to white spray, which is always perceptible during the spraying operation, on investigation will prove to be nothing worse than volumes of discharged surplus air, which becomes vaporous on forced release, from the fact of air being so much lighter than the heavier atoms of paint which is ejected with great force ahead on to the work, and not back, as it has been claimed, into the face of the operator.

"This being the fact, we would judge there need be no danger apprehended in a health sense, through the practical use of the pneumatic paint sprayer, where properly operated. Deeming the above summary a sufficient introductory for the paint spraying issue, we will now proceed to take up the question of comparative cost of paint used, the utility of innovation, etc.

"The following is the estimated cost of the work done in the Pittsburg & Lake Erie Company's freight yard during the period in which the spraying apparatus was in operation. This is compared with the time and cost of work done with the brush the laborers are paid on the piece-work plan:"

	Piece Work.		With Spray.		Saving, per cent.
	Hours.	Cost.	Hours.	Cost.	
Box	3½	.60	3¼	.15	75
Coal	1⅛	.30	¼	.10	66⅔
Coke	3	.50	⅛	.12	76
Flat	⅛	.10	1-6	.05	50
Trucks, all cars	....	.30	....	.12	60
Roof only, box	....	.10	....	.04	60

The following is taken from a paper prepared by Mr. H. G. McMasters, master car painter, Illinois Central R. R.:

"It takes from two to three hours, or we will be liberal and say two hours, to coat a 35-ft. box car with the brush. Now, we feel safe in making the assertion that a man who has never seen a spraying machine before can take one and coat a car in at least one hour at his first attempt, which even at that rate, is a saving of one hour per coat, and this will be increased as the workman becomes accustomed to the machine.

"So far with the sprayer we have been unable to show a very great saving in paint over the brush, but even if we do not make a saving in paint, and use the same amount we did with the brush, the saving in labor will pay us to use it, as the following figures (which we had occasion to take a few days ago) will show:

PRIMING NEW 35-FT. BOX CAR BY HAND.

Labor 2 hours, at 20c.	$ 40	
Material, 14 lbs. paint, at 5c.	70	
Total		$1.10

PRIMING NEW 35-FT. BOX CAR WITH SPRAYING MACHINE.

Labor, 35 minutes, at 20c. per hour	$ 12	
Material, 12 lbs., at 5c.	60	
Total		72
Total saving of		38

Or 34.57 per cent.

"Saving of labor painting by spraying machine, 28c., or 70.83 per cent.

"Saving of material, painting by spraying machine, 10c., or 14.29 per cent.

"Roof and trucks not included.

"The above figures include placing staging around the car, making all air connections, filling and cleaning machine, replacing hose, etc., or the actual cost of priming one car.

"The cost of second and third coating vary slightly, but are materially the same as above. We also find it profitable to use the sprayer on a number of things in the coach shop, but, as we said before, a little experimenting with one will show how really profitable it is."

PRACTICAL PAINTING BY AIR.

The illustrations on the following page show the Bryce Pneumatic Painting Machine in operation painting the Pan House of the Arbuckle Bros. Sugar Refinery in Brooklyn. This building consists of ten (10) floors, each 200 by 87, and from 12 to 25 feet high, each floor having 60 brick columns, 500 feet in each, so that the average space to be painted on each floor is over 27,000 square feet or 272,812 feet in all. The ceilings are of fire proof tile arched, walls and columns of brick. The entire building is being painted by The Bryce Machine under contract with John A. Chater, 132 Nassau Street, New York. King's cold water paint is used and the covering as applied by the machines is entirely opaque and white with one coat. The machines of which there are now two in operation are worked from a Clayton air compressor on the ground floor, air being taken up by an inch hose on the outside of the building and taken through the window on to any floor on which the machines are used. Fig. 326 shows one machine at work on one of the columns which has been left uncovered at the base. The ceilings on this floor are 12 feet to the arch and are sprayed from the floor without any scaffold by the use of a four-foot nozzle; other ceilings are over 14 feet. There is no return of material from the ceiling.

Painting can be done in this way on floors or ceilings at the rate of 2,250 feet an hour by actual test, though 10,000 feet is a good day's work for one man holding the nozzle.

The tank shown on wheels holds 16 gallons of paint. On the left side of tank are shown the valves for injecting air and ejecting air and paint. These are in one casting which terminates in an inch pipe which is screwed into the top of the tank. Inside this pipe and connecting both with the air and paint valves of the casting is a ⅜-inch pipe extending down to within 1½ inches of bottom of tank. The single hose attached on the left of valve casting supplies air. Of the other two small hose on the right of valve casting one takes the paint and the other the air to the nozzle. The valves represented by the small handles as shown in picture are all open. The air passing in at the left passes down the wide short pipe and pressing on the top of the paint in the tank forces it up through the small pipe and out through upper valve and hose shown on the right of casting from whence it passes to the stem of the nozzle, and into an inner tube within the outside tube of the nozzle passing out at a vent at the end of this tube where it is caught and sprayed by the air passing through the outer tube.

The air in addition to performing this duty of forcing up the paint also passes straight from the valve on the left to the lower valve on the right and thence through the hose to the stem of the nozzle where it passes through a valve into the outer tube of the nozzle catching the paint at the end of the inner tube and spraying it into a fine mist. When it is desired to stir up the paint in the tank the valve handle on the left is turned vertically up, when the air passes down the small tube in the tank stirring up the paint and mixing it thoroughly.

The nozzle consists of two tubes one within the other with an air space between fitting into a stem or handle containing openings corresponding with

FIG. 326.—PAINTING ARBUCKLE SUGAR REFINERY BY THE BRYCE PNEUMATIC PAINT MACHINE.

The column to the left partly painted. The upper part has been sprayed with white paint. The lower part still untouched.

openings in both tubes which form the valves for regulating the flow of air and paint. These consist of openings in the outer and inner tubes so arranged that the flow of paint and of air can be regulated separately or together, or either or both shut off with one turn of the hand.

The machine illustrated has been developed with great care and ingenuity and is thoroughly well made and finished in every respect. It is the most highly developed and, with one exception, the only machine in the market at this time, and is thoroughly protected by the earliest patents.

These machines are more specially in demand for painting large surfaces and ceilings with kalsomine and cold water paints also for protective painting of large bridges and iron structures and ships with the different kinds of oil paints. They can also be used for first two coats on barns and houses. One man handling

FIG. 327.
Building 200x87, 10 floors, ceilings 12 feet, 60 columns on each floor.

the nozzle will do the work of from eight to ten men with the brush, with often a complete saving of scaffolding. An additional saving is in the wear of brushes.

At a late hour Mr. Chater reports that the U. S. Navy has purchased these machines for painting war ships in Dry Dock.

THE APPRAISER'S STORES BLDG., PAINTED BY AIR.

At the present time the iron works of the U. S. Appraiser's Stores, foot of Christopher street, New York City, is being painted by compressed air. It is a ten-story building, covering an entire block. The painting is being done by the contractors, Post & McCord. Four painting machines, made by the Turner Machine Co. are being used. The whole outfit comprises one Clayton Compressor and four spraying machines. In operation it requires one man for each spray, and to facilitate he work three additional men are employed to carry paint, move travelers and be in attendance for whatever purpose may be required of them. One man with a spraying machine can paint as much in 4 minutes as can be done by hand in 45 minutes. The paint used is ordinary red lead and oil.

The average work of four men, each with a machine, has been 100,000 square feet in 5 days, working 8 hours each day. Mr. John C. McCord is superintendent of the work. The compressor is located on the fourth floor, and 40

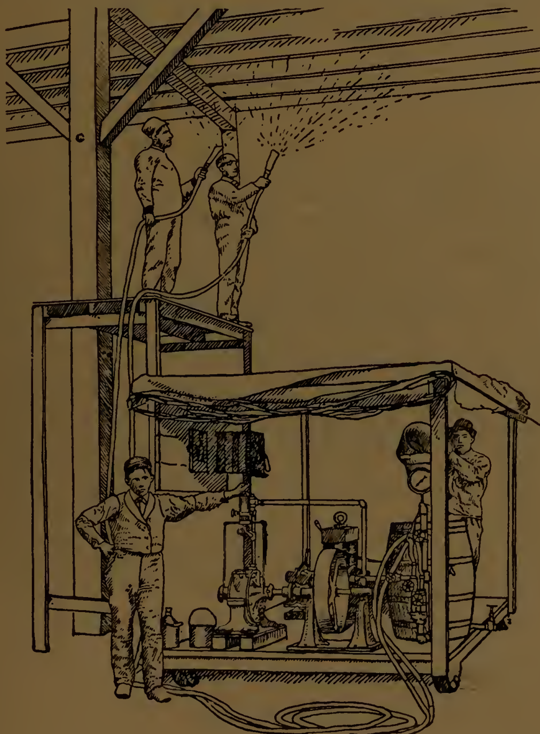

FIG. 328.—APPARATUS USED FOR PAINTING THE WORLD'S FAIR BUILDINGS.

lbs. pressure is carried. The machines work under 15 lbs. pressure, and do the work thoroughly.

The incidents leading up to the painting of the Appraiser's stores are of interest in the way of the development of painting by air. The machine was perfected by Mr. C. Y. Turner, who was assistant decorator under Mr. F. D. Millett at the World's Fair in 1892. The work of painting the buildings was done by a rotary machine, and the material used was kalsomine. It was accomplished with great success. So rapidly was the work done that the inside of the great Manufacturers' Building, which covered 31 acres of ground, was done in one month. The largest amount of surface covered in an eight-hour day was 31,500 feet by one double spray outfit. Since that time a number of outfits have been furnished to manufacturers and others for painting and whitewashing, and the machine of to-day is much advanced from the style used at the World's Fair.

It was necessary to facilitate the painting of the structural iron of the Appraiser's stores. The machines mentioned were put in for a trial test by the Turner Machine Co. Red lead was used, and it was distributed in a most satisfactory manner, and the machines were adopted. The machines in use by the various railroad shops are adaptations of the original Turner machine.

PAINT FOR PNEUMATIC SPRAYING.

Some inquiry having been made as to the requisite nature of paint to be successfully sprayed, we will say that any paste paint thinned down with oil to the proper consistency to be applied with a brush, can be handled with the spray, with sufficient force. It is not customary, however, to use a paint for this purpose (usually oxide of iron mineral) that weighs over ten pounds per gallon. If a semi-paste is used mix 3 parts Sipe's Japan oil with 1 part raw linseed oil thoroughly. Of this mixture take 7 lbs. and mix 3 lbs. of finely ground metallic paste paint, which makes a spraying paint that weighs 10 pounds per gallon. In an experiment of painting a gondola coal car recently we took the Patterson-Sargent Co.'s liquid mineral roof paint, which is a very heavy paint—too heavy for brush, without thinning, and weighs 17 to 18 pounds per gallon—and thinned it down with Sipe's Japan oil to about 11 pounds per gallon, and it worked successfully; but a little greater air pressure and a pound lighter paint per gallon would have produced better results. Sipe's Japan oil, being light-bodied and a good drier, is, with linseed, well adapted for this purpose.—*R. R. Car Journal.*

JETS OF AIR.

Air at 75 pounds gauge pressure will escape from a ¾″ hole in the receiver at the velocity of 548 feet per second, from a short pipe at the rate of 658 feet per second. The velocity of flow varies but slightly at different pressures, only as affected by the opening, which varies the co-efficient of contraction. Approximate results may be obtained in practice by using the above named velocities for any pressure between 45 and 100 pounds.

The rate of flow may be obtained from the size of the opening and the velocity given above.

The heat of compression causes the greatest loss in the use of compressed air. This is being greatly reduced by the use of compound compressors.

When the volume of air is heated 475 degrees above its initial temperature the volume, at the original pressure, will be doubled.

Air leaks in pipes are more expensive than steam leaks of the same size—about two and one-half times as great.

The compression of air, at constant temperature, follows Mariotte's law, and is inversely as the volume, the pressure being calculated in absolute units—15 pounds more than gauge pressure.—*National Engineer.*

PAINTING BUILDINGS BY COMPRESSED AIR.

The following interesting description, by Mr. J. J. Hubbell, is taken from the Michigan Engineers' Annual for 1897:

The buildings belong to the Buckley & Douglas Lumber Co., and included a main building 475 ft. long by 356 ft. wide. The structures covered about five acres, and there was fully 1,000 "squares," or 100,000 square ft. of surface to be covered with paint. Rough hemlock lumber was used in the sides of these buildings, and the problem was to cover this siding with some preservative compound as cheaply as possible. After a full consideration of various washes, a mixture of good raw linseed oil and red oxide of iron was determined on.

Bids were received from three local painters. One of these offered to furnish brushes and ladders and to apply the paint for 35 cents per square; another offered to do it for 28 cents if the company provided all material; and the third made a lump bid of $300 for providing labor alone. Each of these bids was reasonable, but all of the painters deemed two coats necessary, and thought the season too far advanced to undertake the work at the time. In this emergency Mr. Hubbell determined to use compressed air for the work.

He made his own sprayer at a cost of $10, and in addition provided 150 ft. of ¾-inch hose, an air pump taken from a locomotive, and an air reservoir also taken from a locomotive. This latter had a capacity of 10 cu. ft., and was placed near the large building and connected to the air pump by ½-inch gas pipe. He says that he should have used ¾-inch pipe, but the smaller pipe was on hand in quantities. Of the hose, 125 ft. were to connect the nozzle with the air reservoir, and 25 ft. to connect the nozzle with the paint bucket, the latter being elevated to about the level of the nozzle.

The paint came in barrels of 50 gallons each, and to each head of these barrels was screwed an iron flange with a short journal attached. The barrel was hung on these journals and revolved by a crank so as to thoroughly mix the paint, which was then drawn off by a molasses gate set in the side of the barrel, two or three gallons at a time. In use the air pressure ranged from 40 to 50 lbs., and as the air passed through the nozzle it sprayed the paint in a fine cloud looking like a jet of red vapor. The discharge was controlled by a valve in the base of the nozzle, and the operator soon became expert and could paint 8 or 10 ft. above his head and the same distance below his feet. Two men were required, one to keep the paint bucket full, and the other to handle the brush. There was little waste of paint, though every crevice was filled, and the rough surface was covered better than it could have been done by hand. One gallon of paint would cover about 150 sq. ft., and the two men would cover about 5,000 sq. ft. in one day. The windows were protected by a light movable canvas covered frame.

The cost of the oil paint thus applied did not exceed 10 cents per 100 sq. ft., and the cost of painting the buildings, including all labor and a reasonable sum for the use of the air pump, pipe, reservoir and brush, was less than 15 cents per square of 100 sq. ft., or less than one-half the cost of painting by hand.

PNEUMATIC PAINTING MACHINES.

The interesting subject of "painting by compressed air" has the faculty of keeping before the public as conspicuous as any other line of compressed air work. The August issue of the *Railroad Car Journal* prints the following regarding it:

"The ever progressive Louisville & Nashville Railroad Company is improving the appearance of their property along the line of the P. & A. division, between Pensacola and River Junction, by having all the section houses and a number of depots and water stations painted. The handsome new freight warehouse in

FIG. 329.—PAINTING CAR TRUCKS.

this city, now rapidly nearing completion, is also being painted, all this work being done under the supervision of Mr. C. D. Beyer, the foreman painter of the L. & N. Railroad shops in this city. There are about 85 buildings, the fresh, new paint on which will be very gratifying to the travelers along the line."

At the M. C. B. Convention, held in June last, a discussion was opened on this subject by Mr. F. W. Brazier, Assistant Superintendent of Machinery of the Illinois Central Railroad.

The topic assigned to me to speak on, "The Durability of Paint Applied to Freight Cars by Compressed Air," as compared with paint applied by the brush, is a question which our company has taken great interest in. We are at present repainting about 400 cars per week with compressed air. We are positive that we are getting better results, a saving in labor, and our cars are painted more thoroughly than with a brush. We have cars that have been painted about two years, and in order to get reliable information for the benefit of this association, I sent out inquiry letters all over our system to have our foremen painters inspect any and all cars that they could find that were painted with air. I might mention the fact that we found most of the old school painters opposed to the air system

FIG. 330.—PAINTING TOP OF CAR.

when we inaugurated it. From one of our Southern States our painter reports as follows:

Vicksburg, Miss.

"In reply to your letter as to the durability of paint applied by compressed air, and the old method by brush, I would state that after making close observation of several cars done by air and by brush, I find very little difference in them, and if any, it is in favor of cars done with air.

(Signed) J. GLASS,
Foreman Painter."

FIG. 331.—TOUCHING UP THE EAVES.

Other letters follow which bring forth about the same results. Many of them acknowledge their skepticism in the beginning as to the chances of this method becoming a permanent institution in the painting of railroad equipment.

The experience of nearly every one who has tested the capabilities and the durability of the pneumatic painting machines has been of a highly satisfactory nature.

In the trade, painting machines are being supplied by the Chicago Pneumatic Tool Co., and their actual working is shown in the illustrations. They require only one hose—that for air—as the paint is sprayed directly from the

FIG. 332.—PAINTING EDGES OF BOARDS.

machine. Its convenience is evident and the testimony of practical painters will do much toward promoting its use wherever painting is done.

THE MASON PAINTING MACHINE.

It seems as if only a small number of people had heard of painting by compressed air, notwithstanding the many references made to it in this and other journals, and we constantly receive inquiries asking for information regarding this interesting process. A painting machine usually consists of a vessel for containing oil or cold water paint and a means for forcing it through hose to a spraying nozzle by which it is applied. At the point where it is ejected it is met by a small stream of air which atomizes the paint and thus puts it under control so that it may be sprayed on the surface to be painted. That is the operation, but much depends upon the construction of the machine itself, for if not properly constructed it fails in the most important features. In some cases it has been found impossible to operate home made machines or machines made on wrong principles.

A very successful machine for this purpose is the "Mason," manufactured by the Alden Speare's Son Co., 74 John street, New York.

The Mason Painting Machine consists of a hand air compressor, with a steel tank for storage of liquid paint or whitewash and the air. It has no rubber valves to be destroyed by any chemicals which may exist in material used. No material can get at the valves or any part of the mechanism (which is extremely simple in its construction), to put it out of order. By an ingenious device the paint is automatically kept agitated and settling prevented. Only forty pounds pressure required to operate it, and the tank is guaranteed to stand a pressure of two hundred pounds. It can be operated either by hand or power. It will apply with equal economy and facility oil paint, cold water paint or whitewash. It is

FIG. 333.—THE MASON PAINT MACHINE.

complete in itself, but can be arranged to be used in connection with a supply of air when such is at hand.

The cut herewith shows the construction of this machine in complete working order. The Speares Company are manufacturers of cold water paint, and the demand for an apparatus for properly applying their product led them to adopt this one and manufacture it to accommodate their patrons. A full knowledge of the requirements qualify them in offering it with assurances of satisfaction to the user.

PNEUMATIC DESPATCH.

On Thursday, October 7th, 1897, the Tubular Dispatch Co. gave a public demonstration of the Batcheller Pneumatic Dispatch Apparatus at the New York Post Office. Few appliances meet with a more auspicious reception or launch more genuinely into national importance than this one did. The company's line is laid from the Post Office to the Produce Exchange. Among those present at the opening were Hon. Chauncey M. Depew, Second Assistant Postmaster-General Shallenberger, ex-Postmaster-General Tyner, John E. Milholland and many others. At 12 o'clock Mr. Depew pulled the lever that sets the sending apparatus loaded with the carrier in place before the tube. Air pressure was automatically applied, and the carrier was projected on its journey. It went to the Exchange Building, which is 4,000 feet distant, and was returned. The trip took 4.35 minutes. The carrier is 24 inches long and 7 inches diameter.

It contained a variety of goods. The operation was repeated several times, each time carrying sundry articles. The table in front of Mr. Depew looked like that of a magician, whose exhibition brings forth beautiful and dazzling objects. Among the things carried were a bible, a copy of the Constitution of the United States, a bunch of violets, an American flag, fruit, clothing, shoes, bric-a-brac, a bottle of wine, a live cat, etc., etc.

The air pressure necessary was 6 pounds. There is a receiving apparatus at the end of the tube that checks the speed of the carrier by means of an air cushion. Then it is opened automatically and allows the carrier to emerge. It comes out upon a receiving table and strikes against buffers made of felt and other flexible material.

The demonstration was a success, and the hard work of the projectors of this system has terminated by a great triumph.

The system will probably be extended throughout New York City and Brooklyn. The work is now going on in Boston and Philadelphia and other large cities.

PNEUMATIC DESPATCH.

We are glad to note the successful introduction and use of the pneumatic system of conveying mails in cities. The Batcheller system is now in continuous operation in New York City, special carriers being provided for conveying the mails through a tube 8″ in diameter. In this system the carriers slide through the tube, a condition which is probably limited to tubes of 8″ to 10″ in diameter. It would seem that tubes of small diameter cannot be as serviceable or as economical in post offices or package delivery work owing to the labor required in transferring the packages. Tubes large enough to carry mail bags or common express packages would have many advantages and it is likely that a system of this kind will be brought forward. The Bostedo Package and Cash Carrier Company, of Chicago, has designed such a system for transmission of large packages over long distances. It is proposed to use tubes from 18 to 30 inches in diameter, a size large enough to carry the largest mail bags and it is also claimed that the principles involved may be applied advantageously to tubes of any size down to six inches in diameter.

In designing the system the first consideration was to do away with the friction of sliding carriers through the tubes, as is the practice with smaller tubes. In order to do this a carrier was designed mounted upon large wheels, the diameter of each wheel to be at least one-half the diameter of the tube, one wheel in front of the receptacle and the other behind it; the wheels to run either in a groove cast in the tube, or on a rail laid in the tube. The receptable, which is a cylindrical box nearly filling the tube, is prevented from scraping the wall of the tube by four friction rollers, two in front and two behind, set at an angle of about 45 degrees from the vertical axis of the tube. With this construction it is obvious that the tendency of the carrier while moving in a straight line will be to assume a vertical position, the function of the friction rollers coming into play only in turning curves and in the case of the carrier being overloaded on one side.

By the use of ordinary cast iron pipe, another advantage of this system over the systems which use sliding carriers, is that it is unnecessary to bore out the tubes. The tubes will be smooth enough as cast, excepting abnormal roughnesses, which of course should be ground or chipped out. Another advantage is that the packing used will not be a hard problem, as it is not the intention to have the packing actually touch the wall of the tube (except in the terminals). It is sufficient for practical purposes if the packing is within say one-quarter to one-half inch of the wall of the tube, as the proportional area of the clearing space to the cross-section area of the carrier is insignificant. Attention is called to the fact, that it is no more possible for a sliding carrier to actually fill the tube than it is here, the difference being that in this case a uniform annular clearance is left all around the carrier, while in the case of a sliding carrier there is actual contact at the bottom of the tube, with the maximum clearance at the top.

Leaving out for the present any description of the switches, the use of which will probably be in the remote future, if at all, we will describe the ordinary system, consisting of a pair of tubes with a power station at one end.

The system can be operated upon either the exhaust or the pressure principle. For the present we will confine our description to the pressure type. In this system the air makes a complete circuit. It is taken by the blowing engine from the incoming tube, and discharged into the outgoing tube, the two being connected at the outer end. The delivering apparatus is the same at both ends, and its operation is as follows: The end of the tube is normally closed by a valve, and at the proper distance back from the end to effect the desired result, is another valve, which is normally open. Still further back from the end of the tube, the air current is diverted from the tube and directed either into the return tube or into the blowing engine, as the case may be. The carrier, arriving at its destination first passes the opening where the air is diverted from the tube. Immediately after passing this opening, it begins to compress the air ahead of it. The parts of the terminal are so proportioned that the carrier is permitted to pass the normally open valve before sufficient pressure has accumulated ahead of the carrier to close said valve. However, immediately after the carrier passes the normally open valve, the compressed air ahead of the carrier closes the valve behind it. After this valve is closed, the carrier, which is still moving forward, begins to rarefy the air behind it; that is, the air which is between it and the valve which has just closed. The difference in pressure between the compressed air ahead of the carrier and the rarefied air behind it, tends to bring the carrier to a stop, while at the same time the difference in pressure in a supply pipe taken from the main tube and the rarefied air behind the carrier, is utilized to open the end valve, which permits the delivery of the carrier out of the tube and on a track. The parts are so proportioned that most of the momentum of the car is absorbed in operating the two valves. Enough momentum is left, however, to cause the carrier to roll a convenient distance out on the track, where it may be unloaded and loaded. The track then leads around towards the mouth of the return tube.

The despatching apparatus is operated by hand, by means of a controlling box analogous to that on a trolley car. The movement of the operator in despatching carriers is even more simple, and is quite similar to that of the trolley car operator. The track leading into the mouth of the return tube is slightly inclined, so that when the carrier is released by the operator, it rolls into the mouth of the return tube. The return tube has two valves, one being at the mouth of the tube and the other at a convenient distance from the mouth. The air supply pipe to the main tube also has a valve which when closed, diverts the air from its normal course, around behind the carrier which has been allowed to roll into the mouth of the tube. We thus have three gates or valves in the despatching apparatus—the one at the mouth of the tube and the one which diverts the main air current being normally open, and the other valve, which is located some little distance from the mouth of the tube, being normally closed. It is obvious that what is desired after the carrier has rolled into the mouth of the tube is to first close the gate behind it, then open the gate in front of it, and then turn the main air current in behind the carrier in order to propel it into the main tube, where it will be caught by the constant main current; and then to return the three gates to their normal positions. All of this is effected by operating these three gates with pistons, the opposite ends of the cylinders for the three pistons all being connected with the controlling box, and the controlling box also being connected with the main pipe. The controlling box is so arranged that the operator may at will reverse any of the gates, this being effected by the difference in pressure of the atmosphere and the air in the supply pipe from the main; the controlling box being so constructed that the operator, by moving a lever, can put one end of the cylinder which he desires to operate, in communication with the pressure main, and the other end at the same time in communication with the atmosphere.

There are many details of design which it is our purpose to illustrate and describe in a subsequent issue.

PNEUMATIC TUBES.

The carrying of mail or parcels of any kind through pneumatic tubes is a very old idea. The most common illustrations are the "Petit Bleu" in Paris, a practical system which has been in operation for many years. By this system one may write a telegram or a letter and have it forwarded in a sealed envelope to its destination by passing it through a pneumatic dispatch tube. The purpose of this is to facilitate dispatch, and to a certain extent it takes the place of the telegraph or telephone service. These things are largely matters of custom; people in Paris are accustomed to this way of doing things, while in America we resort to the telephone, or we send a telegram or a special delivery letter. Another common illustration of the pneumatic tube is seen in department stores, where packages are transmitted to different parts of the building. These are simple cases, involving few if any difficulties, because the work is done on a small scale. During recent years important advances have been made in the

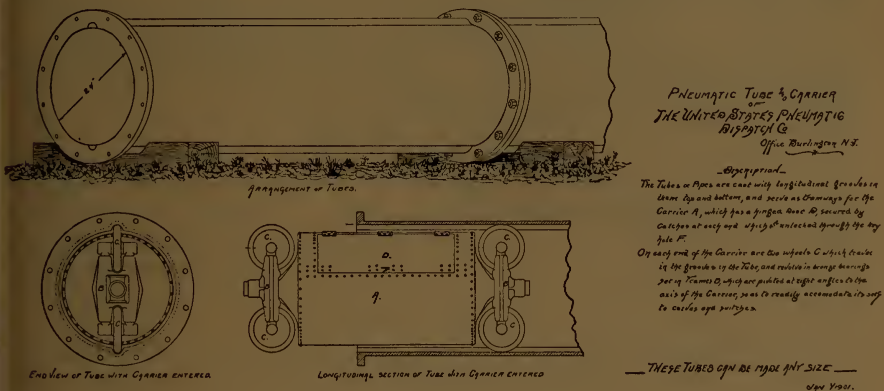

FIG. 334.

direction of perfecting mechanism by which carriers of large diameters are transported through tubes, and the success and utility of the systems now in use in large cities for doing this are matters that are no longer questioned.

Those who are interested in the investigations being carried on by Congress in pneumatic dispatch systems for the transportation of mails in large cities will perhaps be surprised to learn that in addition to the two systems that have received so much publicity, the Batcheller system and the Bostedo system, another thoroughly equipped system, 2,400 feet in length, at Burlington, N. J., has been drawn to the attention of the Congressional Committee.

Mr. John McIntyre has recently made some interesting investigations of this new system, and through him we learn that as long ago as 1896 this system, which is owned by The United States Pneumatic Dispatch Company, was thoroughly investigated by a committee formed of men in high position in the government service, who were appointed by Postmaster-General Wm. L. Wilson. That committee recommended that the system be built between Brooklyn and New York over the Brooklyn Bridge. The Postmaster of New York, Charles Dayton, and the Postmaster of Brooklyn, W. T. Sullivan, heartily supported the report, which Postmaster-General Wilson approved. However, for some reason never explained, another system was built.

The United States Pneumatic Dispatch Company has not advertised its system, nor has it frequented the Capitol building at Washington. This company claims for its system many advantages over the Batcheller system, which is now carrying the mails, or rather, a portion of the mails, in Philadelphia, New York and Boston, and the Bostedo system, which is now being built in Boston for the light package express business. The Batcheller system carries the mail loose, necessitating it being handled by tube company employees at each end of the system—this would be true of the Bostedo system—whereas the carriers used in the Burlington system accommodate at least three or four of the regulation locked mail pouches filled with mail of any class. For mechanical reasons, and, without certain important changes, it is doubtful if the other systems named could be enlarged to accomplish this important point in the transportation of mails.

The system at Burlington is 2,400 feet long, as has been stated, the pipe being unfinished 24 inches inside diameter, cast with grooves at top and bottom, in which the wheels sustaining the weight of the carrier run. At the terminal stations the carriers run out on rails, and therefore do not have to be lifted or carried, as is the case with the Batcheller and Bostedo systems. The carrier is sent through the tube at a speed of 33 miles an hour, with a pressure of 7 ounces. This speed was increased to over 50 miles an hour for the last examining committee. A Connersville blower is used to operate the line. There is a loop of 16 feet radius and several automatic Y's and switches into which the carriers can be guided, thus showing the practicability of diverting the carrier into any sub-post offices or side stations that might be established.

It is not necessary to machine or to bore out tubes used by the United States Pneumatic Dispatch Company. The cost of boring is greater than the cost of the tube itself. The statement made to the Second Assistant Postmaster-General by the Pneumatic Tube Investigating Committee, under date of December 4th, 1900, shows that a bored tube six inches in internal diameter would cost $1.12½ a foot, and such a tube eight inches in internal diameter would cost $1.50 a foot. The tube used by the United States Pneumatic Dispatch Company, however, would cost for one six inches in internal diameter less than forty-five (45) cents a foot, or one eight inches in internal diameter less than sixty-five (65) cents a foot. At the cost given above for a six-inch bored tube ($1.12½ a foot), one of the tubes of the United States Pneumatic Dispatch Company twelve inches in internal diameter could be furnished, and the latter would have a capacity four times as great as the six-inch bored tube, or at the cost given above for an eight-inch bored tube ($1.50 a foot), one of the tubes of the United States Pneumatic Dispatch Company fourteen inches in internal diameter could be furnished having three times the capacity of the eight-inch bored tube. A twenty-four inch tube such as is at the exhibition plant in Burlington would cost less than three dollars ($3.00) a foot.

The cost of operating the United States Pneumatic Dispatch Company's system should be materially less than the bored tube now in use. On the latter it is necessary to maintain a pressure of from three to seven pounds to the square inch, whereas the United States Pneumatic Dispatch Company's carriers can be operated with from five to seven ounces of pressure. It is claimed that with the United States Pneumatic Dispatch Company's system it is possible to transport all the mail of all classes, thus eliminating the cost of wagon service entirely, and to carry all the mail at less cost than is possible with wagons, and that by this system the whole body of the mail may have as rapid dispatch as a small portion, or what might be called supplemental mail.

By this system the mail can be carried in regular pouches, sealed at the dis-

FIG. 335.

patching office by regular postal officials, to be delivered in like sealed condition to postal officials at the receiving points.

This is an important point in that the mail, when once placed in the bags, remains intact, and is not subject to losses due to breaking of bulk, and is, therefore, less liable to damage either through accident or design. The use of air at low pressure is always an advantage, it being a well-known fact that the cost of compressing air increases directly as the pressure, the volume remaining the same.

The simplicity of the air compressing apparatus is greater for lower than for higher pressures, and its efficiency should also be greater. If it is true, as claimed, that this new system of pneumatic dispatch may use air supplied by a blower, we might reasonably expect economy, and in view of the large diameter of the pipe, friction losses are probably reduced to a minimum.

PNEUMATIC DISPATCH TUBES.

It is announced that Philadelphia is to be the first city in the United States to be generally equipped and gridironed with a system of pneumatic dispatch tubes, for mail matter, telegrams and light packages. The pioneer American pneumatic tube for postal service was put in operation in Philadelphia a few years ago, and is a great practical success. It is about a half mile in length, extending from the Philadelphia Stock Exchange to the Post Office. The tube is 6½ inches in diameter and is capable of carrying 48,000 letters per hour.

There are some private or semi-private installations of pneumatic dispatch tubes in use in this country by the telegraph offices and the newspapers, but generally we are far behind European cities in our appreciation and use of this means of transmission. The system has been in efficient operation for years in London, Paris, Berlin and Vienna. The systems employed in these different cities are quite different from each other in the details of construction and operation. For instance, London uses what is known as the radial system, and Paris uses the circuit system. In London, both outgoing and returning tubes are laid radiating from a central station; while in Paris a single pipe from the central station makes a circuit of outlying stations and returns to the starting point. The circuit system is used in Vienna, but in Berlin the circuit has been changed to the radiating system.

The tubes employed in all the European installations are of comparatively small diameter. London operates 42 stations and 34 miles of tubes, carrying, it is estimated, 57,000 messages per day. Paris, with less than 20 stations, transmits nearly as many messages as London. Berlin has 38 stations and 28 miles of double tubing.

In the details, both of construction and operation, there is quite a diversity of practice. In London the individual carriers are operated upon by the propelling force; in Paris, pistons take long trains of carriers after them. In some cases a vacuum in front of the carriers is created, and in others compressed air operates behind them, or sometimes a combination of both methods is employed.

The sticking of carriers in the tubes is a serious occurrence, but means have been devised for meeting such a contingency. The fine system of sewers in Paris leaves all the tubes in that city easily accessible. When a pipe is obstructed a diaphragm is attached to the end of it, and a pistol shot is fired into the tube through an opening just below where the diaphragm is placed. The sound acting on the diaphragm, closes an electric circuit and makes a mark on a chronograph. The sound wave traveling through the tube, meets the obstruction and is reflected, and upon its return makes another mark on the chronograph. The interval of time indicated by the chronograph gives a ready means of determining the distance of the obstruction from the end.

We should be able now in this country to make a fine exhibit and a great success of pneumatic transmission, as we have the benefit of forty years of European experience.—*American Machinist.*

THE PNEUMATIC MAIL TUBE SYSTEM.*

The system by which matter is transported through closed tubes by means of a current of air therein, is not a new idea by any means, though its successful application for commercial purposes is of recent date.

The earliest ideas of pneumatic transportation are found in the records of the Royal Society of London. Here we learn that Denis Papin sent to the Society in the seventeenth century an article on the "Double Pneumatic Pump." He exhausted the air in a long metal tube, causing a piston to move through it, which drew after it a carriage attached by means of a cord.

It was not, however, until 1853 that the first successful pneumatic tube system was built in London. A one and one-half inch pipe was laid between Founder's Court and the Stock Exchange. Its length was 650 feet, and the carrier was propelled through it by means of a vacuum created by an exhausting engine at one end of the line. The roughness of the interior of the iron pipes caused much trouble, and in 1858, when the system was extended, two and one-half inch tubes made of lead were used, the carriers being made of gutta percha with an outer lining of felt.

From this small beginning the London system has grown rapidly and now comprises forty-two stations, connected by thirty-four miles of tubes. The latter are made of cast iron with a lining of lead, and vary in diameter from two and three-sixteenths to three inches. The lines are laid out radially, and the air exhausted at one end and compressed at the other. This system has been adopted in Liverpool, Birmingham, Manchester, Dublin and Glasgow. Experiments were also made in London with an underground pneumatic railroad. In 1863 one was built eighteen hundred feet in length and two feet eight inches square. A second was constructed in 1872 from the Post-office to Euston station, a distance of two and three-fourths miles. This one was somewhat larger than the first, being four and one-half feet wide by four feet high. These tunnels were operated by means of fans, which forced air into one end and exhausted it from the other. They were never a success, however, and were soon abandoned.

In 1865 a system of pneumatic tubes for the transmission of telegraph messages was built in Berlin. Wrought iron pipes, two and one-half inches in diameter, were laid in pairs, one being used for sending and the other for receiving messages. The tubes were connected at one end by a loop and a steady current of air kept up by means of a compressor at one end and an exhauster at the other. The system now in use there, however, is somewhat different, the power being supplied by large storage tanks containing compressed air. There are altogether thirty miles of pipe and thirty-eight stations in the city.

The Paris pneumatic system has been in operation for many years and most of the branch post and telegraph offices are connected with each other by it. A novel method of compressing the air is used, for instead of employing a steam engine, it is compressed in tanks by displacement with water. The diameter of the tubes now used in Paris is 2.55 inches. The carriers are sent out in trains of from six to ten, and are propelled by a leather covered piston at the rear which fits tightly in the pipe.

*Yale Scientific Monthly.

In 1867, at the American Institute Fair held in New York, the late Alfred Beach exhibited a pneumatic tube railroad. A car, holding ten people, ran on a track laid down within a circular wooden cylinder which was about 100 feet long and six feet in diameter. A current of air was supplied by a large fan, running at the rate of two hundred revolutions per minute. He later built a tunnel under Broadway, near Warren street, extending a distance of two hundred feet. The car was driven by a large rotary blower in an adjoining building, and could be made to go in opposite directions by simply reversing the valves of the blower. Mr. Beach also designed a system of pneumatic tubes to convey mail from the street boxes to the postoffice. The letters were to be delivered into cars from revolving hoppers, which were made to turn by pins on the car hitting the vanes, the carriage being propelled by a current of air. He also, a few years later, built a line of over one thousand feet in length with a very smooth interior. This pipe led to a large receiving box connected with an exhausting engine. A letter dropped into the pipe at any point was carried along by the current to the box, where it fell to the bottom, from which it could be easily removed.

For many years the pneumatic tube has been a common means for the transmission of cash, etc., in large stores. The Western Union Telegraph Company, several years ago, connected a few of its offices by a pneumatic system, but the first real attempt to introduce it on a large scale into this country was made in 1893 in Philadelphia. A six-inch main was laid to connect the main post office with the Chestnut street branch, a distance of nearly a mile. On account of the large size of the pipes compared to those used in the European system, the capacity of this plant was much greater. The area of the tubes was increased many times, and of course the carriers were correspondingly larger. The speed of the Philadelphia system was moreover doubled and had improved appliances for receiving and transmitting. This plant was opened in 1893 and has been operated successfully ever since.

When in 1897 the tubular Dispatch Company of New York was authorized to construct a pneumatic tube system for the transmission of mail between the General Postoffice and some of the branch stations, all the different plants then in use were inspected. After careful investigation, the company decided to copy after the Philadelphia line, which had proven so successful, and plans were accordingly drawn for a system running from the postoffice to the Grand Central Station, the Produce Exchange, and to Brooklyn, over the Bridge. The first line to be put into operation was the one running to the Produce Exchange, which was opened in the fall of 1894. The others have since been completed, or will be at an early date.

The company determined to make the tubes of larger capacity than those used in Philadelphia, and to maintain a working speed of thirty miles an hour under a headway of twelve seconds. The line to the Produce Exchange is nearly four thousand feet long and consists of two tubes, side by side, eight inches in diameter, and about five feet below the surface. One is used for outgoing and the other for incoming mail, they being connected at the sub-station by a loop. A powerful compressor forces the air into the outgoing tube at a pressure of seven pounds to the square inch. On account of its elasticity, it flows through the pipe with an increasing velocity, but by the time it reaches the sub-station the pressure has fallen just one-half. From here the current returns by the second or return tube, and as it enters the receiving tank its pressure is equal to that of the atmosphere. This tank is joined to the suction pipe of the compressor, and as the two lines are connected by a loop at the other end, there is a continual circulation of air throughout. The pipes are of cast iron with a very smooth interior finish. All bends are of at least eight feet radius and made of seamless brass with a diameter of not less than eight and three-fourths inches on the inside.

The carriers are made of thin steel plates rolled into a cylinder, riveted and soldered. They have two bearing rings of packing, one at each end, which fit the tube and prevent any air getting by, causing it to move with the same velocity as the current. The shell proper is about two feet long and seven inches in diameter. The front end is concave and has a filling of felt which protects it from any shock it may receive. The rings form the sliding contact and keep the shell proper from touching. The carriers are closed by a hinged door at the rear, which is so arranged that it cannot open while in the tube.

The current is continuous from the starting of the compressors in the morning until they stop at night, so it was necessary to have some means by which the carriers could be inserted and removed from the line without interfering with the flow of air. This is done by means of a transmitter and receiver, one at each station. The former consists of a piece of eight-inch pipe, long enough to enclose the carrier. It is hung on a shaft, overhead, so that it can be swung out from the main line to receive the carrier and then moved back into position where the current forces the latter into the main tube. The ends are smoothed off square so that no air can escape at the joints. When this section is swung out of line two projecting plates move across the ends of the opening and shut off the air, the current meanwhile going around by means of a connection. When the transmitter is not in use the movable section is drawn over to the loading tray and the air goes through the U shaped by-pass. When a carrier is to be sent it is placed in the tray and pushed into the transmitter, then, by pulling a lever, the latter is swung into position and the carrier is forced out. An automatic time-lock prevents them being sent with less than twelve seconds headway, thus ensuring a proper distance between them in the tube. When the carriers arrive at the sub-station the pressure of the air is three and one-half pounds to the square inch, so the tube cannot be opened to remove them. They also have a velocity of about thirty miles an hour, and some means had to be provided for gradually checking their speed. These two things are accomplished by means of a closed receiver which consists of an eight-inch cylinder four feet in length. In its normal position it forms a continuation of the tube by which the carrier arrives, and on entering the receiver, it compresses the air in front and is stopped without any shock. There are a number of openings in the pipe just in front of the receiver connected with the other or returning line by which the current continues back to the main station. The compressed air in the receiver opens a small valve and thus keeps the carrier from being thrown back into the main tube. The receiver is automatically discharged in three or four seconds by a piston, which tilts it to an angle of forty degrees. The carrier slides out onto an inclined platform which is kept in position by a counter weight. The weight of the carrier, however, overbalances this and causes it to drop to a horizontal position, and the carrier is thrown out onto a table in front of the operator. This piston is worked by compressed air supplied from the receiver. Above the front end of the receiving chamber is a plate, arranged so that it comes down and closes the end of the main tube when the receiver is tilted to be discharged.

The transmitters at both ends of the line are the same, but the receiver at the main office is very different from the one at the sub-station, which is described above. At this end it consists of a section of the end of the tube closed at the rear by a gate. The air, now expanded to the same pressure as the atmosphere, passes from the tube through openings, four feet in front of the receiver gate, down to the tank in the basement. The momentum of the carrier is checked in compressing the air in the chamber after it has passed these openings. Part of this compressed air operates a piston which opens the gate mentioned above, then the small pressure of air forces the carrier out onto the receiving table. If there is not sufficient pressure to expell it, the openings can be partly closed by means of a valve. As it passes out, it hits a small finger which causes the gate to be closed.

These, in brief, are the main features of the pneumatic tube system. Improvements are continually being made in the line of quicker handling and greater capacity, and now that it has been proven a success there is every prospect that it will come into general use in all large cities for transmitting mail to the various sub-stations. .Plans are now being considered by the postoffice department to further extend the present lines in New York, as well as in other cities.

J. FOSTER SYMES.

MAIL TUBES IN TIMES OF A BLIZZARD.

THEY SAVED THE LOCAL SERVICE, BEING INDEPENDENT OF SNOWDRIFTS.

One of the worst snow storms that ever visited the Eastern States was experienced during Feb'y 12th, 13th and 14th, 1898. Steam, electric and ordinary traffic were suspended, and the New York *Sun* makes the folllowing report on the Compressed Air system of transmitting mail:

"The snow did not cause half the delay in the local mail service that many smaller storms have caused, and Assistant Postmaser Morgan declared yesterday that it was the pneumatic mail tubes that saved the service. The tubes run from the main Post Office to the Produce Exchange, from the main office to the Grand Central Palace and from the main office to the General Post Office in Brooklyn. The Forty-second street line has a number of branch lines that connect with branch stations between the General Post Office and the Grand Central Palace. The tubes being under ground, of course, unusual conditions on the surface do not affect them, and since the changes that have been made in their management and operation they have done remarkably good service.

It has always been New York's experience in a storm that tied up the street traffic to have the mail service tied up, too. The big wagons could not get around in the storm to collect the mail from the stations and things simply had to wait until the conditions were improved. This has caused untold inconvenience and trouble and in some cases loss to business people. The Assistant Postmaster said yesterday when he was asked about the conditions of the city service:

"There has been little or no delay in our city delivery, and this has been largely due to the effectiveness of the pneumatic tube service. The mail wagon service was seriously hampered and for long distances was rendered practically useless by the snow. But the tubes did their work on time and most of the down-town and uptown mail went through them. They were especially serviceable in delivering the mails to what is called the Wall street section of the city. Brook-lyn and the upper section of Manhattan borough also profited from the fact that the snow could not block the tubes. They certainly have proved to be an espe-cially valuable adjunct to the postal service in weather like this, and have enabled us to deliver large quantities of mail, which, under the old mail wagon system, would have stalled in the main office here."

The Assistant Postmaster explained that the tubes carried nearly all the first-class letter mail between the stations they connected, and that in the delivery of special delivery letters, particularly, there was scarcely any noticeable delay. It took the messengers who carried these letters after they reached the offices a little longer to get around, of course, but that was all. Some of the Post Office folks and some of the employees of the Despatch Company, which owns the tubes, declared that all during the storm the Post Office beat the telegraph companies when they came into competition, and that letters when they bore the 10 cent special delivery stamps, reached their destination ahead of telegraph messages sent at the same time.

The delay in the mail service was confined entirely to the out-of-town service and the service in that part of the city where the tubes do not reach. But the service in those parts of the city was better than usual, too, for the effective work of the tubes made it possible for the postal authorities to withdraw some of the wagons used on the tube route and send them to the unsupplied districts to help out."

RECENT PROGRESS IN THE DEVELOPMENT OF PNEUMATIC DISPATCH TUBES.*

As you all know, pneumatic dispatch tubes are not an invention of recent date; that is to say, their commercial application began forty-five years ago. Every one is more or less familiar with them, as they are used in large retail stores for the transmission of cash from the various counters to the cashier's desk. Many large office buildings are equipped with them for dispatching mes-sages from one office to another. The Western Union Telegraph Company has used them since 1876 in New York City to transmit their telegrams from one office to another, it being found more expeditious than the telegraph.

The United States usually takes the lead in the application of mechanical devices, but in the uses of pneumatic dispatch tubes, we are behind our European neighbors. London, Paris, Berlin and Vienna for years have had their pneumatic

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tube systems for transmitting telegrams between the central and branch post offices. The service is not confined to the large cities, for Liverpool, Brussels and other smaller cities are now equipped with this modern method of transportation.

There is much misconception of the size, capacity, length and use of the tube systems of Europe, for which the daily press is principally responsible. I have seen it stated that Paris and Berlin are connected by pneumatic tubes. It goes without saying that such a statement is untrue. Many people believe that mail is sent through the tubes, but that is also untrue, for the tubes are not large enough for that purpose. They are used only for the transportation of telegrams and messages. The largest tubes in London are only 3 ins. in diameter, while those of Paris and Berlin are about 2¼ ins. Fig. 342 shows the Berlin and London carriers.

The first tube was laid in London in 1853 by the Electric International Telegraph Company, under the direction of Mr. Josiah Latimer Clark. It was 1½ ins.

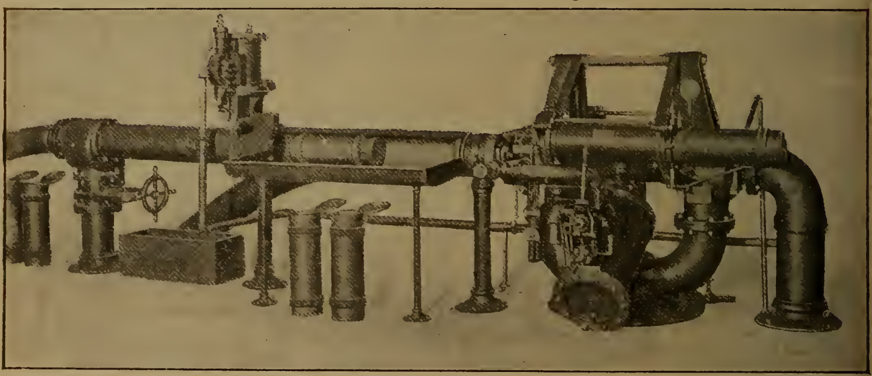

FIG. 336.—SENDING APPARATUS AND OPEN RECEIVER, PRODUCE EXCHANGE LINE, MAIN POST OFFICE, NEW YORK CITY.

in diameter, and extended from Founder's Court to the Stock Exchange, a distance of 220 yards. Year by year the system has been extended, until now the entire business section of the city is covered by the network of tubes radiating from the General Post Office and terminating in the numerous sub-Post Offices. (In England the telegraph is controlled by the Government, and the telegraph offices are in the post offices.) The tubes are of lead, encased in cast iron and laid in pairs for dispatching in opposite directions. Berlin has a similar system to that of London, but in Paris the tubes are laid in circuits with several stations on a circuit. The carriers are forwarded in trains from one station to another around the circuit.

It is not the purpose of this paper to describe these European systems in detail, but I refer to them to give some idea of the state of the art up to 1893.

Admitting that the European cities have gotten the start of us in point of time, we are bound not to be beaten in the end. While they continue to operate their small 2 and 3-inch tubes for telegrams only, we begin by building 6-inch, and use them to transport mail in large quantities, and the beginning was made in the city of Philadelphia five years ago, when the first line was opened by the Hon. John Wanamaker, then Postmaster-General.

It may seem to many of you like a simple step, from 3-inch to 6-inch tubes, but I will say from experience that the small tubes were no guide or help to us in building larger ones. The methods of operation and apparatus used with the small tubes could not be applied to the larger. The principal reason for this lies in the greatly increased weight of the cartridge, or, as we term it, carrier, that is dispatched through the tube. The weight causes friction against the walls of the tube and is a storehouse for energy that must be taken care of when the carrier is brought to rest. A heavy carrier is like a heavy train on a railway. The

FIG. 337.—SENDING APPARATUS AND CLOSED RECEIVER, PRODUCE EXCHANGE LINE, POSTAL STATION H, NEW YORK CITY.

carriers used in the small tubes are stopped by allowing them to strike some solid object, which can be done without injury to them, but the large carriers used in 6 and 8-inch tubes must be brought to rest gradually by means of an air cushion, and this involves the use of automatic receiving apparatus not required in the small tubes. The more important problems that had to be solved in designing the system of 6-inch tubes were the sending apparatus, the receiving apparatus, the carrier and the tubes. This was for a line of two stations. When intermediate stations are used the problems of switches and automatic receiving apparatus to select carriers at their destined stations had to be met.

The first double line of tubes built in Philadelphia was laid from the main Post-office, Ninth and Chestnut Streets, along Chestnut Street to the sub-Post-office, now located in the Bourse, a distance of about 3,000 feet. The tubes were made of cast-iron water pipe, bored upon the interior to an exact diameter of 6⅛ inches. The lengths were joined together by making a counter bore at the bottom of the bells, into which the machined end of the adjoining length fitted, and filling the bell with yarn and lead caulked in the usual manner.

Where it became necessary to turn corners seamless brass tubing was used, bent to a radius of not less than 6 feet. The tubes were simply buried in the ground, one above the other, at a depth varying from 3 to 10 feet, depending upon the location of other underground construction, such as water and gas pipes, conduits, sewers, etc.

The line was, and still is, operated by an air compressor located in the basement of the main Post-office. This compressor is of the duplex type, built by the Clayton Air Compressor Works, and does not differ, except in relative size of cylinders, from the compressors on the market for general purposes. It

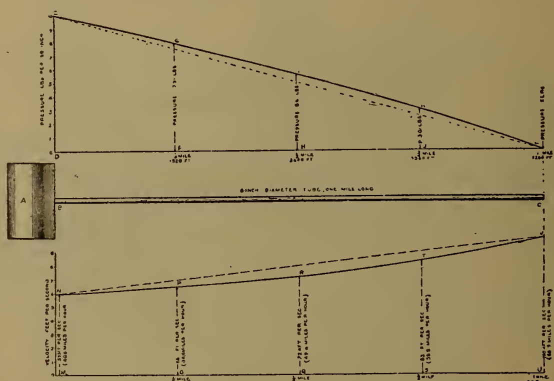

FIG. 338.—DIAGRAM SHOWING THE PRESSURE AND VELOCITY OF THE AIR IN A PNEUMATIC TUBE

developes about 25 horse-power and compresses about 800 cubic feet of free air per minute to a pressure of 7 pounds per square inch. The dispatching and receiving apparatus is located on the main floor of the Post-office near the cancelling machines, and in the rear room of the sub-Post-office in the basement of the Bourse.

The tubes are in operation from nine o'clock in the morning until seven in the evening, excepting the noon hour.

The air current flows continuously from the main Post-office to the Bourse through one tube and returns to the main Post-office through the other, thus forming a loop with the return end connected to the suction pipe of the compressor at the Post-office. There is an opening in the tube to the atmosphere near where it is connected to the compressor, so that the entire circuit contains air at a pressure above the atmosphere.

It is a pressure system rather than a vacuum system, as these terms are commonly understood.

Carriers occupy sixty seconds in transit from the Post-office to the Bourse and fifty-five seconds for the return trip. They can be dispatched at six-second intervals, or ten per minute in each direction.

This 6-inch tube has been in operation for five years and is doing good service to-day.

Not content with this the promoters of this enterprise decided to go one step further and build an 8-inch tube.

The second line was laid in New York City between the main Post-office and branch Post-office P, in the Produce Exchange Building. It is similar in method of operation to the first Philadelphia line, but somewhat longer, the distance between stations being about 4,000 feet. Some improvements were made in the sending apparatus, utilizing the air pressure to do what was formerly done by manual labor. See Figs. 336 and 337.

When this Produce Exchange circuit was opened for business the construction of a second circuit was well under way in New York, extending from the main post-office to branch post-office H, on Forty-fourth Street, near the Grand Central Depot, a distance of 3½ miles, with three intermediate stations on the line; at Postal Station D, Third Avenue and Eighth Street; Madison Square Postal Station, and Postal Station F, at Third Avenue and Twenty-eighth Street.

The main line of this circuit was opened February 11, but the receiving apparatus for the intermediate stations is not yet completed. This is the longest circuit built thus far. The inside diameter of the tubes, like the Produce Exchange circuit, is 8⅛ inches. There are two tubes, one for dispatching up-town and the other down-town. They are operated by air compressors, located one at the post-office and the other at Forty-fourth Street. The time of transit of the carriers in either direction is about seven minutes. The air pressure at the compressors is 13 lbs.

During the autumn of last year a circuit of 8-in. tubes was constructed in Boston between the main post-office and the North Union Railway Station, a distance of about 4,500 feet, or a little less than 1 mile. This is similar in all respects to the Produce Exchange line in New York. It is used to transport the outgoing mail from the post-offices to the trains, and the incoming mail from the trains to the post-office.

On Thursday, April 7, a circuit of tubes between the main post-office and the Pennsylvania Railroad Station at Broad Street, in Philadelphia, was formally opened for the transportation of mail to and from trains. Since then an intermediate station has been established at the Reading Terminal. The tubes are laid from the post-office through Chant Street to Tenth Street, up Tenth Street to Filbert Street, and out Filbert Street to the Pennsylvania station.

Another circuit has been constructed between the main post-office in New York and the main post-office in Brooklyn, by way of Brooklyn Bridge.

The total length of 8-in. tubing in all these circuits is a little more than 17 miles. This has all been manufactured and laid under ground since August 1, last year.

THEORY.

A current of air may be made to flow through a tube by either pumping the air in at one end under a pressure above that of the atmosphere, or by exhausting the air, thereby reducing its pressure below that of the atmosphere. In either case it is the difference of pressure at the two ends of the tube that causes the air to flow. Both methods are used in operating the London and Paris tubes, and both are used in the cash systems of our large retail stores, but all of our large tubes are operated by compressing the air so that the air-pressure in the tubes is at all points above that of the atmosphere. The determining of which system shall be adopted depends largely upon circumstances.

In the operation of short lines of tubes all of the machinery and apparatus can be concentrated at one point by using compressed air in the outgoing tubes and rarified air in the incoming tubes.

So far as power is concerned, the exhaust method is more economical, because nearly all the power is consumed in overcoming the friction of the air in the tube, and this friction varies directly with the density of the air.

There are several reasons why the compressed-air method of operation is better: first, if there are any leaks in the tubes and they happen to be laid in the

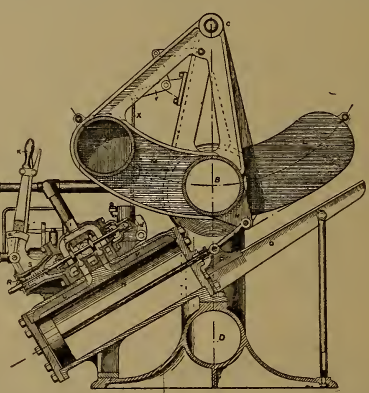

FIG. 339.—CROSS-SECTION OF SENDING APPARATUS.

wet ground, water will be drawn in when the air is exhausted, while it will be kept out if the air pressure is above the atmospheric; second, air cushions, for checking the speed of the carriers when they arrive at a station, are much more efficient and effective with compressed air than with rarefied air; third, cylinders and pistons used to operate sending and receiving apparatus can be made smaller when compressed air is used.

There are two methods of using the current of compressed or rarefied air in the operation of a line, and these are termed the intermittent and constant methods. The first consists in storing compressed air in a suitable tank, or by exhausting the air from a tank; then when we wish to dispatch a carrier we place it in the tube and connect the tube with the tank by opening a valve. As soon as the carrier arrives at the distant end of the tube the valve is closed and the air soon ceases to flow. When a long interval of time elapses between the dispatching of carriers, this is the most economical method of operation; but if carriers have to be dispatched frequently, a great deal of time would be lost in starting and stopping the air current throughout the whole length of the tube.

Under these conditions the second method, which consists in maintaining a constant current of air in the tube, and in having the carriers inserted and ejected at the ends of the tube without stopping the current of air for any appreciable length of time, is much more rapid and efficient. This latter method is the one used in the operation of all our large tubes. The current of air flows continuously all day, and the carriers containing mail are swept along like boats in a rapidly flowing stream. The analogy is quite perfect. The boats obstruct the flow of water and check its speed but little. In order to compute the speed with

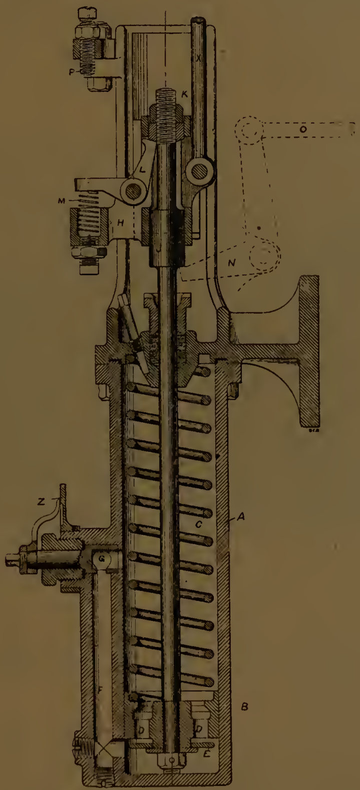

FIG. 340.—TIME-LOCK FOR SENDING APPARATUS.

which the boats will pass from one point to another, we have only to know the speed of the stream between those points when no boat is in it. The presence of the boats does not change the speed appreciably. So it is with carriers in a pneumatic tube; the air flows nearly as rapidly when a carrier is in a tube as when there is none. The friction of the carrier against the inner surface of the tube creates a slight drag, but it checks the speed of the air only a little. Therefore, in order to know the speed with which a carrier will be transported from one station to another, we need only to know the velocity with which the air flows through the tube when no carrier is present.

Let us assume a simple case of an 8-inch tube one mile long, connected at one end to a tank in which a constant air pressure of 10 pounds per square inch is maintained, the other end of the tube being opened to the atmosphere.

I have constructed a diagram showing the air pressure at all points along the tube (see Fig. 338). The abscissæ represents lengths of tube in feet and the ordinates air pressure above the atmospheric in pounds per square inch. At the tank end the pressure is 10 pounds, at the open end zero, and at the quarter, half and three-quarter mile points 7.91, 5.61 and 3.01 respectively. It will be observed that the pressure curve is slightly convex upwards. This is due to the expansion of the air in the tube. The pressure curve of the flow of water in a pipe is a straight line. The fall of pressure along the tube is analagous to the fall of level in a flowing stream or to the fall of potential along a wire in which a current of electricity is flowing.

I have constructed another diagram showing the velocity of the air at every point along the tube. The abscissæ are lengths of tube in feet, the ordinates velocity of the air in feet per second. The velocity at the tank end, quarter, half and three-quarter mile points and at the opened end is 59.5, 65, 72, 83 and 100.4 feet per second, respectively. It will be noticed that the velocity of the air increases as it flows along the tube, and that it increases more rapidly as it approaches the open end of the tube. The increase of velocity is due to the expansion of the air as it flows along the tube, and the expansion results from the fall of pressure. The mean of all the ordinates gives us the mean velocity, which enables us to compute the time of transit of a carrier through the tube. We can also determine from this velocity curve the time of transit between any two points on the tube which may represent stations.

From the velocity with which the air is discharged from the open end of the tube we compute the quantity of air that must be compressed per minute. The quantity of free air and the initial pressure enables us to compute the horsepower required to maintain the current of air constantly flowing. Of course, there are numerous factors which enter into these computations which are only determined by experiments and experience, such, for example, as the quantity of air that escapes from the tube at the sending and receiving apparatus; the fall of pressure of the air in flowing around bends and through the apparatus; the efficiency of the air compressor, etc.

The temperature of the air, from the instant it enters the compressor until it is discharged at the open end of the tube, is an interesting and important factor in the theory of pneumatic transmission. Since pressures above 25 lbs. per square inch are seldom used, the air cylinders of the compressors are not water-jacketed, hence the air is heated by compression to a temperature found by measurement to be above the theoretical amount that we should expect from thermodynamic formulæ. The reason for this will be understood when we remember that the incoming air is heated by contact with the hot walls of the cylinder. When air is compressed to 7 lbs. per square inch, it leaves the compressing cylinder at about 160 degs. F. We should expect much of this heat to be soon lost by conduction and radiation through the walls of the tube, and as the air flows through the tube, constantly expanding, it would not be unreasonable to expect considerable reduction in temperature by the time it reached the open end of the tube—a temperature considerably below that of the atmosphere. Experience teaches us that after leaving the compressor the temperature of the air falls rapidly, and that the temperature in the tubes underground is almost constant, being about that of the surrounding earth. The compression may be considered as adiabatic and the expansion as isothermal with a small error.

The atmosphere at all times contains more or less moisture in a state of vapor, and its capacity for water vapor varies directly with its temperature; that is to say, the higher the temperature the more water vapor will the air contain, and vice versa. The temperature of the air in the tubes is frequently and usually lower than the atmosphere out-of-doors, consequently it often happens that moisture is deposited upon the interior of the tubes. The quantity is never very great, but sometimes the carriers come out of the tube coated upon the exterior

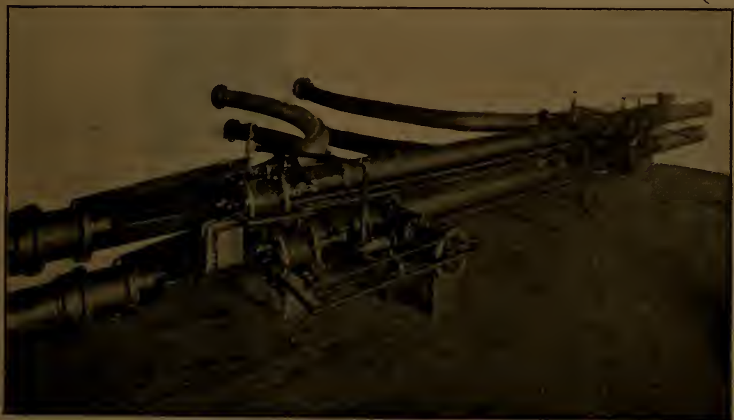

FIG. 341.—SET OF CUT-OFF SWITCHES FOR EIGHT-INCH PNEUMATIC TUBES.

with a thin film of moisture. We use the same air over and over, thereby avoiding drawing into the tube large quantities of moisture-laden air.

Having thus briefly discussed the theory of the flow of air in long tubes, we will now consider some of the necessary mechanical details. Keeping in mind our 8-in. tube, 1 mile long, connected to a tank of compressed air at one end and open to the atmosphere at the other, thereby maintaining a constant flow of air through the tube. In order to utilize this tube and air current for the transportation of mail or merchandise, we must have some means of inserting carriers containing the material to be transported into the tube, without the escape of air. In other words, we must have some form of sending apparatus or transmitter. This might be accomplished by having a section of the tube with valves at each end to stop the flow through this section and conduct it through a by-pass. A carrier could then be inserted into this section of tube and the valves be turned to their normal position. Or, what we find to be more practical is to have a section of the tube that can be swung out of line with the main tube to receive a carrier and then swung back into line again. This is the form of sending apparatus that we use in all our 8-inch tubes. The section of tube is swung by a cylinder and piston operated by the air pressure taken from the tube (see Figs. 336 and 339). The attendant has only to place a carrier in the sending apparatus and pull a lever. By using two swinging sections of tube, one of which is always in line with the main tube, the apparatus is ready at all times to receive a carrier.

In connection with the sending apparatus, a time lock is used to measure and determine the time interval between the dispatching of carriers; in other words, to prevent carriers being dispatched too frequently. The period varies from six to fifteen seconds, depending upon the length of the line. The time lock is found necessary to prevent the collision of carriers and to give the receiving apparatus time to operate. The time lock consists of a dash-pot filled with oil

Fig. 342.—(1) Carrier used in the Berlin system; (2) Largest carrier used in the London system; (3) Six-inch carrier used in the first Philadelphia system; (4) Eight-inch carrier used in New York and Boston.

and arranged to lock the sending apparatus, except when the piston of the dash-pot is at the bottom of its cylinder (see Fig. 340).

If our receiving station be located at the open end of the tube, then we must have some form of receiving apparatus to stop the carriers without shock when they arrive. For this purpose we have in our system what we term an open receiver. It consists of a section of tube about 4 feet long, closed at one end by a sluice gate and attached to the end of the main line. The air flows out through slots in the tube just before it reaches the receiver. When a carrier arrives it runs into this closed section of tube which forms an air cushion. The compression of the air by the stoppage of the carrier serves to operate a small to discharge the carrier, the end of the main tube being closed during this dis-valve, which causes the sluice gate to be raised by a cylinder and piston located above it. When the gate raises the carrier is forced out on to a receiving table, the pressure in the tube being just sufficient to do this. The gate is automatically closed after the carrier has been discharged (see Fig. 336).

If our receiving station be located at any other point on the line of the tube we cannot use this form of open receiver, for the pressure in the tube is so high, as shown on the diagram, that the air would escape with great force, hence we must use what we term a closed receiver, consisting of a section of tube forming a receiving chamber and air cushion that can be placed in line with the main tube to receive the carrier, and then moved out of line with the main tube placement. The receiving chamber is mounted upon trunnions and is swung out and into line with the main tube automatically by means of a cylinder and piston set into operation by the arrival of a carrier.

At intermediate stations on the main line of tubes we sometimes place an automatic receiving apparatus that will stop all carriers passing through the tube, and discharge those intended for that station, while all others are sent on in the

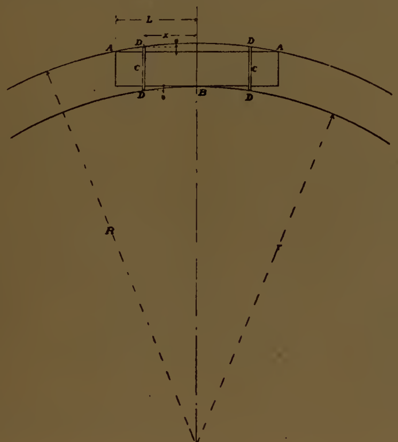

FIG. 343.

tube. This is accomplished by placing various sized metal discs upon the front end of the carriers and having electric contact points at each of the stations set at graduated distances apart to correspond with the sizes of discs on the ends of the carrier. When a carrier arrives at a station where its disc is of the proper diameter to span the distance between the contact points, and thereby close the electric circuit, then that carrier will be discharged from the tube; but if the disc is too small to span the distance between the contact points, then the carrier will pass on in the tube to the next station, and so on.

Intermediate stations are usually supplied with cut-out switches, so that carriers can be sent directly past the station without entering it. These switches are moved by air pressure, controlled electrically from the nearest station (see Fig. 341).

There is no part of this system that has been the object of more thought and study than the carrier that contains the mail or other material to be transported. It is made of a seamless steel tube 23½ inches long, closed at the front end by a sheet metal head and buffer, and closed at the rear end by a hinged cover provided with a lock (see Fig. 342).

The body of the carrier is about an inch smaller than the tube through which it travels, the space between the body of the carrier and the surface of the tube being filled by two fibrous rings that serve not only to prevent the escape of air past the carrier, but as wearing surfaces to slide on the lower side of the tube. These bearing rings are made of cotton fiber, and they will endure until the carrier has traveled about 5,000 miles, when they become worn so small that they have to be replaced by new ones. A carrier weighs 13¾ pounds and will contain 600 ordinary letters.

The tubes used in all the circuits thus for constructed are of cast iron bored accurately upon the interior, except bends, which are made of seamless brass tube. The iron tube is cast in 12-foot lengths, with a bell upon one end similar to gas and water pipes. A counter bore is turned in the bottom of each bell, into which the machined end of the adjoining length fits closely. The joints are made by yarn and lead caulked in the usual manner.

Where short bends have to be made in the tube for the purpose of turning corners in the streets, entering buildings, etc., brass tubing is used bent to a radius of twelve times the diameter of the tube, or a radius of 8 feet for an 8-inch tube. A uniform radius is always used, for it facilitates manufacture.

In order to maintain a uniform and circular cross-section of the tubes during the process of bending they are filled with resin.

The location of the bearing rings on the body of a carrier also has an important relation to the bends in order to give a carrier of maximum capacity. Having determined the length and diameter of the carrier body, we place the bearing rings not on the ends, but at a point where, in passing through a bend of minimum radius, the corners and center of the carrier and the bearing rings will touch the walls of the tube at the same time. This can best be explained by referring to Fig. 343. The rings C C are so placed that in passing through the bend the ends of the carrier touch the outer circumference of the tube at A A, at the same time that the body of the carrier touches the inner circumference at B, and the rings touch both inner and outer circumferences at D D D D.

To manufacture the tubes, brass bends, carriers, sending and receiving and other apparatus used in the system, a factory has been erected at Tioga and Memphis Streets, Philadelphia. Much of the machinery used in the various processes of manufacture has been especially designed for the purpose, and most noteworthy, perhaps, are the machines for boring the cast iron tubes. The tubes are bored in a vertical position, for two reasons: (1) It economizes space; (2) the chips fall away from the cutters.

The boring machines are placed upon galleries about 11 feet above the floor. The bell ends of the tubes are clamped to the machines and rest on a pedestal on the floor below. The boring is done by six cutters attached to a head that is mounted on the lower end of a vertical boring bar. The bar is revolved by gearing and fed downward by a screw attached to the cutter head and extended downward through the center of the tube being bored. The feed screw does not revolve, but is drawn downward by a nut attached to the pedestal on which the tube is supported. The nut is revolved by gearing and a rope belt driven from the machine above. When a tube is placed in the boring machine the feed screw is pulled up through it and attached to the cutter head. The boring bar simply serves to revolve the cutter head and not to guide it. The cutter head is guided by four hardwood blocks that fit the finished bore of the tube closely. The pull of the feed screw also helps to keep the cutter head in place. The cutters are flat pieces of steel, with a cutting edge at 45 degrees with the axis of the tube. The angle of the cutter tends to make the cutter head follow the core of the tube. After the bore is finished another head is attached to the bar, which makes the counter bore at the bottom of the bell.

A special machine has been designed for bending the brass tubes, consisting of three rolls, one of which is adjustable. This operation of bending is one that requires much experience and skill on the part of the operator.

Locating Obstructions.—You will, perhaps, be interested in an experiment

FIG. 344.—CHRONOGRAPH USED IN PHILADELPHIA FOR LOCATING OBSTRUCTIONS IN PNEUMATIC TUBES.

that we made in Philadelphia two years ago to locate a carrier that became lodged in one of the tubes.

The Philadelphia line was laid in the winter season, and before the trench was back-filled the loose earth became frozen and we were obliged to put it into the trench in that condition; consequently, when the ground thawed the tubes settled and one of them was broken. For a long time this break did not obstruct the passages of carriers, but eventually one of the broken ends settled down more than the other and caught one of the carriers, blocking the entire line. We had no means of knowing where the break was located, and to excavate the entire distance between the stations involved great expense and annoyance. I made several attempts to locate it by the fall of pressure, etc., but was not satisfied with the results, so decided to try a method of locating by the velocity of sound.

The plan was to disconnect the terminal apparatus at one of the stations, fire a pistol into the tube, and note the time that elapsed between the discharge of the pistol and the return of the sound as an echo reflected back from the obstructing carrier; then, knowing the velocity of sound, a simple calculation would give us the distance from the station to the carrier.

I had a rough chronograph constructed, using a pulley for a drum, mounted upon a horizontal shaft with a crank for rotation and a screw to give longitudinal motion (see Fig. 344). Time was measured by the beats of a clock pendulum, recorded on the chronograph drum by a stylus which moved under the pull of an electro-magnet at each beat of the pendulum. The pendulum was arranged to close an electric circuit in the usual manner by swinging through a globule of mercury. In addition to the clock a tuning fork was used to measure time by the number of waves traced on the smoked surface of the drum. For the measurement of small fractions of a second the tuning fork is more accurate and convenient than a clock, but when the period extends over several seconds the work of counting thousands of small waves becomes very laborious.

I selected a fork tuned to 512 vibrations per second, which enabled me to measure to 1-1000 of a second with a small error. In fact, with a little care, it was possible to measure to 1-5000 of a second.

The fork was arranged in a horizontal position, having a horse-hair cemented to one prong, which traced a sinuous line on the drum as the latter was turned. The sound of the pistol discharge was recorded by a stylus attached to the end of an aluminum arm that rested against a rubber diaphragm. A chamber in the rear of the diaphragm was connected to the end of the pneumatic tube by a piece of rubber hose which conveyed the sound waves from the tube to the chronograph. A cock was placed in the middle of the hose and partially closed before the pistol was discharged to prevent too great distention of the diaphragm by direct impact of the sound waves. The cock was opened by an attendant after each discharge and before the echo returned, in order that the feeble sound waves of the echo might not fail to be recorded.

The muzzle of the pistol was inserted into the tube through a small hole in the side, the end of the tube being closed by a funnel to which the rubber hose was connected.

When the apparatus was properly adjusted a measurement was taken in the following manner: The clock was started, the tuning fork set in vibration by striking with a mallet or by bowing, and the drum rotated by hand; then the pistol was discharged and the cock in the rubber hose opened. A few moments only were required to count the waves of the tuning fork and from them compute the time.

The experiments were usually repeated several times to eliminate errors. Five experiments gave the following results:

1	2.791	seconds.
2	2.794	"
3	2.793	"
4	2.793	"
5	2.794	"
Mean	2.793	"

A thermometer was placed in the ground beside the pipe and the temperature found to be 39 degrees. It was assumed that this was the temperature of the air in the tube. The velocity of sound at 32 degrees was assumed to be 1,093 feet per second, and the increase of velocity for each degree of temperature to be 1.12 feet; this gives at 39 degrees the velocity of 1,101 feet per second.

In 2.793 seconds the sound would travel 3,075 feet, which locates the carrier at 1,537 feet from the instrument. This indicated that the carrier was lodged 100 feet east of Seventh Street, and workmen were ordered to excavate at that point. Before reaching the tube air was heard escaping from the break, and the carrier was found almost exactly where it had been located by the instrument.

It is impossible to say what the limits of the method are so far as distance is concerned, but experiments of Regnault show that the report of a pistol is no longer heard at a distance of—

1,159 metres in a tube 0.018 m. in diameter.
3,810 " " " 0.300 " "
9.540 " " " 1.100 " "

But the same sound waves will vibrate a sensitive diaphragm at distances of 4,156, 11,430 and 19,851 metres respectively. B. C. BACHELLER.

PNEUMATIC DESPATCH TUBE SYSTEM IN THE ILLINOIS TRUST AND SAVINGS BANK BUILDING, CHICAGO.

A few years ago a banking institution was thought to be complete if it had a good fire and burglar-proof vault and a trust-worthy clerk to remain in the building during the night. As the years have passed improvements have been made, such as the time lock for vault doors, and now a secondary door with a time lock has been adopted as an extra safeguard in case the larger door fails to unlock. In other cities where they have the protective associations, the electric alarm system has been applied. Later came the telephone service, with a small central station in the building, connected with an instrument on the desk of every official, important clerk, and the heads of different departments, and also with the city central station. As a final improvement pneumatic tubes have been adopted. This necessity was first recognized by the First National Bank of Denver, next by the National Bank of Commerce in New York, and then by the Illinois Trust and Savings Bank of Chicago, where they have a complete equipment throughout their large building into which they have moved.

By the adoption of the pneumatic tube system, the officers, heads of departments, tellers and important clerks are in immediate communication with one another; that is to say, when a customer appears at the draft teller's window and asks for a draft, the same is made out, but he is not met with the familiar phrase, "Kindly step down to the vice-president or cashier with this draft and he will sign it." Instead, he waits just a moment while it is sent through the tube to the proper person, who signs it without delay and returns it to the teller ready for the customer. He is thus saved the bother of the trip to the vice-president; likewise the latter is saved the usual talk about the weather and business in general, which in most cases is not very much appreciated. The pneumatic tube system also saves the paying teller the trouble and time of ascertaining from the president or cashier of the institution if a certain check is acceptable. All he has to do is to put the check in the carrier, dispatch it to the president's station and it is immediately returned to him with the O. K. or otherwise, upon it.

In citing the cases above, I showed briefly how the pneumatic tube system overcomes loss of time, bother and annoyance. I will now endeavor to give a brief description of the plant installed for the Illinois Trust and Savings Bank. In this particular instance the arrangement of the system was not decided upon until the

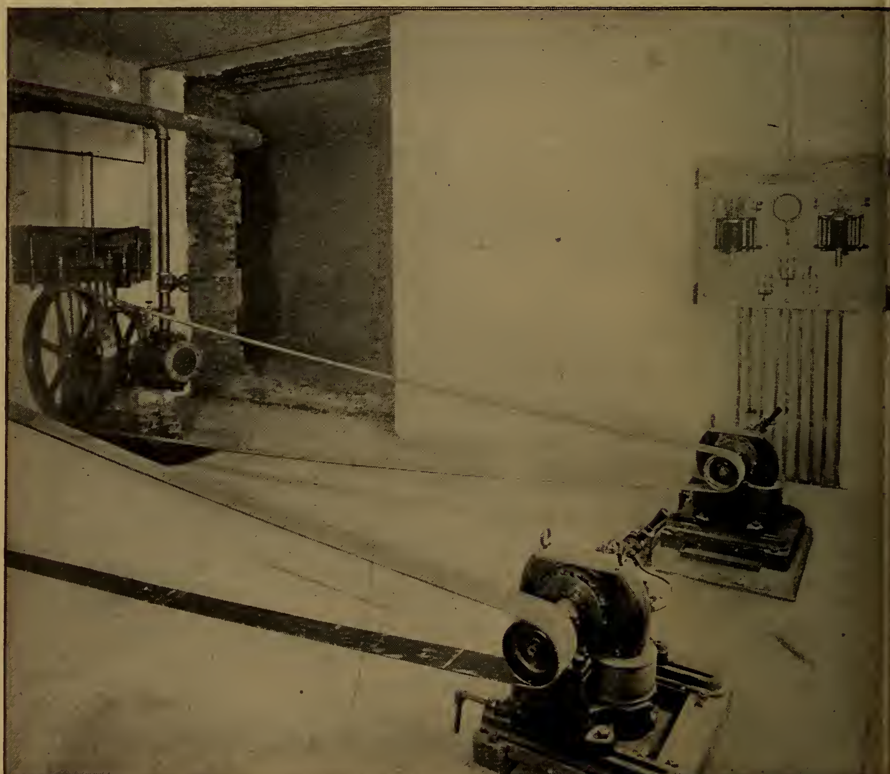

FIG. 345.—ELECTRIC DRIVEN AIR COMPRESSOR.

building plans were too far advanced to make any alterations which would facilitate the construction of the tube system, therefore it was necessary to lay out the plant to the best advantage of all concerned under the existing circumstances. The work of designing, as well as installation, fell upon the writer. After ascertaining from the officers of the bank how they handled their business—that is, what offices were to be connected—the next question was regarding the size of package to be sent through the tubes. It was finally decided that a bond would be the maximum size which would go into a carrier, the measurements being 9 inches long and internal diameter 1¾ ins. Then came the question whether or not the tubes could be laid under the floors and all concealed. After going into the matter very thoroughly, it was found that 2¼″ outside diameter tubing could be laid in this way. As a result contracts were drawn up and signed for the following:

Ten lines of 2¼″ o. d. tubes, No. 19 Stubbs gauge, connecting the following offices and departments:

President and Secretary.
President and Vice-President.
Vice-President and Draft Teller.
Cashier to Collections.
Cashier to Foreign Exchange and Bond Teller.
Cashier to Draft Teller.
Assistant Cashier to Collections.
Assistant Cashier to Foreign Exchange and Bond Teller.
Assistant Cashier to Draft Teller.
Collections to Trust Department.

As the building progressed the system was installed about as follows:

In the basement is located, adjoining and jointly with the sewerage disposal system, a two h. p. motor of the Crocker-Wheeler type (shown in Fig. 345), with a speed of 700 revolutions, running an 8 x 10 Ingersoll-Sergeant Compressor, at a speed of 100 revolutions. The necessary governing devices are controlled by the air pressure in the receiver or reservoir, the size of which is 4 ft. by 8 ft. The minimum pressure carried is 6 pounds, maximum 9 pounds. There are two air supply pipes leading to this reservoir, one on the south side and the other on the north side of the building. The diameter of these pipes is two inches, and they are reduced down proportionately until they reach the last station on their respective sides of the building. At different points along the line of these supply pipes ¾″ diameter feeders are connected running to the several stations. The flooring in the corridors is marble, under which is a 2½″ cement foundation, therefore two coats of asphaltum varnish was given all the pipes to prevent chemical action. The machinery once ready for operation, supply pipes and feeders were installed; then the work of laying the carrier tubes was commenced, part of the latter being laid in cement and part in cinders. The joints were made by means of sleeves and clamps, the former being well cemented to the pipe with shellac, making them absolutely air-tight.

The extra length of carriers and short turns called for a special curve made of cast iron, the radius of which was 15″, enlarged in the centre so as to admit the easy passage of the carrier, shown in Fig. 346, and at the same time overcoming the difficulty of getting around sharp corners without cutting through the marble floor and wainscoting.

To prevent any possible damage to the tubing during the construction of the building by the workmen employed outside of our own, the tubes were tested each day by means of a small positive pressure blower, a carrier being forced through first one way and then the other. As soon as any obstruction was discovered it was immediately located, a short section removed, and if necessary new pieces substituted. It was generally found that these obstructions were dents caused by falling timber or sections of tile. In several instances the carpenters had driven nails through the tubing.

Fig. 347 shows the terminals in the office of the cashier and assistant cashier. Their desks (not shown in the cut) are located adjoining the cabinet on which the terminals are placed.

The operation of this system is about as follows:

The carrier is placed in the tube at the terminals, and the door, a sliding one, is closed, which opens a valve admitting air into the dispatch tube from the supply pipes, thus forcing the carrier through the tube to the other end, at which point it is discharged and falls on top of the cabinet for the purpose. As the carrier passes out of the terminal at the extreme end, it automatically closes an auxiliary door behind the carrier. This door closes the dispatch tube to the atmosphere, and therefore prevents the compressed air in the tube from escaping. The

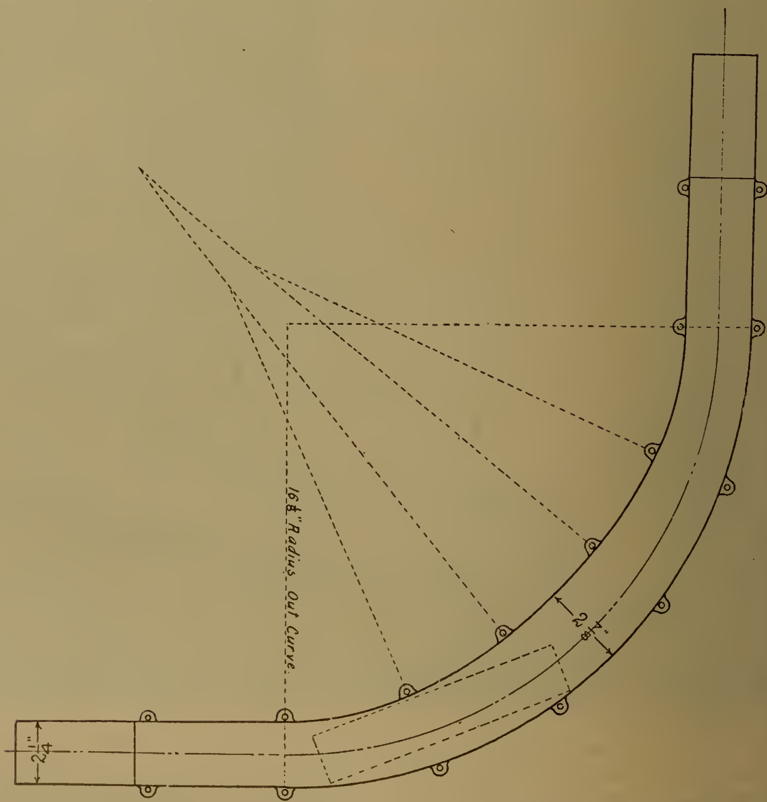

FIG. 346.—CURVE IN PNEUMATIC CARRIER SYSTEM.

sudden stopping of the flow of air produces a pressure upon the diaphragm located in the terminal from which the carrier was dispatched. The diaphragm releases the valve, cutting off the air supply and at the same time opening a vent underneath the terminal, which allows the confined air in the dispatch tube to escape underneath the desk. In a second's duration the air has escaped and the door at the sending end of the tube, as well as the auxiliary door at the receiving

FIG. 347.—TERMINAL STATION OF PNEUMATIC DESPATCH.

end, opens and goes back to the normal position. The tube is then again ready for the sending of a carrier in either direction. The diaphragm controlling the valve in the supply pipe is regulated according to the length of the line. From test it shows that a speed of about 30 ft. per second is attained.

This system is known as the Automatic Pressure System, and differs from the continuous current or vacuum system in that only one carrier tube is used instead of a pair, and the air is compressed and stored in reservoirs or tanks and only used as needed. In this particular design of system the writer claims the following over other designs installed by him as well as others:

First—That the air confined in the dispatch tubes after the discharge of the carrier is allowed to escape underneath the cabinet on which the terminal is placed, thus doing away with the objectionable noise in the room, the blowing away of papers if such should be left on the cabinet.

Second—In sending a carrier the door closes the tube to the atmosphere before opening the valve admitting air from the supply pipes.

Third—The valve action is absolutely positive.

On account of the high pressure maintained in the reservoir, the consumption of air is great, but the three difficulties overcome by this design outweigh the small extravagance. EDMUND A. FORDYCE.

AN OLD UNDERGROUND PNEUMATIC TUBE.

At a meeting of the Langbourn Ward Club, held last night at the London Tavern, Fenchurch street, Mr. George Threlfall read a paper on the old underground pneumatic tube that runs from the General Post Office to Euston Station. The tube was built forty-two years ago for the purpose of conveying mails, parcels, etc., by pneumatic despatch. It was made of cast-iron sections an inch thick, was 4 feet high by 4½ feet wide. The old Pneumatic Despatch Company, which was founded in 1859, was obliged to cease working because it was found that the system of blowing or sucking the cars through the tunnel by air pressure or vacuum was impracticable, owing to leakage of air and other mechanical defects. Mr. Threlfall said it occurred to him that if the tube were still available it might possibly be utilized for its old purpose if worked by electric traction. The tube had been closed for so long that all the plans and records of it seemed to have been lost, and it took practically three years to collect sufficient information and plans to enable him to draft a feasible, if not a perfect, scheme. Speaking of the arrangements to be adopted, Professor Carus Wilson said one unique feature was that the cars would be controlled from a central station, as the tube was too small to admit of drivers going with the trains. The man at the central station would be able to see from an indicator the precise position of a train at any moment, and to make it go quicker or slower or to reverse it as he wished. The speed would be between thirty and forty miles an hour.—*Pall Mall Gazette,* Oct. 5, 1899.

This story of a forgotten tunnel has recently been discussed in the London newspapers, and has excited considerable interest. It seems to have passed out of the minds of the people, and to have been quite as quiescent and forgotten as the old North River tunnel in America, bored three-quarters of the way across the Hudson by Colonel Haskin and English engineers.

Readers of COMPRESSED AIR will recollect an illustration and brief notice of this tunnel in Volume 2, No. 1, published in March, 1897. It seems to have been one of the earliest notions in the use of pneumatics to propel parcels by compressed air in a closed tube. About two centuries ago the idea was discussed by the celebrated Dr. Papin. In the year 1810 a proposal was made by Medhurst—the Danish engineer—to put parcels and passengers in a canal 6 feet high and 5 feet wide, the propelling power being atmospheric air affected by rarefaction and condensation. Later on, an Englishman named Vallance in the year 1824 made a similar suggestion, his plan being to connect Brighton and London by means of a pneumatic tube of such size as to admit carriages; but these suggestions were not put into practical operation until about the year 1865, when the recently discovered London tube was built. The engineer was a Mr. Rammel, whose plans were to exhaust the air from one end of the tube by means of fans. Whatever may have been the cause for the failure of these plans, it is very likely that the experiment was tried on too large a scale. It seems to us to be a similar case to the attempt recently made to run cars on the New York Elevated Railroad by compressed air. The aim was too high, it being an effort to accomplish a result on a large scale without having first had experience in the same direction on smaller lines. All great engineering results are brought about by a course of gradual development. Experience and a close study of that experience developing a system from small things to larger things, is the true way to success.

Since this experiment in London we have seen pneumatic tubes put to practical operations in several cities. The Petit Bleu, so useful in Paris for quick mail service, is a pneumatic tube system, and in New York city mails are conveyed uptown and across the bridge to Brooklyn through the Batcheller pneumatic tubes. This Batcheller system is the largest which we have at present; but even here the tubes are only about 8 inches in diameter, and it is very likely that the success of this system, which is now generally admitted, will result in the laying of tubes of larger sizes until, perhaps, we may do what was attempted in London nearly 40 years ago.

TRANSMISSION THROUGH PNEUMATIC TUBES.

The writer having been employed in designing the extension of a pneumatic dispatch line, in which some heavy gradients were unavoidable, it became necessary to ascertain by calculation the steepest gradient that could be employed so as to obtain sufficient carrying capacity in the new section of the line under given conditions of engine power and of length. Almost every text-book and paper on the velocity of gases in pipes, gave a different formula, and the author therefore found it necessary to attempt to construct a convenient expression for the speeds of carriers of given weight and friction, under various conditions of pressure, gradients, and dimensions of tube. The problem of a pneumatic system is simply this: To make a given quantity of air expand from one pressure to another in such a way as to return a fair equivalent of the work expended in compressing it. It is obviously impossible to regain the full equivalent of the work, because the compression is attended with the liberation of heat, which is dissipated and practically lost. Therefore, in designing a pneumatic system, the first thing is to contrive means of compressing the air as economically as possible; and, in the second place, to get back the available mechanical effort stored up in the compressed air; irrespectively of the work employed in compressing and examining it. The writer considers that small pneumatic tubes may be worked more profitably than large ones. The great convenience of and the practical facilities for working small letter-carrying tubes have been amply proved by the extensive systems already laid down in Paris, Berlin, London and other towns, as adjuncts to the telegraph services. Tubes of somewhat larger diameter would undoubtedly work satisfactorily. Even still larger tubes, of a moderate length, might also be found useful for a variety of special applications. But the author does not believe that a pneumatic line working through a long tunnel could, for passenger traffic, ever compete in point of economy, with locomotive railways. A pneumatic railway is essentially a rope railway. Its rope is elastic, it is true, but it is not light. Every yard run of it in a tunnel large enough to carry passengers, would weigh more than ¼ cwt. And it is rope, too, which has to be moved against considerable friction, and in being compressed and moved wastes power by its liberation of heat. In a pneumatic tunnel, such as that proposed between England and France, in order to move a goods train of 250 tons through at the rate of 25 miles an hour, it would be necessary to employ simultaneously a pressure of 1½ lbs. per sq. in. at one end, and a vacuum of 1½ lbs. per sq. in. at the other. The mechanical effect obtained of these combined—pressure and vacuum—would be consumed as follows:

In accelerating the air	29	millions of foot pounds.
In accelerating the train	12	
By friction of the air	5721	
By friction of the train	330	

The resistance of the air, therefore, upon the walls of the tunnel would alone amount to 93 per cent. of the total mechanical effect employable for the transmission; while the really useful work would be only about 5½ per cent. of it. And to compress and exhaust the air to supply these items of expenditure of mechanical effect, engines would have to exert over 2,000-horse power at each end during the transmission, even on the supposition that the blowing machinery returned an equivalent of mechanical effect such as has never yet been obtained. This would not be an economical way of burning coals.—*Journal of the Telegraph.*

IMPROVED PNEUMATIC TOOLS FOR FOUNDRY USE.*

The use of pneumatic tools for cleaning and chipping castings is not new. Certain defects in the old style of construction, the want of knowledge of how to operate them, together with the prejudices of ignorant workmen, have resulted in eight cases out of ten in the condemnation of the tools for foundry use. The first thing we will deal with will be the objectionable features of the old style of tools, of which the recoil or kick was the most noticeable. This recoil or kick has done more to prevent the adoption of large size pneumatic tools than anything else, as it has enabled the workman who is afraid of losing his place to say with

*A paper read by Mr. George H. Robbins (Philadelphia) at the January, 1898, meeting of the Foundry Men's Association.

some appearance of truth, that holding the tool was injurious to him, producing a paralysis of his arm, etc. To this, and here, let me reply that I know of men who have been running pneumatic tools continuously for the past five years and who have not been affected in the slightest by them in any way whatever. The improved Clement valveless tool is so constructed and so evenly balanced that all kick has been eliminated from it, because it has an air cushion so placed that when in operation the workman is really pushing against air, the elasticity of which takes up all shock and vibration.

Another important objection that is made to the old style pneumatic tool is that so many small parts, valves, springs, etc., enter into its construction. Such a number and variety of parts make the tool very delicate and liable to get out of order.

The improved Clement valveless tool consists of but three parts or pieces—a cylinder that is bored out of a solid piece of steel, a hammer or piston made of tool steel and a butt piece or plug to close the end of the cylinder. The only part of it that moves is the hammer, and that is not dependent on the movement of any other part for its own motion. If it is given fair treatment and regularly oiled, it can be depended on for a long period of steady and reliable service, and knowing this we are warranted in guaranteeing it against all repairs for two years. This, I trust, shows plainly and conclusively to any investigator that the objectionable features in the pneumatic tool of the past are not to be found in the improved Clement tool of to-day.

Let me now speak a moment of the ignorance of operating, and the prejudice existing against pneumatic tools and the reason therefor. No doubt some of you have had pneumatic tools tested in your foundries and perhaps unsuccessfully. Have you, however, considered in such a case how this test was made? Pneumatic tools are made in many sizes, and to use them to advantage they must be used for the purpose to which they are adapted—that is, a small tool for light work and a large tool for heavy work. Then again, at what air pressure did you try this tool? Do you know whether the pressure used was high enough to develop the efficiency of the tool? And last, but not least, in whose hands was the tool placed for trial? Was he a man who would work for your interests, forgetting his own, or was he opposed to the tool because it was a labor-saving device, and because its adoption was liable to bring about the discharge from employment of himself or some of his shopmates? These are all-important considerations, and may explain to you why the test of pneumatic tools in your shop was a failure, if such it was.

The best way to introduce the tools is to place them in the hands of young men, who are, as a rule, ambitious, and who will take a pride in running a new machine. Let them know that the successful operation of the tool will mean a slight advance in their wages. If on the contrary, however, you give tools to a man who believes only in old hand methods, then the amount of work that he will turn out will be, comparatively speaking, small.

The average amount of work that can be done with these tools is as follows: In removing sand from large and heavy castings, one man with a medium size tool and a broad chisel, can readily do as much work in a given time as six men could do by hand methods. One man with a tool can do as much light fine chipping as is usually done by five men in the same period of time; and in rough or heavy chipping one man with the proper size tool can do about the same quantity of work that is generally done by three or four men with the hammer and chisel.

It is sometimes necessary to do chipping to a line, or true surface. A man who is skillful enough to do this class of work with a hammer and chisel can accomplish just twice as much in the same time by using a pneumatic tube for the purpose. The operator has absolute control over the tools used for this fine work, striking a light or heavy blow as he desires, governing the force of the blows by the simple pressure of his hand, and not by throttle valves, etc., that are so liable to wear out.

If any one should doubt the possibility of the operator being able to cut to a line, or having this perfect control over the tool, it affords me pleasure to refer you to the marble and granite cutter, who not only does the most delicate carving and lettering with the tools, but does it on a substance that is vastly more friable and brittle than cast iron.

An air compressor, and an air receiver, and a lot of different sizes of pipe strung around the shop do not always constitute either an efficient or economical air plant. To get the best results there is required:

1. An air compressor of improved pattern, of sufficient size and power to develop and maintain a steady pressure of 80 to 100 pounds to the square inch.

2. An air receiver of sufficient size to equalize the pulsations of the compressor and to cause the air to flow with uniform velocity to the tools.

3. As air in its passage through the pipes is subject to friction in the same manner as water, it is important that your pipe system be carefully designed, as loss by friction may be quite serious. In calculating such loss it would be well to remember that the difference in pressure between the entrance to the pipe and the point of use, termed in hydraulics "loss of head and power lost," is not applicable to compressed air. Compressed air will lose 10 per cent. of its head, but the loss of power will only be about 3 per cent. The reason for this is simple when you remember that compressed air as it loses in pressure it gains in bulk, and thus in a measure by its increased volume compensates for the diminished pressure.

DISCUSSION.

Mr. Howard Evans—You do not mention the amount of power required to drive the compressor, nor state the saving over hand work where the tools are used. You only say that one man can with one tool do so much more work than by hand.

Mr. Robbins—An air compressor of a size sufficient to operate say three tools, 14-ounce hammers, would require 4 horse power to run it—that is, a belt compressor. When a small compressor can be used it is much more economical to run it by belt power than by steam direct. The cost of such a compressor would be in the neighborhood of $180. The cost of the air receiver would be about $40, while the cost of the pipe would depend altogether on the distance the air was to be carried; if 100 feet, say $5. Three tools of the capacity mentioned would cost say $300. A total cost of about $525 for the equipment.

Mr. Evans—Where people have a compressor in already the adoption of these tools is accompanied by considerable less expense, is it not?

Mr. Robbins—Certainly. I have here a small 2-ounce tool, the earning capacity of which is $900 per annum. That is the earning without the expense. The tools actually save the labor of one man for 300 working days in the year. The outfit I have mentioned is large enough to run six of these tools. In taking sand off castings you would require a broad chisel like this (showing a chisel with about 2-inch cutting edge).

Mr. Messick—Are the tools in use in this city?

Mr. Robbins—Yes. They are used at Cramp's, and at the works of the Warden Manufacturing Company, in both boiler shop and foundry. They are used in ship-yards for chipping and calking. When used for calking a man can a man can calk 60 lineal feet per hour; on boiler work about 40 feet. It makes a tighter joint than is possible by hand, the blows not being so hard, but multitudinous. The tool I have shown you uses 10 feet of air per minute at 80 pounds pressure. It can be operated with a pressure as low as 60 pounds, but high pressure is the best, the resulting work being much more efficient.

Mr. Messick—Did you ever try driving rivets with them?

Mr. Robbins—Yes; what you call shell rivets; ⅜-inch cold rivets. A 6-pound hammer will drive them faster than you can put them in the hole.

Mr. Eldridge—Supposing one wished to knock off a riser from a casting. say a riser 2 inches in diameter, would you smooth the casting with the tool as well?

Mr. Robbins—A sledge would be better for knocking off a gate of that size. After the gate is knocked off you can smooth down with the pneumatic tool.

Mr. Evans—Supposing a foundryman having a compressor wished to try these tools, would you give him a trial?

Mr. Robbins—Certainly. He could have them for ten days on trial, and we would visit his foundry and impart all instruction possible.

PNEUMATIC TOOLS.

The pneumatic tools now being manufactured and put on the market by the Philadelphia Pneumatic Tool Company, of Philadelphia, have many important and novel features.

Taking up the several kinds of tools made by them in the order of their importance and wide range of work for which they are adapted, we have first the Chipping and Calking Hammers.

These hammers are made in five sizes, the smallest being designed for light chipping and calking, and the largest for the heaviest kind of work, such as chipping steel castings, cutting off gates, sink heads, etc.

These hammers are all of the "valve" type.

There are only two moving parts in the hammer, the hammer proper and the valve, both moving in the same direction at the same time, so that the jar caused by the hammer striking a blow tends to more firmly seat the valve and not to move it from its seat. This insures uniform working of the hammer, even after it has been worn after years of service.

The material used is of the very best, and the valve hardened and carefully ground and fitted.

For riveting two sizes of hammers are made, the smallest one driving 5/8-inch hot rivets and under, and the largest, or Long-Stroke Hammer, driving 1 1/8-inch hot rivets. The design and construction of the valves of these hammers is the same as in the Chipping Hammers, thus avoiding the irregularity of action due to the wearing of the valve.

The Long-Stroke Hammer, by an ingenious arrangement, ceases to operate as soon as the die is lifted from the rivet, although the throttle valve may be open; this avoids any unnecessary wear or liability to breakage which may occur should the hammer operate when the die is not held against some object. Other important changes and improvements have been made.

ROTARY DRILLS.

Probably the most trying work on Pneumatic Tools is the drilling, reaming and tapping of holes in boiler, bridge and car shops. The work is rushed through by unskilled workmen, and the tool, to do it successfully, must be carefully designed, strongly built and simple in construction. These features have been embodied in the drills made by this company, and are the result of years of experience in their design and manufacture. They are built for the hardest service, but at the same time are finished with a high grade of machine work equal to the other work done by this company. The drills have improved piston blades, fitted with packing strips that require no attention to keep them tight. These are so made that as the machine is used the bore of the cylinder acquires a glassy polish similar to that found in steam engine cylinders. For convenience in tapping, flue rolling, etc., these drills are made reversible.

FOUNDRY RAMMERS.

One of the important steps recently made by this company in introducing labor-saving tools has been the introduction of their Foundry Rammers. With this tool one man can do the work of four or five men, besides ram up a flask much more evenly, and thus reduce the risk of bad castings or increased weight from straining to a minimum. At present they are making the rammers in three sizes; the No. 7 or Light Hand Rammers, the No. 8 or Heavy Hand Rammer, and the No. 9 or Crane Rammer, to be used suspended from a crane.

The No. 7 Rammer is designed for flask work, and ramming in limited space where a large rammer cannot be used. The No. 8 is especially built for loam work and ramming up very large flasks.

The advantages of these rammers are as follows: They strike a uniform blow, work at a uniform rate, one man with a No. 8 Rammer can do the work of six or eight men, and with a No. 9 Rammer the work of from twelve to fifteen men and do it better, more evenly and harder.

Where these rammers are in use they have paid for themselves in a short time, and many duplicate orders have resulted. They are now in use in some of the largest foundries in the country.

The Pneumatic Riveting Machine illustrated below is adapted to a wide range of work on tanks, stacks, bridges, ship framing, structural work, etc. It will drive rivets of any size up to 1⅛-inch, and may be used with any depth of yoke, from 10 inches to 10 feet or more.

The Riveter itself presents many improvements in design. It is absolutely positive in its action, no dependence being placed on springs or other similar devices. The entire action of the machine is under the control of the operator by means of one throttle lever shown in the illustration. The first movement of the lever causes the hammer cylinder to move out against the rivet; the next movement starts the hammer to work upon the rivet. When the rivet head is completed a reverse movement of the lever causes the hammer to stop working and the cylinder to withdraw into the casing by air pressure. The advantage of this arrangment is that the cylinder may be moved out until the button set comes in contact with the hot rivet and held there while any necessary adjustments are made before starting the hammer to work. This will, in many cases, prevent spoiling the rivet and necessitating cutting it out. The withdrawal of the cylinder into its casing by means of air pressure enables the operator to use the machine in any position with the certainty that the cylinder will positively remain inside the casing until he is ready to drive the next rivet. These points will be appreciated by those who use machinery of this kind.

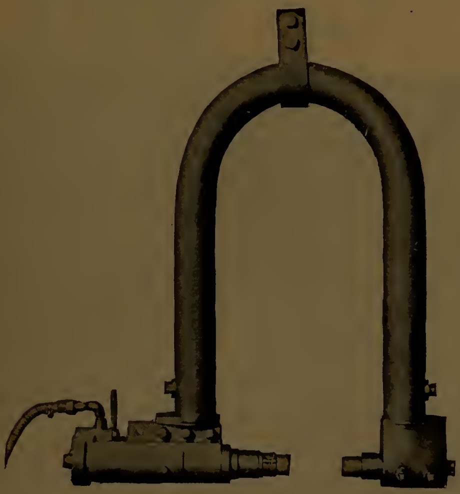

FIG. 348.—YOKE RIVETER.

The machine is light in weight and simple in construction, having but three moving parts. It is fully guaranteed as to efficiency and durability. With each machine we furnish two riveter dies and one holder on die, with necessary collars for adjusting the gap for different lengths of rivets. The machine requires 25 cu. ft. of free air per minute for operation and ample facilities are provided for thoroughly oiling all parts. Users of this class of machinery will find this Pneumatic Yoke Riveter to be a first-class machine, unequaled in material, workmanship and efficiency.

On field work, erecting large water, gas and oil tanks, 80 to 100 rivets per hour have been driven.

COMPRESSED AIR DRILLING MACHINE.

Our outside cover illustration this month is a compressed air drilling machine made by the C. H. Haeseler Co., of Philadelphia. Several machines of

FIG. 349.—PNEUMATIC RAIL DRILLER.

this type are used by the Union Switch and Signal Co., for the purpose of drilling the ends of rails in railroad yards where compressed air is available.

The machine has a capacity for drilling holes up to ⅞" in diameter and will drill such a hole through the web of a rail ½" thick in less than half a minute.

The motor consists cf three reciprocating pistons, working in the same number of cylinders, and is of the latest design. It is very efficient, and strongly made, and as will be noted, is rigged with power feed, operated by hand, requiring but little effort on the part of the operator to force the drill into the work.

BOLT CUTTING MACHINE.

Among the many interesting and novel appliances shown at the M. C. B. and M. M. Convention at Old Point Comfort, Va., in session from June 8th to 18th, was an "Acme Bolt-Cutter" fitted with "Fergusson's Pneumatic Turrets." (See cut.) This machine attracted a great deal of attention from the members of the Conventions on account of the novel use of compressed air, the operator having but to place the bolts in the machine and the air did the rest, carrying the bolt into the threading dies, bringing it out when threaded and throwing the

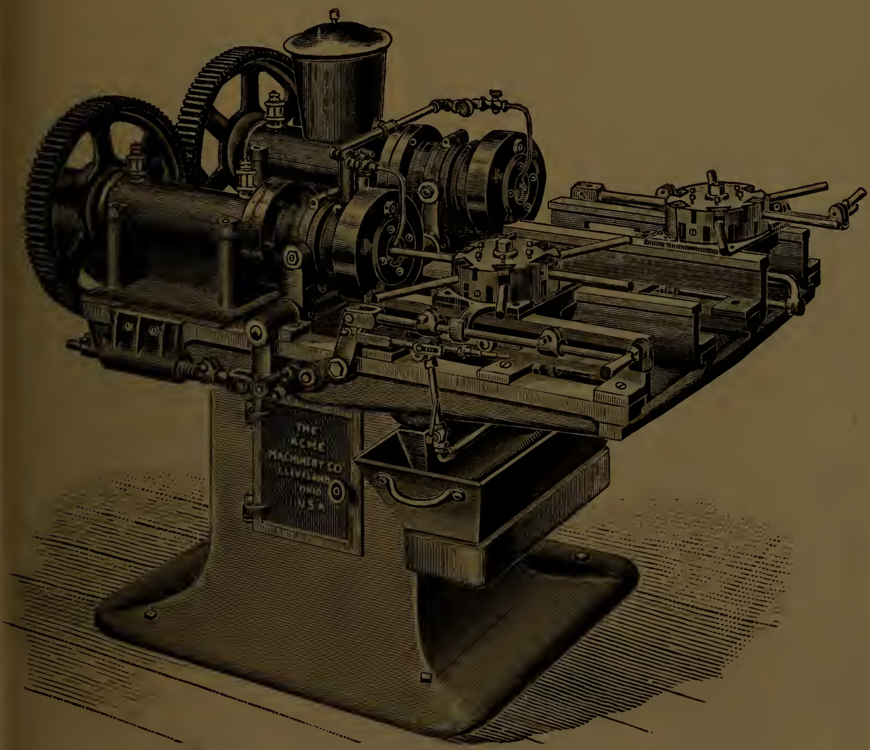

FIG. 350.—ACME BOLT CUTTER WITH PNEUMATIC TURRET.

bolt from its position in the machine, leaving the space occupied by the bolt ready for the operator to put in another. These pneumatic turrets are designed to increase the rapidity with which bolts may be threaded, not by altering the speed of the die-heads, but by reducing the time taken to close the dies and remove and replace the bolts, their action being entirely automatic, each bolt being ejected and the blank started in the fraction of a second.

In increasing the production of the machine nothing is lost in the quality of the product, as the air pressure while the bolt is threading is beneficial both to the dies and to the thread. The product of the machine is very large, as will be seen when we say that as many as 7,200 of ⅝-in. bolts have been threaded on it in nine hours with one operator.

The makers' name is a guarantee of the quality of the machine, which is strictly first-class throughout. Any further information will doubtless be cheerfully furnished by the makers, the Acme Machinery Co., Cleveland, Ohio.

USE OF THE PNEUMATIC CLIPPING TOOL IN SHAPING REFRACTORY MATERIALS FOR FURNACE WORK.

The cuts shown herewith illustrate the application of compressed air for shaping refractory materials for furnace work at the works of the American Gas Furnace Company, Elizabeth, N. J. The bricks warp while being burnt, and to make the surfaces and all joints accurate, and obviating an excess of fire clay

FIG. 351.—CLIPPING FIRE BRICKS.

at the joints, advantage is taken of the pneumatic chipping tool. Not only does this make an excellent surface, preventing the edges being broken off, as for instance when using a hammer and chisel, but holes can be bored accurately from markings made when outer steel shields or casings are applied for furnace and muffle work.

The air is delivered at 45 pounds pressure from a belt driven compressor. By means of an automatic arrangement only sufficient air is compressed to meet the demands of the chipping tools, thereby economizing the amount of power absorbed.

From actual tests a 2″ hole six inches long can be bored in four minutes, and a 1¼″ hole six inches long in three minutes; cutting a groove 1″ x ¼″ deep and 12″ long in two minutes. Plain surface work is done very rapid and effectually. These figures fully demonstrate the economy of the use of air for this purpose, and also for hoisting the material about to be worked upon.

FIG. 352.—BORING FIRE CLAY.

LOCOMOTIVE BELL RINGER.

The cut herewith shows the Bartow Locomotive Bell Ringer which is operated by compressed air, and is now being marketed by the Chicago Pneumatic Tool Co. This has been in use for about two years on several railroads in the East, with the very best of success.

The motor for ringing the bell has no direct connection whatever with the bell, the crank of the bell shaft having a roller which works over the disc shown on motor. The valve is operated from an arm, extending from the piston rod to the valve rod, and two adjustable nuts, one above and one below this arm, adjust the length of the stroke of valve. This also regulates th espeed at which the bell is rung.

There are very few parts to this bell ringer, and in the two years' service they have been in, there have been no repairs. It is easily placed on the engine by a small bracket on the bell frame. The simplicity of the machine can be easily seen, also the economy in running it, the stroke being very short, and only 1¾ in.

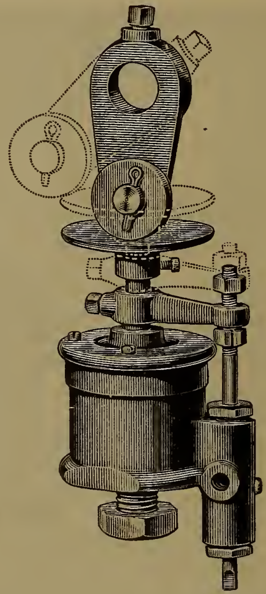

FIG. 353.—LOCOMOTIVE BELL RINGER.

in diameter. It is operated by air from the main reservoir on the engine, and is rung from a valve placed in the cab.

It has been shown that on an engine equipped with a bell ringer, the saving in consumption of fuel has been enough in one month to pay for the device. The explanation of this is that the fireman has so much more time to attend to the firing of the engine, instead of looking out of the window and watching for crossings to ring the bell.

This little device is going to meet with favor among railroad men.

AIR GUN.

As a great deal of trouble has always been experienced in driving out engine frame bolts, cylinder and saddle bolts on locomotives, the use of a cannon many times being brought into play, the Pennsylvania Railroad system has adopted what is known as an air gun for doing this work.

Fig. 354 shows a section of the gun as they make it. It is nothing but a piece of bored-out steel tubing screwed into a cap, which acts as a base. The size of the gun can be varied to suit different kinds of work, the diameter, length of piston and length of stroke being increased if more power is to be obtained. The three-way cock is attached to the air inlet so that after the air has shot up the

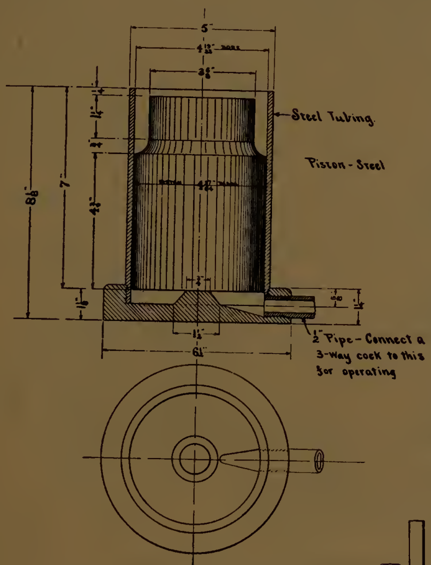

FIG. 354.

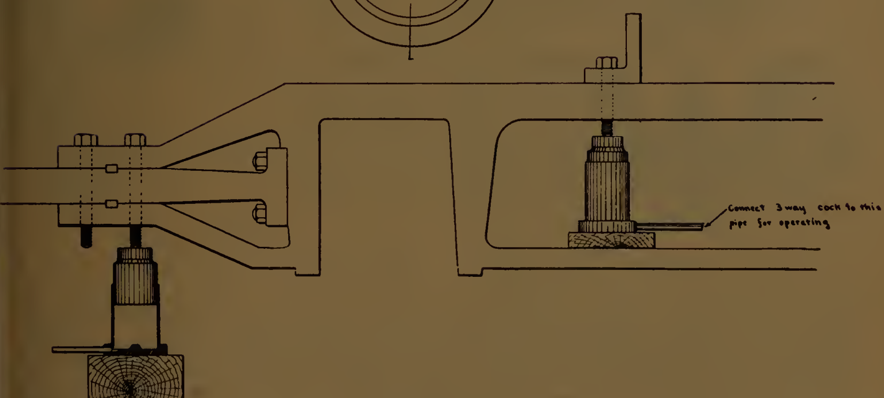

FIG. 355.

piston, the air in gun can escape to the atmosphere when the three-way cock is turned.

Fig. 355 shows part of an engine frame with several of the air guns in place for driving out the bolts. The three-way cock on the air inlet is opened and closed, hitting the bolt with a sharp quick blow. As shown in cut, the gun is blocked up intermittently, acting as a heavy hammer with wood to the required height for operating, which allows it to accommodate itself to many varieties of work.

DROP PIT JACK.

In the Chicago & Alton Railway roundhouse at Bloomington, Ill., there is being installed a locomotive driving wheel drop pit which gives promise of being a most convenient institution. Its jack is not only operated vertically by compressed air, but is transferred from one pit to the other by means of a long horizontal cylinder, with a piston having rods extending through each cylinder head and engaging in either direction with lines of wire rope attached to the jack carriage.

In Fig. 356 can be seen a cross section of the pit, the center line of which is 33 ft. 8 in. from the shop outer wall, toward which the engines are headed in this roundhouse. The shop floor is level with the lower edge of the rail head and the floor of the drop pit is 7 ft. 6 in. below this, while the sub-pit in which the jack runs is 3 ft. 6 ins. in depth below the level of the pit floor. The pit is 81 ins. in width between the walls, the sub-pit is 22 ins. in width, the longitudinal dimen-

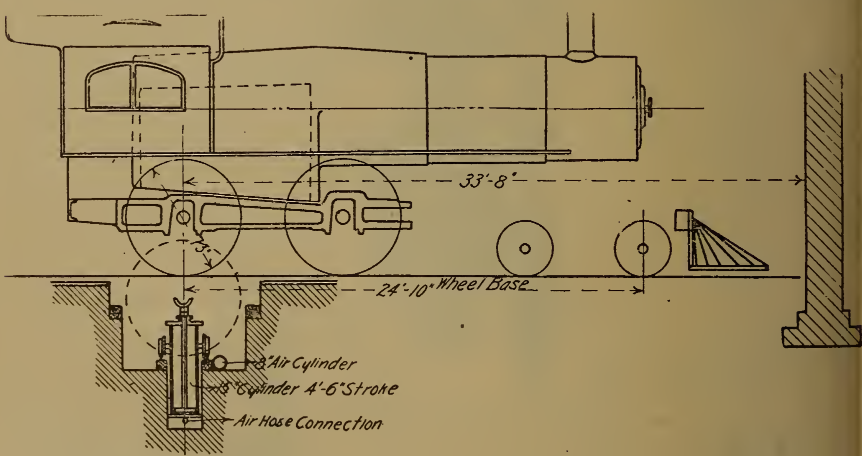

FIG. 356.—NEW DROP PIT AT BLOOMINGTON, C. & A. RY.

sions of both pits are the same and are such as to connect both pits with a couple of feet free space beyond the outside rail of either track. The 8 x 10 ins. stringers which support the section of rails across the pit have their ends supported by longitudinal stringers, in which illustration is also shown the hinge method by means of which the rails supporting stringers are swung around on top of the pit stringers and thus carry the pit section of the rails out of the way.

In Fig. 357 are shown the details of the pneumatic pit jack and of the transfer carriage on which the jack is hung. The jack has a piston 15 ins. in diameter, with a vertical hoist of 4 ft. 6 ins., which enables it, as shown in Fig. 1, to readily remove or replace any driving wheel with which the locomotives on this line are equipped. In Fig. 357 can be seen the details, and in Fig. 356 the position of the horizontal cylinder which, by means of the movement of its piston, pulls the ropes which transfer the jack carriage in either direction. This cylinder lies alongside one of the pit track rail stringers, has a bore of 8 ins. and its piston travels 5 ft. The piston has a rod extending through the cylinder in either direction to the heads of which are attached a double block. Through this block and through two additional single blocks at the ends of the pit are rigged lengths of 3-8 in. wire rope, which connect to both ends of the jack carriage. By means of a suitable valve, air pressure is admitted to this cylinder for moving its piston in the required direction, and this in turn draws the jack carriage as desired. We believe the use of air for this transfer movement is novel, but whether or not this is the case, it certainly affords very convenient method of

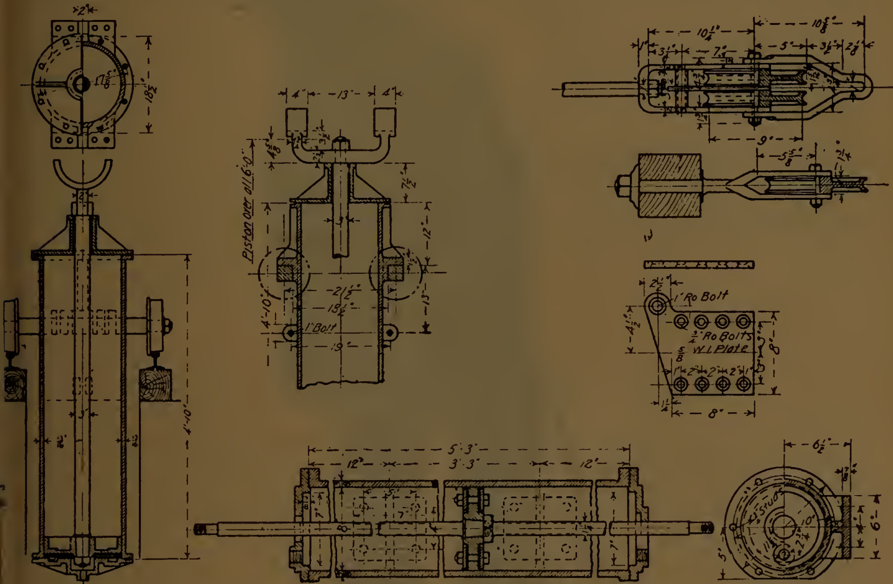

FIG. 357.—DETAILS OF PNEUMATIC APPARATUS.

transferring the jack carriage, which, when laden with a pair of driving wheels to which are attached driving boxes and eccentrics with their straps, are a weight needing considerable effort at times to move. Further study of the illustrations here presented will show any point of additional interest which the arrangement commented on here may occasion.—*Railway and Engineering Review.*

PNEUMATIC HAND RAMMER.

The pneumatic hand rammer, illustrated herewith, is designed to meet a large variety of work in the foundry, not only on the floor, but on heavier loam work, where it may be used to good advantage alone or as an auxiliary to the heavier type of pneumatic rammer which is suspended from a crane. This hand rammer is in general design similar to the suspension rammer, but is made light enough so that its use cannot become irksome to the operator. At the same time it is sufficiently heavy so that its inertia absorbs any variation that may arise from the rapid reciprocation of its piston and the rammer head. There are no exposed working parts to this machine, so that dust and dirt cannot affect its operation and durability. The valve mechanism is entirely inclosed, and is as

FIG. 358.—PNEUMATIC SAND RAMMER.

simple as is consistent with proper distribution of air in the cylinder and smooth working. The rammer rod is hexagon in shape, as shown in the engraving, so that it cannot turn except at the will of the user. It is also arranged so that the piston will remain at the top of its stroke when the machine is stopped. The weight of this rammer is 45 pounds, and it strikes 250 to 300 blows per minute, using air pressure at from 50 to 100 pounds per square inch. Only 15 cubic feet of free air per minute are consumed in continuous operation, as shown in the illustration. The machine is provided with a handle on each side; to the handle on the right side is attached the air supply holes and the admission of air to the cylinder of the rammer is controlled by means of a throttle lever under the thumb of the user; exhaust air passes out through the handle on the opposite side; the speed and force of the blows may be varied at the will of the user. A number of different shaped rammer heads are provided with each machine; they are attached to the rammer rod by means of a taper fit and may be changed in less than one-half minute without letting go of the handles.

The manufactures of this machine, the Philadelphia Pneumatic Tool Co., of Philadelphia, New York and Boston, are furnishing these machines for a great variety of uses. Besides regular foundry work, it has been found to be unsurpassed as a labor saver in ramming up converter bottoms in Bessemer steel plants, and the rammers have been adopted by a great many of the largest plants of this kind in the country. The rammer has also been found useful in ramming the moulds of special shapes of fire brick for use in glass and other furnaces. On any kind of work where ramming has to be done, it is safe to say that this machine in the hands of an unskilled workman will do the work of from four to six men using the ordinary ramming bar.

THE YEAKLEY VACUUM POWER HAMMER.

The Yeakley Vacuum Hammer Company, of 3 Rochester Row, Westminster, have installed at the works of Messrs. John Mowlem & Co., the contractors of Westminster, one of their new vacuum hammers, the working of which we recently inspected. In this hammer a vacuum is used to stop or control a falling weight. As it has been designed to do light and heavy forging in iron and steel without any variation of speed, the hammer head or ram is actuated by vacuum and pressure and controlled by a simple valve mechanism that responds to the slightest touch, being so sensitive that the pressure of a finger on the treadle is sufficient to operate it. It is lifted by vacuum and driven down by air pressure. When the hammer is put in motion, the head or ram lifts up and carries perfectly still at the highest point of its range. It is held there by the vacuum, the air pressure being cut off by the valve. The balance wheels, pitman and piston are running, and the head is at rest. To make it strike, the valve is opened by operating the treadle, and the air pressure is admitted to the ram to drive it down. The instant the valve is closed by removing the foot from the treadle the ram remains up, or lifts up if the valve is closed when the head is down. As it can always be depended upon for one blow, it is available for drop forging. The hammer head acts both as ram and piston in front cylinder.

The principal points claimed for this hammer are that it strikes a light or heavy blow, at will of the operator, the regulation being obtained by the treadle, and gives a dead blow with pressure following clear down, thus preventing work moving about on the anvil. There is, of course, no piston rod to break, and no springs, helves, or rubber cushions to get out of order. The movement of the treadle is adjustable from 1 to 3 inches, and when the work is not too large, the operator can manage both work and hammer perfectly. The foundation is very simple and inexpensive.

The rams are guided on all four sides and have large die surfaces on all sides. This allows several dies or swedges to be placed on the ram together, and each can be used continuously, so as to do several operations in succession at one heat. In fact, this hammer has many of the features of a drop hammer. The large die surface and accuracy are suited to such work as has been done in board drops. The Yeakley hammer action is such that the ram comes down quicker than a drop hammer, but hangs an instant at the end of the stroke with full pressure so as to kill the spring of the metal, so that it does not rebound to the same extent as a drop hammer.

The rams vary from 36 lbs. to 800 lbs. in weight. The weight of the ram can be varied without interfering with the frame. In the latest built the 150-lb. ram weighed 162 lbs. and the 400-lb. ram weighed 480 lbs.

In the smallest sizes the anvil is united with the main frame. In all others it is separated. The head or ram is represented as down, but it lifts instantly when the belt is thrown on the pulley and will strike the moment the treadle is depressed.—*Iron and Coal Trade Review.*

AN INERTIA VALVE PERCUSSIVE TOOL.*

In the last few years the use of compressed air as a motive power for machinery has wonderfully increased, especially for portable tools. This is mainly due to the advantageous qualities of compressed air over steam, the principal of which are:

First. Stability, or in other words, non-condensation, permitting it to be stored indefinitely, or to be transported long distances without loss of pressure, other than that due to leakage and friction of the conduit.

Second. Low temperature at which it can be used in hand tools. Such tools could be run by steam, but they would become so hot that a man could not hold them in the naked hand.

Third. The exhaust consists of fresh cool air, adding to the ventilation and comfort of the workroom or mine, whereas the exhaust from steam motors has to be disposed of outside, and is a nuisance, and with hydraulic systems, the waste water must be carried away in pipes.

Fourth. It can be used at any pressure and is easily produced, and its expansive qualities, while not on a par with steam, owing to the absence of heat, yet can be utilized with good results, a feature entirely absent in hydraulic systems.

Against these advantages are opposed some few disadvantages, such as the losses of power in the compression of air, due to the absorption of energy in the generation of heat, and the subsequent loss of pressure in the compressed

* Paper read before the Engineers' Society of Western Pennsylvania.

air, as it cools down to the temperature of the surrounding atmosphere. The losses of the steam end of the compressor are similar to those of any steam engine, and are well known to all of you.

The absorption of heat from surrounding media, caused by the sudden expansion of compressed air, often to such an extent as to freeze any moisture in the air or immediate neighborhood, will often prevent the use of high pressure air expansively unless the air be reheated. This reheating of compressed air can be done at very small fuel cost for the benefits attained, and is used in many places.

These points, however, are well understood and compressed air is used intelligently.

With these few reminders of the qualities of compressed air, the subject of its application to percussive tools comes up, which can be better understood by prefacing with an outline of the development of percussive engines of different types, followed by a description of the inertia valve type which is the subject of this paper, and a discussion of some of the theoretical and engineering features involved in its design.

Percussive force, as regards the actual work done upon the object struck, is applied in two ways:

First. Directly, when the tool itself is propelled through space and strikes the object, when practically all of the energy of the moving mass is expended on the object struck. The commonest examples are the hand hammer, sledge, steam hammers, rock drills, mining stamps and others of similar character.

Second. Indirectly, when the moving mass strikes an interposed tool, through which the energy is transferred to the object.

In this case a portion of the energy is consumed in overcoming the inertia of the interposed tool; the remainder only performing useful work on the object. The energy thus consumed in overcoming the inertia of the interposed tool, supposing the energy of percussive force to be constant, varies, by well known laws, according to the weight or mass of the interposed body. The mathematical discussion of inertia is out of place in this paper, but those interested in the subject can find full discussion of it in Weisbach's, Rankine's and other works on applied mechanics.

Examples of this second type of application of percussive force are the mason striking his stationary chisel, the quarryman's drill struck by the sledge, and the chisel struck by the piston of a pneumatic hammer.

After hand hammers, which have been used from time immemorial, perhaps the lifting of a weight and subsequent dropping it, was the first step in advance, and one which is still in daily use in drilling oil wells and driving piles.

Trip hammers of crude form were in use as early as 1600, and before them, spring catapults were used to throw great stones against castle walls. In a manner these may be classed as hammers of the first type, as the projectile certainly struck a blow, as do those of our great modern rifles, with a little more force.

Nasmyth's steam hammer, invented in the early forties, was a great step forward, and undoubtedly led to the invention of the rock drill, although as far back as 1683 a drill of the oil well type was used for rock, but only vertical holes could be drilled.

In 1844 one Brunton suggested compressed air in a cylinder as a convenient means of working a hammer to hit a drill, and in 1859 Nasmyth, who was a wonderful engineer, at a meeting of the British Association for the Advancement of Science, suggested that the loss of energy in overcoming the inertia of an interposed tool could be overcome by lancing or projecting the tool itself against the work, and exhibited a sketch of an ingenious machine having a piston with a tool attached to the piston rod, working in a cylinder, closed at the lower end and open at the top, so arranged that when the piston was mechanically pulled to the back of the cylinder, a vacuum would be created below it, and on releasing the piston the atmospheric pressure would drive it down with a constantly increasing velocity. This device, he pointed out, could be used to drill holes at any angle, as it was independent of gravity for its power.

October 15, 1851, Cave, a Frenchman, patented a machine for rock drilling, run by compressed air, in which the valve was actuated by hand, and the drill rotated by hand. It was a double-acting engine and was successfully used, and was the pioneer rock drill in Europe.

Couch, an American, patented a rock drill in 1849 in which both the valve motion and the rotation of the drill were automatically performed by the piston in its motion, and while it was a cumbersome machine, requiring cranes to handle it, it was in its essential features the rock drill of to-day.

Since that time there have been wonderful improvements in detail, and numberless devices made for regulating and controlling the different parts, yet to America belongs the credit of the real development of the rock drill.

There are three methods of automatically controlling the admission of motive fluid in rock drills and other percussive engines.

First. The tappet valve type, in which projections attached to the reciprocating part, strike triggers or other devices which in turn move the valve.

There are several objections to this type. The clearances are necessarily large, the liability to breakage is great, due to the intricacy and multiplicity of parts; the small variation of stroke permittable, and the fact that the valve must be moved before the piston has completed its stroke.

This is a good feature on the back stroke, as it permits of forming a sure cushion preventing piston hitting back cylinder head, but on the front stroke it is bad, as it allows initial pressure air to bear against and partially check the velocity of the piston, hence weakening the possible blow.

Owing to the skill and care with which machines of this type are constructed, most excellent results have been and are now being accomplished with them, and such well-known manufacturers as the Ingersoll-Sergeant and the Rand Drill Companies, continue to sell them in large quaitities.

Second. The fluid moved valve type, wherein the piston itself, at certain parts of its travel, admits a supply of motive fluid to move the valve or to move a supplementary piston which in turn moves the valve.

Such machines, if well made, are not liable to get out of order, but the stroke is subject to limitation within narrow range of length, and air is admitted before end of out stroke, as was described of the tappet valve type.

In neither type has there been much attempt to use the air expansively, as the decreased velocity due to decreasing pressure, and the additional mechanical complications, did not seem to warrant it.

The Optimus Drill, of English make, is an exception. It belongs to the fluid-moved valve type, using the motive fluid compound. The initial fluid

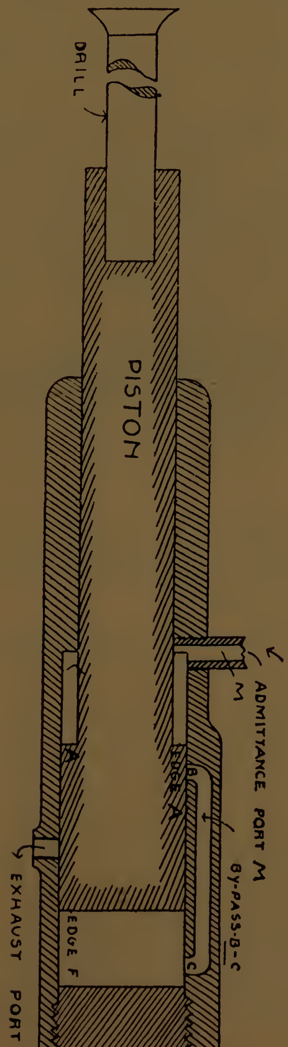

FIG. 359.—DARLINGTON VALVELESS HAMMER.

driving the piston outward, is used expansively to effect the return stroke. It is much in use abroad, but has not met with much favor here.

Third. The so-called valveless type, in which the moving piston acts as its own valve, as in its stroke, it alternately opens and closes certain ports, so that the fluid acts on each end of the piston in turn.

The progenitor of this type was invented by John Darlington, May 13th, 1873, in England, and a great many were used, though now superseded by the modern drills of the first and second types described.

In this machine, the motive fluid acts constantly on the smaller area of the piston. When the piston is at the outer end of its stroke, the space in the rear is open to the atmosphere and the constant pressure on front area forces the piston back. In its motion, it closes the exhaust port and a back cushion is started in the rear. At a certain distance before the motion of piston is entirely checked by the cushion, a by-pass leading from front to rear end of cylinder, is opened; this by-pass being a little longer than the main body of piston. Fluid rushes through this passage to the space in rear of piston, pressing on large diameter of same with initial pressure, drives piston forward against the pressure on small diameter, with a force due to the excess of area, under the same pressure per square inch. Very early in the down stroke, the by-pass is closed again by body of piston, and further force is derived only from the expansion of the body of high pressure fluid, locked in the rear of piston.

Against this decreasing pressure of expansion is opposed the constant pressure on the small front area, so that the net forward force is constantly decreasing, although sufficient, combined with the momentum already acquired, to propel piston its entire stroke with considerable velocity, utilized in effective work on the object struck by the tool. When nearly at end of out stroke, the exhaust in rear is again opened, so that further travel is entirely due to the acquired momentum. As soon as the blow is struck, the piston is stopped, and immediately is pushed back by pressure on front area and the operation repeats.

The conception is unique and beautiful, the drawback being the loss of velocity on the out stroke, as described.

The action of this tool has been explained in detail, at is was in the endeavor to overcome this defect that experiments and study were made of the problem.

In Darlington's drill, the initial pressure was used for the back stroke, and the expansive force used for the out stroke. April 13th, 1880, Wm. L. Neill took out a U. S. patent for a valveless rock drill, reversing this action, so that the effective out stroke was due to initial pressure, and the return stroke to expansion. This device never was used practically, as far as can be ascertained, probably due to the fact that a cushion was formed in front of the piston, when the exhaust was closed, increasing in force as the piston progressed, and decreasing the velocity thereof.

Having thus examined the three principal types of valve motion in ordinary use, we come to the development of the Pneumatic Hammer, which consists essentially of a small portable cylinder in which a piston reciprocates very rapidly, striking a great number of blows per minute on the end of a tool inserted in the end of the cylinder.

It belongs to the second class of percussive tools, having a tool interposed between the hammer and the work.

McCoy may be said to be fairly entitled to the credit of the first application of such tools to heavy work, such as chipping metals, caulking boilers, cutting stone, etc., that had been done previously by hand and hammer. He exhibited his device before the Franklin Institute, which awarded him a medal for a new and meritorious invention of real utility.

He was not, however, the originator of the broad idea, as long before he perfected the tool for heavy work it had been used as a dental plugger, a device working compressed air in a cylinder so that a piston struck the end of a tamping tool, used to insert gold into the cavities of teeth.

There were several patents taken out for such tools and successful results attained in the 70's.

The pneumatic hammers followed in a general way, the valve motions used in rock drills, with modifications adapted to smaller and more portable tools. The valveless, as also tappet and fluid moved valve, types are used. Of the former, the Q. & C. tools are quite well known. For work within their range they are admirable, owing to their simplicity of design, small size and great rapidity of short stroke blows. For light chipping, caulking and other

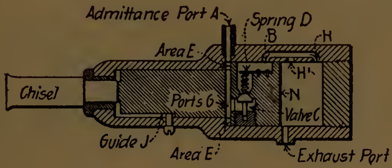

FIG. 360.—KOLTEN TOOL.

similar work they can hardly be excelled. A somewhat similar tool, the Kotten, is made for use in carving stone and marble, die sinking and other delicate work, and has a very short stroke, about ¼″ to ½″, running as high as 10,000 or more strokes per minute.

For heavy chipping, riveting and other work, the blow of a valveless tool is not heavy enough to do the work well, and tools with a controlling valve are used, allowing of much longer stroke, and higher velocities of piston travel.

Of the fluid-moved valve type, the Boyer hammer, made by the Chicago Pneumatic Tool Co., and the Little Giant hammer, made by the Standard Pneumatic Tool Co., are the best known. In these a small valve, located in a chamber in the rear of the piston, traveling parallel or right angles to the axis of the piston, is actuated by air pressing on differential areas, moving it alternately to and fro, opening and closing ports controlling the admission and exhaust to the cylinder. Suitably placed small ports are closed and opened by the piston in its travel, that permit air to act on and move this valve.

Excellent work is accomplished by these tools, and a skilled workman can do from four to six times as much as can be done by hand tools alone. They are in use in nearly all the progressive machine, boiler, bridge and ship works in this country, and in a great many abroad.

In driving rivets greater force is required than in chipping. This can be attained in a pneumatic hammer in two ways: By larger mass in the piston, or by greater velocity.

The force of the blow varies directly as the mass or weight; and as the square of the velocity; hence a tool can be designed with a heavy piston and short stroke with high pressure, or the same result attained by larger cylinder diameter with lower pressure, but the better, and generally adopted method, is to increase the length of stroke, keeping the diameter small. This would follow thoretically as a result of the law given. There is again a practical reason why the diameter should be kept small, because the reaction would otherwise be too great. Since action and re-action are equal and in opposite directions, the total force used to propel the piston out, presses equally against the back cylinder head, and a man can withstand but a limited amount of such pressure when holding the tool, thus limiting the diameter to such size as has been found practicable.

To meet the demand for a long stroke tool, the Chicago Pneumatic Tool Co. have put on the market the "Long Stroke Boyer Hammer" having a piston about 1½-in. diameter, with 9-in. stroke, striking a very hard blow, due to the continued application of a constant force through the long stroke, constantly

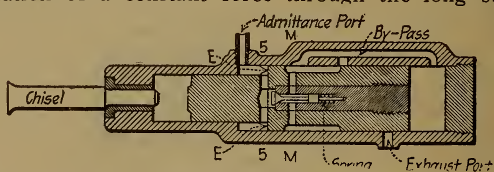

FIG. 361.—LONG STROKE BOYER HAMMER.

accelerating the piston velocity. The valve is moved by tappets and at pressures of about 100 lbs. per square inch. Seven-eighths-in. rivets can be set down much quicker and about as tight as by hand, but the rivets do not fill the holes as well as those driven by compression riveters, driven by air, steam or hydraulic pressure, nor nearly so quickly. For the erection of structural work, or for any field riveting, it fills a long felt want, doing the work sufficiently well.

With this perhaps rather long examination of what has been accomplished in percussive tools, and study of the underlying principles, the subject of this paper, "An Inertia Valve Percussive Tool," will be discussed.

Recalling the Darlington Valveless Rock Drill and referring to the drawing (Fig. 359), we notice that when the rear edge F of the piston passes exhaust port D on the back stroke, that a cushion is at once started in the rear, increasing in pressure as the piston travels back. When the front edge A of the piston passes and opens the entrance B of the by-pass B-C, initial pressure air flows through admittance port M, cylinder cavity and the by-pass to the rear of the piston, immediately checking any further movement and forcing the piston out by reason of the greater area of surface F over surface A. In such forward movement the edge A again closes the port B of by-pass, cutting off the supply of further initial pressure air to the rear, so that any additional pressure or force upon rear area of the piston must be derived from the expansive action of the air locked in behind it, which, you will notice, is opposed by the initial pressure air bearing on surface A, which is constant at all points of stroke, either forward or back.

It seemed, on study of this device, that if some way could be found to allow air of initial pressure to follow up the piston during its entire downward stroke, that much greater piston velocity would be secured.

To accomplish this result, it was obvious that an automatically moved valve of some sort must control the flow of air in such a way as to prevent any access to the rear during the back stroke, and to permit such access during the forward stroke.

The first solution that appeared was the use of a type of poppet valve, with a spring bearing upon it, so that when there was no pressure on one side, the valve would close under unbalanced pressure, but when the pressure was alike on each side, the spring would force it open.

To clearly understand it, referring to the print A is a port admitting air continually against area E. G is a port leading from this area E to the valve chamber shown.

C is a valve with spring D bearing against the side of it that is away from the constant supply of initial pressure in port G, arranged so that pressure against it from port G will close it against pressure of spring, when no pressure exists back of it.

B is a by-pass having two outlets communicating with cylinder h & h^8. F is an exhaust port, adapted to be closed and opened by the rear edge of the piston. J is a guide to prevent piston from turning, as the device as shown required that the valve cavity should not come in contact with the exhaust port F.

In action, air enters through A, pressing against small area E closes valve G and forces the piston back, the space in the rear of piston and in the by-pass and valve cavity having exhausted through port F.

When the piston travels so that the edge E passes port B, air at high pressure goes through by-pass to rear, and at the same time through the port h into the valve cavity, thus equalizing the pressure on the sides of valve C, which opens under the pressure of the spring D, permitting free passage of the air through port E, and the valve cavity port h and by-pass to the hear, forcing the piston out, owing to the excess area.

As it travels out, this passage, either through B or h is continually open, so that a continuous current of air flows through the valve at initial pressure until the exhaust port is opened at F, reducing the pressure in the rear when the valve again closes, and the action is repeated as described.

This seemed very nice on paper and worked fair to middling badly. When the spring C was exactly right in intensity for a given air pressure, it worked nicely, but any variation of pressure interfered with good results. Again, the rush of air through the valve had a strong tendency to close it, requiring a superfine adjustment of the intensity of the spring.

For static pressures the idea was all right, but for dynamic pressures, if one could so call air under pressure in motion, it was not all that could have been desired.

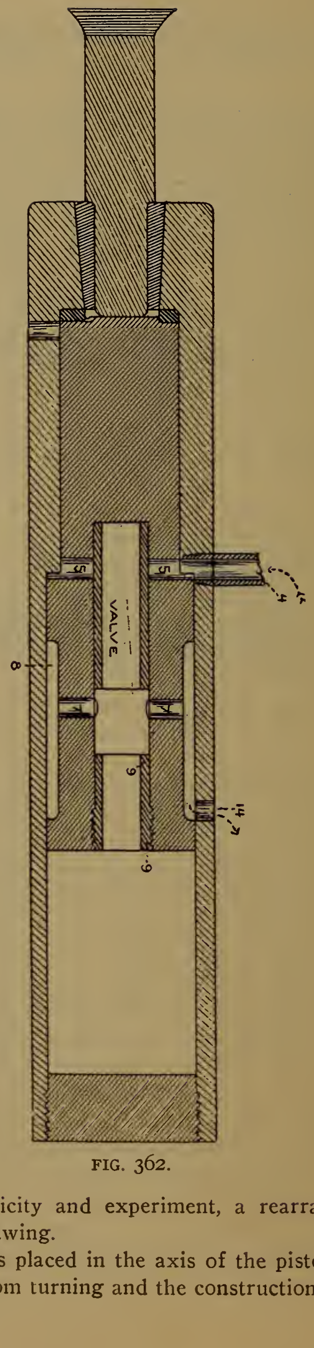

FIG. 362.

In the line of simplicity and experiment, a rearrangement of the parts was made, as shown in drawing.

The poppet valve was placed in the axis of the piston, which did not then require guides to keep it from turning and the construction was simpler. Results somewhat better than in the first machine were attained, but it was discovered that the inertia of the poppet valve interfered with the contemplated action of the device.

This movement of the valve by inertia suggested the use of a form of slide valve that should be controlled entirely by inertia, opening and closing suitable ports in its travel to accomplish the desired ends.

A tool as shown in the drawing was designed, having an axial hole in the centre, within which a small tube could move freely within fixed limits.

A constant supply of air is admitted at 4 against the small area of piston. Ports 5-5 lead from a point adjacent to this small area into valve chamber, which in turn opens to the rear end of piston.

An exhaust port, 14, leads through the cylinder and a groove around exterior of piston communicates by a port 7 to the valve chamber.

In starting, the tubular valve is at the outer end of chamber, thus closing ports 5-5 and leaving ports 7-7 open.

Owing to the constant pressure on the small area, and the exhaustion of pressure in rear of piston, it travels back, and the rear edge closes exhaust port 14, which, however, registers at the same instant with annular groove on piston, establishing a new means of exhaust through the valve chamber, ports 7-7 and annular groove 8 to port 14. This passage remains open until the groove 8 passes exhaust port 14 and the piston cuts off further exhaust. A cushion then commences which tends to check the velocity attained by the piston, but not that of the valve carried thereby and traveling with equal velocity. Being free to move, the valve slides back until it meets stop 9.

In this position the interior exhaust ports 7-7 are closed, and the admittance ports 5-5 are opened, and initial pressure air flows through the valve to the space in rear, driving piston out by reason of the excess area.

The valve remains in this back position, allowing air to flow through it until the piston has struck its blow, when the valve slides, by reason of its inertia, to its outer position, and the action repeats as described.

It will be noticed that full pressure is exerted until after the piston has struck, and also that the valve will shift at any point during the out stroke if the piston is stopped, provided that exhaust can occur. The possible limit of practicable variation of stroke is thus only limited by the distance found necessary to use for a rear cushion to prevent piston from ever striking the back cylinder head.

This varies from ¼ to 1-3 of the stroke length, thus permitting a wonderful variability of stroke.

The tool, as described, worked very well at times, but it was discovered that the valve had a strong tendency to bounce back, especially on the front stroke. This unlooked for movement of the valve had very disastrous effects, as may be imagined, causing the action to be extremely erratic.

To obviate this trouble, brakes were applied to the valve to prevent its sliding so easily. The machine ran well when it got a good start, but the valve was liable to stick at the wrong end of the chamber, and there was great difficulty in starting again until the piston had been jarred by hand so as to bring the valve where it should have been.

Other experiments, such as the use of rubber, lead, wood and other buffers, supposed to be inelastic, were tried in the endeavor to stop the bounce, with but little success, as anything soft enough to prevent bouncing was soon hammered out of all shape, the pieces clogging up the valve chamber.

All sorts of shifts, profoundly wise and exceedingly foolish, met the same fate, until we were almost disheartened and disgusted with the perversity of things inanimate.

In pondering over the failure, the idea of counter-balancing the rebound of the valve by a smaller mass, colliding it with it at the instant rebound commenced, arose.

A little model consisting of a pipe, with two collars fastened to it having between them another piece of pipe large enough to slip freely on the outside of the other, and a little less in length than the distance between the collars, was made.

On holding this device about three or four feet above a block of steel, with the outer tube or "Rider" as it was named bearing against the upper collar, it was dropped vertically. The lower end of the inner tube struck first and started to rebound, but the rider, traveling at the velocity due to the fall, slipped over the main tube until it struck the lower collar, fast on inner tube, thereby

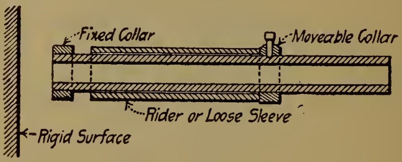

FIG. 363.

checking the upward velocity of the rebounding inner tube, so that the combination practically did not rise perceptibly from the steel block, landing almost as dead as a chunk of putty.

It seemed as if this principle could be applied to the valve, so as to overcome its rebound, and at the same time give the freedom of motion necessary to good action.

A modification of the valve was made with a rider attachment, which, when tried, caused the tool to work with the regularity of clock work.

In designing the valve and rider, a study was made of the coefficients of rebound of various materials, and it was found that a great deal of difference in results and theory existed among the acknowledged authorities on applied mechanics, authors of distinction, such as Rankine, Weisbach and others giving tables with wide variations for similar materials.

In order to be sure, recourse was had to experiment with different materials, to determine what proportionate weights the valve and rider should have to each other.

It has been demonstrated by mathematicians that the modulus of elasticity of rebound is equal to the ratio of the relative bodies after and before impact.

If a body suspended from a small cord from a fixed point be made to oscillate like a pendulum, it will acquire a velocity, at its lowest point, proportional to the chord of the arc through which it has swung, and if the arcs are not very long, the times of descent will be equal for different length arcs; hence, if the suspended body strike a stationary body when at its lowest point, and the angular distance through which it rebounds be noted, the ratio of the original to the return velocity can be determined.

It was found that for steel striking steel, it was as 100 to 60, and for steel striking vulcanized rubber, backed by steel, about 100 to 37. The fibre was used, as it stands the pounding of the valve without itself disintegrating, or upsetting end of valve.

Knowing, then, the modulus of recoil we can figure the velocity a body will acquire at the instant after collision on the rebound, if we know the velocity with which it struck.

If, in addition, we know the weight of the striking mass we can find the energy or momentum at that instant, and have only to make the weight of rider

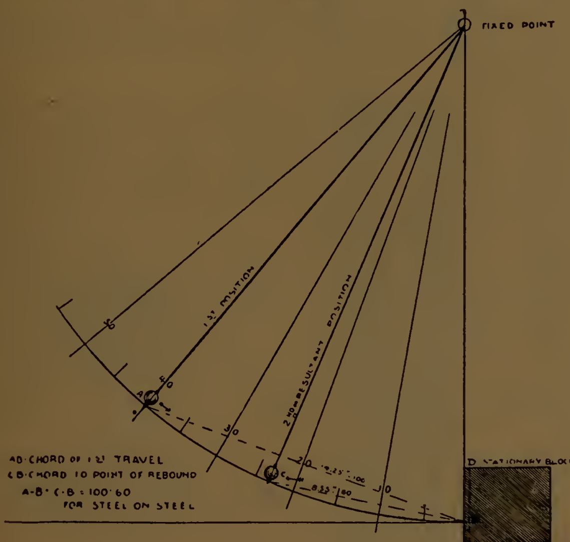

FIG. 364.

such that its momentum, due to the initial velocity, shall be equal to that of the valve rebounding, to practically eliminate the return movement of the valve. When two perfectly elastic bodies of equal weight meet, each rebounds with substantially the same velocity with which they met, but with imperfectly elastic bodies, of unequal masses and velocities, the rebound depends on which has the greater weight and velocity, and on the moduli of recoil, hence we can approximately calculate the weight of rider so that the valve will stop short, and any rebound will occur in the rider only. This rebound can be made so little that it does not influence the valve inself, and the desired result is attained.

In making these investigations, certain interesting points came up that are worthy of further study to fully understand the reasons for them.

The recoil certainly depends upon the elasticity of the colliding bodies, yet the ratios found by experiment seem to bear no recognizable relation to the established coefficients of elasticity, given in text-books on the strength of materials. Evidently the amount of energy in the moving masses and the area of contact influence the result. If the striking area is small, the entire energy, converted into work, is exerted on a small unit of surface, causing a strain per unit area greater than the materials would stand. In this case the limit of elasticity, as ordinarily understood, might be exceeded when the work would be expended on tearing or crushing the material, instead of causing rebound.

On the other hand, if a body of equal weight and velocity to the one described, but having a much larger striking area, were to collide, it might easily be conceived that the strain per unit of striking area would be less than the limit of elasticity of the materials, and that practically most of such energy would be consumed in bending or squeezing the materials, which would spring back to their original position, and in so doing force the colliding body back into space with a velocity dependent upon the strain produced and the coefficients of elasticity of the bodies.

To elucidate the truth of this hypothesis would require a great deal of careful experiment and research, and would be suitable work for some mechanical laboratory connected with a technical school. Accurate information on the subject would be of great value. It might originate a new method of testing materials, although somewhat analogous to impact testing that is now in vogue, although the results in the latter system are derived from measurements of bends made transversely in the specimen struck. By this method, such results would probably be derived from a comparison with the velocities of rebound from standard substances, of bodies of given form and with given velocity.

The latest model of a direct acting chipping tool is shown in the accompanying sketch. You will note that the valve will move at any point of the stroke, if the velocity of piston be checked, and that within the limits for cushion described earlier in this paper, the stroke is variable.

While this variability of stroke is not so essential in a chipping hammer, or any tool of the second class of percussion where an interposed tool receives the blow, yet for machines of the first class, such as rock drills, steam hammers, gold mine stamps, etc., such variability is desirable and essential to attain the best results.

In this hammer the exhaust takes place at very nearly the initial pressure, hence a great deal of energy contained in the compressed air is wasted, although the piston velocity on the down stroke is great, giving a powerful blow.

It seemed as if some of this waste might be obviated by working the air compound, using a different form of inertia valve so as to retain the good features of the device.

It was evident that a constant supply of initial pressure air should be furnished, available at any point of the stroke, but that it should have access to one end of the piston at certain specified times only, and that the valve should permit of opening a passage from this side of piston to the other, which necessarily should be of larger area to allow of the locked in charge of high pressure air acting expansively on both piston areas.

It was also a condition that during the movement of the piston under initial pressure that the other end of the cylinder should be open to exhaust in

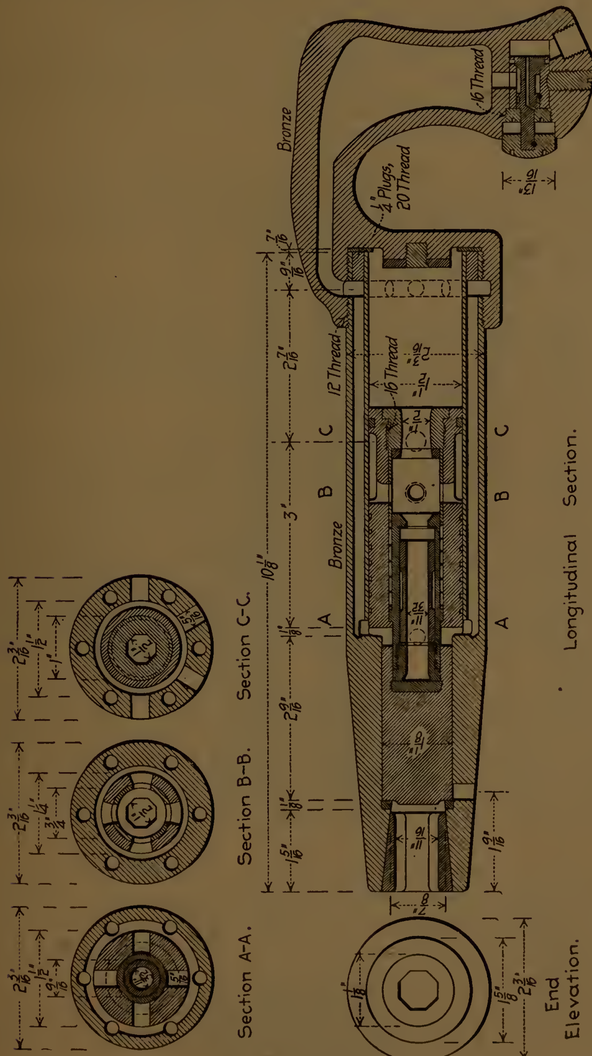

FIG. 365.

such a way that variability of stroke would result, and sufficient cushion formed to prevent piston striking cylinder head.

These conditions were fulfilled in a machine of the type shown in the illustration.

An annular groove was provided on a portion of the exterior of the piston that was in register at all points of the stroke with an admission port of high pressure air. An axial valve chamber was provided, open at the rear end in the body of the piston, having from it ports leading to the constant supply of motive fluid; other ports leading to a point adjacent to the small diameter of the piston and exhaust ports, arranged so that exhaustion could occur through them during the majority of the back stroke, but be closed by the motion of the piston for the remainder of the stroke.

A tubular valve was placed in this central chamber, having on its exterior surface an annular groove, so placed that when the valve was at the outer end of its travel, it would register with the ports from the constant source of supply, and the ports leading to smaller piston area, while at the same time a port through it would permit of exhaustion.

In action, the pressure against the small area of piston drives it back, air in the rear meanwhile having a free vent through the exhaust ports until the piston, in its travel, cuts off exterior exhaust port, thus cushioning the air remaining back of the piston and checking velocity of the piston when the valve moves by its inertia to the rear end of its travel.

In this back position the supply of high pressure air is cut off, as is also the exhaust port, and a port in the valve itself registers with the port leading to the small piston area, permitting the air locked in in front of the piston, free passage to the rear. The pressure immediately tends to equalize on both ends of piston, and owing to the larger area in the rear, the piston is forced out under the force of the expanding air from the front end of cylinder, continually decreasing in pressure as the piston moves, and the volume or space increases. The piston striking causes the valve to shift back to its original position, and the action continues.

It is obvious that if the piston were back when at rest there would be no locked-up air to expand, so that it could not start, and to overcome this difficulty, a spring is placed back of the piston just strong enough to force it out when no air is admitted. No loss of power results, as the energy stored up in it on the back stroke is given out on the front stroke, and it serves to help cushion.

The valve also is provided with a light spring sufficient to keep it in the outer end of its travel when the piston is at rest, so that all will be in readiness to start on opening throttle valve. The inertia of the valve on the down stroke is sufficient, when the piston is constantly accelerating in velocity, to prevent this spring closing the valve prematurely.

The proportion of expansion can be determined if the clearances are known, for any ratio of piston area. It has been found that for air the proportion of 10 to 3 is good, as this gives a terminal exhaust pressure of about 2 pounds per square inch if 80 lbs. were the initial pressure. This permits of prompt exhaustion, and no vacuum is formed in the rear, as would be the case if greater ratio of expansion were adopted. Such a ratio could be used with steam, as a condenser might be attached, but no experiments have been made in that line.

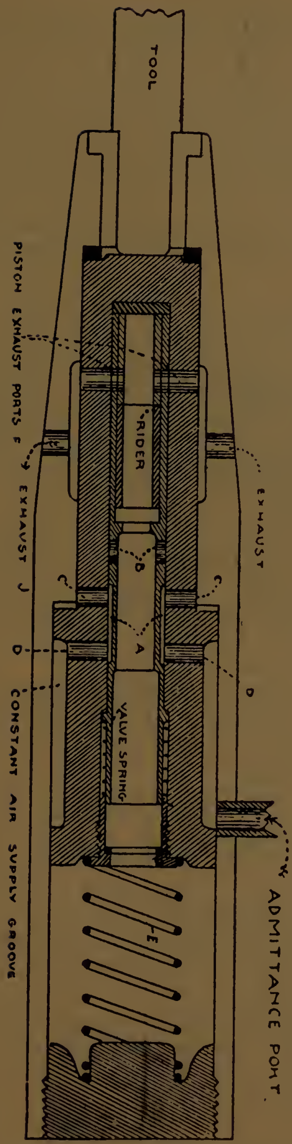

FIG. 366.

With this tool, about three times as much work can be done with the same volume of air as with a direct acting tool, exhausting at initial pressure, or the same work can be done with one-third of the volume of air. It may be seen that the diameters of the tool might have to be larger to effect these results, and that the mass of piston would be larger in consequence. In practice, a longer stroke has been adopted in order to avoid the back kick, due to large diameters, as explained earlier. The length of stroke does not affect the ratio of expansion, as the volumes in front and rear of piston change in definite proportion.

The velocities attained in forward and back strokes in either the compound or single acting hammers, can be calculated with fair accuracy when the diameters, piston areas, pressure per square inch, length of stroke and weight of piston are known, as these are constants or known variables. The amount of friction, leakage and loss due to overcoming inertia are difficult to determine exactly.

Knowing the velocities and the volumes of motive fluid used, the number of strokes per minute and the amount of air consumption, can be closely approximated, and in practice count of the number of strokes and accurate measurement of air consumption by meter, check out within from five to ten per cent. of the theoretical results figured.

Thus a total can be intelligently designed to do the work expected of it, as regards force of blow, frequency of stroke, and air consumption at any given pressure.

This valve motion would seem to be applicable to a great variety of purposes, even to running a compound engine with tolerable economy. The power of the stroke due to expansion is not 5 per cent. less than that due to initial pressure, on the small area, and a machine can be designed to strike by either initial pressure or expansive pressure, as desired. The latter has been chosen as giving simpler construction in the tool.

The valve motion described and the anti-bouncer arrangement are covered by several patents, as is the poppet valve tool described.

The tools, as now made, run very satisfactorily on long and severe tests, and are practicable and useful.

Endurance tests of materials and detail parts are now being made with the view of discovering all weak points.

When these have resulted satisfactorily, the tools will be put on the market.

Owing to the great number of strokes and the small cylinder volumes in the tools already experimented with, it has been impossible to make indicator tests, so a study of the action of tools was only possible by observation of action, air consumption and number of strokes per minute, as the valve itself could not be seen at work. It followed that by induction only could one arrive at the causes of some of the erratic performances and failures of the tools.

CHESTER B. ALBREE.

CASKEY PORTABLE HYDRO PNEUMATIC RIVETER.

The engraving shows a sectional view of a new style portable riveter manufactured by Pedrick & Ayer, Philadelphia, Pa., especially adapted for ship yards and structural iron works, and the use of boiler makers and bridge builders.

The Caskey Portable Hydro Pneumatic Riveter is designed for using compressed air as a prime mover, with the hydro-carbon fluid used in the oil chambers and oil cylinders.

This admits of the machine being operated in very cold weather and in open places with no liability of freezing and causing trouble, as is the case with riveters of hydraulic construction, and is an important feature.

The engraving is largely self-explanatory. The main frame, No. 68, is a steel casting, and can be made in any desired shape, adapted to the conditions and positions in which the riveter is to work.

The oil chamber and pressure cylinder, No. 41, is made from nickel steel forging and accurately machined.

The dolly bar or hydraulic piston, No. 13, is manufactured of the best tool

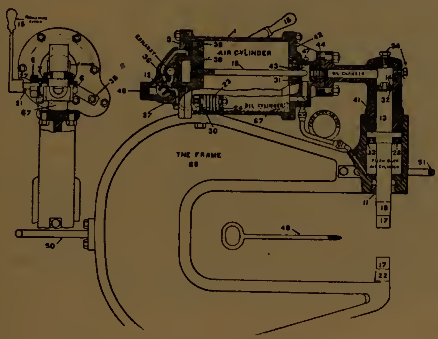

FIG. 367.—CASKEY RIVETER.

steel, accurately machined, hardened and ground. No. 42, inside cylinder head, is of cast steel.

The Caskey Hydro Pneumatic Riveter is built for very hard usage, and the least liability of breakage. There are but four moving parts, and the operating lever, No. 15, is the only moving part exposed.

All packings are easy of examination.

The construction of the machine secures the maximum pressure on a rivet with as little weight in the machine as is possible.

It works rapidly, without shock or jar, is easy to handle and gives a uniform pressure on every rivet.

No blow is given when using this machine and therefore no crystallization takes place upon the rivet when being driven.

The riveter is suspended by a bale which allows it to be moved and operated in either a vertical or horizontal position; by changing the bale it can be used sideways with equal facility.

Suitable handles are provided on front and back for the convenience of the operator in placing it over the work.

The operating lever is so constructed and connected that the operator can control all movements of the riveter whether standing at the side, back or front of the machine.

No adjustment of the length of the dolly bar, or the rivet dies, No. 17, is required when riveting on various thicknesses of metal.

The dolly bar has a movement of 4½ in.

The first 2¼ in. is known as the rapid movement, which is set down direct by the pressure from the receiver tank of 80 pounds. The last 2¼ in. is called the effective movement and develops the maximum pressure, giving a uniform squeeze throughout the entire stroke of the last 2¼ in., which causes the hot rivet in the hole to be very nicely upset, filling the hole solid.

This pressure is exerted on the dolly bar through the hydro-carbon fluid., which is non-freezing, and so long as the operating valve is open, admitting compressed air to the main piston, the maximum squeeze is maintained on the rivet.

After a rivet is headed, the dolly bar and the die are positively moved back from it by a quick movement of the operating lever.

Every detail entering into the construction of the Casket Portable Hydro Pneumatic Riveter has been studied to make it as perfect as possible. It is made of the finest quality of materials, with specially designed machine tools and thoroughly tested before leaving the shops of the manufacturer.

The Caskey riveter is built in twenty-one different styles and sizes for driving rivets from ⅜ in. to 1¼ in. All machines are proportioned for using compressed air at 80 pounds per square inch, and to exert whatever pressure on rivets is required. Messrs. Manning, Maxwell & Moore, 85, 87 and 89 Liberty street, New York City, are the sole sales agents and will be pleased to send descriptive catalogues and further information upon application.

HAND VERSUS AIR-RIVETING POWER.

Actual Cost Compared With Hand Work in the Field for the Erection of New Work and Repairing; also, Drilling for Reinforcing Old Spans.

COMMITTEE REPORT.

To the President and Members of the Association of Railway Superintendents of Bridges and Buildings:

As chairman of this committee I enclose letters received from Messrs. F. S. Edinger, S. P. Co., and O. J. Travis, I. C. R. Co., relating to this question, which I believe is of interest to all; personally I am only able to give at present my experience in this matter, viz.:

Since 1890 this company has been steadily replacing all wooden and combination truss bridges with steel, and up to May, 1899, all riveting in field had been done by hand; since May, 1899, we have erected 22 new steel spans of various lengths, aggregating in all 2,455 lineal feet; besides this, we have repaired several old spans taken down, reinforcing, changing floors, raised to safe clearance, etc. In doing this, we have used pneumatic tools for riveting, chipping, drilling, reaming, etc.

In the erection of the 22 new spans record was kept of the number of rivets driven, viz., 80,065. In the repair work we did not pay as close attention to number driven, but there were a large number.

With pneumatic riveting hammers I find two men and one heater can average daily (10 hours), 500 rivets, whereas by hand 250 rivets per day was a good day's work (more often less), for three men and one heater. One day we drove 700 rivets, by using an additional man to take out fitting-up bolts, etc. This was the work of one air hammer only.

In inspecting rivets I find the work far superior to hand work—less loose rivets, heads invariably perfect, shank of rivet filling hole, and in every way far superior to hand work done by our men, or by others in the past; also work can be done readily in places where great difficulty has been experienced with hand tools.

It seems useless to call attention to the benefit of reamed holes in assembling joints made by pneumatic drills over the "drift-pin work," so much in use, where hand riveting prevails; but with the rapidity that air drills run, the expense of reaming rivet holes has been reduced to a minimum.

The pneumatic plant in use on this road for bridge work consists as follows:

One 12 H. P. Fairbanks, Morse & Co. combined gasoline engine and air compressor.

Two galvanized iron water tanks.

One galvanized iron gasoline tank.

One boiler iron main reservoir, "large."

One boiler iron auxiliary reservoir, "small."

All necessary fittings, etc., and mounted on box car, one No. 2 Boyer pneumatic hammer, old style; two New Boyer 000 1 6-16x5 inches, pneumatic hand-riveting hammer; two hand steam drills (running them with air), with necessary hand, spring, and air dolllies, rivet snaps, forges, drill bits, reamers, and other small tools necessary to this class of work.

The 12 H. P. gasoline engine and air compressor furnishes more than enough air to operate all of our tools at the same time. By using the small reservoir at bridge and main reservoir on car, and operating at 90 pounds pressure, we have had in use at one time three hammers, two drills, two heated forges, and one blacksmith forge, and have been able to get full capacity out of all of them. We have now ordered additional tools, as we find we have sufficient power to operate them, especially when cutting out the old steam drills.

In starting we obtained one No. 2, old style, Boyer hammer, which had been in use by another department; this hammer we repaired, and in "Cost of Plants," referred to later, we have valued same at half price after repaired. Bought two 0000 New Boyer hammers, 1 516x5, and last month we ordered a No. 2 Boyer piston drill and a latest improved New Boyer long-stroke hammer; this hammer and drill I have seen in actual service, and think they are as near perfect as it is possible to get. In using these hammers, we find they are free from vibration or concussion that had been somewhat of a drawback to pneumatic hammers I have noticed in the past. We use hand riveters only in field work on bridges, as we have not driven over ⅞-inch diameter rivets, and think in such class of work it is more economical than a yoke riveter. In handling larger rivets, repairing or rebuilding work done in yards or shops, a yoke riveter could be worked to good advantage. In field work there were many difficulties when doing hand work that would cause delays that are now overcome quickly by use of air. In chipping, cutting out, reaming, drilling, etc., work can be done in a fraction of the time that it used to take, and when done you have a good, presentable piece of work; in fact, I consider pneumatic tools are so far ahead and superior to hand work in everything that it is practically unnecessary to dilate their uses.

It costs us the same to spur out at bridge site, as we always spurred out when running a hand gang, and by increasing pipe line we can invariably find a good location for the outfit cars with small expense.

In putting in staging or falsework for riveters we find the cost is less, and by doing the work faster by air enables slow orders, or delays to movement of trains, to be reduced, and the slowing up or stopping of a train as an item of expense to railway companies.

For your information I have compiled some data on this question, showing actual cost of work. We will take up first cost of pneumatic plant. In explanation, would state, I only show increased cost of plant that, in both hand or air, work tools in common; that is, forges, dollies, chisels, snaps, and all such tools, do [illegible] appear in this comparison, as one practically offsets the other.

difficulty [illegible]
driven by hand. The [illegible] for air compressor, reservoirs, machinery, water
[illegible] mounted on car........................ $1,073.00
are very much better than can be ma[illegible] [illegible]ls........................ 627.00
[illegible]ly perfect.

and a heater form a [illegible]
Total cost [illegible]................................ $1,700.00

Cost to maintain since May, 1899:

Repairs to combined engine and air compressor	$34.00
Repairs to new hammers	6.30
Repairs to old hammers and drills	9.00
Total cost of repairs	$49.30

Proportion of cost of plant chargeable to work per day, on basis of 20 per cent. depreciation per year:

Twenty per cent. of 1,700 = per year $340, or per day basis, 313 working days equals year, $1.09.

Cost to maintain since May, 1899, $49.30,

Or per month, 1-17th of $49.30 = $2.90,

Per day, 26 days to month, 11 cts.

Cost to operate gasoline engine and compressor per day:

Fifteen gasoline, at 11 1-5 cts	$1.68
Oil, waste, etc	.12
	$1.80
Total cost to operate plant per day	$3.00

On basis of running three rivet hammers and forges equal cost for one hammer of	$1.00
Oil for hammer, estimated amount per day	.12
Labor two men, at $2.40 per day	4.80
Labor one man, $2.20 per day	2.20
Total cost to operate one hammer per day	$8.12

Cost of riveting by hand (as noted on commencement of this detail, there are no charges for tools, as the small tools, forges, etc., not shown in riveting by air, practically offsets tools in riveting by hand):

Labor two men, at $2.40 per day	$4.80
Labor two men, at $2.20 per day	4.40
Total cost of hand-rivet gang per day	$9.20

Men with pneumatic riveter will average 500 rivets per day for $8.12, or per hundred, $1.62.

Men with hand power average 250 rivets per day for $9.20, or per hundred, $3.68.

The above figures demonstrate that it costs more than double to drive rivets by hand than by using pneumatic tools.

Another point when you have a compressor outfit, when rebuilding old bridges, by putting in a sand blast you are able to eradicate all rust separate [illegible] you will find in all cases on old iron, which it is practicall[illegible] perhaps not reducing hand. This leaves iron in perfect condition to [illegible] the work. that rust spots have not been hidden [illegible]boring all bolt holes in bridge floor timb[illegible]

In closing, will state I thi[illegible] the drill. This results in a savi[illegible]matic plant is one of the best investments a railroad [illegible], especially now that steel structures are so much in evidence on all first-class roads.

A. B. Manning, Chairman Committee.

I am very much interested in the subject, "Hand vs. Air Riveting Power Used," and am glad of the opportunity to exchange ideas and experiences with others who are using pneumatic tools in field work.

At present we have two complete pneumatic plants in the field, each consisting of a 12-horse-power gasoline driven compressor and tools. The first plant which we purchased consisted of one compressor, two pneumatic yoke riveters, two pneumatic riveting hammers, and two air drills, one of which was fitted with angle gear for getting into corners not accessible to the drill proper.

The first work done with the pneumatic tools was a cover plate job on a 200-feet-through iron span, which required the drilling of about 6,000 holes 15-16 inch diameter through 3/8 inch to 1/2 inch of metal.

Including the cost of setting up the plant for the first time, which was unusually great owing to the inexperience of all hands, the work was done with a saving of about 25 per cent. on the cost of doing the work by hand.

We found that the yoke riveters answered the purpose very well in riveting cover plates and other straight work where, when once suspended, they would reach a number of rivets, but they were great time consumers when it was necessary to move frequently.

The riveting hammers which were quick acting and short stroke did not give good results—the blow being too light to upset the shank of the rivet to fill the hole, and the concussion of the hammer was very distressing to the operator.

We have since secured hammers which have a long, heavy stroke with which we get satisfactory results as to the quality of the work, and the effect on the operator is not injurious.

We have two plants in use at the present time.

The one used by the steel bridge erecting gang consists of the following tools:

One 12-horse-power gasoline driven air compressor.

Five long-stroke pneumatic hammers.

One pneumatic yoke riveter.

One pneumatic clipping hammer.

Two pneumatic drills.

Together with the usual complement of forges and holding-on appliances used in hand riveting.

The yoke riveter holds as well as drives the rivet.

With the long stroke hammers we use the usual suspended dolly-bars, spring-dollies, or lever-dollies, as may be best suited to the condition—the same appliances as would be used were the rivets to be driven by hand—and no more difficulty is experienced in holding the rivets up to the work than were they to be driven by hand. The hammers upset the rivets well into the hole and the heads are very much better than can be made by hand, in fact, nearly all heads are absolutely perfect.

Two men and a heater form a riveting gang, and they drive double the number of rivets per day than the gang of three men and a heater where driven by hand.

Where there are a great many rivets of one length to drive, as in lattice girders, water tanks, etc., we use a portable furnace with an air blast, and one heater supplies two riveting gangs with hot rivets.

The amount of staging required, from which to drive rivets with pneumatic tools, is very much less than is required for hand riveting, as it is only necessary to provide seats or standing room for two men, for which oft-times a single plank suffices. In riveting viaduct towers, laterals in spans, etc., where there are only a few rivets to be driven in a place, the saving on erection of staging alone is a very considerable item.

We now have the air compressor set up in one end of a 50-foot standard tool and material car which, in addition to carrying the compressor, receivers, circulating tanks, and pneumatic tools, serves to transport other tools and rigging from one bridge to another.

We use a Wharton climb-over switch, which is dropped between the rails temporarily, and the car is spurred out on a temporary track, as near to the work as is practicable. This saves the expense of handling and setting up the plant on the ground for each bridge, and is much cheaper.

With plenty of storage room for compressed air, so that the pressure will not run down suddenly, we can operate five riveting hammers at once, with a

12-horse-power compressor or two drills and two hammers without reducing the pressure to less than 75 pounds.

The drills use a great deal more air than the hammers from the fact that they run uninterruptedly, while the hammers when driving 50 rivets of ⅞-inch diameter per minute are using air only about 5 per cent. of the time, which gives the compressor a chance to catch up.

We have a storage capacity of about 80 cu. ft., and I think we could use one or two more riveting hammers by increasing the capacity of our compressed air receivers, as the compressor is frequently cut out by reason of the pressure being at maximum (90 lbs.) and the relief valve open.

With pneumatic tools a great many rivets can be readily driven in places which would be inaccessible to hand tools, from the fact that a rivet can be driven where there is room to insert the hammer, which is about 20 inches long.

The chipping hammer is frequently useful in trimming and capping, and with it all anchor bolt holes in masonry, up to one inch diameter, are drilled by simply inserting an × pointed drill and holding it up to the work. Larger holes are drilled with the heavier hammers. There is a saving of about 25 to 40 per cent. over the cost of hand work in drilling these holes.

In fitting up the work ready for riveting, a reamer is used in the drills, which one man readily handles, and with which all mis-matched holes are reamed, and which insures a full bearing for the rivet and does not burr and separate the plates as is the case where drift pins are used. This, while perhaps not reducing the cost very much, improves the character of the work.

We also use the air drills for boring all bolt holes in bridge floor timbers by inserting an auger in place of the drill. This results in a saving over the cost of hand boring of about 50 per cent., which could be further increased, I think, by using the pneumatic boring machines, which run at higher speed and are more convenient to handle.

The cost of fitting up and riveting on new steel bridges (all rivets ⅞-inch) averages to date 35 per cent. less than if the work had been done by hand for all work done since we have had the pneumatic tools in use. Work now being done with pneumatic plant costs 40 per cent. less than hand work, and we expect to still further increase this percentage as the men become more expert with the tools.

The character of the work is much better than we have been able to do by hand.

In case the work is of too great magnitude for one plant, we install both compressors and combine all of the tools, but usually one plant is sufficient. When not engaged on bridge work, we use our second plant in the erection of steel tanks and in timber work, such as cofferdams, grillages, slip sheathing, etc., where there is a great deal of boring to do. In the erection of steel tanks we use the yoke riveter. For the horizontal seams the yoke is hung on rollers which roll on the top edge of the sheet, and for the vertical seams the yoke is suspended by means of light differential pulleys which allow of adjustment of the yoke to the proper height. The chipping hammers are used for calking.

The saving in pneumatic over hand work on a 60,000 gallon tank is about 25 per cent.

My experience with pneumatic tools has demonstrated to my entire satisfaction that all work to which they are applicable can be done much cheaper and also much better than by hand.

P. S. Edinger, Member of Committee.

With reference to comparison between hand riveting and air machine riveting and drilling, I would say this is a subject where I would consider comparisons odious. I have had one 12-horse-power and one 22-horse-power gasoline compressor at work. The former for nearly two years, the latter for nearly a year on various kinds of work; reinforcing, drilling, riveting and chipping, both in the field and shop. All air work has been done with a most satisfactory measure of economy over hand work. We have done over five or six times as much drilling with a like number of men as we were able to do with rachets, and in places inaccessible to hand rachets, we do over twice to three times as much riveting with air as we can do by hand, and do the work 50 per cent. better. In fact, I cannot say too much in favor of the air machines. They are all that could be desired.

I may add, however, that I have substituted the latest patterns of hammers as fast as they have been improved, and with the best results.

O. J. Travis, Member of Committee.
—*Age of Steel.*

DRILLING AND RIVETING ON THE ELEVATED RAILROAD, NEW YORK.

In connection with the strengthening of the girders on the Manhattan Elevated Railway, which has lately been effected, it was found that considerable economy could be obtained by the use of pneumatic tools, and it was in consequence decided to install a gasoline driven air compressor, together with a pneumatic riveter and a pneumatic drill. The air compressor capacity being limited, the question of the consumption of air of the tools used became of considerable importance, and a riveter made by the Q. & C. Company and a drill made by the Standard Pneumatic Tool Co. were chosen as those satisfying the conditions.

The test for air consumption was made by pumping up the receiver to a certain pressure, then cutting off the compressor and driving the tools entirely from the air contained in the receiver while certain operations were performed. By noting the drop of the pressure the air consumption of the tool while doing the observed work could thus be ascertained by the well known formula of the number of cubic feet of free air contained in the reservoir at different pressures. Thus, supposing the reservoir had a capacity of 10 cubic feet and contained air at a gauge pressure of 90 pounds: This would correspond to an absolute pressure of 105 pounds, or 7 atmospheres absolute, and the number of cubic feet of free air contained in the reservoir would therefore be 70. At a pressure of 30 pounds the same reservoir should be filled with air at a pressure of 3 atmospheres absolute and the cubic feet of free air contained therein would therefore be 30. If in running a tool the pressure were reduced from 90 to 30 pounds, there would therefore have been used 40 cubic feet of free air. While this test is not absolutely correct, since pneumatic tools are usually designed for a pressure of about 80 to 90 pounds, and would consequently work less efficiently at the lower pressures to which the reservoir might be reduced, it offers a fairly accurate comparative test of the different types of tools.

With respect to the riveter: The rivets driven are ¾-inch in diameter in 13-16-inch holes, and in driving 25 rivets the average consumption of free air per

FIG. 368—DRILLING AND RIVETING ELEVATED R. R. STRUCTURE.

rivet was 5 cubic feet of free air. In driving this number of rivets the pressure was reduced considerably, but this may be taken as a fair indication of what is required for this size of rivet with a riveter such as used on this work. When the time of riveting is taken into account occupied by these machines, viz.: about 6 to 7 seconds with this size of rivet, the air consumption as measured corresponds very closely with that figured by the cylinder capacity of the riveter, which is 50 cubic feet of free air per minute for continuous working. The measured consumption, 5 feet in 6 or 7 seconds, is slightly less than this, which is easily accounted for by the fact that there is a certain amount of wire drawing through the ports admitting air to the cylinder at the high velocities at which these machines operate.

The makers of this appliance have devoted considerable attention to the question of pneumatic riveting and have found that the weight of the hammer employed in riveting is an important point with regard to the quality of the work

FIG. 369—RIVETING WITH YOKE RIVETER.

done. If a rivet is hit with a light hammer, irrespective of its velocity, the rivet is flattened out on the end that is hit, but not upset or thickened near the head. In other words, the effect is to squeeze the plates leaving a loose shank. If hit with a slightly heavier hammer, the flattening process is less marked and there is a greater tendency to upset the rivet throughout its entire length, the action being to squeeze the plates and fill the holes. If hit with a very heavy hammer in proportion to the size of the rivet, the head is flattened but slightly, while the rivet is evenly upset throughout its entire length. For these reasons they have adopted a weight of hammer in their pneumatic riveting machines that is practically the same as used in hand riveting.

In a machine for driving ¾-inch or ⅞-inch rivets, the weight of the hammer is 4½ pounds; while in the pneumatic riveter for rivets up to 1¼-inch diameter, a hammer is used weighing 7¾ pounds. With such weights of striking hammers as these, the rivet is not merely flattened only on the head, but thoroughly upset throughout its entire length, and if properly heated, will fill the holes completely, doing work that is equal in quality to that effected by pressure machines.

In pneumatic riveting, it is important that the rivet should be rather differently heated to the way that is usual for hand riveting. They require to be better heated throughout their length and only slightly hotter on the end that is to be driven. The reason for this is, that the best part of the upsetting is done in the first few blows and that if the metal is much softer at the end than toward

FIG. 370—PNEUMATIC RIVETING HAMMER.

the head, the harder metal near the head cannot be upset through the softer. Excessive heat is not required, but simply a more even heat throughout the length of the rivet than in hand riveting. Then again, if the holes are not good, and the rivet when put in is not square with the plate, the riveter should be skewed over so as to drive the rivet back concentric with the hole before hammering is commenced. If the riveter is started working on such a rivet, the first few blows tend to bend the rivet into a still worse shape and it is then impossible to make the head true with the remainder of the rivet.

Dies also require attention: The right size die must be used, or rather the proper length of stock used on the rivet to thoroughly fill the dies, as machine riveting is different from hand riveting in this respect. It is rather similar to pressure work, and if the rivet does not properly fill the die, the edge of the die coming on the sheet prevents the rivet from being thoroughly upset. The Q. & C. Company have given considerable attention to this and other details, such as valves and snap catches, methods of working, etc., and have developed their tools to a point where they are ready to guarantee their machines to drive rivets as large as 1¼-inch in diameter and thoroughly upset them in the sheets, giving results equal to pressure riveting. These tools are all of the valveless type in which the piston controls the admission of air above and below it, and no valve is used except that to turn the air on and off. Such a machine is exceedingly simple in construction and it can be taken apart for cleaning or inspection by the men employed on the work, without the necessity of engaging the services of a skilled mechanic. The construction of these machines admit of the use of a pipe yoke on any gap, some of them being made as large as 10 feet without the slightest trouble. Such a yoke is, of course, exceedingly light, and such riveters are not only especially adaptable to work where the riveter has to be moved about without extensive staging, but frequently it can be used where a machine entailing a heavy or girder form of yoke would be entirely out of the question.

PORTABLE PNEUMATIC RIVETERS IN SHIP-BUILDING.*

Probably the hardest manual labor in all the various operations in building a ship is that of riveting. Combined with this is an amount of technical skill acquired only by long and arduous apprenticeship at the trade, and varying with the class of rivets driven. Like the stone-cutter who can only learn to do first-class work on one particular stone, and is at a loss, for instance, on marble, if trained to granite, so a first-class shell riveter cannot properly drive inside rivets, and vice versa; while the boiler riveter, however good he may be at his own work, is of little use on any part of the ship's hull. With such conditions, a difficult trade to learn, a hard and exhausting one to follow, wearing a man out in his youth, for no one ever saw an old riveter—although in other trades age itself is not necessarily a bar—wages are inevitably high, and most of the work is done by the piece. When the work is to be had, therefore, the riveter makes a great deal of money, but at the expense of his vital energies, which he is too apt to attempt to restore by stimulants, especially as his work is done almost entirely, from the nature of the case, in the open air, exposed to the heat of summer and the cold of winter.

The tools with which he works are furnished entirely by the yard, so that, unlike other mechanics, he is not obliged to have anything of his own, while, as rivets are rivets the world over, little familiarity with the customs of any particular yard is required of him, and he has not much incentive to remain in one place to establish relations of amity and mutual esteem with his superiors.

The riveters, therefore, have been extremely independent, arrogant, and high-handed in their relations with the masters, giving more trouble than all the other classes of labor in a yard put together. In addition to this, the rapidly increasing size of ships, with the corresponding necessity for heavier plating, doublings, etc., requires the use of larger and longer rivets, which cannot be properly closed down by hand, however skilful or willing the men may be.

For all these reasons, in the yard of the Chicago Shipbuilding Company, of which I am the manager, some three years ago a determined effort was begun

* Read at the Fortieth Session of the Institution of Naval Architects.

and an extended series of experiments entered upon to develop machinery capable of being operated by unskilled labor, by which all the rivets in a ship could be driven, which effort has been entirely sucessful, so that in the last ship we have completed there were a little over 250,000 rivets so driven out of a total of 340,000. But for insufficient air supply the proportion would have been greater. The decision to use compressed air for the operation of the machines, instead of hydraulic or electrical power, was made for several reasons. The severe winter climate of Chicago is against the use of hydraulic machinery in the open air, besides which we were aware that hydraulic compression riveters had never made much headway in British yards, though long in the market, and it seemed wiser to try a new line. Electricity, although advancing by leaps and bounds, is an intricate science in itself, with which we are not familiar enough to see much promise in it, and all electrical appliances are very costly and somewhat delicate, apparently unsuited to the rough handling inseparable from ship work. More important, however, was the fact that air can be used for chipping

FIG. 371—SMALL YOKE RIVETER.

and caulking hammers, for drills and reamers, and for hoists, as well as for ventilating and cooling confined places, so that a compressing plant is a necessity in any event, while we, of course, knew that pneumatic compression riveters are universally used and indispensable in American bridge shops.

We had in use already at that time a stationary steam riveter of the ordinary type driving rivets in such proportions of the ship as could be assembled and handled as a whole. Eighteen hundred rivets is an ordinary day's work of ten hours on this machine, at a cost of one-half cent apiece. A very short experience with compression riveters showed that their great weight—reaching over 2,500 lb. for 6 ft. gap—interfered too much with facility of handling to make them either useful or economical. We then turned our attention to the pneumatic hammer, consisting of a cylinder in which a piston reciprocates, delivering an almost continuous series of blows against the end of the chisel, caulking tool, or rivet die. The hammer is light, powerful, short enough to go between frames, and small enough in diameter to get at rivets in corner angle. For small rivets it can be held in the hand, though the work is severe. It is, however, almost impossible to hold on to the rivet by hand, the heavy holding-on hammer being fairly jarred off the head of the rivet by the rivet by the rapidity of the blows from the pneumatic hammer, giving the holder-on no opportunity to bring his tool back into position between blows as in hand riveting.

We quickly devised a simple pneumatic holder-on, however, which admirably serves the purpose, consisting only of a cylinder carrying a piston, behind which air is admitted, the rod extending through the front head and being cupped out to go over the head of the rivet. A piece of pipe secured to the cylinder braces it against any convenient support. Combining these two machines with a yoke, the hammer being mounted on one arm and the holder-on on the other, makes a self-contained machine in which the yoke itself can be made very light, as it has to resist only the pressure of the air against the end of the holder-on cylinder and the reaction of the hammer blows.

Various sizes of these yoke riveters are used, and the weights are as follows for the depths of gap given, the yoke being made of pipe for the larger

FIG. 372—YOKE RIVETER.

sizes:—9 in., 83 lb.; 51½ in., 160 lb.; 70 in., 220 lb. It is very evident, therefore, that these riveters are portable in the highest degree. In fact, in the greater number of places they are moved about by two men entirely by hand, the cross-bar in the throat of those of larger gap forming a slide, and assisting in the movement. Occasionally they are suspended on a trolley from a light framework of pipe. A variation of the device is to mount the hammer in a cylinder as a piston, behind which air is admitted to force the hammer forward as the rivet point is beaten down, the die on the opposite arm of the yoke being then solid, and may be small to get into contracted places. For driving the rivets connecting frames and brackets at the tank top of a double-bottom ship, the yoke is mounted on a pair of rough wooden wheels for ease in handling.

The above descriptions will, I trust, sufficiently make plain our methods for all rivets which can be reached on both sides by a yoke or gap riveter. There remain three classes of rivets in a ship, as follows: (1) Those through decks and tank tops, mostly countersunk, and all driven vertically downwards from above; (2) bulkhead rivets—other than those near the top, or adjoining openings, which can be reached by a yoke—nearly all with full heads; (3) those in the outside shell of the ship, all countersunk. These three classes must be reached by riveters on one side and holders-on on the other, without any connection whatever between them.

The first class are most easily driven, and for them the hammer is mounted on a bent pipe, with a pair of wheels at the bend. The operator raises a handle to bring the flat die on to the rivet, and, the bend of the pipe being loaded with lead, has only to bear down upon it in driving. A second man, with a pneumatic chipping hammer, cuts off the surplus metal, and, the riveting hammer being brought back, a few seconds complete the operation. In this case the pneumatic holder-on is operated from below by a third man, being braced against the bottom of the ship or the next deck below. For the second class, the hammer is fastened to the end of a wooden beam which slides freely on a supporting stud bolted to the bulkhead, an adjustable rod at the other end governing the distance of the hammer from the rivet point. A large number of rivets can be

FIG. 373—LARGE YOKE RIVETER.

reached without shifting the stud. It is necessary, of course, to use the form of hammer described above with the air pressure behind it, and, as the die is cupped out to form the snap point, there is no tendency to slip off the point. The holder-on is mounted in the same way on the other side of the bulkhead.

We now come to the third class, or shell rivets, which in many respects are the most important rivets in the ship, requiring the most careful workmanship and the best finish. It is evident, at the start, that the varying thicknesses of plates, frame flanges and liners, and especially the depth of countersink, render it impracticable to so gauge the length of rivet used that there will always be just enough metal to properly fill the countersink and finish the point, and that, therefore, as in hand riveting, a longer rivet must be used, and after the point is beaten down with the surplus metal crowded off to one side, this surface must be chipped off, and then the point finished up, rounded slightly, and any seams between the rivet and the plate driven together and closed. To do this a certain amount of freedom of motion must be allowed in the hammer, so that its axis may be inclined at a slight angle in any direction with the axis of the rivet itself. This result is attained by mounting the hammer in gimbals on the end of a bar, instead of its being immovably fastened to it, as in the bulkhead riveter. For bottom rivets this bar is attached, by a central bolt on which it revolves, to a trolley running inside a slotted piece of pipe, which is either bolted to the bottom of the ship or held up against it by a simple pneumatic jack at each end. The bar carries at its other end an adjustable brace as in the bulkhead riveter, and there is, of course, an air cylinder behind the hammer to force it in as the point of the rivet is beaten down.

At one setting many rivets can be reached, and the whole arrangement is very satisfactory, a pneumatic holder-on being used inside, and an ordinary pneumatic hammer being used to cut off the surplus metal before final finishing

It is evident that the freedom of movement of the hammer can be secured in other ways, such as a ball-and-socket joint of large radius, but we have found the gimbal mounting more satisfactory, and all that can be desired. While the same arrangement can be used for the side of a ship, it is not very satisfactory there, and a different one is desirable. In this the bar carrying the hammer is vertical, and is fastened to a bored-out tee, sliding freely on a horizontal pipe. This pipe is prevented from moving away from the ship by vertical pieces of bar or angle iron at each end, bolted to the ship parallel to the side and 8 in. or 10 in. away from it. The pipe is hung from pulleys above, and counterweighted so that it moves freely up or down. By the vertical movement of this pipe and the horizontal movement of the sliding tee any rivet can be reached from the gunwale of the lower turn of the bilge, and for a length of about 10 ft., without shifting the rig. Inside the ship a couple of rough wood stanchions are bolted or wedged in position for guides, and a counterweighted piece of 2 in. plank moves against them in unison with the riveter and forms the brace for the pneumatic holder-on, which is easily moved by hand into proper position.

The quality of the work done by all these machines, both inside and shell, is first class in every respect, and far superior to hand work, and such is the unanimous opinion of the inspectors who have been and are on duty in our yard. That this is natural appears from several considerations. The rivets are closed down more rapidly and at a much higher temperature, and, as it is always easy to bring the axis of the hammer in line with the axis of the rivet, and, in fact, natural for the men to so bring it, the rivet is plugged at once by the first blows of the hammer, thoroughly filling the hole throughout, before the point begins to form. The tendency of hand riveters to save labor by forming the point without thorough plugging, leaving a rivet which, though looking all right and passing the tester, is liable to loosen afterwards in service from the constant jar and vibration of the hull, is, therefore, avoided. In many confined places, also, where only one man can strike, and the space for the swing of the hammer is limited to the frame spacing or less, hand rivets are very apt to be poorly driven, but it is evident that such considerations do not affect the machine, and that, if the pneumatic hammer can get to the rivet at all, it is as well put in as in the most open parts of the work.

As to the cost of the work, I submit the following figures, from the last ship completed in our yard:

Inside Rivets.—All ¾ in.

Hand, piecework	25,073	Av. cost,	3.16c
Hand, day work	9,255	"	8.57c
Air	151,167	"	2.06c
Steam	23,544	"	0.51c

Shell Rivets.—⅞ in. and 1 in.

Hand, piecework	51,306	Av. cost,	3.99c
Hand, day work	4,314	"	7.69c
Air	74,493	"	2.96c

The amount that should be added to the machine cost to cover interest, maintenance of plant, and operation of compressor, is undoubtedly much greater than the corresponding amount for hand riveting, which is little beyond hammer heads and handles; but I cannot give it exactly, as we were using much air at the same time for drilling, reaming and caulking, as well as for blowing the

FIG. 375—BABCOCK-GUNNELL SHELL RIVETER.

rivet-heating forges—so much so, in fact, that we exceeded the capacity of the two compressors in use, and not only had to stop putting on more machines and go back to hand riveting, but, for a large portion of the time could not maintain more than 70 lb. pressure in the air mains, which seriously impaired the efficiency of the hammers. We had an air capacity of about 850 cubic feet of free air per minute at 100 lb. pressure, but we have now nearly completed a new compressor of 3,000 ft. capacity, to work at 125 lb. pressure, and anticipate much better results hereafter. It is only fair to call attention to the fact that most lake freight vessels, like the one referred to above, are of very full model, with a large number of frames exactly alike amidships, and that they are launched broadside on, and therefore stand level on the stocks, both of which conditions are favorable to the use of these machines, especially of the shell riveters. Against this, however, it is equally proper to state that much of the development of the inside riveters took place on the boat referred to above, and that the shell riveters had never been tried at all until they commenced on her bottom plating. In the latter case, therefore, all the experimenting and working out of the appliances for rapidly and economically handling the machines, as well as breaking in the men to use them, came on that boat, and the cost appears in the above statement. It must be remembered also that the men who have worked all these machines are not riveters, not even mechanics, but only laborers, and were not on piecework.

The largest rivets we have as yet driven with these machines are 1 in. in diameter. But there is no reason whatever why larger sizes cannot be driven with equally satisfactory results. It is only necessary to use a larger hammer, one of greater diameter and longer stroke. In gasometer work in America, this has been done already with gap riveters and 1¼ in. rivets closed with perfect success, and there can be no question but that a larger size shell riveter will handle rivets of equal diameter with the same facility, the somewhat greater weight of the machine being no disadvantage, as it is counterbalanced and does not come upon the operator at all.

In Chicago we are still experimenting with and developing these tools, and hope to much further increase their efficiency and economy. I have thought, however, that the members of the institution might be glad to know of the results already accomplished in a matter of such importance to shipbuilding.

W. J. Babcock, Member.

NEW PORTABLE PNEUMATIC RAMMER.*

The pleasure I experience in addressing this distinguished company is enhanced by the fact that I am to have the privilege of bringing to its notice an article of such novelty and unquestionable value, that I am sure of your interest and attention.

No doubt many of my hearers have frequently stood over a deep pit in a foundry, and watched with curious interest a gang of laborers ramming up in an aimless, monotonous fashion some large mould, and wondered that in this age of advanced mechanical ideas no one has had the thought to apply to this class of work some device which would take advantage of the great field for economy.

The new rammer which has come in response to this call, is from the brain of a thoroughly practical, mechanical man, whose knowledge of the advantage of labor-saving devices—and the proper application of them, has been derived from a wide and varied experience. The man to whom I refer is Mr. Joseph C. Cramp, Superintendent of the Power and Plant Repair Department of the Wm. Cramp & Sons Ship and Engine Building Company, of this city.

It was, therefore, quite proper and natural that the idea of introducing an article of such mechanical neatness and such commercial value, should have originated in the mind of a thoughtful and practical man.

Convinced that it was in his power to perfect a machine that would be of inestimable value to me in the foundry, I kept nagging at him on the subject, and about a year ago I succeeded in getting him enough interested to put his ideas and thought into tangible shape, the result of which is this Portable Pneumatic

* Paper read at a meeting of the Foundrymen's Association, Philadelphia, April 6, 1898.

Rammer, which will practically revolutionize loam moulding and, to a great extent, large green sand work.

For fully a year, Mr. Cramp worked and puzzled and struggled on; I criticising, Mr. Cramp trying again and again, disappointed but not discouraged, until at last he succeeded in giving me a tool that left nothing to criticise, and the rammer was a success.

The portable rammer consists of two vertical cylinders, held apart by stanchions containing pistons driven either by steam or compressed air, which is regulated by a simple but ingeniously contrived Corliss valve. The size of the cylinder is 3½ inches, the length of stroke is 4½ inches, and with an air pressure of 35 lbs. per sq. inch at the piston, it strikes 200 blows per minute, each blow with the butt rammer head covering an area equal to seven times the area of an ordinary hand-rammer.

This device which at once may suggest itself as scientific and practical, is suspended from a turnbuckle which is attached to a trolley on movable crane, to enable it to move with perfect ease to any portion of the pit to be rammed. Power is supplied through a flexible hose, tapped from the main pipe, running the entire length of the foundry. The crane is portable and can be shifted to any column, thereby covering any spot in the shop.

For the last three months it has been in successful operation every day ramming up moulds of all manner of shapes and sizes, and weights; indeed, it seems almost impossible to describe and explain the vast amount of work it does and labor saved. There are very few moulds that I have ever seen that cannot by this tool be rammed up in one day. I am at present making some very large pumps that require a pit 30 feet long, 14 feet wide and 8 feet deep. According to our regular practice it would take about 25 men three days to ram it up ready for casting. I very easily, with two machines and 12 men, rammed it up in one day—not only saving in money paid for labor, but casting two days earlier, thereby saving considerable time in the room occupied by this mould. I also find that it increases the capacity of my ovens, for I am able to cast the moulds faster after they are dried, and do not have to wait for floor space to put the moulds after they are dried.

The rammer itself is very simple, and has never as yet gotten out of order, but is always ready. There are no break-downs, nor giving out of little things, which very often occur in new mechanical devices, and cause constant irritation to a foreman.

Most any loom mould can, with four men be rammed up in a day. By this I mean any large mould say 10 feet in diameter and 6 to 8 feet deep; of course, small ones can be rammed up correspondingly quicker, and the ramming is more even and far superior than that done by hand, as you all know laborers, when ramming a mould, do so in a sort of aimless way. When the foreman's back is turned, the blow struck is not very hard, and very often the casting strains considerably. Any casting rammed up by this tool will be fully 10 per cent. less in weight than when rammed by hand. I have been able to materially reduce my laboring force since using the rammer, and the running expenses of the shop, for when I have no ramming to do the machine is idle, and at no cost, whereas when hand is used you have the men around the shop drawing their pay just the same. Any tool in a shop to-day that will allow you to do away with men is a money saver even if it does not do work any cheaper, for the correct and great idea in the management of any business to-day is, to have as few men as possible in your shop when you are able to supplant them by modern tools, for there are always lulls and times when you have surplus labor. It may be for a couple of days, or it may be for a few hours—we try to keep men employed on odds and ends because we see we will want them in a few days. I know every foreman present will concur with me on this point.

I have been experimenting with the rammer mostly on ramming up loam moulds, but since it has proven its great value there, I have lately been introducing it on large green sand work. In bedding in large green sand work, you all know the main point is to have a good, evenly rammed bed under it. Thus the rammer will do far superior and far quicker work than by hand.

In regard to the firmness of the ramming, it is at once made self-evident when you come to vent your bed, and all doubt will at once leave you as regards the evenness and hardness of the ramming. Anyone present who has made large castings in green sand will at once fully appreciate the ramming of the bed in two to three hours that ordinarily would take two moulders and helpers one to two days, and then not done as well as when using the rammer.

I am at present having some pneumatic rammers made to put on in place of the butts. I will then commence ramming the moulds up completely with the machine. Such is my faith in it, that I have no doubt that in a few months all of my large castings in green sand will be rammed up with this new tool; that is, with the exception of the cope. How many of you present have hoisted out a large casting, and after digging out the pit, taken out your cinders and plates, have found a large hole in your floor confronting you. You may need this floor space badly, but you have no men to spare to ram it up, and you either have to do it at night, or wait until you can spare the laborers to do it. Now, right here is where the rammer comes in. You can always spare two men—one to run the machine, and one to fill in the sand—and in a very short time you have your pit rammed up even with your floor; there being no soft places for the next casting put there to strain, but a good, hard, evenly rammed floor.

With this rammer, whether the force of the blow is equal to 300 pounds or one pound, which can be very easily regulated by the turnbuckle, every blow struck will be of uniform force, consequently the sand will be rammed evenly, and with the same force throughout every inch of its surface, and no straining of the metal in casting can possibly occur.

Another strange thing about the rammer, although you use it for ramming up your moulds, you can change it and use it to dig your pit out, by simply putting on a rammer with prongs. This will go around and break up the sand so that it can be very easily shoveled out. Instead of having hard digging, you simply have shoveling.

I have already touched lightly on the advantage of reducing as much as possible the froce of the men employed in a foundry or, in fact, in any establishment, and if you will permit me to enter a little more deeply into this subject, I will give you some reasons.

First of all, because of the fewer men you employ the smaller and less complicated is your pay roll; the more will your foreman be relieved from enforcing discipline and surveillance, and be able to devote his time to perfecting their work; there will be less likelihood of strikes occurring, and the less damage if they should occur. A machine that will do the work of a man in the same time is more valuable than that man. Now this tool will do the work of 15 or 20 men, and not only do it better, but in far less time, and when done you simply close a valve, and it is at rest until you need it again.

Before I close, allow me to express a few thoughts on the subject of compressed air. I mentioned that this rammer could be run either with air or steam; but for ramming in a foundry compressed air is far better power. The day is not far distant when it will be more widely used in all of our foundries. The pneumatic chipping tool has come to stay, and although my first experience with it was not favorable, I have changed my mind since getting the right tool, and I can fully recommend its utility and cheapness in chipping castings. The sand blast is another appliance that can economically be attached to any air compressor and do good work. Most of you appreciate the use of air hoists, and I think a traveling crane will, in most foundries give more satisfaction than one run by electricity, for the simple reason that a crane run by air is not so complicated, and does not need such skilled labor to run it or keep it in strict repair. Most any machinist understands air, and very few electricity. In our foundry this is not so apparent, as we have a corps of electricians at work all the time on the ships, and these are at my disposal at once, in case of a break-down; but I presume most of the foundries are not so well favored.

My idea in mentioning the use of air is to bring to your notice the fact that the installing of an air plant to run the rammer is a very useful and paying investment, for you will be greatly surprised at the many things to which you will constantly be applying this power.

In conclusion, allow me to thank most sincerely the officers of this Association for their polite invitation, the members of this beautiful club for the privilege it affords, and to you gentlemen, for your marked courtesy and kind attention.

The pneumatic rammer is now being manufactured by J. W. Paxson & Co., Philadelphia, Pa.

George C. Matlack.

COMPRESSED AIR RIVETING PLANT.

An interesting application of the use of compressed air may be seen a short distance out from the Erie Railroad depot at Jersey City. The Erie Railroad is elevating its tracks through the city, and at every street crossing there is an iron bridge. The work of riveting these bridges until recently has been done by hand, with the usual results that a gang of two men and two boys will drive on an average of 300 rivets a day of ten hours. The rivets to be driven are five-eighths inch and seven-eighths inch diameter.

A compressed air riveting plant has now been substituted for the hand riveters with the result that one man and three boys are driving 1,200 five-eighths inch and 1,000 seven-eighths inch rivets a day, with less effort and in a much more satisfactory manner.

The plant has now been in operation about one month, and so far has proved to be reliable and entirely satisfactory. It consists of a Fairbanks-Morse direct connected gasoline engine air compressor of 12 B.H.P., capable of delivering 70 cu. ft. of free air at 80 lbs. pressure per minute. The compressor is mounted in a box car, together with the water-cooling tank, fuel supply and air receiver. The car is drawn up on a side track near the work and the hose carried up on the structure. This arangement is clearly shown in engraving. The car will be seen at the left in the cut, while the men at work with the pneumatic riveters are in the foreground.

The compressor is fitted with an automatic unloading device which opens the air cylinder exhaust to the atmosphere when the receiver has reached the re-

FIG. 376—RIVETING ON BRIDGE ERIE R. R. ELEVATION. POWER OBTAINED FROM GASOLINE AIR COMPRESSOR IN BOX CAR TO THE LEFT.

quired pressure; the engine governor then acts and cuts down the fuel supply, the speed of the engine remaining constant.

The pneumatic riveters used are those of the Chicago Pneumatic Tool Co. They are somewhat larger than the usual hammers and are designed to set up seven-eighths and one-inch rivets. The air used in one of these hammers is 25 cu. ft. per minute.

There is also at work a Chicago piston pneumatic drill with which the holes are reamed out true before the rivet is inserted. This drill works very rapidly, and one man readily replaces four men using the old drift pin method of aligning holes.

It will be seen from the foregoing that the seventy-foot compressor plant here used will handle two of the large riveters and one drill.

The fuel cost of delivering 70 feet of free air per minute at 80 lbs. is approximately 12 cents per hour. The gasoline used is what is known as 74° common stove gasoline.

DRIVING DRIFT PINS WITH A NEW DEVICE.

An interesting labor-saving appliance which we describe and illustrate, has lately been put into practical use by Mr. D. E. Moran, M. E., of New York.

The contractors for the new water works for the city of Cincinnati had to build a caisson 130 ft. in diam. x 3 ft. thick. The platform of this caisson was made of timber and required about 70,000 drift pins 1 in. diam. x 30 in. long to

FIG. 377—DRIVING DRIFT PINS BY A COMPRESSED AIR DEVICE. WOOD BORING MACHINE IN THE DISTANCE.

make it rigid and to hold the timbers in position. Originally the work of driving the drift pins was done by hand and it took a gang of three laborers, each paid $1.50 per day, to drive 200 drifts per day. The holes for the drifts were drilled with several "Phœnix" Pneumatic wood boring machines built by the C. H. Haeseler Co., of Philadelphia, one of which is shown in operation on right hand side of cut. The depth of these drift pin holes was 34″ by $\frac{15}{16}$″ diameter, or in other words, 4″ longer and $\frac{1}{16}$″ smaller than the pins themselves.

Mr. Moran, not satisfied with the progress of the work, conceived the idea of using an Ingersoll-Sergeant rock drill to dispense with the manual labor of hammering. He mounted a 3⅛ in. drill on a derrick, as shown on the illustration. The piston of the drill carried a hammer striking on an anvil, whose bottom was cupped and placed directly over the drift. By means of a double windlass the drill could either be raised or lowered and the total weight of the drill, with partial weight of the frame, would prevent any recoil when striking. The anvil being cupped at the bottom keeps the drill always central above the drift, and by means of this appliance he was able to drive an average of 800 drifts per day with three men, while only 200 could be driven by hand, this being done at the same expense with the exception of compressed air power for running the drill. The cost of the power, however, was insignificant, as the company building the caisson have several large air compressors used for other purposes.

The frame supporting the drill being mounted on wheels, is easily moved from one drift pin hole to another, and we are informed that the total cost of the frame, with mountings above the original cost of the drill, did not exceed $75. Thus, it will be seen that this simple method has not only saved the contractors about $2.00 per 100 drifts to be driven, but that it has increased the capacity, or, in other words, decreased the time of building the caisson some 75 per cent. We are also informed that the drill did better work than that done by hand labor, as the drifts driven mechanically were never bent, while by hand driving they were very often bent and tops bruised and required considerable labor and loss of time for straightening and final driving home.

A COLLECTION OF BLACKSMITHS' TOOLS.

An interesting feature of the last annual convention of the National Railroad Master Blacksmiths' Association was the introduction and description to the members of a large variety of labor-saving appliances which one or other of the members had devised for assistance in his daily work. Naturally most of these devices were in the line of forms for bending, shaping, upsetting and riveting, for use on those parts of locomotive and car work upon which a large number of processes are necessarily duplicated, and in most instances the tools form a part of the equipment of a pneumatic bulldozer or hammer, also of home production. Photographs and descriptions of several of these appliances have been collected from the secretary and members of that association and are presented here as containing valuable suggestions to those who are engaged upon similar work.

FIG. 378—A PORTABLE PNEUMATIC BULLDOZER.

FIG. 379—PNEUMATIC RIVETING ON DRAWBAR POCKETS.

FIG. 380—TOOLS USED WITH PNEUMATIC BULLDOZER.

Figures 378 to 381 of the accompanying illustrations show a pneumatic machine, a collection of formers for use with it, and some specimens of work done. This machine is in use at the shops of the Pittsburg & Lake Erie Railroad at Pittsburg, in the blacksmith department, under the direction of Mr. A. W. McCaslin. The pneumatic bulldozer was built of scrap or useless material on hand, and consists of two 16-inch cylinders placed tandem fashion on a frame made of two 10-inch I-beams, each 8 feet in length, with a piece of 80-pound rail riveted on the inside of the web of each beam. The frame is covered with a wrought-iron face plate. The piston rod is 4 inches in diameter, and with an air pressure of 125 pounds an effective or working pressure of 25,000 pounds is obtained from each cylinder, or 50,000 pounds from the two cylinders. In using two cylinders upon a machine of this character, Mr. McCaslin states that he finds it more satisfactory to place them tandem rather than side by side, for the reason that the presure from both is in a direct line. This is particularly valuable in upsetting, a class of work for which the machine finds the greatest demand, and which is not always satisfactorily met by the steam hammer.

The machine is capable of eight strokes per minute, and the output of any class of article depends upon the heating capacity and the activity of the operator.

Figure 378 shows the machine in position for bending the lips on drawbar yokes. The V-shaped die connected to the piston rod has a cutter upon one side, which shears off any surplus iron which may result from the bars not being cut off to the exact length required. For this purpose Mr. McCaslin originally used a tool with compound levers, by which means a pressure of 100,000 pounds was obtained. With this arrangement the lip was formed satisfactorily, but it was impossible to prevent the upsetting of the bar in the clamp in which it was held. In Fig. 380, numbers 9 and 10 are tools for forming the yokes themselves, form No. 9 having a bent yoke upon it and the crown-retaining lever lying in front of it.

In Fig. 379 the same machine is shown as arranged for riveting drawbar yokes. The hinged apron receives the drawbar as it is dumped from a truck. The air hoist, which is suspended above the machine, lifts the apron with the drawbar and throws the latter into position for receiving the rivets. The latter are 1⅛ inches in diameter. When the riveting is completed the apron is lowered as it was raised. It is stated that with 50 pounds' air pressure 150 yokes can be riveted in ten hours, and the operation involves no lifting by hand.

Figure 380 shows a group of forms for various purposes, the number of which is being constantly increased. No. 1 is a tool for upsetting a 1⅛-inch ball on the end of ⅝-inch round iron for grab-irons. No. 5 (with O representing the piston rod) is for completing grab-irons. The capacity is 200 from the bar in ten hours. No. 2 is for upsetting the ends of 1¼-inch truss rods. The capacity is 400 in ten hours, or as many as can be handled. No. 3 are forms for bending brake lever carriers. These have rollers in the angle or bearing ends, as has also No. 10, previously mentioned, to lessen friction on the iron. No. 6 are the forms shown on Fig. 381 for bending lips on drawbar yokes. No. 8 is a tool for forming, cutting or unlocking pin levers, and No. 10 (next to No. 9) is the tool in which the connecting end of the lever is formed, and which is bolted to an angle on the face plate of the machine. No. 11 is for forming brake-hanger stirrups. This is the ordinary hand tool, with auxiliary levers for connecting it to the piston crossbar. No. 12 is for upsetting heads on 1¾-inch king or centre pins. The rate is one per minute. Nos. 13 and 15 are adjustable tools for bending arch-bars of any size or to any angle. No. 14 is the piston crossbar to which the movable parts of all formers are bolted. This has rollers on the under side and prevents the piston from turning. Nos. 20 and 21 are yoke-riveting cup tools.

There are many other tools of similar character used with this machine, such as key-way punches, formers for car steps, coach steps, drawbar carriers and air brake work. Fig. 381 shows samples of a variety of the work done and also an axle straightening lathe and crane combined, which have been built at the same shops.

Fig. 382 is a machine for similar work, which was built by Mr. J. E. Mick, of the Baltimore & Ohio Southwestern, at Chillicothe, O. Dies for making draw-

FIG. 381—AXLE STRAIGHTENING LATHE AND SAMPLES OF BENDING.

bar pockets and nearly all kinds of plain work have been made for use with it, and some of the varieties of finished parts are shown in the engraving.

Mr. John Coleman, of the Chicago & Northwestern shops at Clinton, Ia., devised the hammer shown in Fig. 383 for use at the spring fire in drawing and clipping spring leaves, holding down bands while the sides are driven to place, as with a screw press, etc., and a variety of similar light work, in which it has come to be recognized as one of the most useful tools in the shop. The cylinder is 6 by 22 inches and the weight of the hammer and piston rod 300 pounds. It is used with an air pressure of 90 pounds.

The secretary of the Master Blacksmith's Association, Mr. A. L. Woodworth, of the Cincinnati, Hamilton & Dayton, at Lima, O., is the designer of the group of tools shown in Fig. 384. The most conspicuous tool in the engraving is a former for bending corner steps for freight cars, the lever at the left of the figure being removed to show the construction of the dies. When in use the bedplate of the device is clamped to an anvil, as shown. The movement of the levers bends the blank to form the horizontal part of the step, and the offset on each arm catches the blank as the lever closes against the bed, thus turning it down at the end to whatever distance may be desired. Both ends are bent and turned at the same time. With the size of iron used, ⅜ by 2 inches, it is stated that from 250 to 300 steps are made by two men in a fair day's work. It is the intention to apply air power and thus about double the capacity. A sample of the finished product is shown in the foreground at the right.

The tool at the left of the engraving is for bending eyebolts, brake-hanger hooks and the like. The lever in which the iron is held has a slot for that purpose, and is pivoted at the end by a lug, which passes through the bedplate and is

FIG. 382—PNEUMATIC PRESS FOR BENDING.

fastened by a cotter pin. The other lever is held by a stationary pin, which forms the pivot on which it swings. This lever carries a roller. In operation the iron is placed in the slot and a slight movement given to the slotted lever brings the body of the bolt central with the eye. The longer lever, with its roller resting against the iron, is then carried around, wrapping the blank around the stationary pin forming the eye. This tool is also clamped on an anvil when in use, and from 40 to 50 ¾-inch eyebolts may be made in an hour by one man.

The tool just to the right of the anvil is a very successful device for bending collars for the heads of drawbar stems. The size of iron used is ⅝ by 1½ by 8 inches long. The mandrel around which the collars are wrapped is 2⅛ inches in diameter and has a lever to hold the iron in place while being bent. The lower end of the mandrel passes down through a hole in the plate, as shown.

The device is operated by air. The levers which are attached to the piston rod of the air cylinder have at their opposite ends rollers carried by 1¼-inch bolts passing through curved slots in the bed. As soon as the blank is wrapped around the mandrel until the center is reached, the curved slots bring the rollers in close

FIG. 383—PNEUMATIC HAMMER FOR SPRING WORK.

together behind the mandrel, thus making the blank form a perfect circle. The mandrel is then raised, and the collar falls off. The capacity is limited only by the capacity for heating.

The tool to the extreme right is precisely similar in principle, except that it works under the steam hammer, and is intended for bending brake-hanger loops.

In use the plate is bolted in an upright position to the bottom die of the hammer, and the arms are hinged to the upper die. The rollers are flanged in order to hold the iron close against the plate while bending.

A considerable number of other tools of a similar class have been developed as a result of a necessity for rapid work in the various railway blacksmith shops of the country. An indication of the extent to which such tools have been put in service is shown by the statement of one railway blacksmith that he has in his shop nearly 3,000 forms for bending, forging, etc. The above are given as sug-

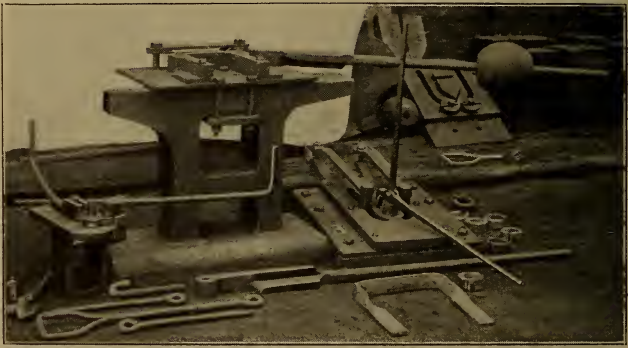

FIG. 384—TOOLS FOR BENDING STEPS, EYEBOLTS, ETC.

gestive of the ease with which a shop equipment may be increased with small initial expense.—*Railway Age.*

THE THOMAS PNEUMATIC SYSTEM OF HANDLING RAILWAY SWITCHES AND SIGNALS.

The fundamental feature of this system is the manipulation of the valves admitting air to and exhaust it from the working cylinders of railway switches and signals by means of pistons of the equalizing type, the pistons being actuated by a sudden increase or decrease of the air pressure.

SWITCHES.

Fig. 385 is axial section of valves for admitting air to and exhausting it from the working cylinders of switch, and also shows section of reservoirs 6 and 6^1.

Fig. 386 is cross-section.

Fig. 387 is top view of reservoirs and valve seats.

Fig. 388 is axial view of working cylinder and top view of chests and reservoirs.

When switch is in its normal position, pressure in controlling pipe 4, chest 5 and reservoir 6, is at 70 lbs., the pressure in chest 5 and reservoir 6 having equalized with the pressure in controlling pipe 4 by means of equalizing port 7;

chest 5 and reservoir 6 are in communication by means of passages 3, Fig. 387. The pressure in controlling pipe 4^1, chest 5^1, and reservoir 6^1, is at 80 lbs., these pressures having equalized through feed port 7^1, Fig. 385, and ports 3^1, Fig. 387. Under these conditions, piston 8 is to the right; and F end of cylinder 1, Fig. 388 is in communication with the atmosphere by way of port 9, slide valve 10, and exhaust port 11. Piston 8^1 is also to the right, and B end of cylinder 1 is in communication with main supply 12, by way of slide valve 10^1 and port 9^1. In order to reverse the switch, pressure in controlling pipe 4 must be increased, and as the increase takes place more rapidly than air can flow through equalizing port 7, piston 8 is moved to the left, taking slide valve 10 with it, thereby admitting air at 80 lbs. pressure from main supply 12 to F end of cylinder 1; at the same time pressure in controlling pipe 4^1 must be reduced, and as the reduction takes place

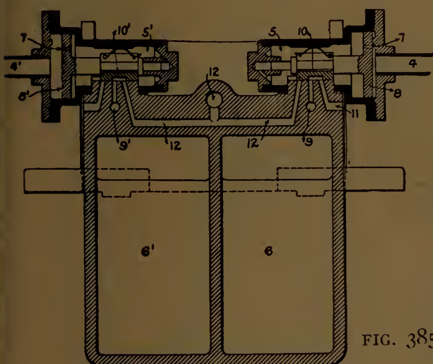

FIG. 385.

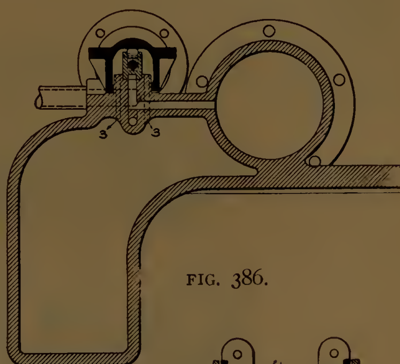

FIG. 386.

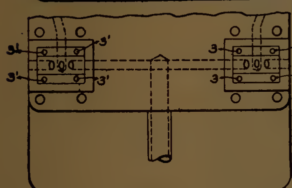

FIG. 387.

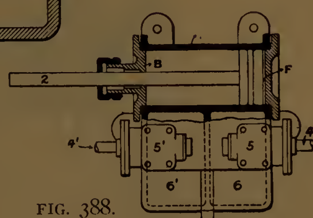

FIG. 388.

RESERVOIRS AND VALVES.

more rapidly than air can pass through equalizing port 7^1, piston 8^1 is moved to the left, valve 10^1 is carried with it, and air is exhausted from B end of cylinder 1, and switch goes over. Reservoirs 6 and 6^1 are added to increase the capacity of chests 5 and 5^1 respectively. The minimum pressure in controlling pipes is 70 lbs., the maximum pressure 80 lbs.

To the frame of interlocking table in tower is attached a switch controlling valve 13, view of which is shown at Fig. 389. Port 4 is connected to controlling pipe 4,, and port 4^1 to controlling pipe 4^1 of Fig. 385. Ports 15 and 16 are each connected to a cast iron reducing reservoir located at some suitable point in tower; port 17 is the exhaust. With operating lever 18 in its normal position, slide valve 14 takes the position as shown in drawing, and air from main supply

19 flows into controlling pipe 4^1. Controlling pipe 4 is in communication with reducing reservoir 15; reservoir 16 is in communication with the atmosphere by way of exhaust port 17. When it is desired to reverse the switch, valve 14 is moved upward, thereby closing communication between body of chest and con-

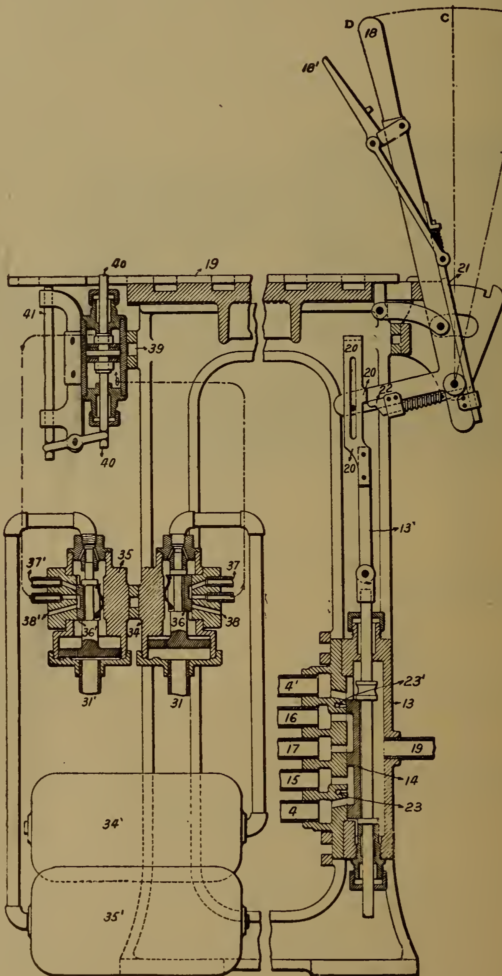

FIG. 389—SECTION OF INTERLOCKING TABLE.

trolling pipe 4^1 and reducing reservoir 16 and as all of the air has been exhausted out of reservoir 16, air from controlling pipe 4^1 flows into this reservoir, thus reducing the pressure in controlling pipe 4^1; at the same time valve 14 uncovers port 4, and pressure in controlling pipe 4 is increased to 80 lbs.; reservoir 15 is also put in communication with the atmosphere, thus exhausting the air out of said reservoir. The reservoirs should be of such size as to reduce the pressure in the controlling pipes about 10 lbs. when communication is established between them.

In order to accomplish the interlocking, it must be so arranged that lever 18 and its tappet 19 must make but one-half of their stroke unless the switch has properly responded, therefore, slide valve 14 must be shifted its full throw during the first half of the stroke of lever 18, said lever to have a silent movement in passing from its C to its E position, at least so far as slide valve 14 is concerned. To the upped end of valve stem 13^1 is secured piece 20. When it is desired to reverse switch, latch lever 18^1 is brought up against lever 18, thus raising latch 21 out of notch in quadrant and putting latch 22 in engagement with lower part of projection on 20. After valve 14 has traveled its full throw, it strikes against stop in chest, thus preventing lever 18 from going further than its C position; latch lever 18^1 is then released and latch 22 is disengaged from 20, after which lever may be taken to its E position, if switch responds properly. When it is desired to put the switch back to its normal position, latch 22 is brought into

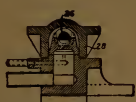

FIG. 391.

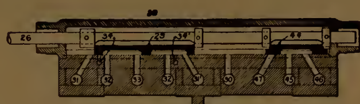

FIG. 390.

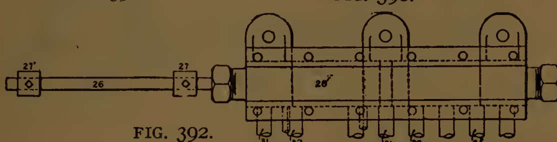

FIG. 392.

SWITCH APPARATUS—INDICATION CHEST.

engagement with top of projection on 20; valve 14 is shifted to its normal position, thus reducing pressure in controlling pipe 4 and increasing pressure in controlling pipe 4^1. Valve 14 is moved its full throw by the time lever 18 reaches its C position. Latch 18^1 is now released and lever may be brought to its D or normal position, provided switch has properly responded.

SWITCH INDICATION.

As it is of utmost importance that there be no question as to whether a switch responds properly or not, two indication pipes are used, it being impossible to get the proper indication with one pipe, for at one move or the other the indication would have to be gotten by reduction of pressure, and as this reduction might be the result of a leak, a false indication would be gotten. With two indication pipes, in one of which the pressure must be reduced and the pressure in the other increased in order to give the indication and release the lever, a false indication cannot be gotten. At Figs. 390 and 393 is shown the apparatus at switch for giving indications. The switch and lock movement has 8 inches stroke, whereas the switch points have only 4 inches, therefore bar 24, Fig. 393, moves 2 inches before the points begin to move and 2 inches after the points are up. To bar 24, which is coupled direct to piston rod 2, is bolted arm 25. Through the outer end of the arm passes valve stem 26, the stem being provided with adjustable knockers 27 and 27^1. With switch in its normal position, slide valve 29, Fig. 390, takes the position shown; chest 28 is supplied with air at 80 lbs. pressure through connection 30, and as indication pipe 31, leading from switch to tower, is in communication with body of chest, it contains air at 80 lbs. pressure. Indication pipe 31^1 being in communication with reducing reservoir 32^1, contains air at 70 lbs. Port 33 is exhaust. Attached to the locking table in the tower (see Fig. 389) are two valves, 34 and 35, and tappet locking device 39. With switch in its normal position, indication pipe 31, valve 34 and reservoir 34^1 contain air at 80 lbs. pressure, and slide valve 36 has established communication between main supply and lower end of cylinder 39, forcing its piston upward. Indication pipe 31^1, valve 35 and reservoir 35^1 contain air at 70 lbs. pressure, and slide valve 36^1 has exhausted

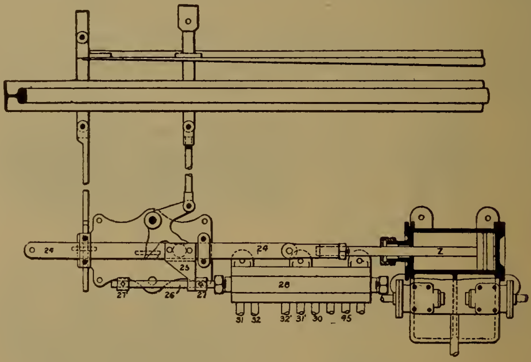

FIG. 393—SWITCH AND LOCKING APPARATUS.

air from upper end of cylinder 39. Rod 41 is so connected to piston rod 40 that when 40 moves downward, 41 moves upward, and vice-versa.

Fig. 394 shows relative position of tappet and locking pins with tappet, lever and switch in their normal position.

Fig. 395 shows relative position of tappet and locking pins with lever and tappet in their C position, should switch fail to respond.

Fig. 396 shows relative position of tappet and locking pins in their C position, if switch responds properly and lever free to be moved to its E position.

Fig. 397 shows relative position of tappet and locking pins with tappet, lever and switch in their reversed position. It will be noted that pin 41 is ready to stop tappet at half-stroke should switch fail to respond when lever is brought from its E to its C position.

Should lever 18 be brought from its D to its C position and switch fail to respond, it would be impossible to complete the stroke of the lever or its tappet 19, as edge 42^1 of slot 42, Figs. 394, 395, 396 and 397, would be brought up against piston rod or pin 40. If switch responded properly, arm 25, Fig. 393, would strike knocker 27^1, valve 29, Fig. 390, would be forced to the left, indication pipe 31 would be put in communication with reducing reservoir 32, and pressure reduced to 70 lbs.; indication pipe 31^1 would be put in communication with body of chest 28, pressure would be increased to 80 lbs., and air would be exhausted out of reservoir 32^1 through exhaust port 33. A reduction of pressure in pipe 31 would cause piston of valve 34 to move downward, and slide valve 36 would exhaust air from bottom end of cylinder 39, an increase of pressure in indication pipe 31^1 would move piston of valve 35 upward, and slide valve 36 would admit air into upper end of cylinder 39, thus lowering pin 40, Figs. 389, 394 and 395, out of engagement with notch 42 and raise pin 41 into notch 43 on opposite side of tappet 19 (see Figs. 396 and 397). The lever can now be put in its reversed or E position. With locking pins in position shown at Fig. 397, pin 41 is ready to stop tappet at half-stroke should switch fail to respond when lever is brought from its E to its C position.

It might be well to add just here that, to interlock the levers of the machine, the beveled type of locking is used; hence, if lever cannot be fully reversed, it locks all levers with which it is interlocked.

Reservoirs 34^1 and 35^1 are used to increase capacity of valves 34 and 35 respectively.

TWO-POSITION SIGNALS.

Fig. 398 is general arrangement of parts on mast.
Fig. 399 is indication chest.
Fig. 400 is vertical section of signal valve and cylinder.
Fig. 401 is cross section of signal valve, cylinder and reservoir.
Fig. 402 is top view of valve seat.

With signal in its normal position, controlling pipe 1, chest 2 and reservoir 3 (see Fig. 401), contain air at 70 lbs. pressure, the equalization between controlling pipe and chest having taken place by means of equalizing port 5, and the equalization between chest 2 and reservoir 3 having taken place through ports 6, Fig. 402; piston 7 and slide valve 8 are to the left, air is exhausted out of operating cylinder 9, and counterweight 10, Fig. 398, has brought blade to its horizontal or danger position. To put signal to safety, pressure must be increased in controlling pipe 1, and as the increase takes place more rapidly on the controlling pipe side of piston 7 than it does on the opposite side of said piston, piston is forced to the right, carrying with it slide valve 8; exhaust port 11 is closed; air from main supply 12 is admitted by way of port 13 to operating cylinder 9, and blade is brought to its vertical or safety position. Reservoir 3 is added to increase capacity of chest 2.

Signal controlling valve 16 (see Fig. 403) is bolted to frame of locking table; 1 is controlling pipe leading from tower to signal; 25 is port leading to reducing reservoir 25^1, 26 is exhaust. With valve 17 in the position shown, controlling pipe 1 is in communication with reducing reservoir 25^1, and pressure in controlling pipe is at 70 lbs. To put signal to safety, valve 17 is brought to its highest position and air at 80 lbs., pressure flows from body of signal controlling valve 16 into the controlling pipe, thus increasing the pressure, and, as heretofore explained, signal goes to safety. To restore signal to danger it is only necessary to put valve 17 in the position shown at Fig. 403, thereby establishing communication between controlling pipe 1 and reducing reservoir 25^1, air flowing into this reservoir reducing the pressure in controlling pipe; piston 7, Fig. 400, is shifted to the left, carrying its slide valve with it, thus exhausting the air out of working cylinder, and counterweight takes signal to danger.

SIGNAL INDICATION.

Assuming that it is more important to know that a signal resumes its danger position than it is to know that it goes to safety, the indication for signals has been arranged so that an increase of pressure must take place in the indication pipe before the lever operating the signal can be brought near enough to its normal position to unlock conflicting levers.

Valve 27, Fig. 399, controls the pressure in the indication pipe 28, leading to tower; 29 is main supply; 31 is exhaust; 30 is port leading to reducing reservoir 30^1, located at foot of mast. With signal in its normal position, indication pipe 28 is in communication with main supply, hence contains air at maximum pressure. Controlling pipe 28 is connected with indication valve 32 in tower (see

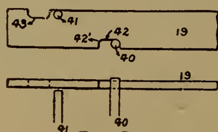

FIG. 394.

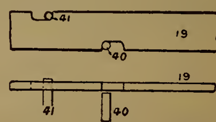

FIG. 396.

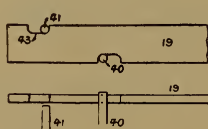

FIG. 395.

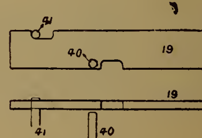

FIG. 397.

POSITION OF TAPPET AND LOCKING PINS.

Fig. 403); 33 is connection to reservoir for increasing the capacity of chest 32; 34 is main supply; 35 leads to upper end of cylinder 37; 36 is exhaust.

Fig. 404 shows relative position of tappet and locking pins with tappet, lever and signal in their normal position.

Fig. 405 shows relative position of tappet and locking pins with lever and tappet in their C position should signal fail to go from danger to safety.

Fig. 406 shows relative position of tappet and locking pins with tappet and lever in their C position and free to be moved to their E position, signal having gone from danger to safety.

Fig. 407 shows relative position of tappet and locking pins with lever and tappet in their reversed position and signal at safety. It will be noted that pin 40 is ready to stop lever at its C position as it is being moved from E towards D if signal does not go to danger.

As heretofore stated, indication pipe 28 contains air at 80 lbs. pressure when signal is at danger; chest 32 and reservoir 33^1 also contain air at 80 lbs. pressure. Under these conditions piston 32^1 of valve 32 is in its highest position, and air from main supply 34 is admitted into upper end of cylinder 37, forcing locking pin 40 down and locking pin 41 up. When lever 18 is brought to its C position, valve 17 has moved its full stroke; said valve is then dropped, and if signal responds properly, slide valve 27^1, Fig. 399, reduces the pressure in indication pipe 28 by establishing communication between said indication pipe and reducing reservoir 30^1, Fig. 398, piston 32^1 of valve 32, Fig. 403, is actuated, air is exhausted out of upper end of cylinder 37, and spring 38 forces locking pin 41 down out of engagement with slot 43, and locking pin 40 up and into engagement with slot 42 (see Fig. 406), and lever and its tappet is now free to move to its E position. Should signal fail to respond properly, pressure in indication pipe

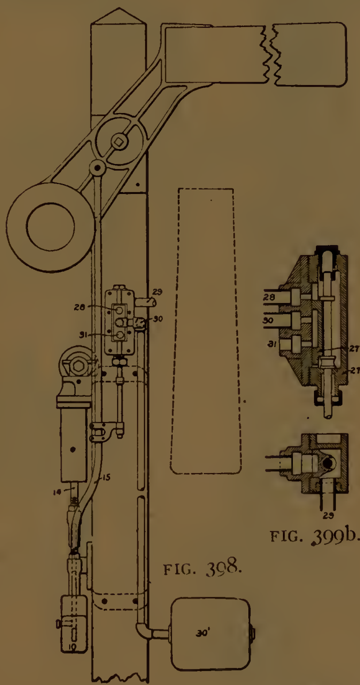

FIG. 398.

FIG. 399.

FIG. 399b.

SEMAPHORE OPERATING PARTS.

28 would not be reduced, air would not be exhausted out of cylinder 37, locking pin 41 would not be withdrawn from slot 43, and lever 18 could not be moved beyond its C position (see Fig. 405). If after lever is brought from its E to its C position, signal should fail to go to danger valve 27^1, Fig. 399, would not be shifted, pressure in indication pipe 28 would not be increased, equalizing piston 32^1 of valve 32 would not be actuated, upper end of cylinder 37 would not be charged with air, pin 40 would not be withdrawn from slot 42, Fig. 406, and lever 18 and its tappet could not be moved beyond its C position, and all conflicting levers would remain locked.

THREE-POSITION SIGNAL.

With lever and controlling valve in their normal positions, controlling pipe 1, which leads to equalizing valve operating the signal from its danger to its caution position, and port 4, which leads to equalizing valve operating signal from

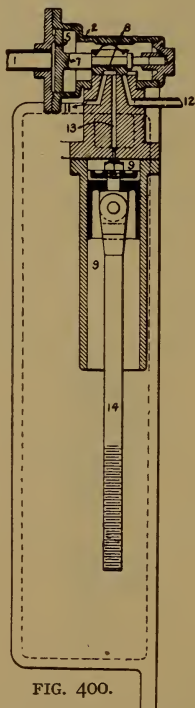

FIG. 400.

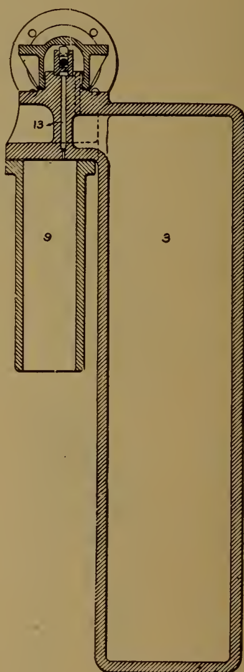

FIG. 401.

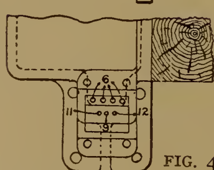

FIG. 402.

SIGNAL VALVE AND CYLINDER.

its caution to its safety position are in communication with reservoirs connected to ports 2 and 5 respectively, and contain air at 70 lbs. pressure, any leaks in the pipes being supplied by ports 39 and 39^{1}.

To bring signal from its danger to its caution position, valves 17 and 17^{1} are moved a half stroke and air at 80 lbs. pressure passes from body of chest, through port 18 in slide valve 17 to controlling pipe 1, equalizing piston on mast is actuated and signal goes to its caution position; at the same time ports 2 and 3 are put in communication and air is exhausted out of the reducing reservoir of controlling pipe 1. If it is desired to give a caution position, latch lever 18^1, Fig. 403, is released, and lever 18 is carried to its reversed position, in order to get the

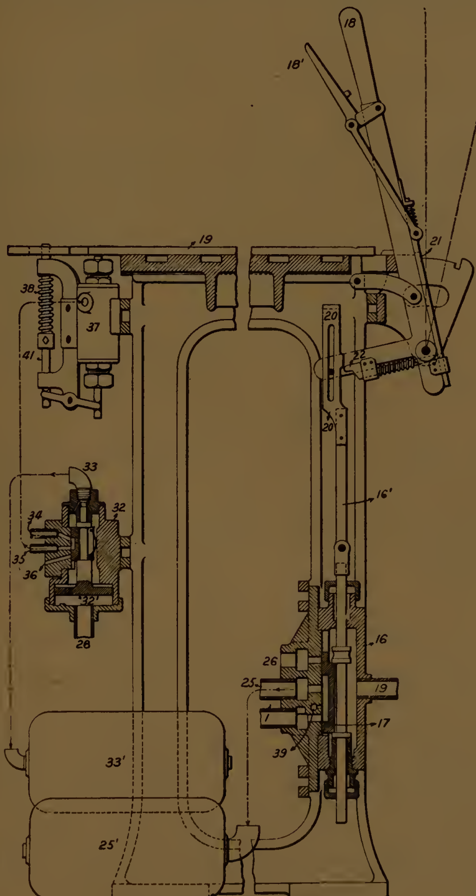

FIG. 403—SIGNAL CONTROLLING VALVE.

necessary locking. This cannot be done, however, until the proper indication is gotten, showing that the signal has reached its caution position. If it is desired to give a safety signal, latch lever 18^1 is not released, but after indication is gotten, showing that signal has reached its caution position, slide valve 17 and 17^1 are moved the remainder of their stroke, and air at 80 lbs. pressure from body of chest passes into port 4 and from thence to equalizing valve which operates the signal from its caution to its safety position; at the same time ports 5 and 6 are put in communication and air is exhausted out of reducing reservoir of controlling pipe 4 into the atmosphere through exhaust port 6.

The equalizing valves, reservoirs and operating cylinders on the mast are duplicates of those used for operating two-position signals, but are coupled as shown, in order that both cylinders can be used in manipulating the blade.

PNEUMATIC SELECTOR.

A pneumatic selector is provided by adding slide valve 44 to indication chest (see Fig. 390). The controlling pipe from tower runs to an equalizing valve similar to signal equalizing valve No. 2, Fig. 400, this valve being fastened by means of a bracket to valve 28, Fig. 390. Port 13 of the equalizing valve leads to port 45, Fig. 390. With switch in its normal position, main supply would pass through port 13 of equalizing valve 13; thence to port 45 of selector slide valve; thence by way of port 46 of selector slide valve to the cylinder of one signal. If switch was in its reverse position, main supply from port 13 of equalizing valve would go to cylinder of the second signal by way of ports 45 and 47 of slide valve 44, Fig. 390.

Where selectors are used, one signal equalizing valve handles two or more signals.

PNEUMATIC SLOTS.

A pneumatic slot is provided by running the controlling pipe from one tower to the back of the controlling valve of a second tower, and introducing a check to properly control the current of air. A leak in this check does not affect the working of the slot, from the fact that a leaky check valve will not allow the increase and reduction of pressure to take place fast enough to operate the equalizing signal valve.

LOCKING DOGS.

Switches and signals must respond properly before levers operating them can be fully reversed. It is obvious that lever can be brought from its D to its C position, which, as heretofore explained, should operate the switch or signal, and that, while the switch or signal is moving, the lever can be returned to its E or D position. Take signal lever for example: When lever is brought from its D to its C position, signal should go to safety. Now, while the increase of pressure is taking place in the controlling pipe, signal is moving from danger to safety, and the decrease of pressure is taking place in indication pipe; there is nothing to prevent lever being returned to its D position, the locking pin striking the bottom of the tappet. Signal lever and its tappet would then be in their normal or danger position and the signal at safety. To obviate this, it must be so arranged that after a lever has been started from its normal or reversed position, it cannot be returned to either of these positions again until it has made full stroke backward or forward, as the case may be. To this end, pawl and ratchet arrangement shown at Fig. 408 is used.

K-L is slot in side of quadrant M; 1 is pin passing through and secured to lever; pawl N is pivoted to outer end of pin 1 and engages with ratchet Q. The lower end of pawl N is pivoted to rod P; rod P has spring P^1. Rod P engages with eye bolt, the bolt being fastened to quadrant. As lever is being carried from its D to its C position, that part of pawl marked N^1 engages with teeth in ratchet Q. If after lever is started from its normal position, any effort is made to return the lever to its normal position before it is carried to its E or reversed position, N^1 engages with the teeth and prevents the movement. When lever reaches about three-quarter stroke, pawl N strikes pin R^1, the position of pawl is reversed, and that part of pawl N″ engages with the teeth in the ratchet and will prevent lever after having been once moved from its E or reversed position, being returned to that position until it has moved to its D position.

LEAKAGE.

As it is almost a matter of impossibility to keep the pipe lines perfectly tight, a system of feed ports have been introduced whereby the low pressure pipes are supplied with air at minimum pressure—that is, 70 lbs. As signals are kept at danger except when they are lowered to permit a train to pass, and as when signals are at danger the indication pipes are in direct communication with the

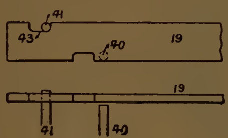

FIG. 404.

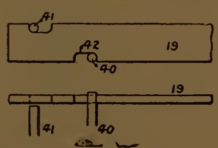

FIG. 406.

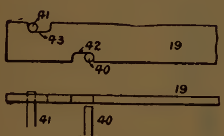

FIG. 405.

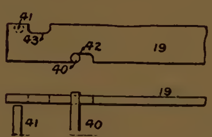

FIG. 407.

POSITION OF TAPPET AND LOCKING PINS.

main supply, and as the indication pipes are only cut off from the main supply when the signals are at caution or safety, it has not been found necessary to arrange to take care of the leakage in the signal indication pipes. See ports 23 and 23^1, Fig. 389; 34 and 34^1, Fig. 390; 39, Fig. 403. Without some method of providing against leakage the switch or signal could be gotten over the first time almost as quickly as though the pipes contained normal pressure, but we would have to wait until the pressure behind the equalizing pistons reached something over 70 lbs., before switch or signal could be moved again.

SIMPLICITY.

As will be seen from the foregoing explanation, there is no delicate or complicated mechanism to get out of order, and that the apparatus does not require delicate adjustment. Springs perform no important function. If thought advisable, those on the signal indication pins can be discarded and weighted levers substituted; but as they are made amply strong, are in full view, and can therefore be easily inspected, there is no reason why they should give rise to trouble.

Absence of electric and hydraulic apparatus contributes largely to the simplicity of the system.

SAFETY.

The pressure must be increased or decreased suddenly, otherwise the equalizing piston will not be actuated. A reduction or increase of pressure caused by a leaky slide valve will not actuate these pistons. To demonstrate this, one of each of the slide valves was made to leak very badly, the leak being very much greater than if valve was permitted to run for years without attention. In each

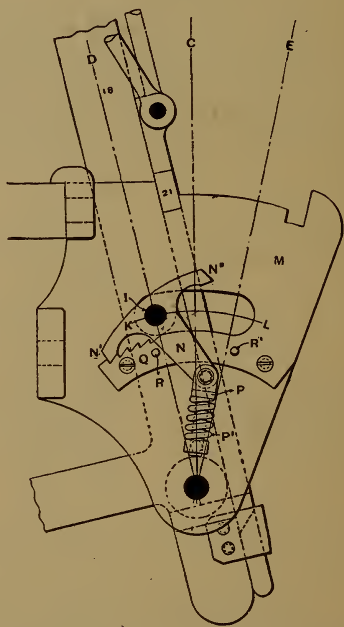

FIG. 408—PAWL AND RATCHET ARRANGEMENT.

instance the increase or reduction of pressure caused by such leaks failed to actuate the equalizing pistons.

Should the high pressure controlling pipe of a switch, or a switch indication, spring a leak, and the pumps or compressors be unable to maintain the pressure against such leak, the switch will not fly over, nor will a false indication be given, for in order to get switch over or to get an indication, a sudden increase of pressure must be had in the low pressure pipe. Should the controlling pipe of a signal spring a leak, and the pumps or compressors be unable to maintain pressure against such leak, the signal will go to danger. It will be remembered that it is necessary to increase the pressure in the signal indication pipe to get tappet unlocked so as to put lever in its normal position.

An experimental plant consisting of 8 levers, handling
2 Switches,
1 Cross-over, and
7 Signals, was put into operation Dec. 1st, 1894. Three-quarter inch gas pipe was used for controlling and indication pipes. No effort was made to protect the pipe lines, most of them being laid on the surface of the ground. With the thermometer at 10° below zero, no trouble was experienced with ice closing up the ports or passages, or causing the equalizing pistons to stick. A careful search was made, but not the slightest particle of ice could be found in any of the valves or passages. With the yard flooded with water to the tops of the ties, the switches and signals responded without interruption. Two 9½″ Westinghouse pumps were used to compress the air for this plant. A ¼″ cock

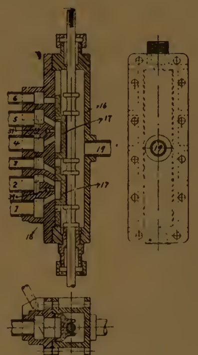

FIG. 394—CONTROLLING VALVE, 3-PISTON SIGNAL.

was left wide open on a pipe line of a signal 1,000 feet away and even with this leak, the signal and its indication responded promptly.

Below is given the time consumed in operating the switches and signals, including indications for same, this record having been taken from the switches and signals comprising the experimental plant:

SWITCH.

100 feet away	0.8	seconds.
250 "	1.05	"
500 "	1.75	"
750 "	2.5	"
1,000 "	3.1	"

SIGNALS.

100 feet away	1.25	seconds	(high)
300 "	1.1	"	(dwarf)
350 "	1.34	"	(high)
500 "	1.91	"	"
1,000 "	3.07	"	"
1,500 "	4.00	"	"
2,000 "	5.56	"	"

It is not necessary to wait for pressure to equalize. By actual test, a switch was handled as follows:

250 feet away....................28 times per minute.
300 " ....20 " "

A signal was handled as follows:

300 feet away....................28 times per minute.
1,000 " ....20 " "

HANDLING SWITCHES AND SIGNALS.

The Nashville, Chattanooga & St. Louis Railway has six interlocking towers between the Union Passenger Station at Nashville and its shops, two miles distant, equipped with the pneumatic system of handling railway switches and signals, as devised by Mr. J. W. Thomas, Jr., and described in our October (1897) issue, page 954. These plants have 176 working levers, handling—

35 Switches,
19 Cross-overs,
4 Derails,
123 Signals, and
9 Crossing gates.

There is in use—

3½ miles of 3″ main,
2 miles of 2″ supplemental main, and
37 miles of ¾″ pipe; the ¾″ pipe being used for operating the switches and signals, and getting indications from same.

Each tower is a block station, and we give below a statement of the trains handled between Union Passenger Station at Nashville and the Centennial Grounds, the railway terminal station being opposite their shops, for the six months ending October 31st, 1897:

TABLE 74—STATEMENT OF TRAINS HANDLED BETWEEN NASHVILLE AND SHOPS—1897.

Month.	No. of Trains.		Av'ge per Day.		Av. per W'rk Day.		Highest any Day.	
	Single Track.	Double Track.	Single Track.	Double Track.	Single Track.	Double Track.	Single Track.	Double Track.
May	7,136	6,639	230.2	214.2	253.3	230.3	284	263
June	7,356	6,892	245	229.7	266.5	247.2	292	280
July	7,431	7,357	239.7	234.9	259.7	255.5	278	275
August	7,357	6,942	237.3	223 9	260.5	247.5	273.	257
September	7,306	6,839	243.5	227.9	262.5	243.5	274	260
October	7,599	7,106	245.1	229.2	269.5	253.4	314	306
Total, 6 months	44,179	41,775						
Ave. per month	7,363	6,962	240.1	226.6	262	246.2		

These trains were handled by signals, no train orders having been issued. Notwithstanding the fact that the system was entirely new, was put up hurriedly, and the signalmen had very little previous training in interlocking work, the traffic was handled without accident, the maximum delay to any train being six minutes.

Length of section of single track............ ½ mile.
Length of double track...................... 1½ miles.

481,525 passengers were handled between the Union Passenger Station and the Centennial Grounds, none of whom received the slightest injury.

THE LYMAN PNEUMATIC CROSSING SIGNAL.

The Lyman Pneumatic Signal Company, of New York City, is now bringing out its patent air compressor or pump, track instruments and other necessary

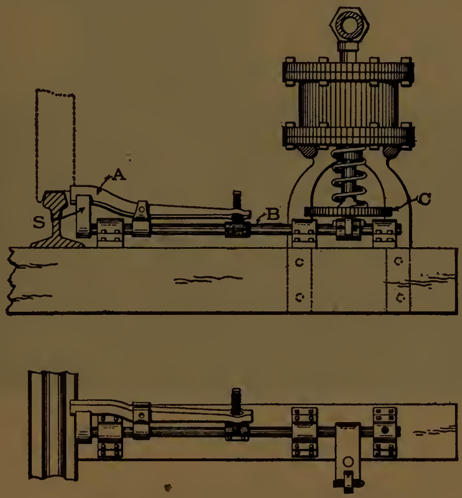

FIG. 409—LYMAN AUTOMATIC AIR-COMPRESSOR.

devices for ringing a highway crossing bell by means of compressed air, and it is announced that one of the bells has been in use for several years on the Delaware, Lackawanna & Western, at Sherburne, N. Y. The bell or gong is rung by an electro magnet in the usual way. The battery and wires are all within the signal box, and the electric circuit is closed by the piston of an air cylinder, which is moved by an air impulse transmitted through an underground pipe from the compressor, located at the distant point. The compressor is actuated by the wheels of passing trains. The amount of pressure required is so small and the adjustment of the apparatus is so sensitive that eight wheel contacts are more than sufficient to set the bell ringing; in other words, an engine and tender alone will furnish ample power to compress the necessary quantity of air.

The principal parts of this signal are shown in the accompanying drawings. Fig. 409 represents the compressor and track instrument, and Fig. 410 is a perspective of the same. The pump shown in Fig. 410 is the one which has been in service four years at Sherburne. The latest pattern is somewhat different in some of its details, it being found unnecessary to have so high a cylinder. Fig. 411 shows the arrangement of cylinders in the signal box at the crossing and Fig. 412 shows the connections to these cylinders and to the bell.

Referring now to Fig. 411, N is the cylinder by which a train from the north sets the bell ringing, and S is actuated by trains coming from the south. The function of cylinder C is to stop the ringing of the bell, and its piston is moved

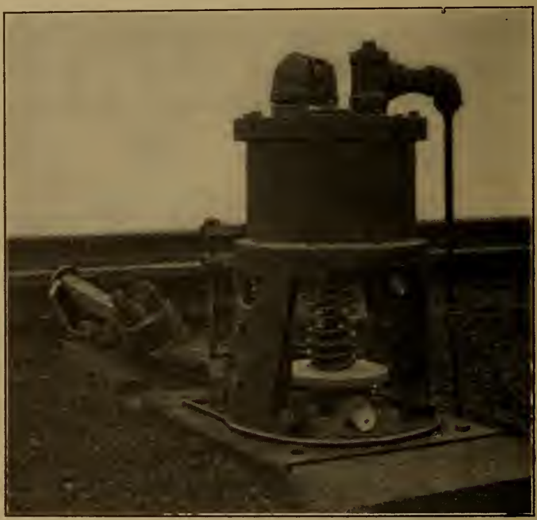

FIG. 410—LYMAN AIR-COMPRESSOR FOR HIGHWAY CROSSING SIGNAL.

by a pump fixed close to the crossing. On single track it is of course actuated by trains in either direction.

An impulse of air coming through n lifts the piston in N and, by means of rod 3, closes the electric circuit which rings the bell. The bell rings as long as the piston of N remains up and this time is governed not only by the length of the train that sends the air impulse, but also by the fit of the piston and the size of the air-escape, which can be adjusted for any desired length of time. When the piston in C is lifted it forces air into the upper ends of N and S and at the same time lifts pins 1 and 2, by which valves a and b are opened, exhausting the pressure in the lower ends of the upper cylinders. The reference letters N, C and S in Fig. 412 have the same general meaning as the same letters in Fig. 411.

The pump (Figs. 409 and 410) was designated so as to give a piston stroke of four inches, but experience showed that with a piston 10 in. in diameter a stroke of 3/8 in. is sufficient, and in the new design the cylinder is made much shorter. As before stated, the shortest possible train furnishes all necessary power to close the bell circuit. Relief valves are provided where necessary to prevent excessive pressure in cylinders.

The track level or bar A (Fig. 409) is designated for use on a single track road, being so adjusted that trains going in one direction have no effect on the pump. The inclined position of this lever is best shown in the perspective, Fig.

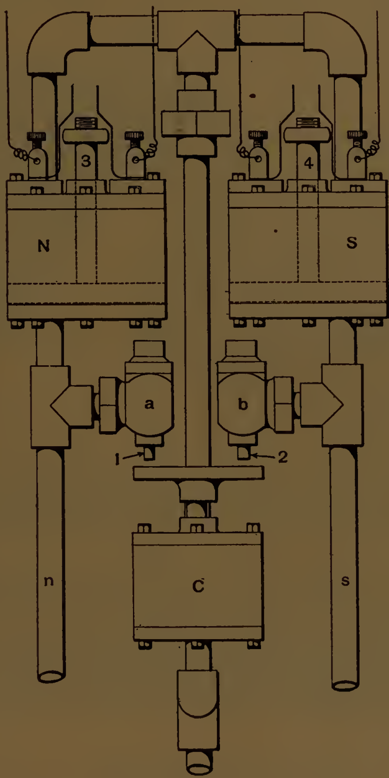

FIG. 411—CYLINDERS FOR PNEUMATIC HIGHWAY CROSSING SIGNAL.

410. The wheels of a train running from right to left (Fig. 410) press against the bar and push it forward, revolving the shaft B (see Fig. 409) and lifting the plate C. A train running from left to right pushes bar A into the slot in S, leaving S and B motionless.

The signal at Sherburne is in constant use and the officers of the railroad company give a good account of it. It is, of course, unaffected by lightning or stray electric currents.

The inventors of this signal have also patented apparatus by which a track instrument and a pump of the kind shown can be used to automatically close and open a highway crossing gate; and to make the use of an automatic gate feasible they use an ingenious ball and socket joint, so that if the gate, in coming down, should strike a man or a horse the blow would be harmless. This is accomplished by making the outer end of the arm (the end farthest from the standard and nearest the center of the street) very light, and joining it to the heavier portion by a joint so controlled by springs that the arm would yield on slight pressure and would move upward or outward. In case a pedestrian or a teamster should be caught between closed gates he would naturally try to escape, and if he should press through the gate the arm would yield without breaking. On both single

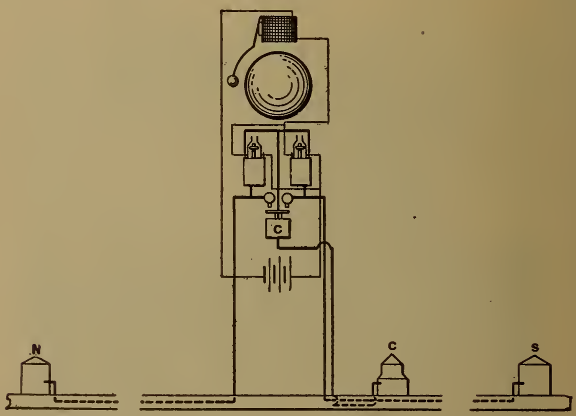

FIG. 412—CONNECTIONS FOR PNEUMATIC CROSSING SIGNAL.

track and double track lines the gates are so arranged that if a train moving away from the crossing actuates the cylinder to open the gates, while a second train is approaching, the latter train holds the gates closed.

A large model of this signal, and also one of an automatic crossing gate, with a miniature locomotive to set the apparatus in operation, is now on exhibition at the company's headquarters, 80 and 82 Fourth avenue, New York City. There is also shown in the model the necessary apparatus to work an automatic block signal system on the same principle employed in the other devices.—*Railroad Gazette.*

PNEUMATIC INTERLOCKING.

It has been the custom for many years to operate the switches and signals of large and important track systems from a central point, in order that greater economy and efficiency in train service might be secured than was possible under the primitive method originally employed, which entailed the use of many men moving continuously from switch to switch, and a diversity of hand signals and targets that, to say the least, were confusing and oftentimes misleading to enginemen.

In concentrating the operation of switches and signals, an important adjunct to their safe operation, heretofore impracticable, became possible; switch and signal levers were readily made to interlock one with another so that a signal could be given for a train to proceed over a given route only after all switches in it were securely set and locked for the safe transit of the train over them. Conversely, a signal giving a train right of way over a route, locked against operation all switches in it until the signal was withdrawn. This method of operating switches and signals is known in railroad vernacular as an "Inter-

FIG. 413—BOSTON SOUTHERN STATION—WESTINGHOUSE INTERLOCKING SYSTEM DURING FEBRUARY (1899) STORM.

locking." The apparatus by which they are moved is termed an "Interlocking Machine," and the structure in which it is located, an "Interlocking Tower."

The levers of an interlocking machine are usually mounted in a cast iron frame secured to the framework of a tower, and are massive affairs connected with the switches by one-inch pipe lines, which are moved longitudinally by the levers in suitable guide rollers or pipe carriers arranged to support them at short intervals upon suitable foundations, carefully set as to alignment. Signals are likewise operated, frequently, but more generally by means of heavy iron wires suitably supported in anti-friction carriers upon stakes or iron straps extending from the pipe line supports.

However carefully applied and however well designed the appliances of such a system, it is found entirely impossible to operate from a single lever, in large plants, all of the devices that are permissible of such operation, owing to the excessive load they would present to the operator if thus connected. It, therefore, is customary to perform by the operation of two, three, four, and occasionally five levers the work that could be performed by a single one were the operator's power unlimited. When this fact confronted the man who virtually made the hand brake

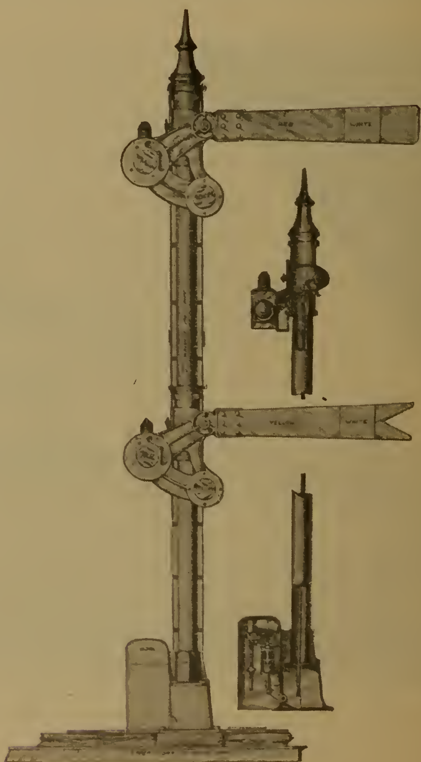

FIG. 414—PNEUMATIC SIGNAL SHOWING OPERATING CONNECTIONS.

a "5th wheel" on passenger coaches, by adapting compressed air, in the hands of one man, to the duties formerly performed by the muscular energy of several, it is not surprising that his attention was turned toward relieving the labor and expediting the manipulations performed in interlocking towers.

With the experience that brought the air brake to its present state of perfection as an encouragement to the undertaking, the development of the Pneumatic Interlocking System was begun by Mr. George Westinghouse, Jr., in 1881, as president of The Union Switch & Signal Co. of Pittsburg, Pa.

After years of laborious and costly experiments, and notwithstanding a very general distrust of the system during its experimental stages, its development was carried through successfully, and to-day it is the system employed at the leading terminal stations in this country and at many minor places. Its introduction at the new Southern Station in Boston has been attracting widespread interest at home and abroad, chiefly because of the magnitude of the station itself, but largely because of the great area and facilities of its track system and of the complexity of the interlocking necessary to handle it. The tracks included in the interlocking system contain 31 double slip switches, 31 pairs of movable frogs and 52 turnouts—the equivalent of 238 ordinary switches. Eleven trains may move simultaneously into or out of the train shed; 148 semaphore signals are provided for the 400 possible routes presented in the switch system.

Each switch and signal is connected directly to the piston of a pneumatic cylinder secured to its support; each cylinder is provided with a valve controlling the admission and discharge of air to and from it. These valves are shifted by electro-magnets under the control of the interlocking machine which consists of diminutive levers each arranged to rotate a shaft through an angle of 60 degrees when operated, and to thereby shift electric contacts arranged thereon so as to produce the desired conditions of the valve magnets (to which they connect) and consequently the desired movements of the switches and signals.

These shafts are also adapted to move bars lying at right angles to and above them, which extend from end to end of the machine, and which by a system of "cross locks" are made to interlock one with another in the manner customary in other and earlier types of interlocking machines. The extremities of these shafts are engaged by the armatures of electro-magnets which are controlled by the switches or signals operated, and which are so actuated and controlled by the latter that the levers and the devices operated by them must coincide in position before a clear route can be produced.

A minature model of the track plan is mounted vertically upon the machine frame, the switches of which move to correspond with those in the yard as the levers are operated, and give at all times a correct representation of the track connections.

The signals are mounted generally upon iron truss bridges, 9 of which are used for their support at the new station. They are of what is termed the "Semaphore" type, consisting of an arm or blade pivoted to a post and extending to the right as viewed by enginemen approaching it. When horizontal this arm signifies danger and is so held by a heavy counterweight normally. When declined 60 degrees from the horizontal it signifies safety and is thus moved, in this system, by action of the compressed air upon the piston of its operating cylinder. This arm carries two colored glasses: a red one before a lamp at night is displayed when at danger and a green one when at safety. From Fig. X a better understanding of this device may be had. The electro-magnet M is in direct control of the interlocking machine. When de-energized its armature is held from the magnet by the spring S and the action of the compressed air upon the valve stem E, formed by the rod extending from the armature into the valve chamber. The pin valve P is likewise held seated by the same forces, shutting off the escape of the air from chamber C to chamber C', the latter being normally connected through the open valve E with the atmosphere, as is also the signal cylinder port S P.

When the magnet is energized the valve stem E is depressed closing the exhaust port E P and opening the pin valve P so that the pressure is permitted to enter chamber C' and consequently the cylinder of the signal, the effect of which is to cause the piston to be depressed and the signal operating rod to be elevated,

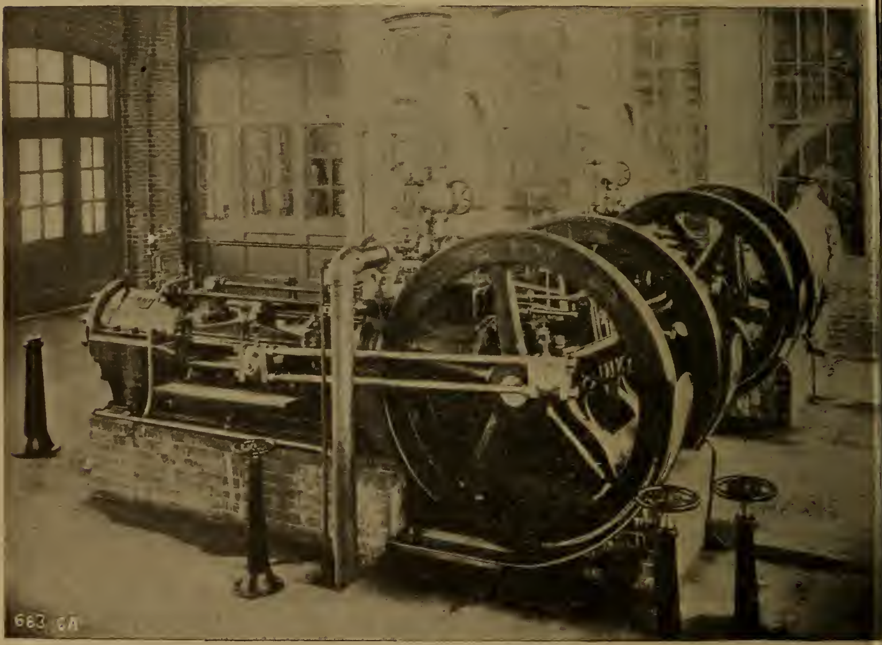

FIG. 415—COMPRESSORS IN POWER HOUSE.

with the result that the counterweighted end of the signal is likewise elevated and the blade lowered to safety.

When the magnet is de-energized the valves assume their normal positions and the air escapes from the signal cylinder, the signal moving by gravity back to danger.

The switch cylinders are double acting and therefore require two such magnetic valves, one controlling the presure at one end of the cylinder and one at the other.

Owing to the large volume of air used in the larger cylinders of the switches, these magnetic pin valves do not give direct admission and discharge of the air to and from the cylinders, but control small auxiliary cylinders which shift a D-valve capable of more readily controlling the pressure to and from the switch cylinders.

This D-valve is further provided with a plunger which engages it and prevents its movement unless the plunger is first withdrawn. The withdrawal of this plunger is effected by a third magnetic valve and auxiliary cylinder and the three magnetic valves are controlled by three separate wires extending from them to contacts of the interlocking machine.

The D-valve lock is a precautionary device entirely and is introduced simply to remove as far as possible the likelihood of a false operation of a switch

FIG. 416—PNEUMATIC SWITCH MOVEMENT COVER REMOVED.

from unusual conditions and from extreme neglect to properly maintain it in normal order.

The switch cylinder operates with an 8-inch stroke a specially designed movement which gives motion to the switch during the forepart of its movement and locks it in position during the last part of it. It also gives motion during its entire stroke to a bar pivotly mounted along the outside of the switch rails that is known as a "Detector Bar," and which is designed to prevent the movement of a switch under a train passing over it, or standing upon it. This bar rises immediately above rail level at the beginning of the piston stroke and before the switch is moved at all; a train upon the switch rails prevents the elevation of the bar and consequently the movement of the switch.

Under each switch cylinder is placed a cast iron reservoir directly connected with the main pressure pipe of the system; from the reservoir an armored hose connection extends upward to the switch valve and forms an elastic medium through which the valve is supplied with compressed air, thus avoiding all risk of injury to the pipe fittings and valves due to change of track alignment, and to the vibration of trains passing over the switches operated.

The compressed air is generated in the company's power house by one or the other of two Ingersoll-Sergeant Piston Inlet Compressors of 14 in. diameter

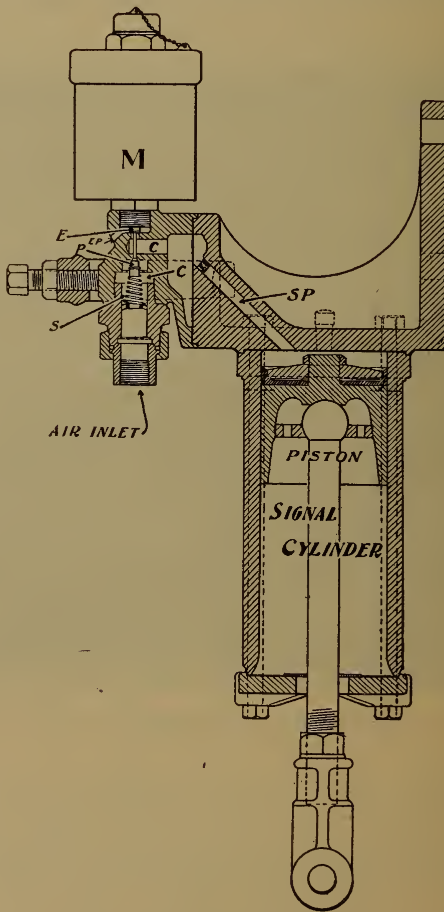

FIG. 417—SIGNAL CYLINDER.

and 18 in. stroke, each capable of pumping 150 cubic feet of free air per minute—an amount vastly in excess of that required for the interlocking system, but an amount of great value in the event of an emergency that momentarily might exhaust the supply in storage. These compressors are therefore running at their minimum speed, about 30 revolutions, instead of at 120 revolutions, their maximum speed,—normally. Each compressor discharges the air as compressed into receiving tanks from which it is conducted to a third receiver before passing through a system of manifold pipes of large radiating surface for reducing it to atmospheric temperature before entering the supply main, and for precipitating the moisture contained in the heated air at a point convenient for its removal periodically. J. C. Coleman.

THE USE OF COMPRESSED AIR IN THE FREIGHT YARD OF THE LAKE SHORE AND MICHIGAN SOUTHERN RY. AT WEST SENECA, N. Y.

A modern freight yard cannot be considered complete unless it is provided with a compressed air plant for testing the brakes on cars when made up into trains before departure, and also for use on the repair track, both for testing brakes and for facilitating the work of repairs. With such a plant the inspectors and repair men have compresed air "on tap" at all times and are, therefore, not compelled to wait for the locomotive to be attached to the train before it can be tested, thus eliminating all delays and having the train ready to leave when the engine is attached.

About three years ago the Lake Shore & Michigan Southern R. R. Co. established at West Seneca, near its eastern terminus, a new freight yard, in which a compressed air plant was installed which meets all requirements in this line.

Compressed air is furnished by a duplex compound air compressor, having a capacity of 342 cubic feet of free air per minute. It is located in the machine shop near the round house and delivers the air into a storage reservoir of about 100 cubic feet capacity located outside of the building. This storage tank is chiefly for the purpose of equalizing pressure and for collecting moisture, for the larger part of the storage capacity of the plant is contained in the 25,000 feet of distributing pipes which are laid through the repair and inspection yards and have a volume, approximately 3,000 cubic feet. A safety valve is provided on the storage tank, which limits the pressure to 105 pounds per square inch, although a regulator on the compressor controls the pressure in such a way that there is seldom, if ever, any use for the safety valve.

The main feed pipe is 2 inches in diameter and is laid on top of the ground, where possible, and boxed in, to a point near the yard office, from which branch pipes of 1½ inches diameter extend to the repair and inspection yards.

The repair yard consists of six tracks, in two groups of three each, the entire space being planked over level with the top of the rail. Four lines of 1¼ inch pipe are laid through this yard, located midway between the tracks and fastened to the planking by ⅜ inch staples, each group being provided with a cut-out cock, so that it can be shut off for repairs without affecting any of the other lines. Connections for attaching hose are provided at every 50 feet, and are made of 1-inch Westinghouse hose coupling threaded and screwed into 1-inch cut-out cocks, and connected to tees in the pipe lines by nipples. These connections are protected from the weather when not in use, by cast iron boxes, which are shown in Fig. 418, and will be described later.

In the repair yard compressed air is used for testing the brakes on cars, and also for raising cars, which is done by means of pneumatic jacks, consisting of a case iron cylinder (Fig. 419) provided with a piston, the rod of which extends through the top head and is provided at its end with a recessed casting which bears against the sills of the car when in use. Air is admitted under the piston by a ½-inch pipe provided with a cut-out cock; the inlet port in the lower head has in it a small check valve which prevents the air from escaping through the inlet pipe should a leak suddenly occur; to lower the piston the air is released by a separate pipe and cock. Two jacks are used to a car and they are connected to the air supply by hose, joined together by a Y-shaped nipple, so that each jack gets the same pressure and the car is raised equally on both sides. Two sizes of jacks are in use, 10 inches in diameter for light cars, and 18 inches for loaded ones. The larger jacks are mounted on wheels to provide an easy means of mov-

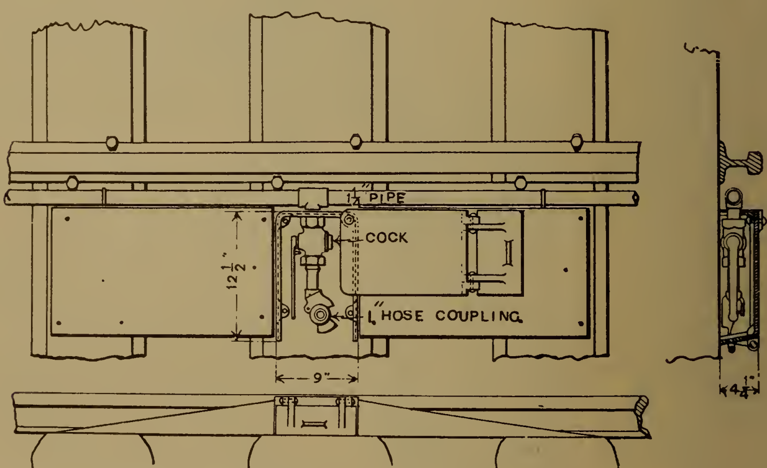

FIG. 418—ARRANGEMENT OF AIR PIPE FOR TESTING AIR BRAKES.

ing them from place to place; the smaller ones are light enough to be carried around, although trucks are provided which are used when they have to be taken any distance.

Air is also used in the repair yard to drive a pneumatic drill or boring machine, and also to furnish blast for the blacksmith forge.

In the inspection yard there is an air line of 1¼ inch pipe for every two tracks. It is laid on top of the ties, close to the rail and fastened by ⅜-inch staples. Connections similar to those on the repair track are provided every 100 feet and are enclosed on three sides by a cast iron casing, resting on the tie, the top and open end being closed when not in use by a hinged cover and end, which is turned out of the way when the test hose is connected. Fig. 418 shows the connection and box and their arrangement on the track. Wedge-shaped pieces of timber are fastened on each side of the box on top of the ties, to prevent trainmen who are walking along the track from stumbling over the obstruction. On account of the length of the lines in the inspection yard, expansion joints had to be provided, which are in the form of U-shaped connections between the ends of sections of the pipe 300 feet long, and are made up of a union, nipples, elbows, hose nipples and short pieces of hose as shown in Fig. 421. These joints are enclosed in boxes, protected by wedges, like the regular connection boxes. Each separate line is provided with a cut-out cock. The pressure of the air is reduced by means of a reducing valve to 70 lbs. before it passes into these pipes and the testing is done by means of an engineer's valve mounted on a wheel barrow and connected to the pipe line and the train by hose. After a train has been

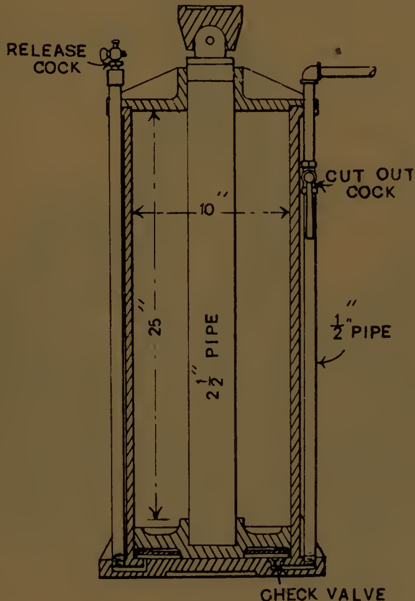

FIG. 419—PNEUMATIC JACK.

tested the train pipes are left charged, so that when the locomotive is attached no time is lost in pumping up the train.

Another plant at West Seneca, which depends largely upon compressed air, but which is separate and independent from that provided for the repair and inspection work, is that for supplying water for the various purposes around the yard, and also for elevating sand for use in locomotive sand boxes.

The water is taken from seven driven wells and also from a creek near by. The wells are from 100 to 105 feet deep, and the one in the creek is about 20 feet deep. Compressed air, at 60 lbs. pressure, is supplied by a straight line air compressor, having a capacity of 384 cubic feet of free air per minute, two compressors being provided to always have one ready in case of emergency. The principles of the Pohle air lift are made use of to bring the water to the level of the yard. The wells are of 6-inch pipe in which a piece of 2½-inch pipe extends almost to the bottom and a ¾-inch air pipe runs down on the outside and enters the 2½-inch pipe near its bottom. The escaping air draws the water up with it and delivers it through the 2½-inch pipe into a main, which carries it to a large surface well of 100,000 gallons capacity, which is floored and housed over and provides a place for the two air compressors and also two water pumps, which deliver the water from this well to the storage tank of 100,000 gallons capacity, 35 feet above the ground. From this point it is distributed to standpipes and hydrants at different points of the yard. The water pumps have a capacity of 500,000 gallons per day and are also in duplicate.

Sand for use on locomotives is thoroughly dried by steam and delivered by the drier near the floor level of the sand house, and is then blown from there to a reservoir on the upper level, from which it flows by gravity to the sand box of the locomotives through pipes with flexible joints. The apparatus for elevating the same consists of a 2-inch vertical pipe into the lower end of which a ¾-inch

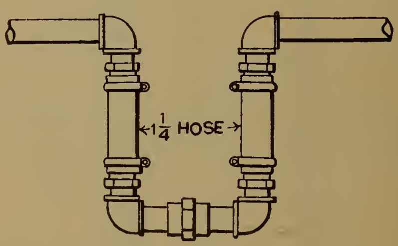

FIG. 421.

pipe extends, drawn down to a ⅜-inch nozzle, and when air is allowed to escape through this nozzle it draws the sand up with it and deposits it in the reservoir on top.

In the use of this apparatus it was found necessary to get rid of the moisture in the air by passing it through a chamber where the moisture could precipitate and be drawn off by a cock at the bottom.

The air compressors used in connection with these plants deserve more than a passing mention, as by their use a large saving is effected over the cost of operating other machines for doing the same work.

The compressor used in connection with the testing tracks and repair yard is a class H, Ingersoll-Sergeant duplex steam driven air compressor with compound air cylinders (Fig. 420), having 10-inch steam and 16 and 10-inch air cylinders with a stroke of 10 inches, giving with 150 revolutions a capacity of 342 cubic feet of free air per minute. The steam cylinders are provided with plain slide valves driven by eccentrics.

The compressor used in connection with the water supply is a standard type made by the same company.

It still seems to be a mooted question among some railroad mechanical men as to what is the most economical machine for compressing air for shop use.

Naturally the first machine used for this purpose at railroad shops was a locomotive air brake pump, of which there are always some spare ones on hand, and these can be used without their cost appearing on the books as a new investment. As the uses to which compressed air is put increased more than one pump was found to be needed to supply the demand and it was soon found that while there was no material outlay chargeable to shop equipment, there was quite a marked difference in the consumption of coal in the boilers, and it is now almost universally conceded that while the air brake pump is the best machine that can

FIG. 420—INGERSOLL-SERGEANT DUPLEX AIR COMPRESSOR—L. S. & M. S. RY.

be procured when used in its legitimate sphere, i. e., on the locomotive for supplying air to operate the brakes, it is a very wasteful one when used to furnish a large suuply for a shop plant, where floor space and water for cooling purposes are readily obtained, and the installation of an air compresser will soon show a marked decrease in coal consumption and repairs. Even when the demand for air is not sufficiently large to warrant the purchase of an independent compressor, one driven by belt by the shop engine will show almost as much economy as a steam driven one.

On the locomotive the air brake pump runs comparatively slow, not pumping a very large amount of air, as after the train is charged it is only necessary to supply what is lost by leakage, excepting after brakes are released, when a few strokes of the pump will usually bring the pressure up to the maximum, and the repairs therefore are comparatively light. When used, however, to supply the large and constant amount of air needed in a shop plant, the wear and tear is considerable and the pump has to be repaired and many parts renewed at very short intervals.

Some years ago the Westinghouse Air Brake Co. conducted a series of tests to ascertain certain data in regard to the air brake pump as compared with air compressors, from the results of which tests some figures have been selected which are given below:

The 9½-inch air brake pump compresses about 45 cubic feet of free air per minute to 90 lbs. pressure, or 2.5 cubic feet per pound of steam. A two-stage compressor, operated by compound non-condensing engine, showed 13.7 cubic feet of air per pound of steam. Assuming that the compressor which has been described as supplying air for the repair and testing yard at West Seneca delivered on an average 250 cubic feet of air per minute, which is less than 60 per cent. of its capacity, and assuming further that on account of having only a simple engine instead of compound, the free air compressed was only 10 cubic feet per pound of steam, which is probably too low, we would obtain a consumption of $\frac{250 \times 60}{11} = 1{,}364$ lbs. of water per hour, which would require, assuming 8 lbs. of water evaporated by the boiler per pound of coal, 170 lbs. of coal per hour.

To compress the same amount of air by means of 9½-inch air brake pumps would require four or five of these, compressing 2.5 cubic feet per pound of water, which at the same figures as given would require $\frac{250 \times 60}{2.5 \times 8} = 750$ lbs. of coal per hour, or 4.4 times as much as required by the compressor.

Assuming a service of 300 days of 10 hours each per year, with coal at $1.00 per ton, the cost of fuel would be 170 × 3,000 × $1.00 =$255 for the compressor, and 4.4 times as much, or $1,122, for the pumps. The price of coal is taken at a minimum figure and the difference in cost will be much more at the price that is usually paid.

The consumption of water would be about as follows: The boiler would have to evaporate for the compressor 1,364 lbs. of water per hour, or about 481,400 gallons per year, for the air brake pumps 6,000 lbs. per hour, or 2,118,000 gallons per year. The compressor would further require for cooling purposes about five gallons per minute, or 900,000 gallons per year, making a total consumption of 1,381,400 gallons, which at 3 cents per 1,000 gallons is a conservative figure, and would amount to $41.44, while the cost of water for the air pumps would be $50.82.

The market price of a compressor of about the size and kind mentioned is approximately $1,700, while that of one 9½ inch air pump is $125.00. Allowing 5 per cent. annually for interest on equipment and 10 per cent. for wear and tear, the latter being high for the compressor and low for the pump, and tabulating all the above figures we get the following:

	First cost.	Expense for 1 year.				
		Fuel.	Water.	Interest.	Depreciation.	Total.
1 compressor........	1700	255	41	85	170	551
6 air brake pumps (9½ in.)...........	750	1122	63	37	75	1297

From which it will be seen that the cost of running the air brake pumps would be 2.4 times as much as that of the compressor and the latter would save its cost, on running expenses alone, in a little over two years, or would almost save the difference in first cost during the first 15 months.

It might be urged that air brake pumps could be used which had previously been in service on locomotives and that there would then be no expense for first cost. Nevertheless the pumps would have been paid for at some previous time. and they represent the investment of a certain amount of money, so that the interest and depreciation should still be considered in their running expenses. When old pumps are used for shop purposes, it is usually the 8-inch pumps that are taken which have been replaced on locomotives by those of larger capacity; these may be valued at $100 each, although the cost of a new one at the present time is higher.

Reverting to the tests referred to as made by the Westinghouse Air Brake Co., it was found that an 8-inch pump compressed 1.85 cubic feet of free air per pound of water. It would therefore require, using the same figures as before.

$$\frac{250 \times 60}{1.85 \times 8} = 1{,}014$$ lbs. of coal per hour to pump the same amount of air by means of 8-inch pumps, or six times as much as required by the compressor, and the cost per year would be $1,530. The water consumption of the pumps would be 2,455,200 gallons per year, costing $73.65. Tabulating these figures we have the following:

	First cost.	Expense for 1 year.				
		Fuel.	Water.	Interest.	Depreciation.	Total.
1 compressor........	1700	255	41	85	170	551
10-8 inch air brake pumps............	1000	1530	73	50	100	1753

From which it will be seen that the 8-inch air brake pumps will cost more than three times as much as the air compressor to operate, and that the compressor will pay for itself in less than a year and a half.

When it is further considered that the compressor requires, if anything, less attention than a number of pumps, that the consumption of oil would certainly be less for the compressor, and that the cost of repairs would be considerably in its favor it would seem that a railroad which continues the use of air brake pumps for shop purposes is maintaining a losing investment.—*Railroad Car Journal.*

LOW-PRESSURE PNEUMATIC INTERLOCKING AT JERSEY CITY.

As heretofore noticed in the *Railroad Gazette,* the Erie Railroad has lately installed at Grove street, Jersey City, about half a mile from the terminal passenger station, an interlocking plant made by the Standard Railroad Signal Co., of Troy, N. Y., in which all of the switches and signals are worked and controlled by compressed air. The system is that of the Pneumatic Railroad Signal Co., of Rochester, whose plant on the New York Central, at Buffalo, N. Y., was described in the *Railroad Gazette* of July 8, 1898. The Standard Company is now the sole licensee for this country under the patents of the Pneumatic Company.

The accompanying illustrations show some of the details of the switches and signals at the Jersey City plant; there are large numbers of freight and switching movements.

The interlocking machine has 59 working levers and five spare spaces. The design of this machine has been considerably modified since the publication of our former description. A view of one of the machines—not that at Grove street, but one substantially similar in appearance—is shown in Fig. 422. The principal features of the system are the same as those which were shown in connection with the Buffalo machine. No electrical apparatus is used; the working air pressure is 15 lbs. per square inch; the pressure in the operating and indicating pipes is 7 lbs. per square inch, and these latter pipes are normally under atmospheric pressure only—that is to say, at all times except when a movement is to be made or an indication is to be given. The final portion of the stroke of the lever is automatic, so that as soon as the signalman has pulled a lever to initiate a switch movement or a signal movement, he can at once turn his attention to the next lever which he has to pull, without waiting for the return air-impulse.

The arrangement of valves and pipes forming the connection between the interlocking machine and a switch cylinder is shown in Fig. 423. The principal parts are: S, switch rails; s1, lock bar; s, switch rod; M, motion plate; C, switch cylinder; D, indicating valve; R2, R3, R4, R5, controlling valves; L, L2, operating bar and slide valves; I, I2, indicator cylinders; H, interlocking tappet; X, air reservoir.

To change the position of the switch the signalman grasps L by the handle and pulls it out. In doing this he admits air (from the main supply through the valve L2) through pipe a to valve R5, which opens communication from the supply pipe X to the right-hand end of cylinder C, pushing the piston to the left. Observing now the slots L and M, it will be noted that after about one-half of the stroke of L has been completed it is stopped by the piston rod of I2; but the operation of valve R5, already accomplished, causes M to move through the whole of its stroke. This stroke of M is uninterrupted, but we may consider it in three parts. The first part, say one-third, does not move the switch, but valve D is moved far enough to close the two pipes on its right, while those on its left

FIG. 422—LOW-PRESSURE PNEUMATIC INTERLOCKING MACHINE.

are open to the atmosphere. At the same time lock bar s1 has been liberated at s2. As M moves through the next or middle portion of its stroke, it moves the switch; but it now produces no effect on valve D, because the rod of D is now engaged by the straight portion of its slot in plate M. The switch being set, the third and final part of the stroke of M locks the switch by pushing s10 through a hole in s1; and also (but not until after s10 has entered its hole) the plate changes valve D so as to connect together the two pipes at its lower end. This conveys pressure from the supply through R5 and D to valve R3, which valve admits air from the supply to I2, forcing the piston rod upward, and, by means of the diagonal portion of the slot in bar L, forcing this bar to complete its stroke. This return action takes place at ordinary distances in from one to three seconds.

By the action of L2 pipe a is now opened to the atmosphere. Valve R5 is now released from pressure, and R4 is closed; so that the right-hand pipe to

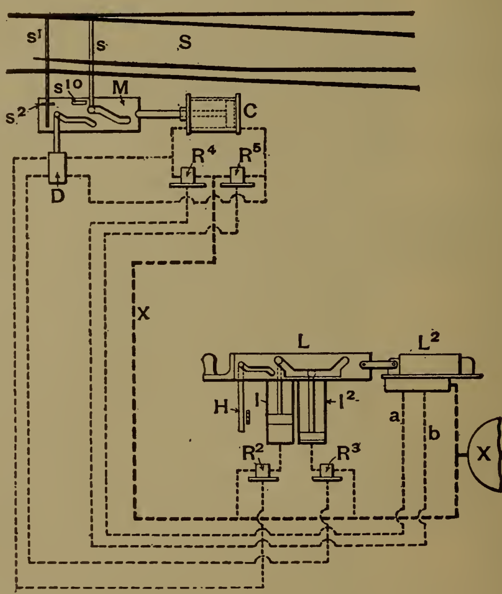

FIG. 423—SWITCH MOVEMENT.

Cylinder C and its connection to and through D are open to the atmosphere. All four operating pipes are now at atmospheric pressure.

By the movement of L, tappet H has been moved so as to produce the proper mechanical locking of conflicting levers (in the first part of the stroke of L) and the proper unlocking (in the last part of this stroke), in the same manner and sequence that the same interlocking would be effected in a mechanical interlocking machine.

To move the switch back to its original position, the opposite set of pipes is used. The bar L is pushed to the right; air through b actuates R4, and the return indication to the cabin actuates R2 and lifts the piston in I.

To work a signal, valves and operating pipes are used of the same general style as those for a switch, but there is only one indicating valve and one indicating cylinder, as it is unnecessary to assure the attendant that a signal is in the go-ahead position. The signal connections are shown in Fig. 424. The principal parts are: A, signal arm; A2, signal cylinder; A3, lever to work indicating valve; B, indicating valve; R2 and R3, diaphragm valves, controlling the admission of air to the top and bottom, respectively, of the signal cylinder; R1, diaphragm valve controlling admission of air to cylinder I. The signal being in the normal or danger position, the indicating valve B is in a position to maintain a connection between the two pipes attached to it; but the instant the signal arm leaves the horizontal position the valve shuts off this connection.

To change the signal the signalman pulls L to the left, the whole length of its stroke. By this movement L2, admitting air to pipe a, actuates valve R3, which supplies air to the lower end of cylinder A2 and pushes up the piston, put-

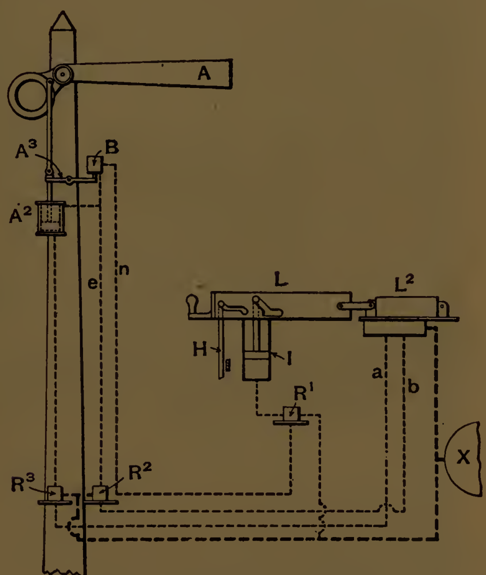

FIG. 424—SIGNAL MOVEMENT.

ting the signal in the inclined or all-clear position. The air impulse is transmitted so quickly that at the average distance—say 500 ft. and less—the movement of the signal is practically simultaneous with the movement of the lever. The signal remains in the inclined position as long as L is pulled to the left. To restore it to the normal or stop position, L is pushed to the right until it is stopped by the piston rod of I (at the end of the horizontal part of the slot in L). With L in this position, pipe b is charged and valve R2 is opened. The passage between pipes e and n (through B) is now closed, so that the opening of R2 admits air from the supply to the upper end of A2. This restores the signal to the horizontal position, and by means of A3 opens valve B. Air now passes from e through b and n to R1, and the latter causes air to enter I and complete the return stroke of L by the action of the piston rod on the diagonal part of the slot. Pipes b, e and n are now at atmospheric pressure, and the parts are in the same position as at the beginning.

In Fig. 425 is shown the diaphragm valve, which is called the "relay," its function being similar to that of an electromagnetic relay in electrical apparatus. This valve is actuated by air at 7 lbs. pressure. This pressure, admitted beneath the circular rubber diaphragm 8 in. in diameter, pushes up the cylindrical valve, placed vertically in the upper part of the case, and thereby liberates air at 15 lbs. per square inch to move the piston in the switch or signal cylinder. The movement of the diaphragm is only ¼ in.

The low-pressure pneumatic interlocking machine is made up of three principal elements: (1) A row of slide valves (called "levers"), like that shown in outline at L and L2, Figs. 423 and 424. The only physical labor imposed on the signalman is that involved in pulling out and pushing in these valves. (2) A mechanical interlocking frame placed vertically on the front of the machine. This is of the common mechanical type, like the Saxby & Farmer or the Johnson, but

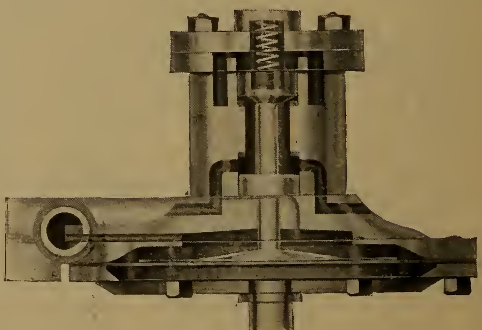

FIG. 425—DIAPHRAGM VALVE.

with the parts made about half the usual size. The manner of connecting the "lever" with the interlocking is indicated by the position and arrangement of the tappet H in Fig. 423. (3) The indicating cylinders and their relays on each "lever" as shown in Figs. 423 and 424.

The operating and indicating pipes extending to the switches and signals are ½ in. in diameter. The supply pipes from the air reservoirs are larger, the size being varied according to the number of switches and signals to be supplied.

The air is first run through a cooling frame for the purpose of precipitating moisture; but with low pressure the company finds that there is practically no trouble from moisture in the pipes.

Both the manufacturers and the railroad company give favorable reports of their continued experience with the plant at Buffalo. The cost for repair material at that plant has been less than $4. and it is believed that the wearing parts of the machine have been so well designed that the maximum of durability can be expected. These parts have very light service and they are made interchangeable, so that they can be quickly and cheaply renewed.

The automatic completion of the stroke of the lever by the return indication is found to be a decided convenience in a busy yard. Where a signalman, after making the first half of the stroke of a lever, has to wait for the return indication, the delay, though very short, is yet an appreciable addition to his cares, for he

FIG. 425—SWITCH MOVEMENT.

delays going to another lever until he has finished his duty with the first one. But with the automatic movement he at once turns his attention to the next lever and thus stands ready (waiting perhaps a second or two) to move that as soon as it shall be freed by the interlocking. Any failure of the automatic movement would, of course, prevent a liberation of the second lever, as the locking bar or bars holding it would not release it unless the preceding lever completed its stroke.

The Standard Railroad Signal Co. has now under construction six low-pressure plants, as follows: For the New York Central & Hudson River R. R. Co., a 96-lever machine at Suspension Bridge, N. Y., a 48-lever machine at Hoffman, N. Y., and a 176-lever machine at the Grand Central Station, New York City; for the Chicago & Western Indiana at Chicago, a 40-lever and a 48-lever machine; and at the Grand Central Depot, Chicago, an 80-lever machine for the Chicago Transfer & Terminal Railroad.—*Railroad Gazette.*

ELECTRICITY AND COMPRESSED AIR.

Electricity and compressed air are in many things friends, not competitors. One should be the hand-maiden of the other to give mutual aid and encouragement. In some things electricity is supreme, and though compressed air were "as free as air" it could not compete. Friendly rivalry of this kind is the very essence of development and prosperity.

Manufacturers of air compressing devices and all friends of compressed air will agree that the stimulus given them by recent developments in electricity is at the bottom of present prosperity in air compressing and air using devices. Competition has not only been the life of trade in this line, but engineers and inventors have watched and profited by the new uses of electricity, creating as it has new fields, in some of which air power serves a useful purpose. An instance of this co-operation is seen in most of the large railway yards in America.

The Electro-Pneumatic switch and signal system is a combination of compressed air and electricity, each performing its part, and each recognized as the best power for the purpose. This system is considered the most comprehensive now in use. It is in constant operation at the Pennsylvania R. R. terminals in Jersey City, Philadelphia and Pittsburg; the Philadelphia & Reading terminal, Philadelphia; the Union Station at St. Louis; the Chicago and North Western R. R. terminal, Chicago; at the Boston & Maine terminal, Boston, and the Communipaw yards of the Central R. R. of N. J. The compressed air may be conveyed along the road bed 20 miles in each direction from the compressor station. Electricity runs parallel with it and serves to open or close valves which admit compressed air to pistons which are connected with the switches and signals.

Electricity handles the trigger while compressed air is the power which does the work.

Here is where air power comes in to the best advantage. It may be transmitted a long distance with little or no loss provided the pipes are tight and the velocity of flow is not excessive. It does not lose power through changes in temperature.

When released or led from the main into a cylinder it acts instantly with a force that is limited only by the area of the piston and the air pressure. After doing its work it is readily exhausted. All this is accomplished by very simple apparatus that is easily understood and readily repaired in any machine shop.

We mention this as one and perhaps the most important case where electricity and compressed air are combined in useful service.

COMPRESSED AIR REFRIGERATION—THE EARLIEST ICE MACHINE.

The earliest known appliance for making ice by compressed air seems to have been invented and put into actual practice by Dr. John Gorrie, of New Orleans, La., whose patent dates May 6, 1851, although ice was actually made in his machine at Apalachicola, Fla., in the summer of 1850.

The machine consisted in its essential operating parts of an air compressing cylinder and piston operated from a crank-shaft by connecting rods.

A small injection pump operated from a cam on the main shaft, so adjusted as to inject a small spray of cold water into the cylinder during the latter

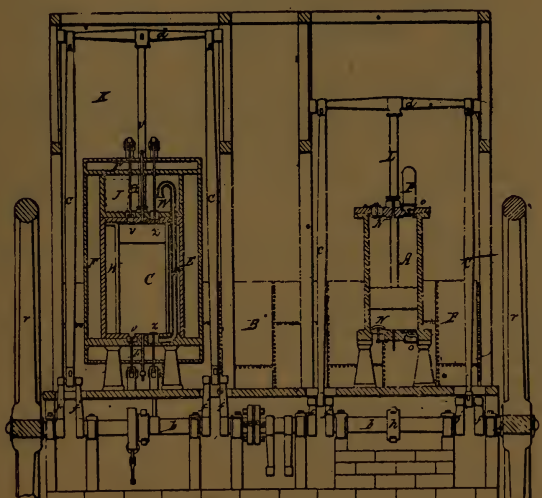

FIG. 426—FRONT ELEVATION—THE EARLIEST ICE MACHINE.

part of compression at each stroke of the piston; thus being the leading practical application of the injection system for cooling the air during compression; the compressed air and injected water being driven together through the exit valves and through a coil of pipe immersed in a tub of cold water, to the receiver, from which the injected and condensed water was drawn off through a waste cock at the bottom.

On the same platform and connected with a crank on the main shaft, was located the expansion cylinder with its piston and connecting rods.

E. Expansion cylinder injection pump, drawing brine from the jacket W and forcing it in a spray into the expansion cylinder, by which the brine is

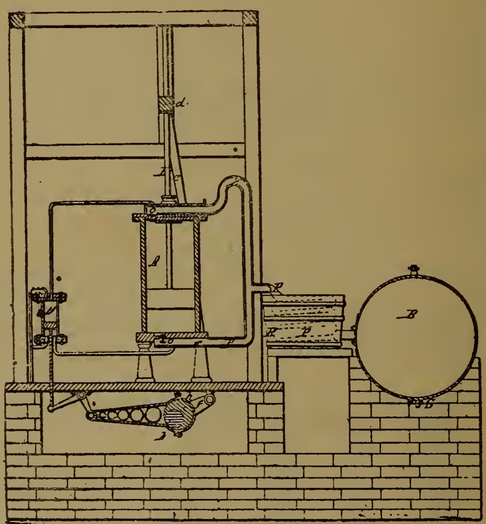

FIG. 427—END VIEW—THE EARLIEST ICE MACHINE.

quickly cooled and discharged with the cold air into the upper section of the brine jacket and tank.

J. The freezing can or tank.

A charging tank containing fresh water for supplying the freezing can, is placed overhead.

The other lettering indicates details readily understood by inspection.

ARTIFICIAL ICE.

On page 993 of this book, a description, with illustrations of the first machine used for the production of artificial ice. This machine was invented by Dr. John Gorrie, of Apalachicola, Fla., and its interest and importance are based upon the fact that the fundamental principles involved by which low temperatures were reached are practically identical with present theory and practice. Dr. Gorrie used compressed air to produce cold, and though the important industry of refrigeration is now mainly based upon the use of ammonia, yet the principles involved are the same. Dr. Gorrie, in his specifications, said:

"It is a well-known law of nature that the condensation of air by compression is accomplished by the development of heat, while the absorption of heat from surrounding bodies, or the manifestation of the sensible effect commonly called cold, uniformly attends the expansion of air, and this is particularly marked when it is liberated from compression. The nature of my invention consists in taking advantage of this law to convert water into ice artificially by absorbing its heat of liquefaction with expanding air."

We neglected to mention the fact that the illustrations and interesting description given of this apparatus were furnished by Mr. George H. Whiteside, of Apalachicola, Fla., who erected the Apalachicola ice factory, and who is now the general manager of the Apalachicola Ice Co.

The substance of Mr. Whiteside's paper was given in a more extended article by him, which was published in "Ice and Refrigeration," in May, 1897.

REFRIGERATION BY COMPRESSED AIR.

DESCRIPTION OF A SYSTEM WHICH HAS BEEN IN EXTENSIVE USE FOR YEARS IN THE UNITED STATES NAVY.

In the "American Machinist" for December 30, 1897, Mr. Richard E. Chandler describes his failure to cool water by blowing through it previously compressed and cooled air. Some editorial remarks upon this failure in the same issue express a desire that others will be encouraged to recount their experience in this line, and having had a large and varied experience in the use of compressed air for cooling refrigerating compartments in buildings and on ship board, in cooling potable water and also in cooling strong brine for use in ice-freezing tanks, I feel that I ought to accept the challenge.

Contrary to the experience of Mr. Chandler, my experience has been a successful one; a process and apparatus for dynamic refrigeration, employing compressed air and effecting all the results above named, invented and put into use by me, has been in extensive use for years in the United States Navy, has been adopted for the Japanese war vessels, and is also in operation on many merchant and passenger steamers and steam yachts.

I would very much like to make the mode of cooling by compressed air comprehensible to the ordinary steam engineer. Though this is by no means an easy task, with permission of the editor I will attempt it.

All dynamic or mechanical refrigeration by use of compressed air or other gases depends upon the following fundamental principles, which have been both mathematically and experimentally demonstrated:

(a) The performance of work by the molecules of any substance or material, as by air or steam in expanding, is done at the expense of heat in such substance or material; heat is thus converted into work.

(b) The performance of work upon the molecules of any substance or material, as in compressing air or steam, results in an increase of heat in the material; work is thus converted into heat.

(c) If air, or other gas, be first compressed, and the heat produced by the work of compression be then taken out of it (cooling by water is the usual way of doing this), and if it then be expanded, *expending the work of expansion upon some other exterior body or substance,* it gets very cold, and in this state may be used to extract heat from, or cool, other substances or bodies.

The italicized words express a condition absolutely essential to a successful refrigerating process.

It was reasoned in the editorial remarks upon Mr. Chandler's failure (above referred to) that as air cannot expand without performing work, and that as the performance of work always implies a simultaneous or prior conversion into mechanical energy (actual or potential) of the heat equivalent of the work, and as the conversion of the heat equivalent into actual mechanical energy in the performance of work by expanding air is coincident with the expansion, compressed air, following full stroke in an air engine (thus doing no work, but acting the same as a liquid or solid to simply transmit pressure), ought, when expanding from the exhaust, to produce the same *final* cooling effect as when expanded in any other way.

Now, it is true, as stated in this argument, that *air cannot expand at all without doing work*; that the expansion of a definite weight of air from a given pressure and temperature to a given lower pressure and temperature without any accession of heat while expanding always results in the performance of a definite quantity of work, and that this work is the equivalent of a definite amount of heat previously contained in the air which expands, and which cannot simultaneously exist as both heat and work; but it does not, therefore, logically follow that *when the last part of a cycle of operations* in compressing and expanding air has been reached, there will have resulted a reduction of temperature (below the initial temperature of the air passed through the cycle) representing anything more than a small fraction of the heat equivalent of the work performed by the expansion.

Whether the *final* reduction of temperature below the initial temperature will be th equivalent of the work of expansion (less what may be lost through frictional reheating) or not, *will depend upon the application of that work.*

If, subsequently to the expansion, all the work generated by it be reconverted into heat, before the close of the cycle of operations, and this heat be expended in reheating the expanded air, there will be no final lowering of temperature; there will generally be some final increase of heat due to friction.

Therefore, in the argument (issue of December 30) under consideration, though the premises are all sound, the conclusion is not justified thereby. The compressed air after following the piston full stroke is capable of yielding the full cooling equivalent* of the work of expansion, *if expanded under proper conditions;* letting it exhaust freely into the outer air, or into water, as Mr. Chandler did, is not the right way.

Pushing the compressed air after it has followed full stroke (and before expanding) into the cylinder of another engine of such size and cut-off that at the end of its stroke the expansion would be complete—the piston applying the

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* Cooling is the passage of heat out from a body or *negative* heating as distinguished from *positive* heating or the passage of heat into a body. The equivalent of either is numerically expressed in thermal units, the number expressing passage of heat out having the minus sign, while that expressing passage of heat in has the plus sign. In this mathematical sense it is therefore as logical to write "cooling equivalent" for loss of heat by performance of work as "heat equivalent" for gain of heat in a body upon which work is performed.

work of expansion to some exterior object—would be, though indirect, a right way to get the full available cooling effect. But how is it that expansion into a surrounding medium fails to do the same thing?

To gain clear ideas we must regard the whole cycle of operations—not merely some part of it—and determine whether the cooling effect of one operation is, or is not, counteracted by another.

Cycle of Three Operations.—Compression not followed by cooling before free expansion from a valve opening adds the full heat equivalent of the work of compression to the finally expanded air; the latter will then be hotter and will have a larger volume immediately after expansion than before it was compressed, and the third operation of the cycle is its giving off of this heat, resulting in its contraction and the resumption of its normal volume. This cycle is, therefore, a heating cycle in its final stage, notwithstanding there is a full expansion of the compressed air. The cooling due to expansion in one operation is not only neutralized in another part, but the entire heat equivalent of the work of compression is ultimately transmitted to the medium into which the air is finally discharged.

Cycle of Four Operations.—This may be the same as the above, except that the air is cooled in some way (say, by water) after compression, and then allowed to expand freely out into a surrounding medium. The heat equivalent of the work of compression is carried away in the cooling water. Now, if the expansion be made freely into a gaseous or liquid medium the air expanded will at first be cooled by the full equivalent of the work of expansion, but only a small fraction of this cooling effect will remain available at the end of the expansion.

This can be made plainer by an example of such treatment of a specific quantity of air; the surest way to get right on any question of thermodynamics is to deal with specific quantities.

Let us deal with one pound of air, supposed to be already compressed to 220.5 pounds per square inch (15 times atmospheric pressure at sea level) and cooled to 72 degrees Fahr. (or 531 degrees absolute temperature); thus two of the operations of the cycle have already been performed.

Let us suppose this air confined in a metallic cylinder of 12.555 inches internal diameter and the same internal length. Such a cylinder will just contain the one pound of air, which, at the stated temperature and pressure, will have a volume of 1540.68 cubic inches.

Let us suppose that one end of this cylinder is so arranged that it can be fully and suddenly opened or closed, thus permitting the freest conceivable expansion and instantaneous closure.

Let this cylinder, charged as assumed, be placed in an otherwise vacuous inclosure hermetically closed and having a net cubic capacity of 11.415 feet over and above the space occupied by the charged cylinder, and let it be also supposed that the walls of this inclosure have the temperature of 72 degrees Fahr., and that they are so well insulated that no heat can penetrate them.

Now, suppose the removable end of the inclosed and charged cylinder to be suddenly opened, and instantly closed again the moment that the air has expanded to atmospheric pressure in the previously vacuous space. Three of the operations of the cycle have now been performed; the previously vacuous space outside surrounding the charged cylinder will be filled with air at 72 degrees

Fahr. and at atmospheric pressure; the incloure cylinder will be filled with very cold air at atmospheric pressure, which is available for refrigerating effect in the fourth operation of the cycle wherein the restoration of the air to the same pressure and temperature as before the compression is completed. The amount of this cooling effect is easily calculable, on the supposition that it can all be practically applied. The theoretical temperature of the air remaining in the cylinder is 217.08 degrees Fahr.; this is a very low temperature, but, as the air in the cylinder is only 0.163 pound, the total amount of refrigeration is small as compared with what is possible under proper conditions. The total theoretical cooling effect possible from one pound of air expanded from 220.5 pounds per square inch and 72 degrees Fahr. down to atmospheric pressure, if applied to cooling water from 80 degrees Fahr. down to 40 degrees Fahr. is 61.2 negative British thermal units, of which there are obtained in our supposed experiment not quite 10 B. T. U.

The total work of expansion is 52.992 foot pounds, which is *all* expended in generating velocity in the one pound of air at the time of its release from pressure. It would be easy to calculate the average velocity thus generated, but it is sufficient to note that what air remains in the cylinder has substantially no velocity. The 0.877 pound of air shot out strikes the walls of the inclosure and the impact and arrest of motion regenerates the heat which previously generated the work, and thus all the *final* cooling effect is confined to the air remaining in the discharged cylinder.

The interval of time between the discharge and the impact which reheats the air is so short that, practically, these events may be regarded as simultaneous, and the air forced out of the cylinder might be considered practically as performing work and expending it upon itself simultaneously, so that the cooling effect of the expansion is neutralized by the heating effect of the work performed upon itself; but, as a matter of fact, the events are successive; heat is converted into work, work is converted into the potential of velocity and, lastly, the potential of velocity is converted into heat again at the instant of impact.

If, instead of into small vacuous space, the compressed air were allowed to escape into a limitless vacuous space, it would never lose its velocity and never regain its temperature, and consequently the cycle of operations would never be completed.*

If, instead of into the vacuous space, the air were permitted to expand freely into a gaseous or liquid medium, the reheating effect of the arrest of its motion by impact would be just the same, and all the residual cooling effect would be that of the air remaining in the cylinder.

The heating of gaseous molecules by impact against surfaces of solids or liquids, or against other gaseous molecules, is precisely analogous to the heating of projectiles when shot against targets or when they meet in their trajectories.

The supposititious experiment described explains why in an air engine fol lowing full stroke the air remaining in the cylinder until it is pushed out gets very cold. While the air is expanding out of the exhaust what so escapes

* A complete cycle of operations restores the air to the same volume and temperature it had previous to compression.

reheats by impact and a little by friction in passing through the nozzle; while that which, after more or less complete expansion, is thrust out by the returning piston is very cold, because it has expended its work of expansion in shooting out the air in advance of it, and, when at last thrust out, it has practically no velocity, and cannot, therefore, be reheated by impact. There is, therefore, in the operation of such an engine, the local, restricted cooling effect which causes annoyance by freezing up ports, precisely as stated in the editorial remarks upon Mr. Chandler's failure.

Let us now suppose the cylinder containing the compressed air to be replaced by a cylinder of the same internal diameter. With a piston having a stroke of 85.7 inches, the cylinder being so insulated that no heat can pass into or through its walls from or to the contained air (expansion or compression of gases under such conditions is said to be *adiabatic*).

Our one pound of air, compressed and cooled as before, will now occupy 12.555 inches of the length of the cylinder behind the piston. Therefore, when the air has followed the piston through this distance, let there be a sharp cut-off and thereafter let the air expand, driving the piston, whose rod (extending out to some means for performing work, say, a cross-head, pitman and crank) applies all the work of expansion to the performance of outer work, such as pumping water, assisting to drive an air compressor or lifting a weight. At the end of the stroke the whole space in the cylinder except that occupied by the piston will be filled with air at a pressure of 14.7 pounds per square inch, and at the theoretical temperature of 217.08 degrees Fahr. Now when the exhaust opens this air will not rush out, of itself; there will be no further expansion, and the air will remain in the cylinder till pushed out; when so pushed out it has a comparatively low velocity, and, therefore, is heated very little by friction and scarcely at all by impact; we, therefore, reach the final stage of the cycle of operations with the whole pound of air very cold and theoretically requiring 61.2 thermal units to restore it to its condition before compression, and thus to complete the cycle. All this heat will now be abstracted by the cold air from warmer surroundings or contiguous substances, whether water, air, substances to be preserved by refrigeration, or brine for use in an ice-freezing tank.

In practice, of course, such a proportion of stroke to diameter in an air-expanding cylinder would never be met with; it was only assumed for the purpose of argument. Practically, also, theoretical results are not very nearly attained, as perfect adiabatic compression or expansion is impracticable, and there are frictional and other losses.

The more gently the air can be pushed out of the cylinder the less reheating it will receive. Suddenness of exhaust is detrimental.

The whole matter can be summed up as follows:

(a) Air in expanding always performs work.

(b) As we cannot expand into a limitless vacuum, as much of this work as is converted into velocity, will be reconverted into heat by impact.

(c) Because, if the air be expanded out of a valve opening, without following and expanding behind a piston, all the work of its expansion is converted first into velocity and immediately thereafter by impact converted into heat, the cooling effect of the expansion is immediately neutralized by this heat, and this method of cooling produces only a small local refrigerating effect plus that resulting from the slight molecular cohesion.—LEICESTER ALLEN, in *American Machinist.*

ALLEN REFRIGERATING PROCESS.

In these days when people are looking toward liquid air as a means of refrigeration it must not be forgotten that compressed air already plays an important part in refrigeration and particularly in marine service.

What is called the Allen Dense Air Machine is installed on many boats of various description. The process is about as follows:

Air under pressure (generally sixty pounds) is taken in by an air compressor and compressed to commonly 210 pounds. This heats up the air, storing in it such amount of heat as is the equivalent for the labor expended upon the compression. It is then passed through a copper pipe coil immersed in circulating water and this removes the heat to nearly the temperature of the water.

Then the air passes into the valve chest of the expander, which is, in construction, a usual steam engine with a cut-off valve. The valves admit the highly compressed air upon the piston to a certain point of the stroke and then shut it off. The piston continues to travel to the end of the stroke, the air exerting pressure upon it (constantly diminishing, of course). This takes out the air in such a quantity of heat as the labor performed by the air, while expending, requires for its performance.

The result is a very low temperature of the air at the end of the stroke. The return stroke of the piston pushes it out through thickly insulated pipes to such places as are to be refrigerated, viz.: the ice making box, the meat chamber and the drinking water butt. In all these the air is, of course, tightly inclosed in pipes or other strong apparatus, being under the original pressure at which it entered the compressor (sixty pounds) and the cold is given out through the metallic surfaces.

Frozen meat can be kept practically without change for an almost indefinite time. When kept at nearly the freezing point without change it may be kept for a number of weeks in good condition. A good practical rule for the amount of refrigerating pipes required in the meat chamber to keep this at the freezing point is: One square foot of pipe surface for every two and one-quarter to two and three-quarters square feet of interior surface of well insulated meat chamber, omitting interior divisions. It is necessary to arrange the piping so that the air in them is compelled to pass all surfaces with fair velocity.

From the meat chamber the cold air goes to the refrigerating pipes in the drinking water butt, passing first to the bottom layer and then gradually upward.

After that it returns to the compressor inlet of the machine.

In arrangements where not all the cold is taken out of the air by the refrigerator apparatus, the highly compressed air after cooling in the copper coil is further cooled in a special apparatus, where it is brought into surface contact with the returning and still cold air, before entering the expander.

Temperatures of 70 degrees to 90 degrees below zero are thus practically obtained in usual machines.

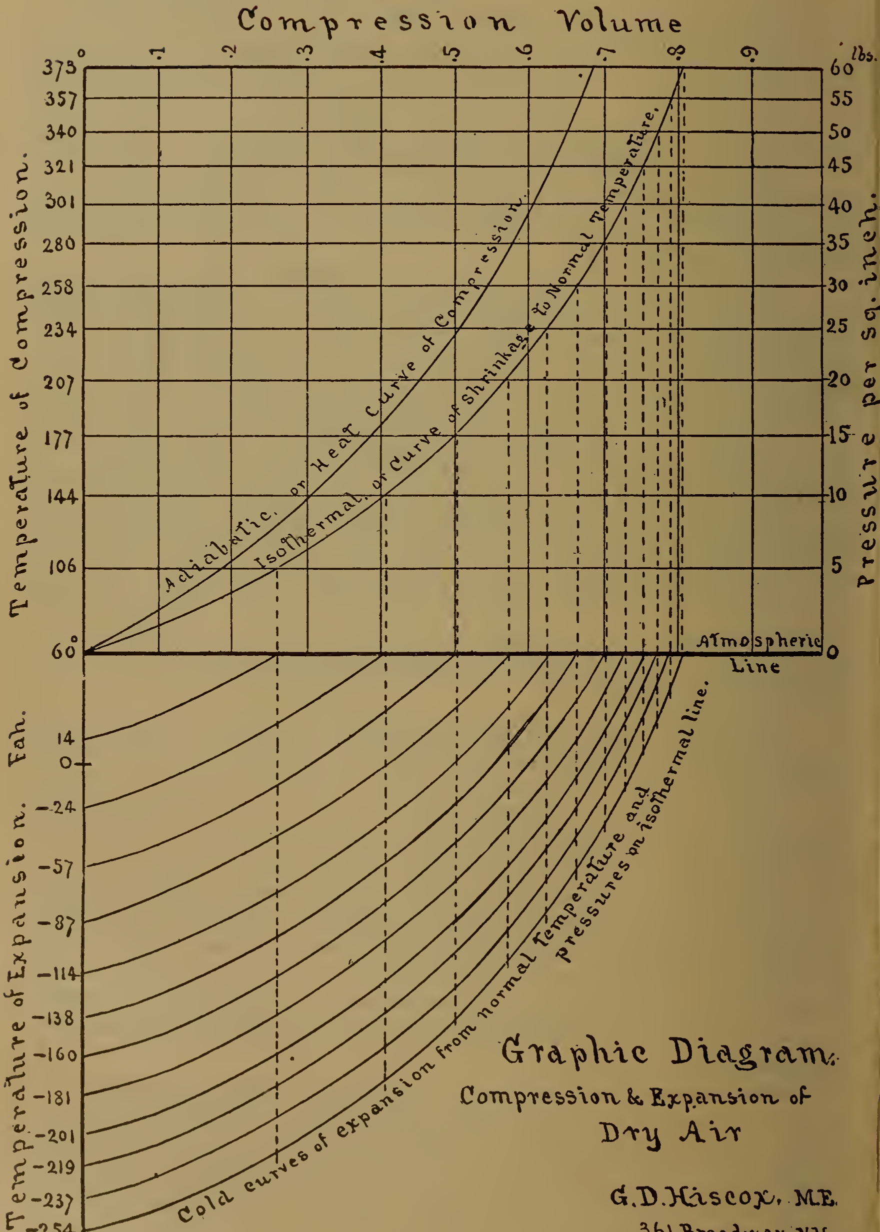
COLD STORAGE AND COLD ROOMS FROM COMPRESSED AIR.

In view of the largely increasing demand for the means of preserving food in the warmer sections of the United States, and in tropical climates, where ice cannot be obtained, or the cost is so great as to preclude its use, the use of compressed air as a constant cooling medium is one of the means at the command and control of every one who is able to place a small outlay for a valuable boon to household comfort; and for the profit that may be realized from the power to preserve fruit, vegetables and meat for sale, or for the time and opportunity for shipment to a market.

There are large tracts of country in the Southern section of the United States in which are situated plantations and farms, the owners and managers of which, having the financial means to supply comforts to life by the use of cold preserved food, who are entirely beyond the reach of ice, either natural or artificial, and to whom such wants may be supplied by the means of any small power such as a windmill, a waterfall or a gasoline engine, operating a pump for the compression of air. In Mexico, the Central American and South American states, the field for useful work by wind and water power alone for contributing to domestic comfort by the preservation of food is immense; where power from nature as through a windmill or waterwheel can be utilized. The distance need not be considered beyond the cost of a small pipe for conveying the compressed air, as a considerable length is needed to cool the air to its normal temperature which has been heated by the operation of compression; when by expansion to atmospheric pressure the same amount of heat may be eliminated from the expanding air as was accumulated by its compression, and from which a large cooling efficiency may be obtained.

The graphic diagram has been made to show at sight the cooling effect produced by the free expansion of dry air from various pressures and from the normal temperature of 60 degrees Fahrenheit. The conditions of air expansion for any natural temperature of the stored air may be found by simply adding the difference to the expansion column when normally above 60 degrees, or subtracting when below 60 degrees. Thus, in an atmospheric temperature of 80 degrees, the cold produced by expanding from 20 pounds pressure would be minus 67 degrees instead of minus 87, as shown in the diagram. From 50 pounds pressure and 90 deg. atmospheric temperature, the cold air of expansion would be minus 108 deg. instead of minus 138, as in the diagram; thus for any atmospheric condition of temperature and pressure, the theoretical condition of cold by expansion may be known by simple inspection of their several relations as shown in the diagram.

The diagram shows much that is interesting in regard to the general conditions and effect of air compression and expansion. It will be seen that the column of pressures on the right corresponds with the column of heat developed by compression on the left, while the upper or adiabatic curve shows the condition of temperature, pressure and volume at the moment of compression. The lower or isothermal line shows the shrinkage of the volume due to the cooling of air to its normal temperature.



Compression Volume
0 .1 .2 .3 .4 .5 .6 .7 .8 .9
lbs.
373° 357 340 321 301 280 258 234 207 177 144 106 60°
60 55 50 45 40 35 30 25 20 15 10 5 0
Temperature of Compression.
Pressure per sq. inch.
Adiabatic. or Heat Curve of Compression.
Isothermal. or Curve of Shrinkage to Normal Temperature.
Atmospheric Line
14 0 -24 -57 -87 -114 -138 -160 -181 -201 -219 -237 -254
Temperature of Expansion. Fah.
Cold curves of expansion from normal Temperature and Pressures on isothermal line.
Graphic Diagram.
Compression & Expansion of Dry Air
G.D.Hiscox, M.E.
361 Broadway N.Y.

FIG. 428.

The vertical dotted lines from the intersection of the isothermal line with the horizontal lines of pressure, meeting the atmospheric line, from the starting points for the curves of expansion extended on the same scale of temperature corresponding with the scale of compression.

The intersection of the dotted lines extended through the curved lines of expansion show also in a graphic way the fractional expansions from one stage of compression to another lower one as measured by the expansion scale at the left hand side. Thus a volume of air at 60 pound pressure and 60° temperature, when expanded to 30 pound pressure, its temperature will fall to the intersection of the extended dotted line of 30° with the 60 pound curve, which measured on the expansion scale is —57°, and so on for any other pressures.

In applying the conditions of air expansion to the practical effects of refrigeration or the cooling of rooms for cold storage and preservation of food, a large departure from the theoretical figures for the degree of cold by air expansion must be made on the favorable side for success.

The absorption of heat from the walls of a cold room, the cooling of a large body of air in the room and of food products stored and the greater loss from frequent opening of a cold room for the removal and refilling, with the natural leakage of cold air around the doors, makes the margin of loss in cold air production a larger one than at first appears when brought into actual use.

The amount of specific heat contained in a given volume of air is about 1-800 of the amount contained in the same volume of water for any number of degrees change of temperature at ordinary climatic temperatures, so that there is a large margin between the volume of cold air required to cool a room filled with air only and the volume required to cool a room filled with fruit, vegetables, milk, butter or meat containing from 50 to 90 per cent. of water and of which the solid parts also have a far higher specific heat than air.

This property of water-loaded food accounts for the time required to cool a loaded cold storage room over the time required for cooling an empty one, as well as the necessity for so packing the material of storagė that the cold air can circulate freely and bring every part to the required temperature in the shortest possible time.

As to the work that compressed air will do in cooling rooms, there is a large marginal range in the quantity of free air required for a specific temperature, due to the conditions of temperature of the material to be cooled and the amount of compression in the air to be expanded for this duty.

Assuming, for example, a cold room for a farm or plantation of 1,000 cu. ft. capacity, or say 12 ft. square by 7 ft. high, thoroughly insulated, with a double door at side for storing; a single or trap door with a small ventilator at top, with steps from the trap door for every-day use, and also lighted from the top. By this means a loss of cold air is prevented by its greater specific gravity holding it at the bottom. The room may be kept uniformly at 34° Fahr., in an outside temperature averaging 80°. To cool such a room from 80° to 34° requires a loss of 46° in a volume of 1,000 cu. ft. of air, say 77 pounds, the specific heat of which is 0·2377 water = 1. Then 77 x 0·2377 = 18·3 heat units must be absorbed for every degree of change in temperature. Then 18·3 x 46° = 841 heat units must be abstracted to bring it to 34° Fahr., leaving out the cooling of the walls, which will be only a matter of time in the initial operation.

Assuming to use an air pressure of only 30 pound per sq. inch, then in the graphic diagram, tracing the dotted line from the isothermal curve junction of 30 pound and following its curve of expansion, we have —138 x 60° to the atmospheric line = 198° difference in temperature by expansion from 30 pound pressure, or 198 heat units per pound of air. Then

$$\frac{841}{198} = 4{\cdot}24$$ lb. or 55½ cu. ft. of free air at 30 lb. pressure will be required to cool the room to 34°.

A compressor of 5 cu. ft. per minute capacity, using less than one horse power will furnish enough air to reduce the temperature of the room from 80° to 34° in about 15 minutes, and should then easily furnish cold air for absorption of heat from the material of storage and to supply the waste made necessary by ventilation and radiation with a constant work of less than a half horse power. This power comes within the scope of a cheap class of water wheels, water motors, and the smaller sizes of gasoline engines and windmills.

Where intermittent power must be used, as with windmills and power engines, a system of storage of compressed air may be used with perfect satisfaction as affording a constant flow of air into the cold room and also into a small refrigerator, which will be found a most useful adjunct for kitchen use and the cooling of drinking water.

The amount of pipe surface required for cooling compressed air to the normal temperature is a matter of much importance, as its delivery at the point of expansion, to be effective, must be at, or very near, the temperature of the outside atmosphere.

The method of keeping the air-cooling pipe at the proper temperature fixes the amount of pipe surface to be provided.

For 30 pound pressure, 15 sq. ft. of cooling surface per cu. ft. of free air used per minute is a fair proportion for an air-cooling coil exposed to a free circulation of the atmosphere and shaded from the sun's heat.

This would indicate a coil of 150 feet of 1½-inch pipe for the requirement of a cold room as above stated, which may also include the leading pipe from compressor to cold room, if favorably situated for cooling. Where it is convenient to use water for cooling, either by a sprinkler or by submerging the coil in a tank of water fed from a stream or by pumping, the size of the coil may be greatly reduced, according to the temperature of the water.

For an intermittent power as a windmill, or a gasoline engine that would not be convenient to run at night, a storage of air will be necessary by the use of a proportionally increased power during the day for accumulating compressed air in tanks.

The storage of sufficient air for a ten hours' run of the above plant will require tanks to hold about 1,200 cu. ft., or say three tanks of cylindrical form 5 feet diameter, 21 feet long. As the atmospheric temperature always falls at night in tropical and semi-tropical regions, the conditions of compressed air supply may be much modified in the storage quantity above outlined, and where constant power can be obtained, the whole question of cold storage for private use becomes a cheap and simple one.

The arrangement of the nozzle or orifice for delivering the compressed air, and at which point the expansion takes place, is important and requires its area to be exactly gauged to the proper size for the delivery of the desired volume of air at the assigned pressure. At 30 pounds pressure, air flows through an orifice in a thin plate at the rate of 525 feet per second. Then for the plant as above described, for the issuance of 5 cu. ft. of free air per minute under a compression of 3 volumes in 1 is $\frac{5}{3 \times 60} = 0.02777$ cu. ft. of compressed air per second, and $\frac{0.02777}{525} = 0.0000529$ of a square foot area. Then $0.0000529 \times 144 = 0.0076176$ of a square inch. Then enlarging for the coefficient of efflux, the orifice should be ⅛ inch diameter, with a valve back of it to shut off the air flow when required. Means should also be provided for blowing off any water that may condense in the air pipes or storage tanks by the cooling of the air after compression.

With proper care and a moderate outlay the system of cold storage by compressed air becomes a simple, efficient and economical adjunct to the living comforts of every home in a warm climate not blessed with a nearby ice-making plant.

G. D. HISCOX, M. E.

COLD STORAGE AND COLD ROOMS FROM COMPRESSED AIR.

We have received a number of communications from our correspondents on the subject of a paper which we published, entitled, "Cold Storage and Cold Rooms from Compressed Air," by Mr. G. D. Hiscox. We publish some of these communications, and will be very glad to continue the discussion, which can not fail to be productive of good results.

This is a subject about which a great deal may be said and concerning which there is a wide diversity of opinion. There are many things about compressed air in respect to which engineers differ; in fact, we know of no science of equal importance which is less subject to well-defined rules than that of compressed air. The laws of thermodynamics are complex. Rules that apply to dry air must be corrected for air under normal conditions, for there is no such thing in general practice as dry air. Heat and cold, which are so much in evidence when treating of compressed air, are only relative terms. We do not really know what heat is; in fact, our best judgment is that there is no such thing as heat; that it is only the sensible effect of motion; hence, it is natural to expect that a paper upon "Cold Storage by Compressed Air" might contain matter so purely theoretical that engineers will not agree with the conclusions derived.

COMPRESSED AIR does not pretend to be responsible for the ideas given by its correspondents over their signatures. Mr. Hiscox is a well known mechanical engineer of acknowledged ability and of wide experience; he is as competent perhaps to treat of this subject as anybody else, and is just as liable to make mistakes or to indulge in theories which may not accord with practice. The trouble is that we have so litle practice on this subject that our ideas and conclusions must be largely matters of theory.

Prof. Sims, of the State University of Iowa, has very properly called attention to an error of figures in Mr. Hiscox's article. This has been corrected by Mr. Hiscox, who promptly saw the point made by Prof. Sims.

The error of $\frac{1}{800}$ as the relative heat value of equal volumes of air and water should have been $\frac{1}{3413}$ and the result of the computation should have been divided by the specific heat of air .2377, making 17.9 lbs., or 232 cubic feet of air required to cool the room and extending the time of cooling to one hour.

The actual expansion temperature from — 138 to the required temperature of the room is — 138 + 34 = 172° Fahr., which should have entered the formula, making it $\frac{841}{172 \times .2377} = 40.88$ lbs. of air, or 531.[44] cubic feet of air. The compressor of 5 cubic feet capacity would then require nearly two hours to reduce the temperature of the room to 34°, and somewhat longer when the room is charged with its storage of material having a greater specific heat than air.

Mr. Dickerson makes the point that the figures given by Mr. Hiscox are entirely theoretical and that theoretical temperatures due to the expansion of cold air can not be approached in practice. This statement is, we think, quite true. The theoretical figures given by Mr. Hiscox, when based on the free expansion of air, can not be reached in practice; but when the air is used to do work in the cylinder of an engine, as for instance a pump, the cooling effect is very great, and in degree we think it follows closely the theoretical figures. Where water is present—as it always is—the specific heat of water will affect the air and prevent extreme temperatures being reached, but the simplest and most practical way to get a low temperature through the expansion of compressed air is by letting it do work and exhaust into the chamber to be cooled. The cold air is in this way produced exactly as the heat is produced at the compressor, and it should be equal in degree. The piston of an air compressor does a certain amount of work upon the air, this air does no work in return, hence the resultant effect of this work is heat. Heat and mechanical energy, or heat and work, are convertible terms. We can produce heat by work, or we can produce work through heat, converting one into the other with as much certainty as we can convert ice into water, or electricity into heat, or water into steam.

Sir Humphry Davy, in the year 1799, published a paper giving the results of experiments which determined the true relation between heat and motion. He showed a case in which there was actual conversion of mechanical power into heat. This was accomplished by the rubbing together of two pieces of ice until they were melted and converted into water. In this case the heat which produced this conversion could not have come from the ice, because after the melting had taken place the temperature of the water was slightly above the freezing point, that of the ice remaining the same; nor could this have come from surrounding bodies because of the nature of the experiment, hence Davy reaches the conclusion that "Heat or that power which prevents the actual contact of the corpuscles of bodies, and which is the cause of our peculiar sensations of heat and cold, may be defined as a peculiar motion, probably a vibration of the corpuscles of bodies tending to separate them."

In Davy's work on "Chemical Philosophy" he makes the statement that "The immediate cause of the phenomena of heat is motion, and the laws of its communication are precisely the same as the laws of the communication of motion."

The laws that govern the production of heat apply equally and in the same degree to the production of cold. We know that where pumps in mines are driven by compressed air, freezing at the exhaust is a common difficulty, and it is well known that the air discharged from the exhaust is cold. The degree of cold depends upon the expansion. If the air is admitted to the pump at a high pressure and is exhausted, the lowering of temperature will be greater than if admitted at a lower pressure. Where there is no cut-off, as in the case of a common mine pump, it would seem that the low temperature is produced not so much within the cylinder as at the exhaust. With a cut-off valve as in the case of steam engines, the air is admitted, cut off, and expanded down to a point near atmospheric pressure before the exhaust takes place, in this case the lowering of temperature takes place within the cylinder; but with a common pump it is likely that the contraction of section produces at the point of contraction a very high resistance.

This brings us to the consideration of an interesting and quite unexplained condition of things. If we have a tank charged with compressed air and let the air be discharged through a free opening into a room, there will be practically no reduction of temperature except immediately at the nozzle, and even here the reduction is slight. Mr. Moran, Mechanical Engineer for Sooysmith & Co., tried an experiment with air expansion with a view of freezing loose ground. He drove pipes into the ground which were connected at one end with a tank containing compressed air, and open at the other. These pipes were connected in series, so that when the valve was opened the air from the tank would pass through them, reaching atmospheric pressure at the other end. There was not only no reduction in temperature, but on the contrary there was a slight increase.

This and similar experiments have shown us that the simple discharge of compressed air through an opening into the atmosphere does not produce refrigeration; but when this discharge takes place through a very fine opening, the cold is intense. Even liquid air has been produced by simply expanding compressed air from high pressures down to atmospheric pressure through contracted openings. We know that in electricity the passage of a current through a contracted medium, as for instance through a fine wire, produces heat. This is shown in the common incandescent lamp, yet when we pass compressed air through a finely restricted medium, as for instance an opening the size of a needle, the reverse is true—that is, cold is produced; and the higher the pressure of the air, or the greater the resistance, the more marked is the reduction of temperature.

It has been suggested that in the case of air internal work is done in overcoming the resistance at the opening and that it is heat which is abstracted from the air in doing this work which accounts for the extreme low temperature results.

MINNEAPOLIS, MINN., Dec. 31, '97.

EDITOR COMPRESSED AIR:—

Referring to the article written by Mr. G. D. Hiscox on "Cold Storage from Compressed Air" (page 1001).

The refrigerating effect obtained by expanding compressed air through a small orifice is very small in proportion to the amount of work expended in compressing it, on account of the frictional resistance of the contracted opening. The compressed air should be expanded against a piston doing work, then exhausted through a large opening at very near atmospheric pressure, to get the maximum cooling effect from it. I have tried the first way, and know how it acts. See also the effect on steam of throttling, for proof.

MADISON COOPER, JR.

EDITOR COMPRESSED AIR:—

DEAR SIR:—The article in the December number of COMPRESSED AIR, entitled, "Cold Storage and Cold Rooms from Compressed Air," by G. D. Hiscox, is almost entirely theoretical in regard to the figures and data given, and admits of criticism for not impressing that fact more fully upon the mind of the reader. A person not familiar with the subject would be apt to arrive at erroneous conclusions after reading it; and if they were to put in a cold storage plant as figured and described, the writer is afraid that they would be sadly disappointed.

The statement is made in the first part of the article that "when by expanesion to atmospheric pressure the same amount of heat may be eliminated from the expanding air as was accumulated by its compression, and from which a large cooling efficiency may be obtained," and later in the article some computations for cooling down a room of 1,000 cu. ft. capacity are made, based on that assumption. The fact that the theoretical temperatures due to the expansion of cold air cannot be approached in practice seems to have been entirely ignored.

The highest cooling efficiency with cold air is obtained by such machines as the Bell-Coleman Cold Air Machine and the Allen Dense Air Machine. Even with these machines the pratical cooling effect is only a little over 40 per cent. of the theoretical cooling effect, and with an expansion orifice as described in article referred to, the cooling effect would be much lower, especially with the low pressure of 30 pounds per sq. in., as mentioned. In the cold air refrigerating machines referred to, the cooling effect is obtained by causing the air to do work in a regular engine. Theoretically the free expansion of air should produce no cooling effect, but actually there is some cooling effect, but not to the degree mentioned in Mr. Hiscox's article. If such a case is actually in practice where any great cooling effect is obtained with as low a pressure as 30 pounds to the sq. in., the writer would like very much to hear of it.

Very truly yours, W. H. DICKERSON, M. E.

New York.

Iowa City, Iowa, Jan. 3, '98.

Editor Compressed Air:—

Allow me the privilege of commenting on the article in the last issue on "Cold Storage and Cold P– –s from Compressed Air."

The author states that the "amount of specific heat contained in a given volume of air is 1-800th of the amount contained in the same volume of water" per degree range of temp.

Specific heat is not an "amount," and while it is clear to see that he means the amount of heat, or heat units, his fraction is in error.

1 lb. air = 13 cu. ft. = .2377 heat units per deg. range temp.

13 cu. ft. H_2O = 800 lbs. = 800 heat units per deg. range temp.

$$\text{Ratio} = \frac{1}{3200} \text{ about.}$$

Again having determined that 841 h. u. must be absorbed from a certain room to reduce it to 34° F., he first calculates that air at — 138° warmed to + 34° (as min.) will give range of — 138 + 60 = 198°.

But supposing this did not include error, he says:

"Then $\frac{841}{198}$ = 4.24 lbs. or 55½ cu. ft. of free air at 30 lbs. pressure will be required to cool the room to 34°"—or say 25 per cent. of the amount required.

A. V. SIMS.

FREEZING OF GROUND BY EXPANSION OF AIR.

A recent article in the November, '99, issue of this magazine, entitled "Allen Refrigerating Process," has called to mind a very unique application of the Allen Dense Air System of refrigeration.

In excavating where quicksand is encountered work is greatly facilitated by freezing, and it was an instance of this kind that brought up the idea that compressed air could be adapted to the work; as the system of circulating brine is used in instances of this kind, but like most other appliances of this nature, it has its imperfections. Take for example a leaky pipe which by allowing the brine to come in contact with the frozen earth will soon destroy the freezing effect which has taken hours to accomplish.

The instance in mind was in 1895, at the time of the building of the Speedway along the Harlem River, where in excavating for the walls quicksand was encountered. Sooysmith & Company, now known as the Engineering Contract Co., and who control the freezing process of excavation for this country, having met difficulties of this kind, decided to attempt the use of compressed air for freezing the ground prior to excavating. To accomplish this they equipped an air compressor with an air expansion cylinder mounted where the ordinary air compressor cylinder is placed and extended the piston rod through so as to connect by means of a coupling to the piston rod of the compression cylinder which was mounted on a foundation in line with the steam and expansion cylinders. The valves of the expansion cylinders were of the Meyer cut-off type and were operated by extending the valve stems of the steam cylinder and connecting in such a way as to permit adjusting the cut off of either steam or air valves separately. To make a closed system, pipes were driven into the quicksand at regular intervals, these, of course, having the bottoms closed. Air from the expansion cylinder was led into the bottom of these by means of small pipes and allowed to pass back up through the annular space between the inner and outer pipes thus absorbing heat from the earth around the large pipe. The connections to these pipes were made at the ground surface so that the air having fulfilled its mission was taken back to the compression cylinder. Between the compression and expansion cylinders a cooler was placed so that the heat of compression should be removed and incidentally the moisture precipitated before the air was expanded, this insuring a low temperature after expansion. The air compression and expansion cylinders were proportioned with the idea of having their pressures in a ratio the same as for the Allen Dense Air or Roelker System, namely, 210 to 225 pounds at the end of compression while after expansion and hence in the circulating line about 65 pounds pressure. A priming pump was used for charging this line and supplying air lost by leaks.

This outfit was on trial for a period of several weeks, the temperature of the circulating air ranging from zero to 15 degrees F. The results of freezing the quicksand were not all that could be desired for it was found that there was an underground stream of running water passing around the refrigerating pipes which on account of its quantity would not permit freezing. Because of this water, it was concluded that it would be impossible to do the work by freezing and the idea was abandoned and a coffer-dam constructed instead.

It will be noted that the temperatures given above do not compare very favorably with 60 to 90 degrees below zero, as obtained on shipboard. This is readily accounted for, however, by the fact that the installations on shipboard are permanent and therefore set up with greater care in respect to non-conducting transmission pipes, less leaks, etc., than for temporary use only.

Some difficulty was found in the freezing of the moisture of the air in the expansion cylinder. This was largely due to the leaks in the refrigerating line which necessitated priming the system frequently with fresh air and consequently introducing moisture meanwhile. On shipboard the lines are so tightly constructed that very little priming has to be done and the small amount of moisture is removed by traps. Devices for removing water from the line were also used on the Speedway work, but it was not brought to the state of perfection it doubtless would have been had the effect of running water not made it advisable to take recourse to some other means of doing the excavating.

The non-success of this particular case should not permit us to conclude that the idea is not a feasible one for it is sure to have its field in places where it is found necessary to freeze ground at extreme depths where it would require a large power to handle brine, while air would set up a circulation due to the unbalanced condition of the warm ascending and the cold descending columns of air.

SAND BLAST METHOD.

SAID TO BE THE BEST FOR CLEANING SHIPS.

The test of the new sandblast method for cleaning the hulls of ships, made at the Navy Yard last week, will in all probability be followed by the introduction of the system into the different naval stations of the United States. The experimental tests on the bottom of the cruiser Atlanta, fully demonstrated the advantages of the new system over the method of doing the work by hand, now prevalent in the various navy yards. Not only does the sandblast system remove all foreign matter from the hulls in much less time than it takes to do the same work by the present system, but it is also cheaper. Naval officers who investigated the tests of the sandblast method made at the yard, have expressed themselves as greatly pleased with it and it is expected that the officials will recommend its adoption to the navy department.

The method is not a new idea, having been in operation for some years in nearly all the large dock yards and naval stations of Great Britain. The system has been most successful there. The machinery needed is simple and comparatively inexpensive, comprising a pneumatic air pump, which forces the compressed air through a hose. An arrangement is attached to the end of the hose by which fine sand is played into it. As the air is turned on the sand is played on the ship's bottom by the operator, who directs the stream to the points where cleansing is needed.

The compressed air pump is of the simplest character, and furnishes a pressure of only fifteen pounds to the square inch. This is powerful enough, however, to drive away all foreign matter from the steel plates of the ship's bottom in a remarkably short space of time, and it leaves the steel plates polished and as smooth as if they had been rubbed with emory paper. Paint, rust, scales and barnacles disappear as if by magic under the blast of the sand from the hose, and the inventors of the new method claim that it is five times as quick as the old hand method of cleaning a ship's hull. During the tests of the sand blast on the cruiser Atlanta, which was in dry-dock undergoing repairs, a space of ten feet square was thoroughly cleaned and polished smoothly in a few minutes. Hard paint, nearly one-eighth inch thick, was taken off with ease.

Naval Constructor F. W. Bowles, Captain of the Yard, Higginson, and Equipment Officer, Captain Sperry, were present when the experimental tests were made, and all three officers expressed themselves as greatly pleased with the result of the trials. Naval Constructor Bowles was especially impressed with the showing made by the sandblast method and commended its efficiency for cleaning steel plates. An effort will be made by the proprietors of the sand-blast to introduce their apparatus into the naval service.

CLEANING STRUCTURAL IRON BY SAND BLAST.

The city of New York is now trying the experiment of cleaning structural steel by the sand blast. The One Hundred and Fifty-fifth street viaduct is a steel structure and is used as a roadway with walks on each side. It suspends

FIG. 429—SAND BLAST IN OPERATION.

from Washington Heights across the Harlem River. At about the middle of the viaduct is the terminal of the Manhattan Elevated Railroad, and at this point there are almost continually one or more locomotives which throw out smoke and gases that ascend upward and radiate in the maze of trusses above. The effect of this has been to quickly destroy the paints that have been applied and to leave the surface of the metal exposed to the weather, and a consequent rapid deterioration from corrosion. Four coats of paint have been applied in five years, and the necessity of doing something to protect the structure led to the experiment. The makers of the best paints are applying their best products side by side under equal conditions. The metal structure is cleaned in advance by the sand blast. The apparatus employed consists of two air compressors and a Ward and Nash improved Sand Blast apparatus of three mixers.

The free air delivered is nearly 400 cubic feet per minute, the pressure being maintained at about 20 pounds. The air is conveyed about 300 feet to an air receiver which stands near the sand mixing apparatus. The sand mixers are shown in the illustration. The sand is thrown in the hopper at the top and it finds its way down to the bottom of the mixer, where it meets the air, and the two commingled flow through a 1½" rubber hose and is delivered through a cast iron nozzle with a hole 9-16 inch diameter. The sand and air pass through this tube at a velocity of over ten miles an hour. The operator holds the nozzle close to the surface to be cleaned and flying sand striking the scale and the paint which still adheres, loosens it and finally cuts it completely away, leaving the metal as innocent of covering as the moment it came from the foundry. It is absolutely and thoroughly cleaned. The metal now presents a perfect surface for painting, and painters begin work of painting every day at three o'clock in the

FIG. 430—SECTION OF STRUCTURE SHOWING SCALE AND CLEANED SURFACE.

afternoon, the earlier part of the day having been consumed by the cleaners. Two nozzles are kept at work at the viaduct. Combined, they are able to clean 700 to 800 square feet per day. There is a man for each nozzle, an engineer for the compressors and several men to carry sand and sweep and carry away refuse. Twelve tons of scale were taken off of the structure by means of a clean air blast before the sand was used.

It is assumed that this thorough and careful process of cleaning will so prepare the metal that the paint will now be firmly set when applied, and that it will fulfill its mission of preservation. The cost of cleaning by this method has not yet been determined, and fuller accounts of this will appear in future numbers.

THE SAND BLAST.

A. R. Lynch, Foreman Painter of the P., C., C. & St. L. R. R., Dennison, Ohio, writes as follows to the *Railroad Car Journal*:

In recent issues of the *Journal* I see that much attention is being given to compressed air in its many and varied uses. It enters largely into the workings of the up-to-date paint shop. One of the best uses we have found for it at Dennison is the sand blast for removing old paint, scales, rust, etc., from locomotive tanks. I was at the convention at Old Point Comfort, but was not present during the discussion of this subject, and I was not a little surprised, and regretted very much to learn that the sand blast process did not have a greater number of friends and more enthusiastic support than it seems to have had. It certainly deserves the consideration of any one who has locomotive tanks to paint. We have been using it for about eighteen months, and it has cost us, on an average, $2.50 per tank—some tanks being hard and some easy to blow off—but should it cost twice that much I would consider the operation cheap, for all our tanks that have been treated with the sand are in excellent condition, showing no sign of rust or scales, and after having been in service over a year can be put in as good repair as new by cleaning and giving one coat of engine finish and relettering (or "cut-in" if you choose). This makes a saving of about $10 as compared to the usual way of repainting tanks. Considering the thoroughness of the cleaning and the durability of the work which follows, we are led to believe that there is no method so perfect and economical for removing old paint, scales and rust from tanks as the sand blast. At our shop the sand blast has come to stay, and after we have once gone over our tanks we will have no trouble with scaling or rusting nor any need of a "rust killer."

THE SAND BLAST PROCESS AS APPLIED TO THE CLEANING OF THE WALLS OF PARDEE HALL, LAFAYETTE COLLEGE.

After the walls of Pardee Hall, Lafayette College, left standing from the fire, had been inspected and pronounced safe for rebuilding, the problem arose as to how the smoke stains on them could be removed.

Various plans suggested themselves as to the cheapest and most effective manner of accomplishing this, but to the recommendation of Mr. W. S. Ayer, C. E., '72, was due the final adoption of the sand blast. The application of the sand blast to glass cutting and to cleaning castings is very common, but it had never been applied to the cleaning of stone walls and its usefulness for this purpose was largely a matter of conjecture.

The air compressor and receiver for the operation were loaned to the college by the Ingersoll-Sergeant Drill Co., from their works at Easton, Pa.

The compressor was supplied with steam from a 10 h. p. vertical boiler belonging to the college at a maximum pressure of 50 lbs. The compressor was one of the company's direct acting type having a 10″ x 10″ steam cylinder and a 10″ x 14½″ air cylinder. The cylinders are directly in line, the piston rods being connected to a common crosshead. To each side of the cross-head are attached connecting rods which drive a pair of fly-wheels rotating on a shaft immediately in front of the steam cylinder. On the same shaft are placed two eccentrics for actuating the Meyer's expansion valve in the steam chest.

Air is supplied to the air cylinder through a pipe running through a stuffing-box in the rear end of the air cylinder. This pipe leads to an air chamber in the piston from which air is alternately allowed to pass into opposite ends of the cylinder. This is accomplished by means of a pair of valve rings on the piston. The action of these rings is shown by the sketch.

A and B represent the rings on each end of the piston in section. When the piston moves to the right B is in and A out, compressing the air to the right of the piston and admitting it to the left. When the piston reaches the end of its

FIG. 431—CLEANING STONE WITH SAND BLAST.

stroke and stops, the momentum of the valve rings throws B open and shuts A. On the return stroke the air pressure holds them in these positions and the operations are reversed. Holes are cut in the webs of the rings through which pins are run, limiting the motion of the rings to about ¼″ in this machine.

The advantage claimed for these valves over the spring valves in ordinary use is that they remain open during the full length of the stroke, enabling the compressor to get a full cylinder of air at the atmospheric pressure; while the spring valves, requiring a difference of pressure between the outside air and the interior of the cylinder to keep them open, supply air at less than the atmospheric pressure and are apt to close before the end of the stroke, when the piston is running slowly and the influx of air very small.

The air is discharged through special check valves placed at the ends of the cylinder whose action will be explained later.

The compressor is furnished with a regulator to take the load off the air piston when the pressure in the receiver reaches a given point, and at the same instant, to throttle the supply of steam to a point just sufficient to keep the compressor turning over. When the pressure goes down past the limit usually eight or ten pounds below the running pressure, the load is thrown on, the steam again admitted and compression is resumed in the regular way.

The regulator which accomplishes this consists essentially of a weighted piston (the cylinder in which it acts being connected to the receiver) connected to a small slide valve. From the regulator, pipes are run to the discharge valves at each end of the air cylinder and to a throttle valve in the steam pipe.

Normally the weighted piston is down and the pipes leading from the regulator to the discharge valves and to the throttle valve are filled with air at receiver pressure. The result is that the air pressure back of the discharge valves causes them to act as check valves, letting air out but not into the cylinder, and the throttle valve is held open giving full steam pressure to the engine. When the air pressure rises above a limit determined by the weight applied to the piston, the piston will rise, resulting in the air (which was under pressure in the pipes referred to) being exhausted. When this pressure is relieved the discharge valves are thrown wide open by the air pressure in the cylinder, and stay wide open, the result being, of course, that the inlet valve rings are held shut and the piston has receiver pressure on both sides, and moves back and forth in equilibrium. At the same instant the throttle valve closes to a point which admits just enough of steam to overcome friction and keep the engine moving fast enough to prevent centering. The extent to which the regulator throttle valve closes is regulated by an adjustable nut.

From the air receiver the air was carried by a pipe to the third floor of the building and from thence by a hose to the portable sand blast apparatus.

The sand blast apparatus was built and loaned to the college by Ward and Nash, of Boston, Mass.

It consisted of a circular iron receiver with a funnel or hopper inside.

Sand is fed into it through one valve while the air goes in through another. The funnel does not fit tight to the interior of the cylinder so that the air pressure above and below it are the same. The air passes through the end of the pipe and out through hose to the nozzle and the sand dropping down from the bottom of the funnel is carried with it. By means of a lever a slider is pushed in or out and the flow of sand regulated.

The great disadvantage of the apparatus was that the air pressure was so great that the valve could not be opened when the machine was in operation so that the compressor had to be stopped whenever the apparatus had to be recharged with sand. In some of the machines manufactured by Ward and Nash, an air lock is introduced and this difficulty overcome. From the sand blast apparatus the stream of air and sand was carried through a three-inch hose to the wall and discharged upon it through a half-inch nozzle.

The velocity of the sand was quite high and the bombardment of the particles cut away the discolored surface in a very rapid and satisfactory manner. The pointing between the stones was cut away but that had nearly all been cracked by the fire and would have had to be done over again at any rate. The sand stone arches and facing around the windows was cut away very rapidly and care had to be taken that the dressed edges were not spoiled.

The sand used was the best sea shore, clean and sharp. It had to be thoroughly dried before using not only to prevent its caking in the machine but to improve its cutting properties. The sand after using was found to be worn quite round and smooth and was of little use for the same purpose again. The consumption of sand, however, was very moderate. Four buckets were required to charge the apparatus and this was sufficient to clean several yards of wall surface. Care had to be taken not to feed the sand too rapidly, otherwise the apparatus became clogged until the pressure rose high enough to drive out the sand, and then it poured out of the nozzle in a thick stream and at such a low velocity as to be useless for cutting purposes.

The air pressure used was quite low, a pressure ranging from 12 to 15 lbs. per square inch proving most effective. J. C. Heckman, '99.

PNEUMATIC CAISSONS FOR ORDINARY FOUNDATIONS.

At many places on our larger rivers it is so difficult to get first-class foundations, and keep other than first-class ones after once put in, that the only really safe way is to employ pneumatic caissons. For the ordinary large highway bridge as built by county or city, this is seldom considered, owing to the fact that comparatively very few officials having charge of this work know anything of pneumatic foundations, and until recently such work has been too expensive for bridges of this class. Pneumatic work has been made much cheaper by competition and skillful handling, until for large highway bridges where good foundations are hard to get it is not only the best method, but almost as cheap as pile foundations. When the pneumatic caisson foundation is completed there is no question as to its stability, and no future expense for protection to hold it. A well built bridge on this foundation is for the use of generations to come, and, unlike many bridges on other foundations, will not need replacing before the present generation has passed away.

A recent experience with a bridge on the Scioto River is a good example of pneumatic work for highway bridges. In 1871 the County Commissioners of Ross County, Ohio, built a bridge across the Scioto River at the old ford at the foot of Main Street, Chillocothe.

It has been with great difficulty that all previous foundations for Scioto River bridges in Ross County had been put in by use of cofferdams, owing to the river gravel being very coarse and full of bowlders, and, taking this into consideration, it was decided to adopt the pneumatic foundations, as being the surest and safest plan, and certain to reach bed-rock no matter what might be encountered. A few days after bids were received, the contract was awarded to Willard & Cornwell to construct two masonry piers on pneumatic caisson foundations. with crib filled with concrete to within five feet of low water, according to plan shown. On August 12th work was begun on setting up the air-compressor and getting ready for caisson No. 1. The contractors' plant for this work consisted

FIG. 432—CAISSON NO. 3 BLOWING SAND.

of a double compressor with cylinders 14x16x18 inches, run by a boiler of locomotive type capable of generating 120 horse-power; a 115-volt dynamo of nine amperes capacity, run by a vertical engine supplied with steam from the big boiler; an air receiver fifty-six inches in diameter and fifteen feet long, and all necessary pumps, pipes, connections, fittings, etc., with hoisting engines, derricks, mortar boxes, tools and everything necessary for heavy masonry and concrete work. The compressor and boiler were set up on the solid roadbed, a few feet west of the old abutment, the compressor being next to the abutment, the boiler immediately west, and the dynamo and engine, for generating electricity for lighting the caisson, engine-house and office being in the same building and just south of the compressor and boiler, the whole being covered by a substantial frame shed 18x36 feet. An office, 10x12 feet, adjoins this building on the east. The receiver was placed north of the compressor, on the edge of the fill. A driven well at the foot of the embankment on this side, with a force pump, supplies water for the boiler and drinking water for the men. An eight-inch natural gas main runs within 1,000 feet of the engine house, and an inch pipe was laid from it and connected to the boiler to supply fuel for generating steam.

Both caissons were built exactly according to plan, twelve feet wide by thirty-two feet long and six feet deep inside, and sheeted inside and out with two-inch plank. The sides and roof of the caisson are two feet thick, built of 12x12-inch timber, each course being fastened to the courses below with ¾ and ⅞-inch drift bolts, thirty inches long and placed four or five feet apart. The two courses of the sides and ends are firmly fastened together by two rows of ⅞-inch bolts extending clear through both. The two bottom layers of timber are beveled off on the inside until only about four inches wide at the bottom, and on the bottom a 2x6-inch plank is firmly spiked, forming the "cutting edge" of the caisson. Two 12x12-inch tie-beams are dovetailed into the sides of the caisson, thus dividing the inside into three equal "pockets." There are five holes through the roof, a four-inch hole at the centre of each end "pocket" for the blow-out pipes; in the middle pocket an 18-inch hole near one beam and a 20-inch hole near the other beam for the supply pipe and air shaft, respectively, with a 4-inch hole near the latter for the air supply pipe. When one course of the roof is placed, the shafts are fastened on by means of bolts through this course and the flanges of the shafts. The air shaft is thirty-six inches in diameter, of the best ¼-inch boiler iron, thoroughly riveted together at the lap joints and to inside flanges of 1½-inch cast iron at each end, each flange having twenty-eight ¾-inch holes for bolts to fasten joints together. The flanges are on the inside, so they can be used for the lock doors to fit against, and the bolts being on the inside can be removed and the top sections of the pipe taken out when pneumatic work is finished. The supply pipe is eighteen inches in diameter, of the same material as the air shaft, and 3-16-inch thick. It is riveted together the same as the air shaft, except that the cast flange is on the outside and has but eighteen holes for bolts. These shafts are in joints varying from nine to fifteen feet in length. The timber used in caisson walls in crib and outside sheeting may be any good round timber in lengths of ten to twenty-four feet. In this work hickory, lynn, sycamore, red oak, etc., were used for all work except inside sheeting, which was of dressed pine. The inside of the caisson, from the cutting edge to the roof, and all over the roof, was caulked carefully in each joint between the timbers and around all bolt heads, then sheeted from bevel edge to roof and overhead, every joint of the sheeting being thoroughly caulked. Caisson No. 1, which was to go in the middle of the river, was built on timber runways on the bank, arranged so they could be raised at one end and slide the caisson off into the water when it should be ready to launch. Two heavy ropes were placed around the caisson and tied to posts behind, the runways were covered with soft soap, and the ends raised until the caisson was started and held only by the ropes, which were cut simultaneously, and the caisson slid out into deep water and floated with the top but little above the surface. On September 8th it was launched, towed into position, and anchored by ropes leading to some old piles at one side, and to a heavy anchor and a piece of old bridge iron up stream. When launched, but one course of roof or decking had been put on, and as soon as anchored to place the other course was put on and the crib on top built up several feet. This cribbing is of 12x12-inch timber, laid so as to make the outside of crib twelve feet by thirty-two feet, every other course tied together by two 12x12-inch cross ties dovetailed in, and the whole fastened together with thirty-inch drift bolts every four or five feet. The sheeting is also carried up continuous on the outside from the cutting edge. The top of the decking was then thoroughly grouted, the crib filled with concrete to the height of several feet, until the "cutting edge" rested on the river bottom and the top was four or five feet above water. This concrete was composed of one part Portland cement, two and one-half parts sand, and five parts gravel, with a good many large bowlders bedded in each layer. A three-inch pipe was laid from the receiver down the bank and along the river bed to the pier, and connected to the air supply pipe by a double flexible pipe joint. At noon of September 12th air was turned on and the work of sinking was carried on day and night by two crews, each working ten hours. Each crew of "sand-hogs," as the men engaged in this work are called, consists of a foreman, two blow-pipe feeders, four shovelers, an inside lock-tender and an outside lock-tender. The working chamber is lighted with three sixteen-candle power electric lights, and there is one in each section of the air shaft. The blow-out pipes just below the roof of the caisson are fitted with large valves with a four-inch opening. A piece of pipe from the valve extends to the bottom of the caisson, and when the valve is opened all sand, gravel and rock less than four inches in diameter brought up to the end of the pipe is forced out by the air pressure. On the top of each blow-out pipe is fastened a "goose neck," a curved joint to turn the material away from the crib. This "goose neck" is cast iron, with a four-inch opening and heavy walls, especially on the upper side where the gravel strikes, for it comes out with such force that an ordinary pipe bent to a curve would last but a few hours. All rock too large to blow out through the pipes is "locked" out through the air shaft in sacks. To sink the caisson all material is cleaned out level with the "cutting edge," then it is "ditched" by shoveling several inches of material from under the "cutting edge" and given a "blow" by opening one of the valves and letting out the greater part of the air. Relieved of the lift of the compressed air, and with the weight of concrete on top, the caisson settles down from six to ten inches, or until the cutting edge is again on solid gravel. While the air is escaping the working chamber is filling with water, and will frequently be two-thirds full when done "blowing." Caisson No. 1, for eighteen or twenty feet below the bed of the river, went down smoothly and rapidly without delay. At this depth was encountered a layer of bowlders varying in weight from five pounds to over one hundred pounds, and at the bottom of the layer were three coping stones from the top of the old east pier, which had been washed out. These stones were thirty feet below low water and sixty-six feet from where the pier had stood showing how deep the scour had been when the water was highest. As the water fell and the current became less swift, the larger rock coming down were deposited, and then the smaller rock, gravel and sand. This layer of rock was what had stopped the sounding rod, but immediately below was six or eight feet of quicksand, and then another layer of gravel and rocks, but bed rock was not struck until forty-three feet below low water. The bed rock consisted of black shale and limestone in alternating layers of about two inches in thickness. The caisson was landed and rock leveled down after twenty-three days' work, and on the morning of October 6th concreting the air chamber was begun. To concrete the air chamber a two-inch pipe connection is made from the air pipe to a point just below the top flange of the supply pipe. This pipe has a valve, No. 1, near the air pipe, and another valve, No. 2, on a T between valve No. 1 and the supply shaft. A top door opening down is then put on the supply shaft and the fastening taken off the lower door. A batch of concrete is shoveled into the supply pipe, the upper door pulled up, valve No. 2 closed and No. 1 opened. This puts compressed air in the supply shaft and allows the lower door to equalize open and the concrete falls into the working chamber, where it is rammed under the bevel edges and over the bottom by the "sand hogs." The lower door is then shut, valve No. 1 closed and No. 2 opened, allowing the compressed air in the supply shaft to equalize out and the top door opens. The process is repeated until the chamber is filled with concrete and barely a narrow passageway for one man is left between the lower doors of the supply shaft and air shaft. The lower doors are then shut, and the last man equalizes out. A regular air pressure is then kept on for twelve or eighteen hours, until the concrete sets. The air is then turned off, and the shafts filled with concrete as quickjly as possible. As soon as the air pressure is taken off the lower doors drop and the space left in the working chamber is also filled with concrete, which runs in from the shafts. This finishes the foundation from bed rock to above low water.

Caisson No. 2 was built about ten feet back of the washed-out abutment, part of the old approach being leveled down to near low water mark so it could build exactly where it was to sink, and at noon of the 14th day of October, air was put on caisson No. 2. This caisson was above the water level, and before putting on air it had been sunk about two feet. As the pressure at first would be low, temporary blow-pipes were put in the side near the roof, and used to blow out sand and gravel until they were down to water level. This required less air to blow out material than to lift it through the roof. When down to water level these pipes were removed and the holes plugged. This caisson went down without special incident until the "cutting edge" was about fifteen feet below low water, when a good sized red oak tree was encountered. Several blasts were put into holes bored in the tree under the cutting edge, until the trunk was severed at this point. The tree was then sawed up and removed through the air locks. Dynamite was used to blast out this tree, and also to blast to pieces large stone found in the caissons. When blasting the men stayed in the air shaft, and frequently in the working chamber itself, for the concussion from a blast is not felt under air pressure as it would be on the outside. Test rods were driven at several points inside, and there was apparently a level bed rock about twenty feet below low water. Accordingly on October 8th the cutting edge being about five feet from the bottom of the rods, the first footing course was laid, and the next day the second course offset six inches all around, making it 11x31 feet. According to the rods, we were then about two and one-half feet from bed rock. The "sand hogs" now attempted to pull the ⅞-inch sounding rods which had been cut off as the caisson was sunk, and found they could not move them, although but two and one-half feet were in the ground. They even broke a large chain by using leverage to pull on the rods—we then had them dig down at one point, and they brought up a sample of a peculiar material that was neither peat nor lignite, although it was evidently the bottom of an old swamp. The material was tough and like rubber when a pointed rod was driven into it, but a piece taken out proved to be brittle and of no strength. We now drove rods through it and

FIG. 433—FLASHLIGHT IN CAISSON.

found that after two or three feet they again drove part of the way, with great ease, until striking bed rock on a level with bed rock under caisson No. 1. It was decided not to land the caisson on the lignitic peat, as there was evidently quicksand under this layer, and the sinking was continued. This material was hard to work, and the "sand hogs" were seven days making two feet in depth. The first course of stone, and part of the second, was below water before it was decided to continue, and therefore the 11x31 feet of masonry had to be brought on up. A great many difficulties were encountered in sinking this last twenty-two feet, and it was not completed until November 30th. The compressor broke down twice, and high water got above the masonry and stopped the work once for several days. The first footing course dragged considerable and held back the caisson in sinking, and the ends at different times were as much as a foot out of level. In bringing the pier back to a level, several of the joints in the masonry were opened, but no stone cracked. Below this lignitic peat the sand and gravel was of a different character than that above, or what was encountered in sinking caisson No. 1. First there was eight or ten feet of sand almost as fine as quicksand, and working like quicksand, then the rest was coarse gravel with bowlders. This sand and gravel was dark, but contained but little soil, the color being given by hornblende and other dark rock in the drift. Within a foot of the bed rock was found a skull, which proved to be that of a pre-glacial hog. The lignitic peat is a formation of the glacial period.

Pier No. 3 was to be erected 154 feet east of the river, to hold the end of an approach span which was to take the place of that much embankment. One of the spans of the old bridge was repaired for this approach, and it was oriniganlly intended to use four-foot tubes sunk to solid foundation to hold the east end, but when bids were received the bid of $2,900 was made for a pneumatic caisson sunk to twenty feet below low water, with masonry pier. The bids for the tubes were from $1,012 to $2,200, and the Commissioners at first awarded the contract to the lowest bidder on tubes, but within three weeks the sinking of caisson No. 2 proved what difficulties might be encountered in sinking tubes and possibly result in failure, and the bidder on tubes willingly consenting, the contract for pneumatic caisson was awarded to the contractor who was building the other two. This caisson was built ten feet four inches by twenty-seven feet four inches on the outside, with walls of 10 x 12-inch timbers, making the inside twenty-three feet eight inches by six feet eight inches. Temporary blow-pipes near the roof were also used in sinking caisson No. 3, this time being placed in the ends. On December 12th air was turned on No. 3, and it was sunk through a layer of drift gravel, a layer of loose rocks, and a layer of quicksand, and landed on the lignitic pea nineteen feet below low water, and the concreting was completed on December 28th. High water delayed work on this caisson four days, breaking the air pipe in the middle of the river. This completed the pneumatic work, and the masonry, having been kept up pretty closely, was completed on January 6, 1899. All masonry work was of heavy freestone rock from Otway, near the Ohio River, in Scioto County. Three thicknesses, seventeen inches, twenty-one inches, and twenty-eight inches, were used. The masonry was quarry-faced, with full dressed beds and laid in Portland cement mortar mixed in proportion of one part cement to two parts sand. No grouting was used except in holes too small to ram concrete in, the backing being of stone placed far enough apart to allow concrete to be rammed in solidly between. Piers No. 1 and No. 2 are shown in the plan while pier No. 3 was lighter, being but twenty-four feet long by five feet three inches wide under the coping, and built with square ends. It being in place of an abutment, the earth fill is given a natural slope at the ends and in front of the masonry.

Many persons were allowed to go down in the caissons to see the process of working. For the trip they were fitted out with overalls, jacket, an old hat and rubber boots. The top door of the air lock or shaft had a rope fastened in the ring to handle it by when the air was off. When the door was closed and the air pressure on several tons would be required to open it by force, but as soon as the signal was given—five taps with the hammer by the outside lock-tender—and answered by the tender inside, the valve would be opened and the air allowed to escape, the door at the bottom having been previously closed, and when the air pressure was all off the top door would drop. The lock or shaft is a dark, forbidding-looking place, full of a fog which soon clears out, disclosing an iron ladder down one side and electric lamps for light. After going in, the top door is pulled up by the outside tender, and the pressure pipe opened. As soon as the pressure becomes considerable, the novice becomes "plugged," owing to the pressure on the ear drums pressing them in, but by holding the nose with thumb and finger, and with the mouth closed, a hard blow from the lungs, with distended cheeks, presses them out again, and relief is had. This can also be overcome by placing the ears close to the outlet pipe and opening the valve. When the pressure in the lock has become equal to that in the working chamber, the lower door drops, and the caisson can be entered. Owing to the excitement and the thought of what might happen, the perspiration comes easy, but the temperature is very little higher than outside. The blow-out pipes extend to the bottom of the end pockets, and when opened the sand and gravel rush to the end of the pipe like tacks to a magnet. Some air escapes with the gravel, the air becomes foggy, and the water comes in to a depth of six inches, or more; then the blow-out is closed until the air clears, and the water is driven out. The end of the supply pipe is curved and provided with a flap valve, which would close at once in case the supply pipe across the river broke, or the air was shut off in any way.

To sink the caisson the "sand hogs" dig out under the cutting edge, which process is called ditching, then the air is allowed to partially escape, and the caisson sinks or drops down. The chamber becomes foggy and half fills with water, but when the compressed air comes in strong again it clears up and the water is expelled.

The bid in detail upon which this work was awarded is as follows: For pneumatic caisson and crib filled with Portland cement concrete, on a basis of thirty feet or less below low water for pier No. 1, and twenty-four feet for pier No. 2, top of both cribs to be five feet below low water, $8,300; for rock, slate, logs, or bridge iron removed through locks, $9 per cubic yard; for excavation in slate or bed rock requiring blasting, $7 per cubic yard; for extra depth to forty feet below low water, $150 per lineal foot; for extra depth forty to sixty feet below low water, $160 per lineal foot; pier masonry, $7.25 per cubic yard. This was $12.77 per cubic yard of caisson and crib, not including rock, etc., that might be locked out, and $10.16 per cubic yard for extra depth to forty feet below low water. For pier No. 3 caisson and crib sunk to twenty feet below low water and filled with Louisville cement concrete, $1,600; for all material locked out. $193; for abutment masonry, $6.75 per cubic yard. This is $11.47 per cubic yard of caisson and crib, including all locked out material. Pier No. 1 was sunk 13.15 feet extra depth, and No. 2 18.68 feet extra depth, costing $4,832.80. Twenty-five cubic yards of rock was locked out of No. 1, and eighty-two cubic yards out of No. 2, at a total cost of $988.20, making Pier 1 and Pier 2 within five feet of low water cost $14,121, or $12.61 per cubic yard. The total amount of masonry in piers No. 1 and No. 2 above the level of five feet below low water, 498.73 cubic yards, and cost $3,615.79, or a total of $17,736.79, or an average for two piers entire of $10.95 per cubic yard. The contractors obtained most of the material and labor at very reasonable prices. For timber $11 per 1,000 feet B. M.; for sand, gravel and bowlders, 25 cents per yard; for stone, $3.35 per cubic yard, delivered at bridge site; for Portland cement, $2.15 per barrel, all delivered at bridge site. Ordinary labor was $1.25 per day; the cost of other labor was from $1.50 to $2.00 per day, except stone-cutters, who received 25 cents per hour; foremen received from $2 to $5 per day.

We have adapted the above from an article published in *Bridges and Framed Structures* by A. W. Jones.

THE PNEUMATIC CAISSON FOUNDATIONS FOR THE BROAD-EXCHANGE BUILDING, NEW YORK CITY.

The Broad-Exchange Building, now under construction at the corner of Broad street and Exchange place, in New York City, will be the largest office building in the United States. It will be 23 stories, or 286 feet, high above the street, and will cover an irregular area of about 27,000 square feet, with frontages of 236 feet on Exchange place and of 106 2-3 feet on Broad street, and with a wing about 100 feet long and 35 feet wide extending south toward Beaver street. The exact dimensions of the ground plan are shown by Fig. 1. Altogether there will be 10,000 tons of steel employed in the framework, which will be enclosed with walls of granite to the top of the first story, of Indiana limestone to the top of the third story, and of brick and terra cotta for the remainder of the height. The framework will be carried by 100 lines of columns, each founded on a separate steel caisson sunk either to bedrock or to the hardpan overlying it. The large number of caissons which were sunk and the extreme celerity with which, under the conditions, this work was done, make the foundation construction of particular interest, and we present here a description of the apparatus and methods of work employed.

PRELIMINARY WORK.

The foundation work of the Broad-Exchange Building is of interest, not so much for its character, which was not particularly novel, as it is for its extent and for the difficulties which resulted from the short time available for carrying it out. To make these matters clear it is necessary to set forth the actual conditions in some detail.

The Broad-Exchange Building is being built for a syndicate of New York capitalists, the general contractors being the George A. Fuller Company, of New York City. The contract called for the completion of the building ready for the tenants by May 1, 1901. On May 1, 1900, the work was placed in the hands of Clinton & Russell, of New York City, as architects, and of Purdy & Henderson, of New York City, as structural engineers. So far as actual construction was concerned, therefore, the condition of affairs was that not a line of the plans had been placed on paper twelve months previous to the day set for the tenants to move into the building. Evidently the utmost haste was imperative. Furthermore, it must be remembered that this haste was necessary at a time when the rush of work had placed all of the large steel mills behindhand with their orders, and that large quantities of steel work were the first materials needed for the beginning of construction.

The problem was a twofold one; plans had to be prepared in a remarkably short time, and the methods had to be devised to secure the manufactured materials to put these plans into material form in the building. Under ordinary condi-

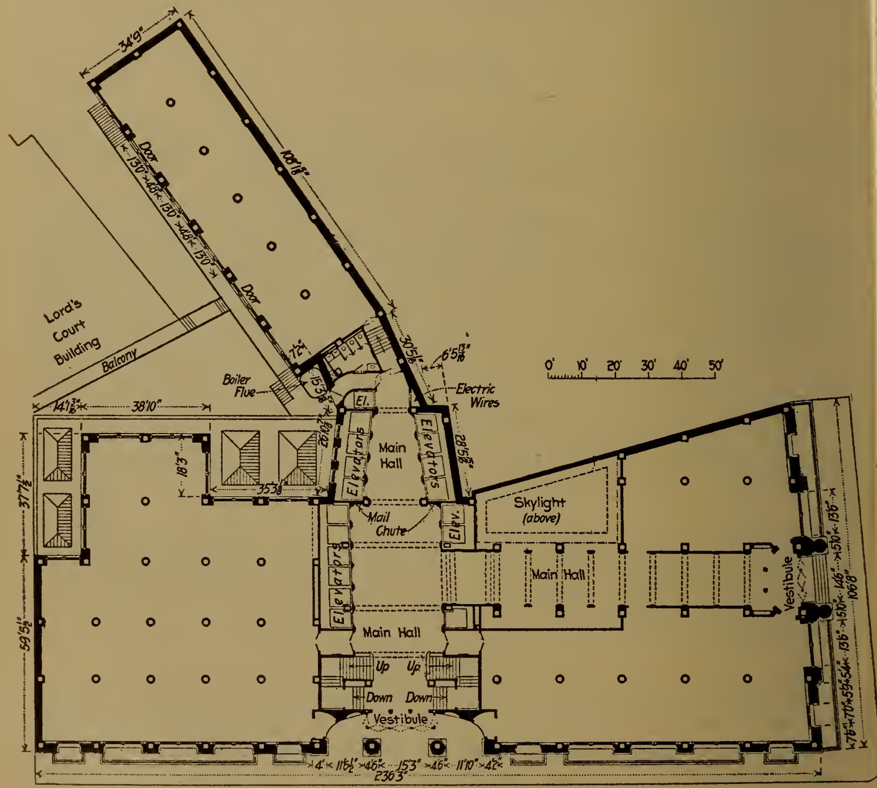


FIG. 434—FIRST FLOOR PLAN OF BROAD-EXCHANGE BUILDING, NEW YORK CITY.

tions the engineers would have waited until the architects had settled upon at least the general lay-out of the building before beginning work, but to follow this precedent in this instance would have necessitated a delay which, although it was short, neither they nor the architects were disposed to endure patiently. Accordingly the engineering studies were begun without knowing at all what the final plans of the architects would be. It is obvious that these studies had to be in a great measure of a tentative character.

The first act was to adopt a tentative plan calling for 106 lines of columns, and to estimate and assume the column loads. This work gave something of a definite basis upon which to begin studies of a foundation plan. The general contractors had had in mind using pile foundations, but before adopting this construction it was decided to make a comparative study of several types of construction. The next work, therefore, was to design and to estimate the costs and relative advantages of pile foundations, foundations consisting of steel cylinders filled with concrete, and of foundations consisting of pneumatic steel caissons filled with concrete. As the result of these comparative studies a report was presented on May 23, in which the use of pneumatic caisson foundations was advised. The decision was accepted by the general contractors and, stated briefly, was influenced by the following considerations:

(1) By using pneumatic caissons comparatively certain results in the time required for the work were ensured. Some of the material penetrated was exceedingly unstable; it was quite certain that pneumatic caissons could be sunk

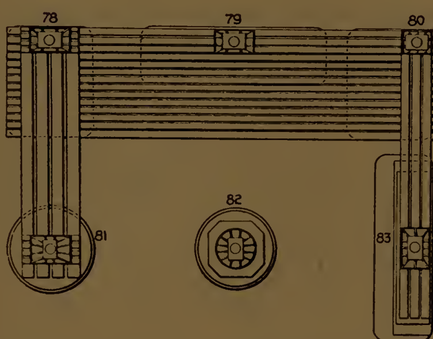


FIG. 435—SKETCH PLAN OF EQUALIZING GIRDER SYSTEM FOR COLUMNS 78, 79 AND 80.

through this material without danger of unforeseen delays, but there was no such certainty if either of the other forms of construction were adopted. (2) By using pneumatic caissons the good character of the foundation work could be ensured beyond a doubt, and this was not possible if either of the other constructions was employed. (3) The reputation of pneumatic caisson foundations for excellence was considered to be a material advantage to the builders and owners from a business standpoint. There was also another consideration which influenced the selection of pneumatic caissons, and this was that whatever style of foundation might be adopted for the other columns, those coming on the party lines would have to be founded on pneumatic caissons in order to prevent disturbing the foundations of the adjacent buildings.

With the consent of the general contractors to the use of pneumatic caisson foundations, one factor of the problem has been disposed of. By this time the architects had determined in a general way the lay-out of the building, and it was possible to decide approximately upon the number of columns to be employed. It was not possible, however, to locate these columns definitely, and hence their exact loading could not be calculated. From the data available, however, two things were certain: (1) that the number of columns to be provided with foundations would be at least 100, and (2) that the loads on these columns would run between a certain maximum and minimum. Obviously, therefore, if a typical caisson should be designed which could be made in a number of sizes between those required for the known maximum and minimum loads, it would be possible to order a number of each size in advance of definite knowledge where each was to be located, and yet with the certainty that they could all be used somewhere. There was very little risk in such a mode of procedure, and the gain in time of manufacture which made it possible was an important advantage.

The column caissons were, therefore, divided into two classes. The first class comprised the caissons for the wall columns on the party lines, which required special design in each instance, and could not, therefore, be designed until the location and loading of the columns which they were to carry were definitely known. The second class comprised all but a few of the columns not coming on party lines, and for which a typical general design of caisson was possible. The typical design of caisson adopted was a cylindrical caisson of steel; the diameters were fixed at 7, 7½, 8, 8½, 9 and 9½ feet. The next step was to secure some one who would manufacture these steel caissons quickly. To obtain immediate manufacture and delivery by any of the large steel works was found to be out of the question, and a search was begun among the smaller concerns capable of handling the work. This search proved unusually successful. A contract was made with the Lukens Rolling Mill Company, of Coatesville, Pa., to roll the steel sheets in three days, and with the Coatesville Boiler Works to begin the delivery of the caissons in ten days from the date that the steel sheets were delivered to them, provided they were furnished with the I-beam bracing, which they could not manufacture, at once and in shape ready for use. To secure the I-beam bracing the engineers went to a number of places where a small lot could be obtained, and to ensure its prompt delivery to the Coatesville Boiler Company, a man was sent on the car with every lot to prevent any hold-up of the shipment by the railways.

Shortly after the order for the manufacture of the caissons had been given, the architects presented a definite plan of the building. This plan enabled the engineers to begin the definite design of the steel work, and the plans were far enough advanced by the time the first delivery of caissons was made to enable them to be located at once, and the sinking begun. Before describing the work of sinking the caissons, the general character of the foundation construction and the details of the caisson construction will be described and illustrated.

GENERAL PLAN OF FOUNDATIONS.

The foundations were designed upon the general plan that each line of columns should have its individual caisson foundation. All the caissons except those located along a portion of the south and west party lines are cylindrical and carry the column footings concentric with their top. The party wall caissons are rectangular with their longer parallel to the party-line. As will be seen the cylindrical caissons vary from 7 feet to 9½ feet in diameter, the greater number being of the smaller size. They are filled with concrete to the top, and most of them also have a granite capping the full size of the caisson. The column bases are circular in plan and are bolted directly to the caisson masonry.

In the case of the rectangular caissons the column loads are distributed to the masonry by means of I-beam grillages, as shown by the various sectional elevations. The most complicated of these distributing girder systems is that for the group of columns at the south end of the wing, an enlarged plan of which is shown by Fig. 435. The two bays or panels between columns Nos. 78, 79 and 80 have a system of wind bracing consisting of X-braces of channels.

CAISSON CONSTRUCTION.

Details of the caisson are shown by Figs. 436 and 437. Fig. 436 shows one of the 7-foot cylindrical caissons, but the construction of those of larger diameter is practically the same. Fig. 437 shows one of the rectangular caissons; the others, except one, No. 98, which is of trapizoidal form, are exactly like this except in dimensions. All the caissons were built of medium steel 5-16 inch thick for the caisson proper, and ¼ inch thick for the cofferdam portion. The caissons all have reinforced cutting edges and a working chamber 6 feet 6 inches high. The minor details of construction are clearly shown by the drawings.

METHODS OF WORK.

Borings made at ten different points over the foundation area showed first a layer of filling from 2 feet to 6 feet thick overlying a layer of fine sand and clay mixed, which extended to hard-pan at an average depth of about 40 feet below the street surface. The fine sand and clay mixed proved to be a very unstable material; when wet it ran almost as freely as water. The hard-pan was, however, of the firmest and most stable character, being practically a rock and directly below it came the gneiss bedrock. Upon the showing made by the borings general instructions were drawn for the sinking of the caissons, which were, somewhat condensed, as follows:

If the hard-pan over the rock is not more than 6 feet deep, the shaft should be open to the bottom and cleaned out, so that the concrete shall have a perfect bearing on the clean rock. If the rock is not more than about 1 foot out of level and the hard-pan is about 2 feet thick or more, the concrete can be placed directly on the rock. If the hard-pan is thin or there is none, and the face of the rock is generally even, it must be leveled off or cut or shaped in some way so that it will resist any tendency to lateral displacement. If the rock is very uneven it must be leveled off or channeled or fixed in some good way to afford a satisfactory footing for the concrete shaft, not only for the direct load it must carry, but also to resist any tendency to lateral displacement.

If rock is not found after the excavation has been carried fully 4 feet into good hard-pan, drive a crowbar, in not less than two places, to locate the rock. If it is found within 2 feet excavate out the hard-pan to a secure bearing on the rock. If it is not found, clean out a footing on the hard-pan over an area somewhat larger on all sides than the size of the cutting edge of the caisson, as given in the schedule below:

7-foot diameter must be excavated 8 inches more, all sides.
7½-foot diameter must be excavated 18 inches more, all sides.
8-foot diameter must be excavated 9 inches more, all sides.
8½-foot diameter must be excavated 10 inches more, all sides.
9-foot diameter must be excavated 11 inches more, all sides.
9½-foot diameter must be excavated 12 inches more, all sides.

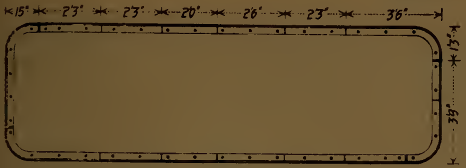
By this schedule of arrangement the bearing area of the caisson masonry was increased from 39 per cent. for the 7½-foot caissons to 49 per cent. for the 9½-foot caissons.

The contract for the pneumatic work in sinking the caissons was awarded to the Engineering Contract Company, of New York City. The general contractors located the caissons, set them up ready for sinking, furnished the concrete, and supplied the derricks and hoisting machinery; the Engineering Contract Company furnished the compressed air, the steam power and the labor, and sunk the caissons and placed the concrete under pressure. The concreting in the open was done by the general contractors. The engineers checked the location of the caissons and watched that they were kept plumb. The engineer in charge also went into each caisson to see that the excavation had been properly finished and also supervised the placing of the concrete. With this brief explanation of the apportionment of the work, it will be described as a single task to avoid confusion.

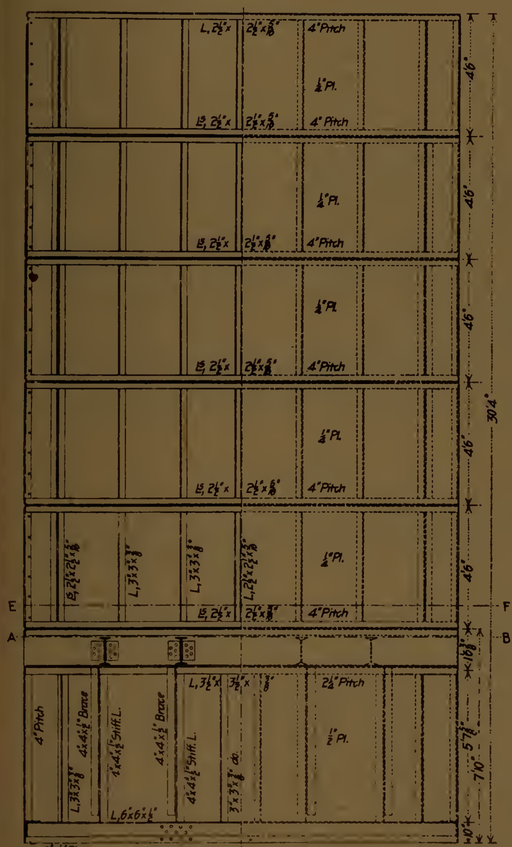
The bottom of the foundation excavation was about 15 feet below the street surface, and at the level of the street surface a strong timber platform was built covering the whole area. The caissons and all structural material for the foundations were unloaded onto this platform, and it also carried the power plant and machinery. Chutes, stairways and traps at various points in the platform allowed the materials to be sent below as they were needed.

The air compressor plant for the caisson work consisted of two 16-24 × 12-18-inch Ingersoll-Sergeant air compressors, supplied with steam by a 4-inch pipe from the mains of the New York Steam Company. These compressors delivered into a 6 × 18-foot cylindrical receiver. To cool the compressed air for delivery to the caissons, two methods were employed. When at the beginning of the work no more than four caissons were being sunk at once, it was found possible to keep the air below 80 degrees F. by pumping cold water through the receiver. At a later stage of the work when as many as ten caissons were under way at once, an additional cooling device was employed which consisted of 54 pipes ¾-inch in diameter contained in an 18-inch × 15-foot cylinder. The air from the compressors was passed through the pipes and cold water was kept in constant circulation through the cylinder. From the cooling cylinder the air passed into the receiver at a temperature of about 70 degrees F.

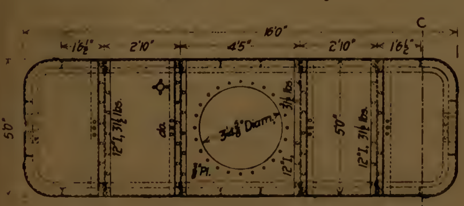
For the first five or six feet of their descent, or to water level, the excavation inside the caissons was done in the open, and then air pressure was put on. As the sinking progressed the cofferdam of the caisson was added to, so as to be always above water level, and was filled with concrete around the central air shaft. The maximum air pressure used was 18 lbs. Generally the weight of the concrete in the cofferdam and a load of ten or twelve tons of pig iron were sufficient to sink the caissons. The caisson men worked in three shifts of eight



Horizontal Section E-F.

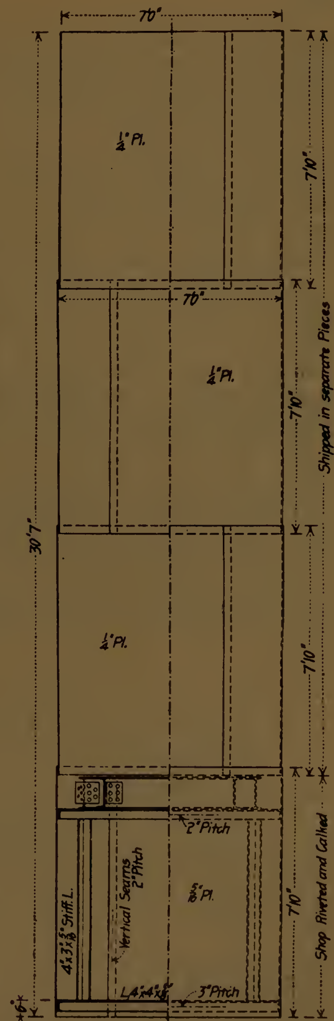


Sectional Elevation.

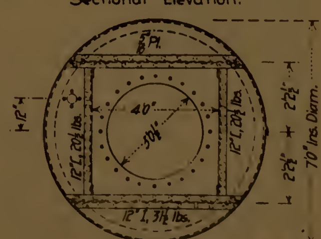


Horizontal Section A-B.

FIG. 436.



Sectional Elevation.



Plan of Working Chamber.

FIG. 437.

hours each, and there were nine gangs of six men in each shift. Each gang had three men in the working chamber, one man in the air lock and two outside. Air pressure was maintained at 30 lbs. in the receiver and was throttled down to the required pressure at each caisson.

All the caissons were provided with 36-inch shafts, which in the majority of cases were divided diametrically by two inside angle guides. The bucket used was semicircular in plan, and worked up and down in one compartment of the shaft, while the other compartment contained a ladder and served as a main shaft. In other cases a cylindrical bucket 18 inches in diameter was employed.

At first the concrete was mixed on the main platform near the caisson in which it was to be used. Later on two small platforms were built at central points about 10 feet or 12 feet above the main platform, and each of them was equipped with a balanced wheelbarrow-elevator running to the bottom of the main excavation. The cement, sand and broken stone were hoisted to the upper platform and mixed by hand. The mixture was then shoveled into a gravity mixer, which discharged onto the floor of the main platform. From the point of discharge the concrete was taken by wheelbarrows to the caissons. Pressure was maintained in the working chamber until the concrete was set, and then the air lock was removed and the cofferdam was filled and the capstone placed. The final work was the placing of the column pedestals.

In conclusion it should be noted that 88 caissons were sunk in 47 days. The most rapid sinking recorded was 2 feet in one hour and 27 feet in 20 hours.

SINKING CYLINDER FOUNDATIONS IN VALPARAISO.

The following account of an important application of compressed air is given in *The Engineer.*

Amongst the works designed and executed in the Port of Valparaiso foi the Government of Chili in 1874-83 was a wrought iron mole or pier, for the discharge of ocean-going steamers of the largest class.

The special circumstances of the case—the great depth of water at a short distance from the shore, and the proverbially severe storms of "Valparaiso Northers" to which the work would be subjected to in the open bay—were the chief factors leading to the design for a pier which should present the least obstruction to the force of the storms, should be economical in construction considering the depth of water—42 ft. to 48 ft.—and should also possess the advantages of convenience and permanence. In view of the conditions to be fulfilled, it was decided to build a pier of wrought iron girders, supported on fifty-two wrought iron cylinder foundations, 11 ft. 4 in. diameter, placed at equal distances and sunk a sufficient depth into the bottom of the sea to give them the required stability. They were to be filled with Portland cement concrete, and braced together by fender girders and the flooring of the pier. The superstructure was provided with hydraulic cranes for lifting ordinary merchandise up to 1½ tons, and with one big crane capable of lifting exceptionally heavy weights up to 45 tons.

But it is not the purpose of this article to deal with the work as a whole, but with the pneumatic method used in sinking the cylinder foundations. The pneumatic apparatus used at Valparaiso was designed by the late Mr. John Hughes, M. Inst. C. E., at that time engineer-in-chief, who was well known in connection with this class of work from the time it was first used by him in sinking the foundations of Rochester Bridge in 1851. As will be seen by the accompanying illustrations, the latter form of apparatus presented many novel and interesting features. The cylinders themselves were formed of wrought iron, the bottom length of 15 ft. being riveted together in one piece. The first 5 ft. 6 in. from the bottom upwards was formed of two thicknesses of ¾ in. plates riveted together, with rivets countersunk on the outside, and with the usual cutting edge at the bottom of the cylinder. On the inside were angle iron knees supporting a shelf 5 ft. from the bottom, and closing an annular space between the outside cylinder, which was 11 ft. 4 in. internal diameter, and an inner cylinder 8 ft. in diameter, thus leaving the annular space exactly half the area of the whole cylinder, or 50 square feet. When this space was afterwards filled in with concrete, weighing approximately twice the weight of water, it was sufficient to balance the cylinder and compensate for the buoyancy created by the exclusion of the water by the compressed air.

The inner cylinder was made of ½-in. plates and the outside with the exception of the bottom 5 ft. 6 in., was made of ⅜-in. plates, riveted together and stiffened with angle iron rings. With the exception of the bottom length of 15 ft. the outer cylinder was made in sections 8 ft. long, with angle iron rings at either end for the purpose of joining them together with 1 in. bolts. Owing to the large number of cylinders, and their comparatively short distances from one another, it was deemed expedient, in view of the rough weather to be contended with, to erect a temporary timber staging for placing the cylinders, rather than employ any other method which might have presented various inconveniences in the transport of concrete and other material. On this timber staging, which, owing to the nature of the case, was in itself a work of some magnitude, six timber guides, 15 in. by 12 in. by 14 ft. long, were securely placed at the exact site for each cylinder. It was also furnished with three lines of rails for 45 ton traveling cranes, and with four lines of metre gauge for trucks used in transport of concrete and in the removal of the excavated material, &c. The staging was 25 ft. high above water level, and was made of piles 12 in. by 12 in. stiffened with diagonal bracing above and below water.

The operation of sinking a cylinder was as follows:—Heavy temporary timbers having been placed on the lower part of the stage at about water level, forming a strong platform between the guides previously referred to, the bottom length of 15 ft. was brought from the shore by means of a traveling crane, and deposited on it. The inner and outer cylinders were then built up to a height of 39 ft., and weighing altogether close on forty tons, were lifted by means of the traveler to a sufficient height to enable the timbers on which they rested to be withdrawn. The whole cylinder was then lowered into the sea until it floated by reason of the annular space between the inner and outer cylinders. A wrought iron cover was then placed over the inside cylinder, the joint being made air-tight by means of inch bolts and packing. On this cover two lengths of 3 ft. diameter shaft cylinders were bolted, and other lengths of these and of the outside cylinder were added, till the whole rested on the bottom with the top of the cylinder rising above the upper stage. As the cylinder sank the annular space was filled in with

Portland cement concrete 3½ to 1 up to the height of the cover, and the concrete continued above that in the same form by means of temporary curbing. It was mixed by hand on bankers designed for the purpose, and placed one on either side of the cylinder, the material being brought from the shore in small tip wagons.

The cylinder in this position was ready for the reception of the bell or pneumatic apparatus proper. From Fig. 438 it will be seen that it consisted of a wrought iron case with semi-circular ends made to fit on to the shaft cylinders,

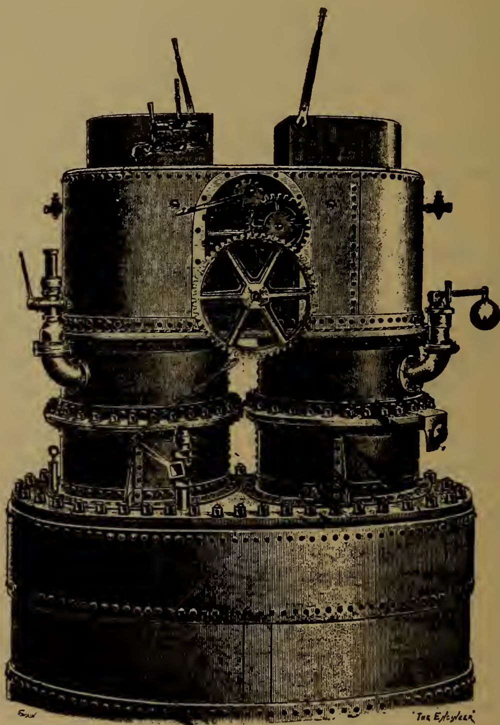


FIG. 438—HUGHES AIR LOCK—VALPARAISO HARBOR.

and was designed with a view of requiring no men under pressure except those actually engaged in excavation. The air locks were formed as follows:—The two D shaped cases were furnished with covers or flaps worked from the outside by means of a hand lever fixed on the bar forming the hinge, which passed out through a small stuffing-box, the joint between the cover and the top of the case being made air-tight by means of an india-rubber ring attached to the former. A similar ring was fastened underneath the bottom of the D-shaped case for the purpose of forming an air-tight joint with the bottom portion of the air lock or skip case. This was suspended by two chains of gauge links, one on either side, passing round chain sheaves, so that when both the D-shaped chambers were closed and the compressed air admitted, one skip case could be raised and the other lowered simultaneously by means of the winch worked on the outside, the main shaft of which passed from side to side of the air bell through stuffing-boxes and carried the driving sheaves on the inside. It was the top of either of the skip cases coming in contact alternately with the rubber ring on the bottom of the case which made the joint complete and allowed the air lock thus formed to be opened by letting the compressed air escape from the inside of it. The cocks for the inlet or outlet of compressed air to the air locks were 1½ in. bore, and linked together so as to be worked by one lever, controlled on the outside by the man in charge. Smaller cocks, ¼-in. bore, were provided on the inside, to be used by the workmen coming in or out, so that they could control the rapidity of the change of pressure to suit themselves.

The buckets or skips for hoisting the excavated material were made to fit closely the inside of the skip case, and a convenient method of attaching a chain for emptying them was arranged by means of a pipe passing through from side to side of the bucket close to the bottom. Through this pipe a short bar of iron was thrust as it was raised from the air lock by a steam crane. The iron bar projected sufficiently on either side to admit of the attachment of the tripping chain.

The air bell was furnished with a signal gong, pressure gauge, safety valve. and air supply connections, with check valve and stop cock, as an additional precaution to be used in the event of a breakage in the hose joining the air supply pipe and the air bell. There was also a 3-in. cock in the cover of the 8-ft. cylinder for use in case of its being necessary to eject water from the cylinder otherwise than by forcing it through the bottom. Means were provided also for attaching a small flexible pipe for drawing off compressed air for working a pump to supply water for the concrete. The arrangement was completed with a small wire rope ladder hung from beside the air locks, and reaching nearly to the bottom of the cylinder, to enable the men to go up or down in case the machinery required adjustment in any way. It was at first intended to work the hoisting and lowering by compressed air by fitting steam cylinders to the winch on the outside, but labor being cheap enough, it was not thought necessary. The compressed air was furnished by means of a stationary engine on shore, with two air pumps, 15 in diameter, 2 ft. 8 in. stroke, surrounded by tanks of flowing water to keep them cool. It was led thence by iron pipes to within a few feet of the cylinders, the connection with them being made with a flexible hose, 3 in. internal diameter. As a rule, two foundations were sunk simultaneously. As the excavated material was removed from the bottom edge, the cylinders generally followed down by their own weight, but it was sometimes found necessary to let all the compressed air escape from the inside, and thus get rid of the buoyancy caused by the displacement of the water by the compressed air.

The great increase of weight brought into play by this means generally resulted in the cylinder sinking rapidly to a depth of 5 ft., 6 ft., or more at a time, but there was always the risk of a considerable quantity of sand, etc., being forced in by the inrush of water from below.

When the cylinders were sunk to the required depth—which in some cases amounted to 107 ft. below water—some 8 ft. or 10 ft. of concrete was put in carefully, and the air pressure maintained till it set.

It was during the hardening of this concrete that the chief use was made of the safety valve which by maintaining the pressure at a certain point, obviated the possibility of compressed air blowing out at the bottom of the cylinder, and so causing unsound work or troublesome leaks in the concrete.

The concrete put in under pressure was placed directly in the skip cases, which were tipped like buckets inside the cylinder, so that no buckets or skips were required.

When it was sufficiently hardened, the pneumatic apparatus, including the cover of the 8 ft. cylinder, was removed, and the whole of the cylinder filled up with concrete 8 to 1, cast in from above. Two men were employed under pressure at a time in each cylinder, working four hour shifts; and in some cases the usual results of working under compressed air were noted, viz., bleeding at the nose and ears, headache, rheumatic pains, etc., but with one exception—there were no fatalities. In one case fatal results followed from the neglect of a workman to give the usual signal that it was a man and not material that was coming out. The consequence was that the pressure was released suddenly, and he found himself paralyzed from the waist downwards. He at once went again under pressure, and came out gradually; but the mischief was already done, and the attempted remedy was of no avail. He died in hospital some three months afterwards from the indirect effects of the paralysis.

As a rule two cylinders were being sunk under pressure at the same time as two others were got ready for the operation.

REGULATING TEMPERATURE OF BUILDINGS BY COMPRESSED AIR.

We are enabled to present a plan showing in detail the system employed by the Davis & Roesch Co., of New York, for the regulation of temperature in buildings of all kinds. To control the temperature of rooms it is necessary to regulate the heat, and, wherever convenient, to also regulate the ventilation. The above system provides fully for both, and the results have proved to be very satisfactory. An installation similar to the one shown in the drawing has lately been made in the residence of Mayor Charles J. Fisk, of Plainfield, N. J. The temperature of the rooms is kept at the desired degree by the operation of thermostats, distributed throughout the house, and compressed air is conducted through 1-16 inch tubes to the thermostats and to the flues which admit the hot air, completing a circuit that automatically opens and shuts the dampers in the flues and also the drafts of the furnace.

The heating of the house mentioned is by the indirect hot water system, but any system of heating may be controlled in a similar manner.

As operated in this instance the cold air enters from the outside and passes to a chamber, where the radiators are located, and the air is there heated and continues on to the rooms.

The thermostats are placed in the rooms to be controlled, and connection is made between them and the dampers in the flues by the compressed air tubes.

With the temperature at 50 degrees and the heat just beginning to radiate, the indicator of the thermostat is placed at the degree on the thermometer at which the temperature is desired. The temperature desired in the illustration is 70 degrees Fahr. The heat coming into the room acts upon the thermostat, and when the temperature reaches 70 degrees the compressed air is turned on by the thermostat; the diaphragm attachments controlling the dampers are fitted, and the heat is shut off. The moment the temperature falls below 70 degrees the compressed air is released and the dampers are opened. In this way a steady temperature is maintained, the system working constantly with variations within one degree of temperature.

FIG. 439—THERMOSTAT.

A small hydraulic air compressor, of novel design and automatically regulated, is placed in the cellar; this supplies the air receiver, maintaining a constant air pressure of about ten pounds, although only about five pounds pressure is required to operate the system.

Fig. 439 shows the internal mechanism of the thermostat. It is operated by the direct action of compressed air, and although appearing of complex construction is in reality very simple of action and requires but litle care. It is easy to adjust and controls the slightest variation in temperature. The action of the instrument is produced by the expansion or contraction of scientifically combined metals so sensitive as to respond even to the warmth of the human breath.

In another installation which we have seen, the window and hall transoms of an office building are also connected with the system. The operation is as above described, opening the transoms and closing the valves of the steam radiators when the temperature has risen to the desired point, and closing the transoms and turning on the steam as soon as it begins to fall.

The system can be applied to any number of rooms, and each room may be regulated at different degrees of temperature.

The device insures the maintenance of a comfortable and healthy temperature, and at the same time, by directly controlling the generation of the supply of heat, produces economy in the use of fuel, using it only as the requirements of the various rooms indicated by their several thermostats demand.

SPREADER CAR, G. C. & S. F. RY.

A line of improvement which seems to be meeting with considerable development in maintenance-of-way work this season is the designing of spreader cars for leveling down earth or ballast at the side of the track. The car is the creation of Mr. E. McCann, general foreman of bridges and buildings of the Gulf, Colorado & Santa Fe R. R., where is has been put into service. The machine was built at the request of General Superintendent W. C. Nixon, who has kindly supplied us with data.

The machine consists of spreader wings fitted to an ordinary flatcar and provided with hoisting apparatus. The wings are of the ordinary heavy plank construction, faced with boiler plate and hinged to the car by means of heavy struts ironed off and well braced with angle irons. Each wing is divided into two sections, the rear section extending from the ends of the ties outward, and the forward section from the rail to the ends of the ties and overlapping the rear section. The intention of the forward section is, of course, to clear away material from the rail and uncover the ties, while the rear section cuts to a depth even with the bottom of the ties, or below if desired. The front section is hinged to a heavy bar extending diagonally across the corner of the car, and a piece of stout chain is attached to the rear section to take the longitudinal stress. The side pressure against the front section is received by a hinged strut, which abuts against a stop block bolted to the under side of the end sill of the car. The side thrust against the rear section of the wing is received by struts abutting against heavy timbers extending across the car, underneath the sills. There is a heavy timber box at either end of the car for ballast loading, to hold the car to the track.

The apparatus for hoisting the wings consists of four 8-inch cylinders mounted upon the top of a framework which is sufficiently high to clear the wings in their raised position. These cylinders operate pistons which have a travel of about 5 feet, and the piston rods are fitted to a cross head, to which are attached two pulleys, around each of which is doubled a wire cable for hoisting the wing on one side of the car. The pistons thus pull the end of the cable a distance equal to twice the travel of the piston. The wings are operated by one man, who stands upon a platform suspended from the top of the frame and handles the air cocks of the cylinders. The air for operating the hoisting cylinders is taken from the brake system of the train, air storage being provided for by a reservoir located at one end of the car, on top of the ballast box. The cable for lifting the wing on each side is attached to the rear section, which also lifts the forward section, which comes to rest in a notch in the corner of one of the posts of the A-frame. In lifting the wings they are revolved past the center and thus rest in stable equilibrium. In lowering the wings to position they are shoved over the center by means of a lever and dropped to working position by gravity, being controlled in their fall by air in the cylinders. The wings can be put into working position within a minute from the time the car stops for that purpose, and in passing over bridges or cattle guards they can be raised to clear in a very few seconds, and let down again into working position without requiring the train to stop. As a precaution against any failure of the air supply a rope tackle is suspended from the framework for hoisting the wings in case of necessity.

The machine was built to prepare banks to receive the ballast after having been widened out by material unloaded from trains. The machine has been in operation for about four months, during which time some minor improvements have been made, one of which consists of a roller on the forward section of the wing, to prevent the end of the wing from scraping against the rail and also to permit it to pass safely over rail braces and joint splices. In the use of machine, dirt has been leveled down on the shoulders for a distance of a half mile in 13 minutes from the time the engine stopped to begin work until the machine was folded up to clear. The operation of the machine has been found to be so satisfactory that others will be built for the work of this company. The present machine was built in the company's shops at Cleburne, Tex.—*Railway and Engineering Review.*

PNEUMATIC WORK.*

I wish, before commencing the few remarks I have to make, to thank you for the honor you have conferred on me in asking me to speak on this subject. I wish to thank you before I begin, because your committeeman, Mr. John W. Neil, asked me how long I expected to speak. I told him I thought I could say all I have to say in a quarter of an hour. He smiled and said: "So long?" I will try and cut it shorter.

In the first place, in regard to the pneumatic work foundation, to be done by the pneumatic method, your invitation committee asked me to read a paper on "'Pneumatic Foundations." In these days of bicycles we are all very familiar with the pneumatic tire; some of us know the luxury of the pneumatic mattresss. We associate in our minds with anything "pneumatic" an idea of something springy; that will bounce. I can assure you that is not the kind of a foundation Mr. Bouscaren wants for his pumping engine; he does not want something that will jump up and down at every stroke of the pumps, but he wants something

*Address of Mr. D. E. Moran to the Central States Water Works Association.

very solid. That is what we are trying to give him. The pneumatic method in general is simply a way of doing what under different conditions could be done without the pneumatic method. We simply employ it to keep out the water. It has been a growth, a gradual development from the old diving-bell. It is not necessary for me to tell you what a diving-bell is, as you are familiar with its principle, and know that it is shaped something like a goblet turned upside down, and allowed to settle in the water; as it settles, its weight keeping it steady and the sides at the same level, the air caught and imprisoned in the diving-bell is compressed; the more the contained air is compressed, and the less becomes the air content and the greater the content of water. That was used in the last century by some ingenious man, first as an experiment, then afterward in recovering treasure from sunken wrecks. It had a limited use in that way. It was not until the development of the machinery end of the business that somebody put compressed air into it, and it became of value to the engineer. The diving-bell in its simplest form had a certain amount of water in it; that water prevented work being done right at the bottom of the well. (The speaker drew a rough sketch on the blackboard to illustrate the principle stated.) Where the diving-bell rested it was necessary for men to work in a certain depth of water which rose in the bell. Now, by the introduction of compressed air, the pressure in the air space could be made to equal the water pressure below; the result would be that the water would be prevented from thus rising in the bell as it did before the use of the compressed air; and the workmen thus could stand on the bottom, where the bell rested, dry-shod.

The development from that to the modern caisson was a gradual growth, as I have said.

One of the earliest instances in which the pneumatic method was used in the building of a pier was the Salt Ash Bridge, built by Brunel. I have not my books of reference here, or I might have looked this up; but it is unimportant. It was a crude method, extremely clumsy and difficult. There was a wooden foundation for the pier cut up into innumerable small pockets, with tortuous narrow passage for egress. The work was done under great difficulties; the workmen had to go up in these narrow chambers in the caisson, fill bags with mud, and then carry them to the air-lock; and in that way the excavation was made. It was very slow and very difficult. The development from that day to this has been a development in the direction of the perfecting of the caisson as an excavating machine. The caisson has now become like a box turned upside down; and the larger the opening inside, and the easier the means of getting material out, the easier the caisson for working in it. As the structure requires considerable strength in all its parts, the calculation of a caisson is a matter of great difficulty, because the strain that comes upon it is not a definite one, as in bridge structures, where you can separate the strains and deal with them as you please. In a caisson there is no telling what strains will come upon it. The real pressure is a problem that defies accurate calculation. There is no assumption upon which it can be exactly calculated. It must be gotten at as the result of experience guided by engineering knowledge.

From the primitive diving-bell, which had no method of ingress or egress, except under the edge, the modern caisson has developed and become a structure in its simple form like a rectangular pier, thus: (making sketch on blackboard). Openings are carried up through the pier, or whatever the structure is, through the caisson and through the masonry on top. There are several ways of making the excavation. It is necessary to get dirt out from below the pier in order to sink the caisson. The first, and perhaps the simplest method, which you will probably see at California this afternoon, is by blowing it out. The air pressure in the caisson being in general slightly higher than the water pressure, this air pressure has been found sufficient to carry a certain amount of material with it through the pipe. It is usual to put in a 4-inch ordinary iron pipe, having at the top an elbow generally of a large radius. This pipe is carried through the caisson in an air-tight manner. The lower end has a plug valve giving a full 4-inch circular opening; and below the valve an extension of the pipe and usually another elbow. Sand or other fine material, as the air escapes, is fed by hand or shovels in front of the pipe; and the current of air going through the pipe carries with it a very large proportion of this soft material. That method is very simple, very rapid, very safe; but it does not work with rock. It works with difficulty with certain kinds of clay. Certain kinds of clay we cut up with a jet of water and carry it through the pipe. That led to the introduction of an excavating air-lock.

I want to say a word about air-locks. An air-lock is an arrangement for getting from the inner pressure to the outside pressure. In its simplest form it consists of a cylinder, or boiler, with two heads. On the upper head there is a door, and the lower head also has a door. One of these doors is always kept closed to retain the pressure. Both doors open downwards. At its lower end there is a shaft or pipe connecting it with the caisson; men or material can come up this shaft and go through this lower door, and while it is opened the upper door is closed. At this time the pressure in the air-lock will be the same as the pressure in the caisson. The lower door is then closed, shutting off the supply of air from the caisson into the lock; the valve at the upper door is then opened, allowing the compressed air contained in the lock to escape; and when the air in the lock is the same as the outside pressure, the upper door will drop, and communication is opened with the outside air. In the same way, returning, the lower door being closed, the men may go through the upper door, which will then be closed and the lower valve opened, allowing the air in the caisson to flow in the air-lock till the pressure there is equal to the pressure in the caisson, when the lower door is dropped, and then communication is open to the caisson. This lock can be used in excavation by having the workmen carry up through it bags of broken rock, or other material. That was improved upon later on by the so-called "O'Connor bucket." The bucket carried a valve on the top of the bale, which closed the hoist-pipe. In this arrangement the hoist-pipe, or shaft, passed through the roof of the caisson, and terminated at its lower end in a cylindrical extension projecting into the working chamber below the roof of the caisson. Just below the roof of the caisson the shaft contracted slightly, and was fitted with a conical valve seat corresponding to a valve-plate of circular form fastened to the bale of the excavating bucket. When the excavating bucket was lowered through the shaft into position in this cylindrical extension in the wooden chamber, the valve on the bale fitted into the conical valve seat, and was held there by means of set screws, operated from the interior of the working chamber. Doors in the side of this cylindrical extension were then opened, allowing dirt and small pieces of rock to be shoveled into the bucket. When the bucket was filled, these doors were closed, the pressure equalized, and the the conical valve released, when the bucket and its contents could be hoisted to the surface, dumped, and returned for another load.

An improvement on this method was a pneumatic hoist devised by the eminent bridge engineer, Mr. Geo. S. Morison. I have never seen this method in operation, but understand that it is satisfactory and efficient. It goes among the "sand-hogs" by the euphonious name of "Morrison's go-devil."

I am using at California a lock which enables an ordinary bucket, or even a barrel of cement, to be passed in and out of the caisson without detaching it from the hoisting rope leading to the derrick. The lock has a simple lower door hinged on a shaft, which shaft extends to the outside of the lock through a stuffing-box. On the outside is a counter-weight lever and counter-weight, to balance the door and afford means of operating from the outside. Above the lower door is a cylindrical section, called the bucket chamber, large enough to contain the bucket. The opening above the bucket chamber, instead of being closed by a single door, is closed by two doors working to and from the center. When these doors are closed they completely close the opening, and form a tight joint with each other, with the exception of a small opening at the center. In this small opening at the center fits a stuffing-box of simple design, through which the hoist-rope passes. The two doors then close around the rope contained in the stuffing-box and completely prevent the escape of air through the opening, while permitting the rope to pass freely. As soon as the bucket is filled in the working chamber an electric bell rings above, and the engineer at the derrick hoists the bucket into the bucket chamber. The lower door is than closed, a valve is opened permitting the air in the lock to escape, the upper doors are then opened, and the bucket is hoisted out, the stuffing-box remaining on the rope just above the bucket. In returning, the operations are reversed.

The caisson is an excavating machine, as well as a foundation, and must be considered in that light. Its development has been largely due to the specialists who have been employed in this line of work. Just as in the bridge shops in America the design has been developed, so in caisson work men like Eades, Sooysmith, Morrison, Hermany, and others have added from time to time new points, all tending to make the caisson more and more efficient in its dual capacity of an excavating machine and foundation.

Before I leave the subject of the development of the caisson, I must say a word for "the man behind the gun"—the "sand-hog." He is a tramp; he has no home, no family, no morals, no religion; he is nothing but a "sand-hog." He got the name from the fact that at one of those jobs at Havre de Grace, close to the Chesapeake Bay, the farmers' hogs used to go down at low tide and root in the sand; they covered themselves with mud; and the workers in the caisson, seeing the close resemblance between themselves and the farmers' hogs rooting in the mud, christened themselves "sand-hogs;" and ever since then they have gone by that name. They are a class by themselves, and follow a pressure job from one part of the country to the other. About the time we are ready to put on the air, some seedy individual pokes in his head at the window and says: "Say, Mr.

Moran, when are you going to put on the air?" Yet the sand-hog has done much to develop pneumatic work. It was a "sand-hog" who first suggested the idea, or observed the fact, that by allowing a slight flow of air above the blow-pipe soft material could be better and more easily blown out; and so, without remembering the name of the "sand-hog" who suggested the plan, we arrange to have a little vent in our blow-pipe.

The "sand-hog" is an interesting study to me; he has his peculiar disease, the "caisson disease," called by the "sand-hog" the "bends." The action of high-pressure compressed air on an ordinary man is temporary; you feel it while you are in it; an hour after you are out you don't feel it, and you are all right. But it may make great havoc with the human system. It affects the ears. If the Eustachian tube is clogged, the pressure on the outside will rupture the ear drum. I know engineers and "sand-hogs" who are deaf from that cause. It also will produce paralysis, temporary or permanent; and it may produce death. The subject has been studied both from a medical and practical standpoint. I am glad to say that in recent years the mortality and injury from the use of compressed air is greatly reduced. Still, there is always present danger in compressed air work. The "sand-hog" knows nothing about the "caisson disease," technically so-called. He only knows it as "the bends" from practical experience. It was many years before I found out how this disease got the name of "the bends." It seems that when Eades was putting down the foundation of the St. Louis bridge, there was a peculiar form of style of carriage among fashionable ladies of this land, which was known, and is, no doubt, remembered by many of you, as it is by myself, as "the Grecian bend." And when a workman came out of the caisson and felt pains in his knees, and a "crick" in his back, and when he could not walk easily or well, his friends would laugh at him and say: "You are trying to walk the Grecian bend." In time the "Grecian" was dropped, and the disease was named by the workmen "the bends." I don't think our workmen here on this job will be so troubled, because the air pressure is very light. We can do much to relieve them now-a-days if they do get "the bends."

Now, gentlemen, this is a windy subject. We have to keep our compressors running day and night; and sometimes I think when I get started on this subject I also will run on all day and night; but I will not do it! I am at the end of my fifteen minutes and will close, thanking you for your kind attention.

A hearty vote of thanks was tendered to Mr. Moran at the end of his remarks.

SURFACING RAILROAD TRACK BY MEANS OF COMPRESSER AIR.

We present two views of the method of surfacing railroad track by means of compressed air; one, a shop view of the mechanism in its present development, the other, a view taken while in operation in broken stone, in maintenance, the most difficult and expensive of all ballast.

The theory underlying the method pursued since the birth of the railroad has been, that material be driven by blows under the ties to resist the vertical gravity of trains, but in practice no two men thus tamp equally, the train develops the weak or unequal points, and each recurrent tamping to correct the inequalities largely destroys the work previously done.

In the compressed air method, the theory and practice is reversed.

The inevitable train gravity is availed of and relied upon to consolidate the foundation to its full possibility, and the cavities beneath the ties disclosed by raising the track to the desired surface are then filled from the ends of the ties with

FIG. 440—MACHINE FOR SURFACING RAILROAD TRACK BY MEANS OF COMPRESSED AIR.

suitable material conveyed by the air blast without other disturbance of the compacted roadbed.

In renewing ties (50,000,000 per year are required in this country alone), the same theory is followed.

The spikes of the new tie are not driven home, but the tie is held up to the rail and thoroughly filled with suitable material from its open side, the ballast other than at the ends is then replaced and dressed, and the tie gets its first tamping by train gravity, "shimming" it if necessary until the bed has reached its greatest compactness, and then home spiking it and filling the vacant space as before described.

The method finds immediate favor with trackmen, as, while each man is obliged to steadily perform his part in the operation, lest the work of all stop, the manual exertion required of each is very much less than in the old method.

The material found in use to be the most satisfactory is clean gravel, furnace slag and stone screenings, reduced to a size not too large to enter the cavities under the ties.

The advocates of the process claim for it:

The advantage of using under the tie, a material suitable as to size and

FIG. 441—SURFACING RAILROAD TRACK BY MEANS OF COMPRESSED AIR.

substance, without regard to the oft-times inferior quality of the ballast in the roadbed.

Evenness of its work.

Readiness of its operation in slight elevations, down to ¼ inch.

Greater accomplishment per linear foot of track, per man per hour.

Greater serviceability of the tie in coarse ballasts, owing to limited area of bearing points, and to base destruction by present tamping practice.

Practicability for use in metal tie track, hitherto not surfaceable.

The conserving of the time and labor previously bestowed upon the work.

BALLAST INJECTOR.

A compressed air apparatus for placing ballast under depressed railroad ties has been invented. It consists of a small Root Blower run by hand, and a double-tubed injector. The blower is clamped upon a rail for support. It supplies air through a flexible hose to the injector, which has a hopper at the top. Suitable ballasting material is fed to the hopper. Air is allowed to flow through the air supply pipe, and the ballast is drawn from the hopper. Air and ballast meet at the bottom of the tubes. The air carries the ballast under the tie from one end nearly to the other. It operates with great nicety, and has been experimentally tried on several roads. It does not displace the ballast at the sides of the tie. No tamping by hand is necessary. The inventor claims great saving in cost in ballast, heretofore requiring expensive work in surfacing.

RECENT EXPERIMENTS IN TAMPING TRACK BY COMPRESSED AIR.*

In this country the engine has grown into a practically perfect mechanism, and the station and the coach to the convenience and comfort of a hotel. Bessemer's invention and the application to it of modern machinery of tremendous power, has made it possible to double the weight of the rail section without increase in its cost, though we now, seeking a low first cost, wrongfully merely squeeze the metal into the prescribed section, instead of as in earlier days, rolling it to a finish. And the joint problem, to the solution of which the inventive genius of the world has devoted itself for years, is still with us unsolved.

In one very material feature of railroad physics, of which I wish more particularly to speak, we have made no advance. As George Stephenson surfaced his track, so do we to-day, theoretically and practically, seeking to overcome the inequalities caused by train gravity in the foundation of our ties, by pounding more material under them in resistance to that gravity. We realize its general ineffectiveness, but few seem to appreciate its importance as an item in the general operating expense account.

Mr. Tratman, in his latest work (Railway Track and Track Work, 1897), has evidently made a strenuous effort in this direction. For the railways of this country alone, he gives for 1895, out of a total expenditure for operating expense of seven hundred and twenty-five millions, the cost of the work of one hundred and eighty-five thousand foremen and sectionmen, as sixty-nine millions, excluding rail and tie renewals, renewals and repairs of culverts, bridges, fences, buildings, and kindred structures, but he also evidently fails in finding the record of cost of this item.

We can try to arrive at it approximately from other sources.

Nearly all roadmasters and foremen fix the proportion of their pay roll expended on tamping as at least 50 per cent.

One hundred and eighty-five thousand foremen and section men, make an average of a little more than one man per mile, and their average pay is annually nearly or quite four hundred dollars—or by this estimate for this item, two hundred dollars per mile, nearly four cents per linear track foot.

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* Paper by Mr. F. R. Coates, Roadmaster N. Y. Div. N. Y., N. H. & H. R. R., read before the Annual Convention of the New England Roadmasters' Association, Revere House, Boston, August 17, 1898.

In the most expansive tamping, and the most severe upon the men—coarse broken stone—foremen who have recently been asked to answer the question say that in this work, done as well as it can be done, and as it should, of course, be done, one and one-half feet per hour is the expectancy of performance, equal to a cost of eight and one-third to ten cents per track foot. Actual timing has verified this, and it has been sustained by the opinion of higher officials in maintenance of way departments, though they assert that this work requires no repetition for a year or more.

In sand or gravelly loam ballast, where the tamping bar is useless, where shovel tamping is practiced and the best work not expected, nor obtainable, no figures as to cost are available. It is probably much less than the average given above of two hundred dollars per mile, and a total of thirty-seven million dollars per annum, but probability is increased, in our belief, in the very much higher average on roads that expect the best results and strive to attain them.

There ought to be a better way to do this work—cheaper, easier for the men, and more even and permanent in its results.

In track surfacing we now expend an undetermined amount of time and money in tearing out the settled ballast until we expose the lower face of the depressed ties, and then raising them to the required level we drive material under them for a new foundation, and necessarily in doing so, disturb or destroy the old foundation. Then we refill and redress the ballast, and leave the track in the hope that the new foundation will prove as good as the old one made by train gravity, for the locomotive is the final tamper, its twenty tons weight on each tie finds all the inequalities of men's tamping, and will compact each tie's foundation until full resistance is met, without consideration for the work done by the men.

We all recognize this, and none will question that train gravity is the inevitable final tamping agent, and the best one, if it can be availed of and relied upon to do the work, and this is a question of creating the conditions necessary to its utilization.

Theoretically, it would appear that if depressed ties or tracks were raised to the desired level, first removing only the ballast at the ends of the ties, there would be exposed the cavities beneath the ties requiring filling, their base and walls already compacted to the susceptible limit of the material, be that material what it may, from broken stones, the best, down to "gumbo," the very worst. In compacting this foundation, train gravity and the elements have done all that they are capable of, and have done it better than is possible by any other means.

Thus far there has been but little departure from our usual custom, excepting that we have at the same moment raised and held both sides of the track, and under any method of tamping there is no doubt that this should always be done when needed.

If now these exposed cavities can be filled with a suitable material, we should expect that trains, having previously exhausted their power in compacting the foundation, could now only exert it on the new material just filled in between the tie and the old foundation and would be confined to the compressing of that material, thus conserving and availing ourselves of all the time and labor previously expended on the old foundation, which now we find ready for us, and thoroughly compacted.

The theory is indisputable; the problem is to complete the process.

We will now consider the duties that ballast is called upon to perform, and find that they are fourfold.

First—It must be capable of draining the track.

Second—It supports the ties and thus holds the track to surface.

Third—It assists in preventing the track from creeping.

Fourth—It retains the line.

The question which now presents itself is how to surface the track with the least injury to the ballast and the bed it has made. From the foregoing it is evident that the only method is by working from the ends of the ties.

In England, on some of the roads, in order not to break up the foundation. the tie is lifted and gravel sprinkled under it from a small shovel shaped about like our tamping bar, the spade being a little larger. But the objection to this is, that though the train does the tamping, the side walls are broken down.

The most promising effort in this direction has been in experimental work during the past five years in the use of the air blast.

Its possibility once determined, the mechanical means were to be devised.

The conditions were:

First—Ready portability.

Second—Determination of the necessary proportions between appliances and work to be done.

Third—Adaptability to the use of all kinds of material and all conditions of surfacing work.

These requirements have, with few exceptions, been fairly met, though mechanical improvements will, with more extensive use, undoubtedly suggest themselves in the future as in the past.

The Root blacksmith's blower has thus far been found best adapted for conversion to this use. The mechanism is used by the ordinary track gang of four men, one or two of them being required to furnish the power, and all engaging in clearing the tie ends during intervals of train waiting. Where the work is of sufficient magnitude, a double gang uses one machine on each rail, materially adding to the rate of progress of each. The on-looker is at once impressed with one fact—there is no possibility of "soldiering" by any one man; each man fills his place, and the pause of one stops the work of all.

The mechanism having demonstrated its practicability, a serious problem is is to develop the most economical method of placing suitable material convenient for use. In the ordinary picking up of low joints and loose ties in gravel road beds, the hand screens for excluding the particles too large to pass through the injector or to enter the cavity beneath the tie, seem to amply meet the requirement, and equally so where fresh material has been brought for more thorough work. Where the best of all ballast, stone, is available, the screening of the material to a size that can be used in the average cavity, say through a three-quarter inch screen, can readily be done at the breaker, and should be done without additional charge. If for use in coarse broken stone ballast, it has been found best to screen out the particles below one-fourth inch in a first filling, as a large part of the screenings under this size wastes among the interstices of the ballast. The dust is everywhere objectionable and breakers should not load it for track use.

The author of this paper is of the opinion that small stone is much more suitable for tamping than large, using it from three-fourths of an inch to one and one-half inches.

"In order to get a comparative estimate of the velocity with which water would drain through these different sizes, under similar conditions, the same bucket was used and four five-eighths inch holes bored in the bottom, ninety degrees apart. By pouring in the same amount in each case, which was six quarts, with the coarser stone it passed through in twenty seconds, with the next size in twenty-two seconds, and with the smallest in twenty-four seconds. A larger stone is not so good for tamping as one of such size as will pass through a one and one-half inch ring. At times the roadbed will get into such condition as to retain water, and in this event the smaller the stone the more solid will be the foundation and the less the amount of water it will hold.

"In view of these facts, it is conclusively proven that a small stone is much more preferable for ballast than a large one. And, further, if the specifications require the size of ballast to be such as will pass through a one and one-half inch ring, the large stones which meet the requirements in two dimensions, but are large in the third, will be kept out."

In other kinds of roadbeds, a clean ballast, free from earthy matter, ought to be used, and the amount required for this purpose is small in comparison with the amount required for full ballasting.

The mechanism in its present development is entirely a "surfacing," not a "track raising device," and the range of its applicability would seem to be from one-fourth inch up to one and one-half inch and the size of the material up to three-fourths inch.

Material passed through a three-fourths inch round screen can be used, but its flow is much slower than the smaller sizes, as also is the speed of its projections. This can be readily realized when we know that a fair speed of the compressor shows but eight-tenths inch mercury pressure for the air which is conveying the material beneath the ties.

I have seen the performance of another application of the air blast to this use, which, dispensing with all the mechanism, gives greater projectile force, but I am requested not to speak of it in detail until its adaptability is better developed and determined. Where the power is available it increases the accomplishment of each man among the trackmen by the proportion of them now used in furnishing power on hand compressors. I am told also that the electrical experts are clear in their opinion that where the electrical current is available, a portable motor will furnish all the power needed; thus, while retaining the compressor, also correspondingly increasing each man's performance on the track.

In the experiments made at Stamford, Conn., on the N. Y., N. H. & H. Railroad, two adjacent pieces of track, each fourteen rail lengths, were taken, they being under the same conditions of traffic. One was surfaced by men on a spurt and the other by the machine. The former attained a speed of five feet per man per hour, and the latter eight and two-tenths feet. In this, however, no allowance was made for screening the material, which would in all probability reduce the speed to eight feet per hour. In one year it required the expenditure of thirty-six hours of one man's time to maintain the surface of the portion put up by hand, and of two hours for that which had been surfaced by the machine.

Our present method is largely a matter of "strength and stupidity." The method under consideration is machinery action and its best service must be the outcome of practice, for there are conditions, which we have not been forced to notice in our present practice, which must be met, when learned, in the new.

For instance, in using gravel ballast, it is difficult to secure even work where squared and hewn ties are indiscriminately used. The cavity under the square tie is a perfect box, but the base of the hewn tie when raised from its bed leaves two vertical conical spaces above, too small to be reached and filled, but the restlessness of water-worn material—gravel—is excited by train pressure and the pebbles "churn" until the sandy portion has been forced upward, into every crevice. The remedy is to use the bar in downward tamping of the edges of the hewn ties, so as to close these small spaces at the side of the tie before the passage of a train, and it would seem advisable in using this method, in gravel or similar roadbeds, when the best work is desired, to always vertically tamp hewn ties.

In the application of the one use of air above referred to, the condition of the material seems to be of little importance, though the flow of dry material is, of course, the most rapid. In the use under consideration—the hand compressor—creating a back pressure in the descending ballast tube, bituminous cinder, because of its light gravity, is worked with difficulty; not a serious objection to those who believe it unfitted for tamping material in main track.

In using the hand compressor, the dryness of the material naturally contributes largely to the rapidity of its delivery.

Lengthened tie service is claimed for it, notably in coarse stone ballast, where many permit the bad practice of tamping the track up to grade instead of otherwise lifting it, frequent tamping resulting in champing off the tie base until the tie section assumes the shape of the letter U. Users of the air method find the splinters thus driven into the cavity a serious obstruction.

The method is believed to have solved the hitherto unsolved problem of the tamping of the interior of the steel tie. This, though of great importance upon the 35,000 miles of metal ties in Europe, requires no consideration from us at present.

As the cost of our present method is, so far as I know, practically unknown, it is too early to discuss the economy of the new method. Permanency of the work of the respective methods is a feature equally important with the first cost. Comparative tests for at least one year would seem to be necessary to determine these two points, though, I am reliably informed that in gravel roadbeds the speed obtained was far in excess of that procurable with bars and the work required no repetition until the relaying of the track three years subsequently.

THE "BELLY POUNDER."

A nery novel application of the Steam Rock Drill is shown in the illustration on our cover, and in this form is known among the packing houses as a "Belly Pounder," or, to speak more plainly, it is used in taking the "kinks" out of the hog bellies and straightening them out, as they come to the machine in a frozen state, afterwards being cured and packed in boxes for shipment. The machine shown in the photograph is a modification of the Rock Drill, with the rotating mechanism replaced by a straight guide, forcing the piston to strike a direct, straight blow without rotating. The piston has a specially forged head, to which is bolted a wooden block, or paddle, about 8″ x 14″ and 2″ in thickness. Instead

FIG. 442—BELLY POUNDER.

of the usual form of crank on the feed screw, it is replaced by a pair of bevel gears and extension crank, locating the handle convenient to the operator standing on the floor. This permits of the raising or lowering of the machine to accommodate varying thickness of meat. The mounting shown is the regular double screw column, such as is used for mounting the drill in tunnel work, the drill being attached to the arm in the same manner. The cylinder of the machine is 2¾″ in diameter, and it can be operated with compressed air as well as steam.

This "Pounder" is now being used by quite a number of the large packers, several of the machines being in operation at the Union Stock Yards, Chicago. The illustration shown was made from a photograph taken at the works of The International Packing Company, Chicago. The saving effected by their use will be appreciated when it is stated that with one of these machines a packer is able to take care of 400 hogs per hour, or to pound 800 bellies in that time. The users report that the work is much better done, requiring less trimming and waste. This, with only two men necessary to the operation of the machine, where they formerly employed six men with paddles to accomplish the same amount of work by hand; a saving in labor of four men. This item alone would in a short time more than pay for the cost of the machine.

PNEUMATIC ELEVATOR DOOR MECHANISM.

In these days of sky scraper office buildings the elevator is looked upon as the soul of the building, and it is the elevator service that rents the offices more than any other detail. A good deal of thought and studying is done to increase the efficiency of the elevator service. You may run high-speed elevators, but you cannot make your passengers run on and off the elevator, and that is where the time is lost. The elevator runner has to open the door to let his passengers out, and then close it, and in a great many cases much haste means less speed, as he has to stop the car and return to close the door.

The Burdett-Rowntree Manufacturing Co., of 76-82 W. Jackson Street, Chicago, and of 120 Liberty Street, New York City, are the inventors and patentees of pneumatic elevator door mechanism, which causes the door to open by the time the car is level with the floor, and when the car is ready to leave the floor the man releases the foot button and goes on, knowing that if the door opened it will have to close. The mechanism is simplicity itself, consisting of a cylinder, piston, piston rod, and the admission of air is controlled by a pivoted D slide valve, opened by a tripping device on the car, and closed by a spring which throws the valve the other way. The door is entirely controlled by the operator, within a range of 20 inches, 10 on each side of floor. There is a small bar which interlocks with the valve trip and locks the door, preventing it from being opened from the outside; also, in the '98 machines, the full pressure of air is on the rear end of piston at all times except when opening, and there being no dead centers the door has to keep closed. The doors are practically noiseless, being cushioned on a dash pot of oil, both opening and closing. This does away with all adjustment of the valves, there being only one small admission cock, which regulates the amount of air needed. The air is supplied from a pipe which runs the full length of the elevator well, tapping it for the machines at each floor. In the basement is placed an automatic air pump, receiver, and a reducing valve, which reduces the air to 15 pounds, that being the pressure used by the machines. The gain in service is very material. In the Surety Building in New York City they claim a saving of 20 seconds per round trip of elevator, and in the course of a day this would add into time very materially. In the Stephen Girard Building, Philadelphia, a 13-story building, are four elevators, which carry 4,000 people per day. Mr. Dinsmore, Engineer for the Girard Estate, told the writer that they could not begin to handle their traffic without the door mechanism. The largest installation, consisting of 216 doors, is in the Empire Building, New York City. There are 180 single, 26 double, and ten folding gates within the cars. These machines are of the latest designs and with all the changes found necessary since the first plant was installed three years ago. There are now 41 office buildings equipped with these gates, and there are a large number of orders for projected buildings. They have been found to be of the greatest utility in department stores, where their traffic consists of women and children, who are naturally slow and timid in entering and leaving the elevator, and where it is necessary for the operator to have his eye on the passengers and his hand ready to assist them, his foot oper-

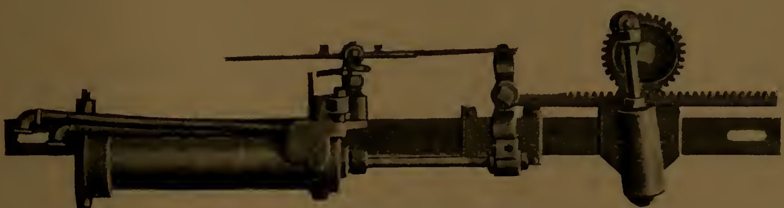

FIG. 443—ELEVATOR DOOR MECHANISM.

ating the door. In B. Altman & Co.'s dry goods store they have double doors opening to the full width of the car operated by the mechanism. Also Marshall Field of Chicago, and R. H. White's department store of Boston, are now equipping their elevator doors with these devices.

PNEUMATIC GUN IN WARFARE.

Interest in dynamite guns has been stimulated by the practical tests given to them in action during the late war with Spain, in Cuba. The Sims-Dudley field gun being at the front, proved to be very efficient, and demonstrated that in the hands of intelligent artillerymen this gun is successful. In the fight of the "Rough Riders" before Santiago Sergeant H. A. Borrowe had charge of the gun. He reported that the gun had been in action three times, and in all 20 shots had been fired with great effect. Other regiments were supplied with these guns and did excellent service. The testimony of officers and correspondents is to the effect that these guns have a fine moral effect, as well as being very destructive. This gun is popularly called a "dynamite gun," although any desired form of explosive may be used. It usually throws a projectile charged with Nobel's gelatine, which can be handled, stored and used with greater safety than any other nitroglycerine explosive, and still produces in its explosion a more destructive effect than that of any other explosive. It is impossible to throw such material by the direct fire of powder, as the concussion would without doubt explode the charge. Therefore, the power used in the ejection of the projectile is compressed air, generated by a small charge of smokeless powder. The volume of gas produced by combustion of the powder compresses the air contained in the tubes of the gun, and this air acts as a yielding cushion between the powder and the projectile, and as the transmitter of the force from the one to the other. The ejecting force thus acts upon the projectile with a prolonged and gradually increasing effect, instead of with the sharpness and suddeness of direct powder explosion.

The bore of the gun is 2½ inches and the length of the projectile tube is about 14 feet. This tube is of a special composition, having a tensile strength of 80,000 pounds to the square inch. The barrel is not rifled, the rotation of the projectile being accomplished after leaving the gun by the action of the air upon the inclined wings on the spindle. The total length of the projectile is 36 inches and it weighs when loaded 11½ pounds. It carries four pounds of Nobel's gelatine, which is equal in destructive power to at least 80 pounds of ordinary powder, and a Merriam fuse provides for the explosion upon impact or decided retardation, as by water, or the explosion may be arranged to occur at a predetermined interval subsequently.

Below the projectile tube is the combustion and compression chamber, which is a 4½-inch steel tube 7 feet long. The firing is by an ordinary cartridge shell, containing seven or eight ounces of smokeless powder. This cartridge is placed in a small central tube, which projects only a short distance forward into the combustion chamber. The breech mechanisms are both thrown open by a single motion, the projectile and the cartridge are inserted at once, the breech mechanisms are closed by a single movement, and the gun is ready to fire. The firing is done by pulling a lanyard in the usual manner. Absolute certainty of operation is assured by the details and arrangement of the mechanism. There is no possibility of any discharge of the gun until both the projectile and the cartridge are in their correct positions and everything is ready to fire. In these particulars, Mr. Sims, the inventor of the well-known dirigible torpedo, has contributed much to perfect the original invention of Mr. Dudley.

When the cartridge is fired the charge is driven forward in the large tube, while all the contained air is driven backward and through a large connecting passage into the projectile tube, so that practically all the air contained in both tubes is between the projectile and the hot gases. The action of the explosion upon this large body of air also insures a gradual instead of a sudden application of the pressure upon the projectile. The pressure is, however, applied so effectively that the range of this gun is from one and one-half to two miles, with a still greater range for those of larger caliber.

The gun weighs 1,044 pounds. It can be quickly taken apart for transportation on mule back, or in difficult places all the parts can be carried by men. The parts can be assembled and the gun made ready for action in ten minutes. The cost of each discharge of this gun is but $35, while the guns using powder alone, with which it would be fair to compare it, weigh many tons and cost hundreds of dollars for each discharge. The zone of destruction caused by the explosion of the projectile is nearly 100 feet, and where its fire is directed at masses of troops the shock is so frightful that many besides the killed and the actually wounded are thrown out of the fight.

The gun may be fired at almost any desired elevation or depression, so as to be available for attaching an elevated position or in firing at an object directly below the gun. The recoil of the gun is inconsiderable, and little noise is produced, so that it is difficult to locate the gun at distances exceeding half a mile. In case of danger of capture the gun is made inoperative by unscrewing the cap from one of the tubes and carrying it off, or by taking off the breech mechanism, which can be done in two minutes.

The larger guns of this type may be used in countermining. Mounted forward on a ship they can clear a channel of all dangerous obstructions, exploding by concussion submarine mines as the ship advanced. This interesting gun is made by the Sims-Dudley Defense Co., 120 Liberty Street, New York.

PORTABLE MOTOR.

The development of the Stow Flexible Shaft affords an interesting example of the progress of the age of mechanics. It is used to operate drilling, tapping, reaming and grinding tools for portable work.

It has gone through the experience of "rope drive" from any convenient shaft. Then electricity was adapted with fairly good results—the chief objections were expense, danger and the necessity of a skilled mechanic to run it.

A Compressed Air Motor is now employed and embodies the required convenience and economy.

The motor is mounted on wheels so as to be moved easily from one point to another. The following description of its general construction will show its adaptability to machine shop works.

The motor complete on its base, as shown in Fig. 444, in which one side-plate has been removed to show the interior construction, weighs 300 lbs, and occupies a space 20 inches long, 18 inches wide over wheels and 19 inches high. With an air pressure of 80 lbs., it is capable of developing 8 horse power. It is provided with a 6-inch pulley (P) on one end of the shaft, while at the other end is a projecting counter-shaft capable of running at two speeds, and on which can be slipped a patent universal joint flexible shaft coupling.

With a pressure of 80 lbs. the maximum speed of the engine is 1,400 revolutions per minute.

The construction of the motor is extremely simple, and consists of a substantial cast-iron base plate 20x14 ins, Fig. 445, upon which, in a water and dust tight box, 12⅜ x 7⅛ x 13 7-16-ins., are two small oscillating cylinders, having a diameter 3 inches and a stroke of 3 inches. The two piston rods connect directly tc a solid forged shaft, 1¼ inches in diamater, which has three good-sized bearings, two in the end plates, and one in the center column, which is cast with the bed plate. This column also contains the inner trunnion bearings for the cylinders, and into its top is screwed a heavy lifting ring, which is used to support the motor over the work when desired, or it can be used to transport the motor about the shop if there is a traveling crane. The outer trunnion bearings are in the end plates, as will be seen in both figures.

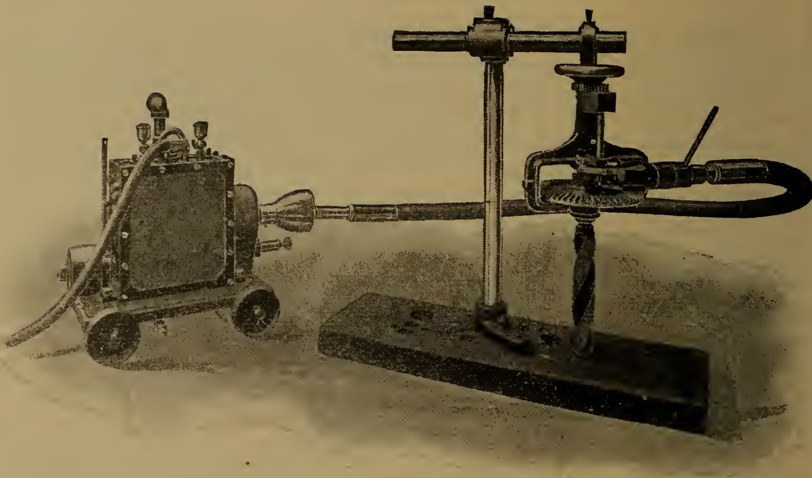

FIG. 444—STOW FLEXIBLE SHAFT AND MOTOR.

The back of the cylinders, corresponding to the cylinder head, is turned concentric with the trunnion to present a convex cylinder face to the valve block (B), which is a cast-iron block with a concave cylindrical face corresponding to

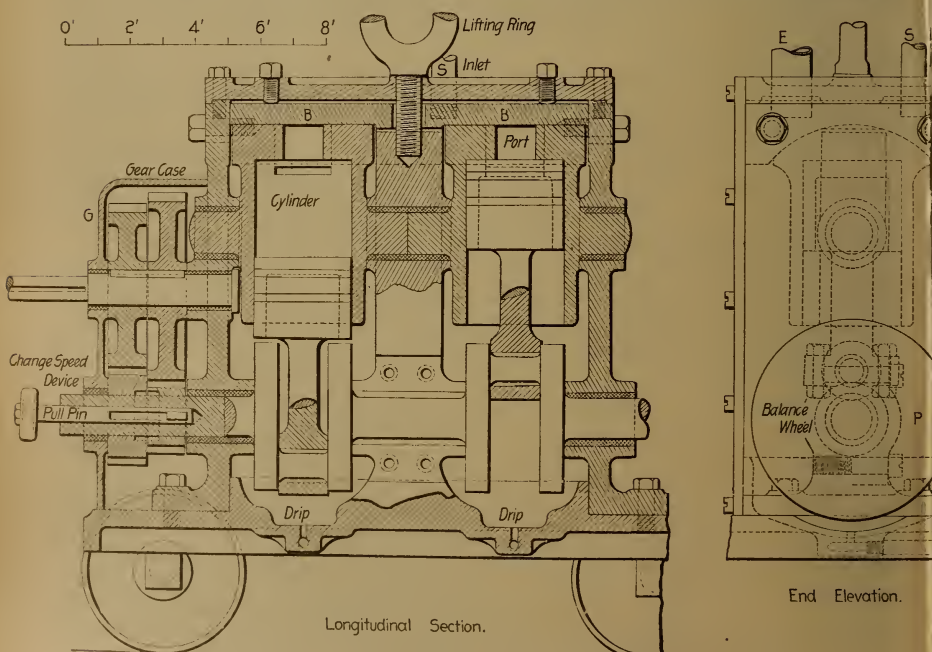

FIG. 445—DETAILS OF COMPRESSED AIR ENGINE.

the outer ends of the cylinders and containing properly-spaced inlets (S) and exhaust ports (E). This valve block is held in place against the cylinder ends by suitable springs and adjustment screws. The gear case (G) at the end opposite the pulley contains two pairs of gears, a 2-in. and a 5¾-in., and a 2¾-in. and a 5-in. The smaller gears are mounted upon the engine shaft, which is hollow at the end and contains a slip key, provided to lock either gear to the engine-shaft. The larger gears are firmly keyed to a short counter-shaft, from which power to operate the flexible shaft is taken. At the maximum speed of 1,400 revolutions per minute, there are, therefore, two shaft speeds, 485, 773, according to the pair of gears in operation, which is controlled by simply pushing in or pulling out the slip key. Any other speed can be obtained by throttling the air supply, with, however, a corresponding reduction in power. While designed primarily to operate flexible shafts, the motor is also arranged to take the place of any small engine, and the driving pulley admits of its use for a variety of purposes; for example, it can be placed near and belted directly to a polishing machine, an emery grinder, brass lathe, etc.

The motor is being built and introduced by the Stow Flexible Shaft Co., 26th and Callowhill Sts., Philadelphia, Pa.

THE HOUSTON PNEUMATIC TRACK SANDER.

It is a well known fact that the amount of sand used by a locomotive is ordinarily three or four times that which is actually needed to perform the work, as the sand pipes running from sand boxes to rail are one and one-fourth (1¼) inch diameter. Through these run a full stream of sand to the rail, fully 75 per cent. of which leaves the rail before the driving wheels reach it, and is therefore wasted.

Where sand is delivered to the rails by gravity only, you cannot accomplish prompt and quick delivery of sand to rails when wanted.

This device consists of a Siphon and Ejector, simple in construction and easily kept in order. It takes up the sand and forces it with great velocity instantly to the point of contact between driving wheel and rail to either front or rear drivers of any type of locomotive. Distance from sand box to point of delivery can be any distance.

The sand pipes used in connection with this device are very small, being only one-half inch, by which a close discharge and a neat and economical construction can be accomplished.

Sharp angles in the sand pipe do not affect the flow of sand, as the strong air blast forces the sand through them, and to any distance.

The Siphon and Ejector used in connection with this device are especially designed to give the sand a great forward velocity and momentum with a small amount of air.

The sand to both back and front drivers is operated by one valve in cab. This valve is of a very novel construction and is designed so as to regrind itself.

It is claimed that this device will save 75 per cent. of sand in ordinary usage, and much better results have been attained on some roads.

The feature of giving sand to both front and rear driveis from one box is well worth considering.

It can be applied to an engine in six hours by two men, and is applicable to old boxes as easily as to new ones.

THE FOSTER REGULATOR.

The frequent inquiries we have for pressure regulators have led us to show the illustration herewith, which is a view of the Foster combined pressure regulator and automatic stop valve for high initial air pressure. This valve has been used successfully in various experimental works and in connection with some very important ones where high pressures were employed.

Probably the most difficult problem to solve in connection with the use of high initial air pressures up to 3,000 lbs., in order to make it commercially suc-

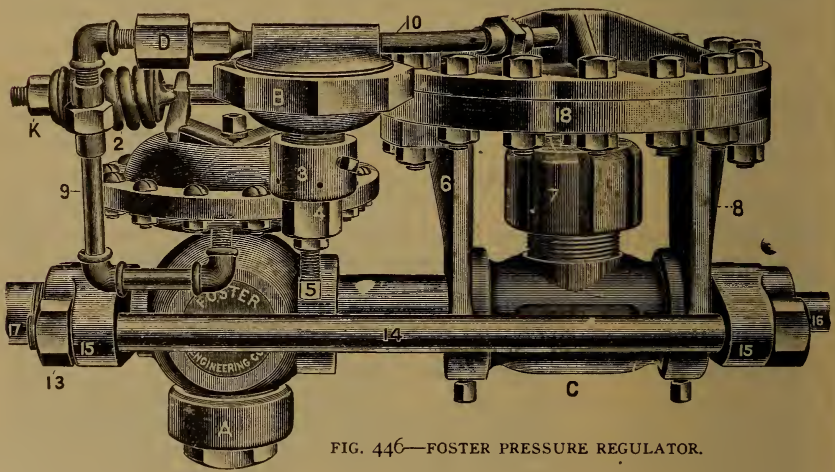

FIG. 446—FOSTER PRESSURE REGULATOR.

cessful, is the automatic regulation of the air so as to maintain a constant uniform delivery pressure against a variable initial pressure, which may be at any point between 150 and 3,000 lbs. on the square inch.

The operation of a reducing valve is controlled by the delivery pressure acting on a diaphragm or its equivalent, against a spring or its equivalent. It will, therefore, be readily understood that with an initial pressure of 2,000 or 3,000 lbs. the valve may not have to open more than one or two thousandths of an inch in order to give the necessary delivery.

A is the regulating valve, B an auxiliary valve, and C the stop valve. Air is admitted through pipe 16, and passing through the stop valve enters the regulating valve (which latter is constructed on principles similar to the regular Class W), and is delivered at pipe 17. The delivery pressure entering the diaphragm chamber of the regulating valve, passes through pipe 9 and strainer D to the auxiliary valve, which is controlled by a diaphragm operating against the spring contained in the casing 4, the pressure of the spring being regulated by screw 5. If, for instance, the regulator is set to deliver 100 lbs., and the discharge pressure should be shut off, the tendency would be to increase the discharge pressure in pipe 17, if there should be any leak through the regulator valve. This pressure acting on the diaphragm in auxiliary valve B, will, when it reaches say 120 lbs., open the valve and allow the air to pass through pipe 10 to a diaphragm chamber, 18 in stop valve C. The area of this diaphragm in stop valve C is sufficient to give about 12,000 lbs. pressure, which, operating on a steel beveled plunger, forces it into its seat with power enough to make a crushed joint on the valve seat, thus effectually closing off the flow of air. When this delivery pressure falls to its normal condition, say 100 lbs., the spring in casing 4 opens the auxiliary valve and allows the air in the diaphragm chamber of the stop valve to exhaust through the small ports 3 into the air. The initial pressure then acting upon the steel plunger forces the stop valve open.

In a recent test of this valve where there was frequent stopping and starting of an air motor, it was found that the stop valve automatically closed off the air at every stop of the motor, and immediately opened when the motor was started.

The device is self-contained, as shown in the engraving—the connections between the stop and regulating valves being made up with crushed joints, held in place by two rods, 14, clamping the two end pieces, 15, together.

THE CLEANING OF CARPETS.

One of the complications peculiar to life in large cities is the difficulty that besets the householder when he desires to have his carpets cleaned. The old-fashioned way of shaking or beating them from the windows is prohibited in most large cities, and the alternative of taking them to the fields is, for various reasons, cut off. Brushing will serve for a certain period, but in time a more effective treatment becomes imperative, and experience has long since shown that, unless the work is conducted with great care and method, the cleaning process may be as destructive as that of the Indian *dhobi* or washerman. The weight alone of many carpets renders the most careful handling necessary, and if the carpet be valuable as well as old, it may suffer serious deterioration in the process of cleaning. The original method of cleaning carpets was carried out with the aid of sticks, handled by laborers, and lubricated with beer—for the job was a very thirsty one. It was carried out in the nearest convenient field, and if there was any wind, the dust went with it; if not, the beaters were enveloped in a very unwholesome cloud. Sticks would occasionally go through the carpet, and it generally returned from the cleaning a good deal the worse for wear. The first attempt at mechanical dry cleaning was made with a machine something like that used for beating rough cocoon silk waste after washing. Next, a fan was added to carry off the dust; then leather beaters superseded the sticks, and finally compressed air was employed in numerous fine streams, which without the least violence seems to drive out every particle of dust in any carpet, however dirty. A visit to the headquarters of the Patent Steam Carpet Cleaning Works at York Road, King's Cross, London, will enable those who are interested in the subject to see the process in operation.

The beating machine, by which the carpet is struck on the underside by revolving leather beaters, will take in carpets 54 ft. wide and of any length. Thcy are passed forward and backward through the machine until they cease to give off any dust, all the dust being carried off by an exhausting fan and discharged into a chamber where it meets the exhaust steam from the engines. The effect of the steam as it condenses on the particles of dust is to increase the weight of the dust and cause it to fall to the ground. The workmen attending these machines pass their days in a clean atmosphere, the current passing them to enter the machine. The compressed air machine is the latest improvement which, as has already been stated, dispenses altogether with beaters. A powerful pair of engines, capable of developing 200 horse power, is used to drive the air compressors which provide the air supply at a pressure of 70 lbs. per sq. in. The air escapes from a row of jets in a pipe striking the surface of the carpet and dislodging all the dirt. The cleaning machine itself is a very simple affair. The carpet is passed over a long cylindrical roller built like a cage. Above this cage, at a distance of about 2 inches, is suspended the jet pipe, parallel with the roller. The pipe has a short back-and-forward movement communicated by the engine, and the carpet passes slowly over the roller beneath the vibrating jets of air. An exhausting fan carries off all the dust and the air from the jets to a chamber where steam precipitates all the solid particles. The process is continued until when struck with a rod the carpet gives off no dust. In this manner the most valuable carpets may be cleansed without risk of injury to their texture.

The company have works at Manchester, Leeds, Dublin and Glasgow, as well as in London. This process has an interest which extends far beyond the business of carpet cleaning. It will doubtless find further application in the separation of dust and dirt from many materials, and it points to means for the reduction of the offensiveness and unwholesomeness of many trades which at present have to be segregated. There is a distinct relationship between the carpet cleaning process and the more recent one for cleaning railway carriages with an *air brush,* which works with extraordinary rapidity, and neither wears the linings nor rubs dirt into them, as is the case with the hair brush. Compressed air has, during the last few years, been recovering from a damaged reputation acquired through misuse. In many cases it was used at excessive pressures, at other times the pressure was too low. The methods of compressing it were also defective. It is now used successfully for a great variety of purposes, including the driving of underground machinery in mines, propelling tram cars, driving cranes and machine tools, rock boring in tunnels, pneumatic transport, cooling stores of perishable merchandise, etc. For the transmission of small powers in factories compressed air is most convenient. It needs no exhaust pipes and no covering on the conduits. Its efficiency is greatly augmented by being heated before use in motors, but the heat must be supplied immediately before use, as hot air cools very rapidly in pipes.—*The Indian Textile Journal.*

PNEUMATIC CARPET RENOVATOR.

Interest has been aroused by an invention for cleaning carpets and we herewith illustrate the device itself and the method of operating it.

The carpet renovator, which was recently designed and patented by J. S. Thurman, formerly M. E. of the Mo. Pac. Ry. system at St. Louis, Mo., consists of a box or receptacle into which a blast of air is injected in the shape of a fan. The blast of air striking the carpet throws the dust through the tortuous passage and deposits the dust on the inside of the box; that dust, which is lighter than

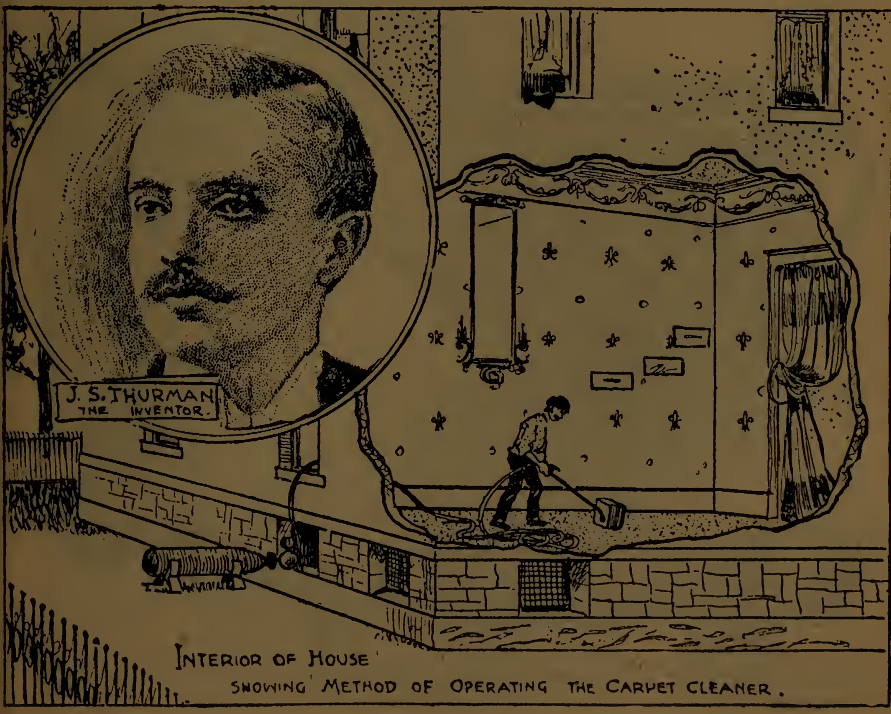

FIG. 447—SYSTEM OF CLEANING CARPETS WITH AIR.

air, is caught by a screen before the air is exhausted into the room. The dust collector is about 8 in. long by 5 in. wide by about 6 in. high, and the blast of air is 1.64 in. wide by 8 in. long. This dust collector is pushed back and forth over the carpet by an operator and collects from 98 to 100 per cent. of all the dust that the carpet contains.

The source of air supply is obtained by compressing air into bottles or Mannesmann tubes at 2,500 lbs. pressure. These bottles are filled with compressed air at a central plant, and equipped with machinery specially designed to compress air to a high pressure. On these bottles are attached a reducing valve to reduce the air from 2,500 lbs. to 50 lbs. per sq. in. The bottles, after being filled at a central plant, are delivered to the sidewalk in front of the residence to be cleaned. The hose is then connected to the reducing valve on the bottle and the other end of the hose taken into the house and the dust collector is attached. The dust collector is then run once over the carpets, which is sufficient to cleanse them of all dust and restore the carpet to its natural color. Before the carpets are

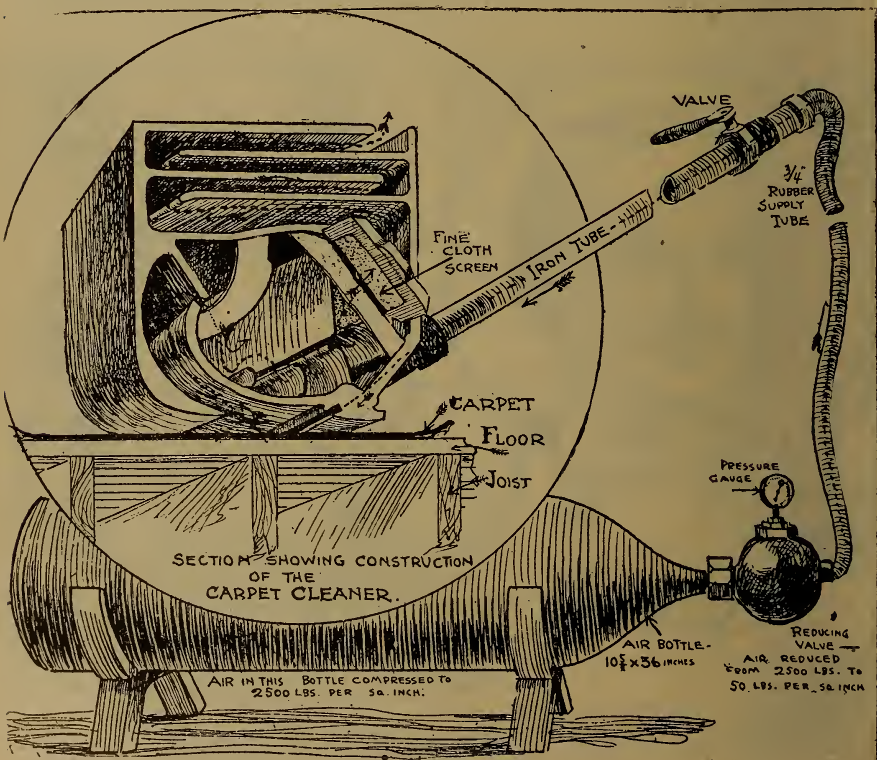

FIG. 448—DETAILS OF CARPET CLEANER.

cleaned the walls are cleaned and also the tapestries and cushions. It requires only about two hours to clean a nine-room house, and the charge will be nominal.

By the present method carpets are taken up and removed to a cleaning establishment, which requires three to four days, while with compressed air the work is accomplished in a far better and more satisfactory manner in two hours. In other words, the husband leaves home in the morning and when he returns in the evening the home is cleaned.

MECHANICAL HOUSECLEANING.

Some months ago there was described in these columns a device known as the "House Renovator," which is a dustless system of cleaning, renovating and disinfecting hotels, residences, office buildings, hospitals and public institutions with compressed air. The scheme in general is not entirely new. Railroads have been cleaning their passenger and sleeping cars with compressed air successfully

FIG. 449—HOUSE RENOVATOR.

during the past ten years, but the device mentioned is designed for the purpose of not only knocking the dust and dirt out of their lodging places, but to imprison them before they have a chance to obtain another habitation.

We all remember, nay, observe, the patient houseworker with a broom. She goes after the particles that lurk in the woof of the carpet and to give her due credit she gets many of them, but it's a wearing process and ends up with a lame

FIG. 450—CLEANING CARPET BY COMPRESSED AIR—ELECTRIC AIR COMPRESSOR.

back. The filmy dust picks out dark furniture, and children write their names in juvenile glee. It is further pursued and battered from one place to another, until somehow or other it gets out of sight again for awhile. After awhile the accumulations multiply and then comes housecleaning.

Here is where Mr. Thurman, of St. Louis, steps in. He claims not to disturb your carpets. By his system the walls are cleaned of all the dirt and dust, the carpets are thoroughly renovated, removing and collecting all the dirt and dust the carpet contains, also removing that dirt which is between the carpet and the floor. After the carpets are cleaned they are thoroughly disinfected, the disinfectants being blown on the walls and into the carpets with compressed air.

The process has many features which appeal to every one. The lessening of tiresome labor and the purifying of the atmosphere of living apartments are among the important ones.

By this method one man can clean from eight to twelve rooms per day, which includes walls, carpets, rugs, draperies, bedding and upholstered furniture.

Fig. 450 shows the system operating in hotels, using an electric air compressor mounted on a rubber-tired truck in which the power is supplied to operate the compressor from the electric light wires. This machine compresses air up to 90 pounds per square inch and stores the air in the air reservoirs mounted on

FIG. 451—CLEANING CARPETS OF PRIVATE HOUSE.

the truck; the supply of air to operate the dustless carpet renovator is drawn from these reservoirs. The renovator is pushed back and forth over the floor in a similar manner to the ordinary carpet sweepers now in common use. The renovator collects all the dust which the carpet contains, and after the room is cleaned the dust is dumped out into a receptacle.

Fig. 451 shows the system operating in private houses having no electric light wire connection, the supply of air being obtained from bottles. These bottles are made of suitable size and are rolled of a solid billet of steel, into which is pumped compressed air at 3,000 pounds' pressure per square inch. On the neck of these bottles are attached reducing valves, which reduce the air from 3,000 to 70 pounds per square inch. These bottles are filled at a central station, using high pressure air compressors, which are made especially for this company. These compressors are capable of filling from 18 to 20 bottles per day, and one bottle has sufficient capacity to clean five ordinary rooms and are tested up to 13,000 pounds per square inch. After the bottles are filled at the compressor they are loaded on a wagon and are delivered on the sidewalk of the residences to be cleaned. The hose is attached to the reducing valve of the bottle and is carried into the house and furnishes the proper amount of air to renovate the carpets and collect the dirt and impurities therefrom, as illustrated.

Mr. J. S. Thurman, the inventor of this system, has recently organized a company known as the General Compressed Air House Cleaning Company, and who are contractors and engineers for complete house cleaning equipment and compressed air plants, with offices in the Lincoln Trust Building, St. Louis. At the present time the company is arranging with parties who desire to get into this business in various cities and towns of the country, and are also arranging with hotels and institutions for the same purpose.

THE KRAUSE AIR FILTER.

A novel apparatus in the shape of an Air Filter has recently been patented and placed on the market by Mr. Arthur E. Krause, of 345 Fairmount Avenue, Jersey City, N. J.

The object of an Air Filter is to prevent dust, grit, ashes, etc., and any impurities from entering the intake in Air Compressors, Air Pumps, Blowers, and, in fact, all machinery handling air, and in which grit or impurities are detrimental not only to the operation of the machine itself, but also to the operation of such other machinery depending upon the first.

Air filters have been tried at different times, but have been discarded on account of the great amount of space taken in order to obtain adequate filtering surfaces, and also for the reason that the intake pressure was considerably reduced below the atmosphere.

Mr. Krause's Filter, which we illustrate herewith, is very simple and takes very little space. For instance, a filter suitable for a 1½" intake pipe would be only 6" dia. by 5" long, and such a filter can be attached to intake pipes for Air Pumps, Air Compressors, Blowers, Gas Engines, etc.

The construction of the filter is as follows: Circular shaped flat bags made of felt, cotton, asbestos, or any other suitable material, with thin outer edges sewed together and having a concentric opening so as to obtain access to the interior of the bag from both sides.

Into the interior of each bag there are inserted two flat ring-shaped washers made of sheet metal, one of these washers having protruding bosses stamped thereon, the other washer is perfectly plain.

When placed within the bags the bosses of one washer are placed against the flat side of the other washer, thus making a separating space between the two washers, which serves as a free passage for any air filtered into the bag from the outside. After the washers are thus inserted within the bags, a certain number of them are placed over the above-mentioned tierods, the number of bags depending upon the length of the supports and amount of filtering surface desired.

After all of the bags are thus placed over the supports, a metal washer, or disc, having three holes corresponding to the position of the three supports, is placed over the bags, and the thumb nuts are screwed up against the disc, thus forcing the separate bags together at the edges of the central openings, so that perfectly tight joints are secured.

There is no pressure exerted on any part of the surfaces of the bags, so that the air has perfectly free access to such surfaces, and after filtering through the

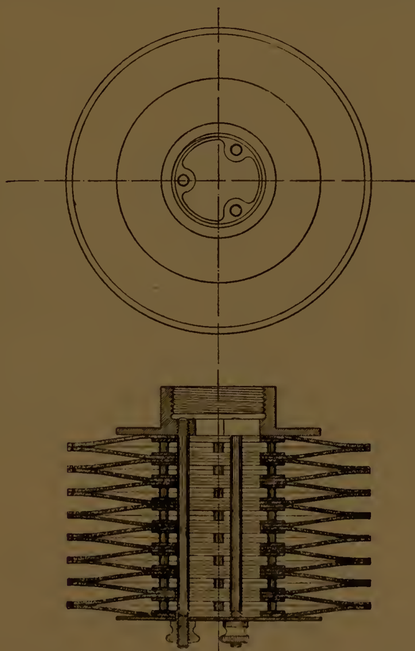

FIG. 452—THE KRAUSE AIR FILTER.

bags from the outside, the air passes through the free space between the inside washers and into the interior of the body of the filter, from whence it is drawn off by the air pump or compressor entirely freed from dust or grit.

It will be readily understood that this arrangement of the filtering bags will permit of a very extensive filtering surface within a very small space, at the same time allowing ample air spaces between the bags to render all of such surface effective and efficient.

These filters can be cleaned or dusted while the machinery to which they are attached is in operation, or a new set of bags can be inserted in a few minutes' time.

To show the great amount of filtering surface which can be obtained in a very small space, we want to say that a 1½" filter, as constructed, would consist of 22 bags, each bag having on each side a surface of 15 sq. inches, making the total filtering surface 660 sq. inches, and the space occupied by same does not exceed ⅛ of a cubic foot. Thus it will be seen that a filter covering one cubic foot in volume could have a filtering surface of 36 sq. ft.

Of course the filtering surface depends not only upon the size pipe or opening, but also upon the quantity of air to be filtered, and upon the amount of dust or grit which may be contained in the air.

Owing to the large air filtering surface the resistance to the inflow of air is hardly appreciable if the filter is dusted occasionally.

AIR METERS.

In one of the early numbers of Compressed Air we called attention to the fact that a reliable air meter for measuring air volumes was in demand. We have recently been informed that Mr. Clemens Herschel, the distinguished hydraulic engineer who designed the Venturi water meter, is prepared to apply the Venturi principle to air. There seems no reason to doubt that this meter, which has established its place as the simplest reliable means of measuring large water volumes, might apply equally as well to compressed air. A great advantage of the Venturi principle is that it does not retard the flow of the liquid or gas measured. Mr. Herschel, whose address is No. 2 Wall Street, this city, will take the details of this subject up with those contemplating its introduction.

AIR MOTOR FOR COPENHAGEN.

By the steamship "Hekla," of the Thingvalla Line, which has just cleared for Copenhagen, a full set of street-car equipment, consisting of compressor, storage tanks, valves, motor, etc., was shipped to a syndicate formed in Denmark for the introduction of air motors in Scandinavian countries, regarding which the following translation from a Copenhagen newspaper is interesting to American readers, who have not yet had the pleasure of seeing air adopted by any American street railroad, although it is understood that a number of contracts are being held open, pending the consolidation of the air companies:

"Mr. Josephsen, as president of the Danish Air Power Co., has been working with the Copenhagen authorities to bring about the use of air motors in the streets of Copenhagen for street car service, and to this end the Danish syndicate has arranged with the American Air Power Co., of New York City, for a full equipment, and in the meantime the company is acquiring the rights for the most desirable streets in Copenhagen."

COMPRESSED AIR ON THE HOLLAND TORPEDO BOAT.

A study of the John P. Holland Torpedo Boat Co.'s latest type of submarine boat convinces the student of naval architecture that she is light of draught, seaworthy as a cork, handy as a toy, and able to dive into the depths of the sea like a mackerel, and that from the standpoint of mobility and power of attack she is better than a battle ship and a torpedo boat moved in unison for attack upon a port or a fleet. The modern battle ship is a massive, floating fortress, embodying the ideas of military engineers, and the traditions of the naval constructors of Great Britain and France, who superimposed the Ericsson turret principles upon the broadside man-of-war of forty years ago. The torpedo boat of the best existing type is merely an evolution from the bomb boats and powder ketches of fifty years ago, whereas the Holland submarine boat is constructed in strict accordance with the latest improved ideas and inventions, all of which are combined to make her swift to execute the end for which she has been contrived.

The science of submarine boat construction germinated when David Bushnell, of Saybrook, Conn., in 1777, invented and built a craft which because of its shape he named, the Tortoise. In a letter to Thomas Jefferson, he stated that the craft was made habitable under water for twenty minutes, by the use of air pumped into two small copper cylinders, these cylinders were fitted with crude stop cocks, and placed as nearly as possible to the nose of the sole occupant of the craft, who navigated it by means of an oar. But one attempt to use the craft was made, and that turned out badly for the navigator and inventor.

Bushnell afterward made an improved submarine boat, which met with public derision, but many years afterward his grand-son, C. S. Bushnell, of New Haven, Conn., adopted several of his grandsire's ideas in a submarine boat which he and John Ericsson built and offered to the government. It was rejected, then Ericsson began work on plans for a monitor type ship, and Bushnell by the force of his energy, induced the Navy Department, which was bitterly prejudiced against Ericsson, to accept the Monitor, subject to tests in battle at the expense of Bushnell and others, who furnished the capital that built and equipped her.

Great was the surprise of the doubting Thomases of the navies of the world, when a terrible conflict thrust itself on the wooden fleet in Hampton Roads, and in the heat of battle with the Confederate knife aimed at her heart, Columbia saw by the light of three ships burned by the Merrimac, the Monitor, despised and rejected by nearly every navy, steam into the broad bay to achieve a glorious victory, save the capital of the nation from capture, and sound the death knell of wooden navies.

Because the science of constructing compressed air apparatus was in a crude state in the days of the Civil War, Ericsson and Bushnell, were unable to accomplish satisfactory result in submarine craft, and for lack of compressed air apparatus, the ships of the monitor type were almost uninhabitable. So naval science stopped short until in due season the advance of compressed air science by leaps and bounds gave naval architects a fulcrum on which to place a bar to lift a world of progressive ideas into perfect shape. The great defect of the monitor type was their crude system of ventilation that failed utterly at sea or in harbor; the excessive heat generated by the boilers, the rotting of the woodwork, and the gal-

FIG. 453—THE HOLLAND TORPEDO BOAT.

vanic action set up by the action of bilge water upon copper and iron fittings formed such a pest house as to render them more dangerous to life than the shot and shell of the enemy.

Jefferson Davis in his account of the Civil War, states that submarine torpedo boats were the constant theme on the tongues and pens of the Confederate torpedo division, who sank fifty-eight Federal vessels and kept the blockading squadrons out of Charleston, Savannah, Wilmington and Mobile for several years by the use of torpedoes. Several sorts of submarine boats were built by these officers, but all failed to meet expectations; one was sent out from Charleston to attempt the blowing up of Commodore Goldsborough's fleet; but she was never heard of after setting out and diving beneath the surface. It was supposed by the Confederates, that the crude system of supplying air failed, or that the pressure of the sea burst in the sides of the boat and drowned the dozen men aboard.

That was the last attempt at submarine work until more than twenty years ago, when Mr. John P. Holland, began a series of experiments with boats of his own invention. These experiments have been continued by him from that day to this and have resulted in the boat now manœuvered by him in New York bay. The principles of construction are adapted for any required size and armament according to the requirements of purchasers. The existing boat tends to resemble nothing so much as a Salisbury dory inverted upon a Nantucket whale boat. She is 53 feet long, eleven wide amidships, and of seventy-five tons displacement. The hull is made of steel plates, riveted to a steel skeleton frame. Amidship is a conning tower so made as to extend from two to three feet high, or telescope flush with the hull. Within the hull, immediately below the conning tower, are the two rudders, one for surface sailing, the other to regulate the depth at which the boat is operated when submerged, and the speaking tubes, electric bells, and a table connected with apparatus for manipulating camera lucida, used when the boat is submerged for portraying the appearance of the surface for miles around. The view is secured by means of a steel tube thrust above the waters and fitted with camera apparatus. There are three sources of energy for propelling the boat above and below the water, expelling water, discharging torpedoes and dynamite guns, and lighting the ship internally and externally; these sources are compressed air, gasoline and electricity.

The most important agent is compressed air, without which it would be impossible to operate the boat five minutes under the sea. The air compressor which breathes the breath of life into the craft, is an Ingersoll-Sergeant Drill Co.'s single acting compressor, belt driven from a gasoline engine, when the boat is on the surface, and from an electric motor switched to a storage battery, when the boat is submerged. The compressor is capable of compressing air to 2,500 pounds pressure; the diameter of the low pressure cylinder is 6 inches, the high pressure cylinder is 1¾-inch diameter, with 8-inch stroke. Both cylinders are immersed in a water box, which cools the air during compression. Solid discs serve for fly wheels. The space occupied is only six feet and five inches long, and two feet high. The highest value of the compressed air is for the respiration of the crew, numbering ten men. For this purpose the air is expanded through two reducing and one regulating valve, and is set free at the normal atmospheric pressure.

Six times the requisite volume of air is available; the surplus air is used for counteracting the deleterious effects of the ventilating pumps, which would produce a near approach to a vacuum, if the air supply from the tanks was interrupted in its even flow. The steering and diving gear are operated by compressed air, which also maintains the air pressure throughout the boat to equalize the pressure of the sea when the boat is submerged. The boat is quickly submerged by admitting sea water to a series of steel tanks connected with the compressed air system. A dive of 40 feet below the surface is made with safety and comfort in a minute. When the commander signals to elevate the boat from the depths, air is forced into the water tanks under high pressure, and as the water is expelled the boat

FIG. 454—HOLLAND BOAT DIVING.

rises swiftly to the surface. The air tanks have been tested to stand a pressure of 3,000 pounds to the square inch, and are calculated to hold out for a submergence lasting ten hours, but if the supply should fail after nine or ten hours, the tanks can be replenished by means of a tube projected to the surface as a suction pipe.

The armament of the boat consists of one dynamite gun, one automobile torpedo tube, and one aerial torpedo tube. These tubes and gun are made terrible engines of propulsion of projectiles by the power of compressed air, which not only enables the torpedo and gun operators to hurl torpedoes and great masses of dynamite with deadly precision and irresistible force, but immediately restores to the boat the weight of 800 to 1,000 pounds lost when a projectile or mass of dynamite is discharged. The muzzle energy of the dynamite gun is 750 tons, a force powerful enough to crash through the bottom or below the water line of the mightiest battle ship afloat, and send her hurling to the bottom of the sea in the twinkling of an eye.

Like nearly all valuable inventions in the domain of naval science, the Holland boat represents a series of long continued experiments conducted by civilians contending with numerous difficulties, and she is an embodiment of the belief of the most advanced naval architects, that from the latest achievement in submarine engineering, the battle ships and cruisers are at the mercy of the submarine boat that lurks beneath the sea, noiseless, and as swift to strike deadly blows as the sword fish which steals under the mighty carcass of the whale, and with one lightning-like thrust of its sword reddens the sea with the blood of the mightiest monster of the deep, which with the churning of the waters, and a flip of its flukes, rears upward for a brief second and then plunges down to the uttermost depths of the sea lifeless and inert.

Ere long the Holland boat may be tested in battle here or beyond seas, for war looms across the track that the ship of the world's progress is coursing; who can tell what lies in its bosom? But there is a sound heard from that direction which tells us it will not be the unarmed or the weak nation that will fare best when the thunderbolts crash from the war clouds.

War has endured through thirty centuries recorded by history unchanged or unchangeable; it rests as solid as the bottom of the sea, uninfluenced by the motion of the waves of time. Pugnacity and warlike tastes are as strong in the masses of mankind to-day as at any time in history, and the predominant spirit of several highly civilized nations is the policy of war, victory and domination.

G. WILFRED PEARCE.

PNEUMATIC PLANER FEED.

There has been patented recently by Alexander Gordon, president of the Niles Tool Works Co., Hamilton, Ohio, an application of air in the operation of planing machines which will be of advantage to that type of machines and add to their efficiency. In this device the feed is actuated by air. It is positive and reliable, and has a very wide range. A quicker return than ordinarily obtained is desirable. By operating clutch pulleys by air, any desired speed is obtained, with mechanism which is very simple, has few parts, and none subject to excessive wear.

We illustrate herewith this pneumatic feed and quick return. The air is taken from the compressed air supply, such as is now in use for general machine shop purposes, or from a small pump that may be attached to the machine in any convenient position, and be driven by a belt from the countershaft. It is carried from the pump or compressor through a suitable pipe to air cylinder which controls the feed and driving clutch mechanism.

A specially constructed valve admits it to the cylinder. This valve is operated through simple connections, fully shown in the drawings by the shifter arm and reversing tappets on the planer table. When the table carries the tappet or dog against the reversing lever, instead of shifting the belts, as in the ordinary planer, it moves the valve lever controlling the air admission to the cylinder. This instantly throws the piston in the cylinder to the opposite end, carrying the rack to which it is attached forward or backward to operate the feed rack. At the same moment the clutch operating the worm shaft is thrown over and the direction of the table motion is reversed. This shifting arrangement is simple and efficient.

By examining the drawings it will be noticed that the piston rod is carried through the cylinder toward the back of the planer and is connected to a lever. The opposite end of this lever is attached to a rod running across and under the bed to the worm shaft. On the worm shaft end of this rod is a segment gear whose teeth work into a short rack. The rack is attached to a rod which moves the central member of the clutch from one pulley to the other, and the pulleys are operated one by straight and one by cross belt.

Fig. 455 shows the clutch pulleys, bearings, sleeves, casing and also the clutch shifter rod in the interior of the worm shaft and clearly

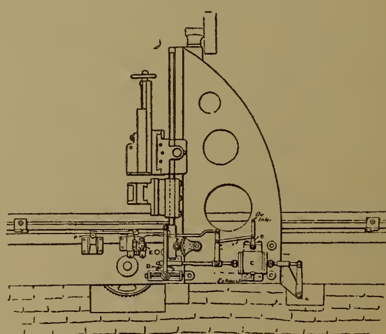

FIG. 455—PNEUMATIC PLANER FEED.

shows the various features of these parts. The belts run continuously in one direction, thus preventing the excessive wear due to shifting, to overcoming momentum of pulleys and other parts, and to the rubbing of the edges of the belt in the shifter eyes. The belts can be made as wide as the necessities of the case require, not being limited by any of the conditions always prevailing in other planers. The clutch, from its peculiar construction, holds most tenaciously under very slight pressure, and is quite easily released.

No adjustment is required in keeping the clutches in working order, as they will do their duty until the wood facing is entirely gone, and the replacing of this facing or lining will not cost nearly as much as the repairs to and the replacing of belts.

This is an effective machine for variable speeds, as the pulleys controlling the cutting speed can easily be made cones and belt shifted, as on a lathe. The pulleys operating the return stroke could also be made in this manner, and the speed increased or decreased, as the piece being planed was very heavy or very light. The return may be made 6 or 8 to 1, with air cushions positively preventing all shock.

A number of these planers, from 30 x 30 to 10 x 10 inches, are in successful operation at the Niles Tool Works, and a 54-inch planer, for planing locomotive frames, with 35-inch traverse of table, is now under construction. The quick return on this planer is especially desirable by reason of its length and the comparatively slow speed of the cut.—*Iron Age.*

PNEUMATIC CHECK SYSTEM.

What is claimed to be a valuable feature of protection to property is the Pneumatic Watchman Check and Regulator system, installed by the Pneumatic Watchman Check Co., of Columbus, O. In this system, what is called the clock

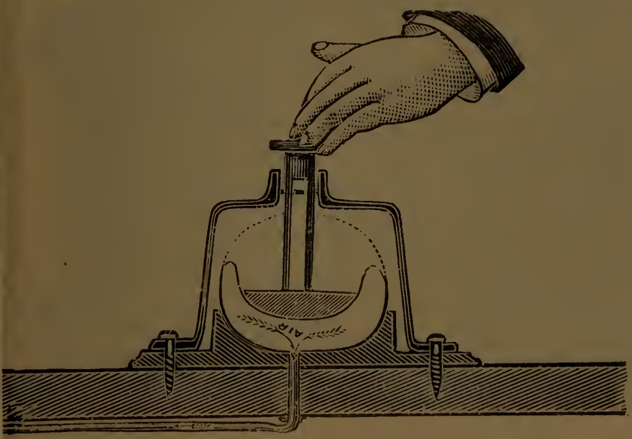

FIG. 456—PNEUMATIC PUSH BUTTON.

or Recorder, is generally placed in the office of a plant or property, and the stations are located at various places about, inside or outside, it is desired the watchman to go when upon his rounds during the night. Each and every station is connected to the Recorder in the office by means of a small metal tubing, the size of a wire. This tubing is a composition of lead and tin and zinc, there is nothing about it ever to rust, to corrode, or to be affected in any way by the conditions of the atmosphere, or by heat or cold. The stations themselves are small iron boxes about three inches high. A sectional view of one of them is given in Fig. 1 Inside of this iron box is a rubber ball made of a special composition or rubber, designed especially to stand the hard usage which it must undergo. The watchman carries a key which is in the shape of a tube with a button or knob upon the end of it. He inserts this key into the station and as he does so, it pushes down or compresses the rubber ball upon the inside, and as he thus compresses the ball, it forces the air through the tubing into the clock. The station may be located as much as 2,000 or 3,000 feet away from the clock, or it can be placed at one or two feet away.

Inside of the Recorder is a set of corrugated diaphragms, made of german silver. A section of one will be noticed in Fig. 456. As the air is forced from the station through the tubing into such diaphragm, it causes the diaphragm to be inflated and rise up. On the top of the diaphragms is a small rod into which is screwed a needle and as the diaphragm is forced up by the air, it pushes the needle up, and in so doing, the needle punctures a paper dial, which dial is turned by a clock movement. Thus at any minute, day or night, whenever a key is placed into a station, it immediately forces the air through the tubing into the diaphragm, and this causes the needle to puncture in the proper spaces upon the dial show-

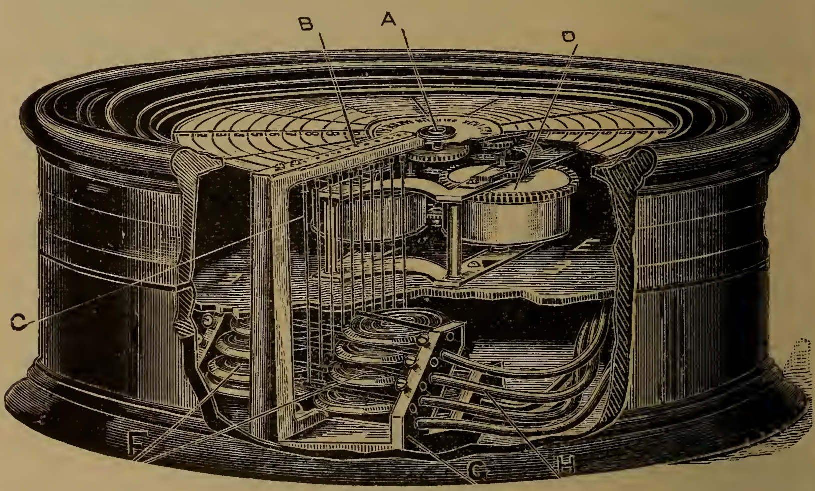

FIG. 457—RECORDER.

ing the number of the station and also the minute it has been operated. A station may be operated any number of times. Fig. 457 is a sectional view of the Recorder. In the bottom of the Recorder is located the frame containing the diaphragms. Just above them is a deck or partition which covers over the diaphragms. On top of this deck is fastened the clock movement, which revolves the paper dial, keeping the time, the same as a clock, only there are no hands like in a clock. The whole dial face revolves. This machine, besides being used for the purpose of checking the movements and keeping a record of the night watchman, is also used in newspaper offices, to keep track of the form as it goes from one department to another. The Recorder is generally placed in the business manager's office. There is a station located in the composing room, one in the stereotyping room, one in the press room, and another in the circulation department. When the form leaves the composing room, the workman there simply presses a key into the station located at such place and immediately it makes a record to the exact minute on the paper dial in the Recorder in the manager's office showing just when the form left the composing room. When it is received in the stereotyping room, the workman there presses the station in that department. Also when the form leaves the stereotyping room, it shows when it was received and when it left such department. The same also in the press room and the circulation

FIG. 458—ANOTHER TYPE OF RECORDER.

department. This machine has been placed in newspaper offices throughout the country. Besides being in operation in hundreds of factories and manufacturing establishments throughout the country, it is also used by railroads in their freight stations and also in their shop properties wherever night watchmen are employed.

CHIMES.

For a few years past chimes in church towers have been coming into favor. A number of cities in European countries have orchestras of this kind, that date back to the 17th or 18th centuries. There are several in this country and every one of them have had the problem of how to ring them to contend with. This question has been so filled with obstacles, that even after the bells were bought and hung in place they have remained silent.

Pious persons of wealth knowing of no other lasting gift to make their favorite church, have bequeathed or presented chimes, leaving the ringing of them to the church itself. We know of one case where there are 44 bells and no music has been obtained from them, although they have been in place for many years. The ringing of chimes is a work, however, that is never wholly abandoned by church trustees, consequently, some of these churches have erected crude appliances, that ring the bells in a more or less satisfactory manner. Electricity has been the hope of many, and there are places where bells are rung by electric appliances, but they have never proved satisfactory. The chime bells of St. Germain-L'Auxerrois, in the city of Paris, were finished in 1878. Their construction extended over a period of 15 years, and yet they never rang successfully until a few years ago. To show the system employed in that instance, we present a picture of the key-board, cylinder and mechanism of these chimes. The system as a whole occupies a space of no less than 60 ft. in height, and an octagonal surface of 108 square ft. The weight room is 19 ft. in height by 11½ in width. The cylinders of the bell weights have diameters varying from 10 to 52 inches; each cylinder with its wheel work, accessories, and striking train constitutes a true clock.

One of the finest set of chimes in the United States is that of St. Patrick's Cathedral, Fifth avenue, New York City. Nineteen bells constitute the set, and they were donated by Cathedral Parishioners and others.

THE FOLLOWING LIST GIVES THE WEIGHT AND TONE OF EACH OF THE BELLS, AND THE NAME OF THE DONOR.

	Name of Bell.	Tone.	Weight in Pounds.	Donor.
1	St. Patrick	B flat	6,300	Cathedral Parishioners.
2	Our Lady's	C	4,400	John B. Manning.
3	St. Joseph	D	3,300	Joseph J. O'Donohue.
4	Holy Name	E flat	2,600	The Sodalities of the Holy Name throughout the city.
5	St. Michael	E	2,200	Michael S. Coleman.
6	St. Ann	F	1,850	Henry McAleenan.
7	St. Elizabeth	G	1,300	The Marquise San Marzano.
8	St. Augustine of Hippo	A flat	1,100	Augustine Daly.
9	St. Anthony of Padua	A	965	In memory of Edward Fox.
10	St. Agnes	B flat	770	In memory of James Edward Fox.
11	St. John Evangelist	B	660	John D. Crimmins.
12	St. Bridget	C	550	In memory of Aloysia Miniter.
13	St. Francis Xavier	C sharp	460	The Catholic Club.
14	St. Peter	D	385	George B. Coleman.
15	St. Cecilia	E flat	330	Mrs. Thomas F. Ryan.
16	St. Helena	E	275	Eleonora Keyes.
17	St. Alphonsus Liguori	F	220	Maria A. Mills.
18	St. Thomas Aquinas	F sharp	200	Thomas Kelly.
19	St. Godfrey	G	165	In memory of John and Mary Koop.

These bells hang in the northern spire of the Cathedral, 180 feet above ground. The following ritual of the bells is observed. The Angelus is rung at 8 a. m., 12 m. and 6 p. m. daily, and the De Profundis bell is rung daily at 7 p. m. The chimes play on Sundays and greater festivals or national holidays, and pious occasions. The bells are tolled at funerals.

The same perplexing question arose when these bells arrived from France, where they were made. A committee was appointed by His Grace, Archbishop Corrigan, with Mr. Cornelius O'Rielly as Chairman, and Fathers Connolly and Lavelle, and Mr. John A. Sullivan as members. The subject was gone into thoroughly and all of the various systems examined exhaustively. Every one of the systems then in vogue seemed by this committee inadequate and lacking the modern facilities that marked almost every other method of doing things. The crudeness of methods, expense of installation and the necessity of having expert attendants caused all systems known to be rejected. Many propositions were sub-

FIG. 459—KEYBOARD, CYLINDER AND MECHANISM OF THE CHIMES OF ST. GERMAIN-L'AUXERROIS.

mitted. The bells were installed in the Cathedral spire in the autumn of 1897. In December, 1897, COMPRESSED AIR printed the following: "An inquiry comes to us asking for the services of some compressed air genius who can devise a practical compressed air apparatus for ringing chime bells. A short time ago 19 stationary chime bells, the heaviest of which is about 6,000 pounds, and the lightest about 300 pounds, were placed in St. Patrick's Cathedral, New York. It was intended to ring them by electricity, but thus far no device has been acceptable. It has been suggested that by a suitable installation compressed air would do the work satisfactorily. The church authorities will lend any assistance to enable experiments to be carried on, providing the plan submitted appears feasible."

This was the signal for work in this direction. Several compressed air experts came forward with sketches and designs to cover the requirements of these bells. The committee secured expert advice and finally accepted the system submitted by Mr. Hertford C. Champ, of New York, who had been a reader of COMPRESSED AIR, and who had made this subject his study. His plan was so simple and embodied the essential features to such extent that this system was finally adopted and the work begun. The plan as installed consists of compressed air and electricity, the one being the motive power causing the bells to ring, and the other being employed as the means of operating the mechanism which strikes the bells. Chime bell ringing by compressed air had never been tried before, and Mr. Champ's genius has been severely taxed to complete a system that will in all probability be the most complete one ever used for this purpose. Following the proposition from the beginning we find a complete air-power plant consisting of an Ingersoll-Sergeant, Class "E" compressor, with air cylinder 8 in. diameter by 8 in. length of stroke, driven by a 15 H. P. 240 volt direct current six pole type Lundell motor, made by the Sprague Electric Co. These machines are rigidly mounted upon a heavy cast iron base plate designed and finished in Mr.

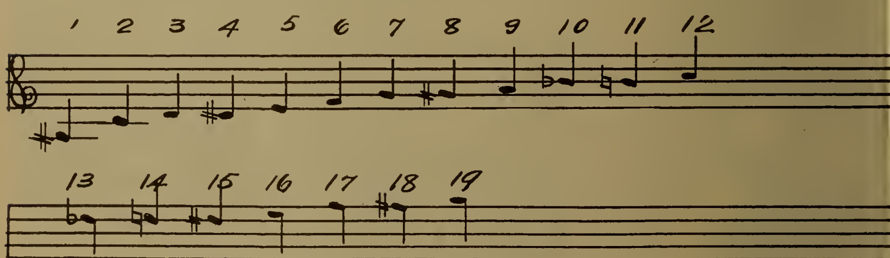

FIG. 460—CHIMES OF ST. PATRICK'S CATHEDRAL.

Champ's shop, and set on a rock foundation in the sub-basement of the Cathedral Rectory. The armature of motor is fitted with a pinion meshing into a cut spur wheel fitted on one end of the compressor crank shaft. This power unit is considered extremely compact in its dimensions, runs remarkably well, and is capable of supplying the equivalent of 69 cubic feet free air per minute, which air is taken from a deep and decidedly cool area-way alongside the power room, and is delivered into a receiver 6 feet high by 24 in. diameter, from which latter the air power is conducted through a 2 in. pipe a distance of 600 feet to another receiver in the belfry. The two receivers have sufficient storage to at all times cause the bells to ring when they are wanted. Air is compressed to 80 pounds, so that there is always surplus for any emergency that may arise. A 2 inch pipe is carried as a main line, passing under each bell. From this main supply pipe, which is of itself a reservoir of air, ¾ in. connections are made with the striking mechanism. After we have compressed the air we find it within 2 inches of the piston that moves the clapper to strike the bell. The key-board is located in the sacristy of the church. A cable is led to the church spire, and wires are connected to the magnet of the striking mechanism. Both the powers are here controlled from a distance.

The operator at the key-board presses a key corresponding to the bell that he wishes to have struck. This makes an electric connection which serves to open a valve admitting compressed air to a piston connected with a clapper which strikes the bell. Electricity is the trigger and compressed air the power in this work. There can be no measurable delay in the stroke. A duplication of this operation brings the nineteen bells under the control of the operator in the sacristy, where by means of the key-board showing the notes of the bells he rings the chimes to any air desired. The details as described show the practicability of this system.

STERILIZED AIR FOR THE PRESERVATION OF FRUITS AND PRO VISIONS.

What has become generally known as the "Perkins Process" for the conservation of perishable products, opens a new field for scientific research, as well as the use of compressed air.

The system attempts to—and so far the results prove it does—check the two prime factors of decay, viz., temperature and humidity. The latter has been almost entirely overlooked in present methods, and yet is of the greater importance.

It is no unusual occurrence in the pure, rarified atmosphere of the Sierras, at an altitude of 3,000 feet and over, even at a temperature ranging from 80° to 100° F., to have fruit—noticeably the grape—ripen and without decay become thoroughly preserved on the stem. Hunters and miners keep their meats hanging in a tree, with the free air of heaven blowing around it and for weeks cut their delicious, full flavored steaks, until the whole is used.

Following nature's course and guidance, after years of patient study, with chemical, microscopical and mechanical tests and experiments, the process has developed into a practical and effective service.

A brief article could not do justice to the treatment, from a scientific standpoint, of the subject of decay in animal or vegetable life. The Q. E. D. that a new life comes into existence on the death of every old one, is positive. The delicate peach hangs a perfect picture of beauty on its branch, the ruddy blush half hidden among the glistening leaves. It is just ready to finish the ripening—the first stages of its decay. The warmth of the atmosphere and the sun's rays set the acid and sugar into fermentation; the carbonic acid gas developed pushes outward through the flesh, mellowing and fitting it for a luscious morsel, but at the same time carrying a viscid moisture to the surface, and there on the beautiful skin are the resting spores of the mycelium, awaiting the moisture and warmth to vitalize. After vitalization, there is the union of the hyphea, or the male and female spores, followed by the perfecting of fungus growth in root, trunks, branch, bud, blossom, and explosion of the seed bulb, sending its innumerable spores in every direction, to hasten the work of destruction and decay on some other form of vegetable life. Clearly, then, perfect conservation must regulate temperature, absorb moisture, dispose of the carbonic acid gas and impurities, and sterilize the growth of the fungus.

Compressed air under proper pressure is thoroughly sterilized, and one of the principal features of the "process" is the ingenious method by which the moisture is wrung, or rather separated from the air and deposited.

At some future time we may note the construction and operation of this service for car and steamship transportation and for storage purposes.

At Dr. Perkins' laboratory in Chicago, the tests for compression, expansion, friction, drying and sterilizing are developing new possibilities for other purposes than those the inventor at first intended.

Although the "process" is in its infancy, machinery is being manufactured for the service in several foreign countries where the greater interest seems to be manifested in the introduction of improved methods for transportation.

AIR BEDS.

In this age of invention of labor-saving devices and improved appliances for our personal comfort, we are only too ready to attribute everything to the

FIG. 461—AN ANCIENT AIR BED.

spirit of the times, and we are quite surprised to find that something new, as we are pleased to call it, is really something old, and something very old at that. Take the subject of the sketch given herewith, Fig. 461, representing a view of an air bed dating back several centuries. This proves the air bed is not of modern origin. It was known to the ancients and apparently used. The illustration is one of several figures attached to the first German translation of Vegetius, A. D. 1511. It represents soldiers reposing on them in time of war, with the mode of inflating them by bellows.

Heliogabalus used to amuse himself with the guests he invited to his banquets by seating them on large bags or beds, "full of wind," which being made suddenly to collapse, threw the guests on the ground.

Although this case in point does not rival in importance the Colossus of Rhodes or Curios' Amphitheatre, holding 80,000 persons and built so as to swing about in the course of a few hours and form two theatres back to back, still it might serve to answer the question, What is new in the world?

A CLOCK BY AIR.

The new Fisher Building in Chicago is furnished with a clock run by compressed air. It is a monster time-piece on the eighteenth floor, and sets the hands on numerous dials throughout the building. This great clock is a sort of central plant, and it controls almost any number of secondary clocks or dials. Compressed air forms the connection between them. An air pressure of about fifteen pounds to the square inch is required, and that is usually obtained from a small air pump where other compressing apparatus are not available.

When the air pressure is turned on in the main pipe it exerts its pressure all over the building. At each dial there is a little air pocket, a simple escapement, and a couple of gear wheels. When the air pressure fills the pocket, the escapement starts and the hands move ahead one minute. Then the air is exhausted, the pocket empties, and the escapement sets itself ready for another impulse. In this way each minute sets the dials all telling the correct time according to the master clock. Hence the secondary time-pieces are never more than thirty seconds wrong, either fast or slow.

In the Fisher Building there are now about twenty-five of these dials in use, and more are being added as fast as tenants arrive.

SOMETHING NEW IN JAIL CONSTRUCTION.

The "Pneumatic Safety Jail" is the significant name given to the latest design of steel jail cell recently perfected by the Pneumatic Safety Vault and Jail Co., of Chattanooga, Tenn. The inventors believe they have attained a greater degree of safety and security than is afforded by any other design of jail made, and, as the word "Pneumatic" would suggest, part of the means employed is compressed air. If the jailer has timely warning that the lock or door is being tampered with, or any of the cell bars are being cut or filed, he can always take measures to frustrate the intended escape. To give this sure warning before any material damage can be done is the part compressed air plays in the new jail. The following description will convey an idea of its principal features of construction. The exterior walls of the cells are constructed of vertical tubes with hard tempered steel cores, spaced about 4½ inches between centres. The floor and ceiling are of double plates with an air space between. The horizontal bars through which the verticals pass are square in section and contain a small air pipe continuous all round the outer cell walls. An air pressure of 15 or 20 lbs. is maintained by a pump placed at any desired point in the

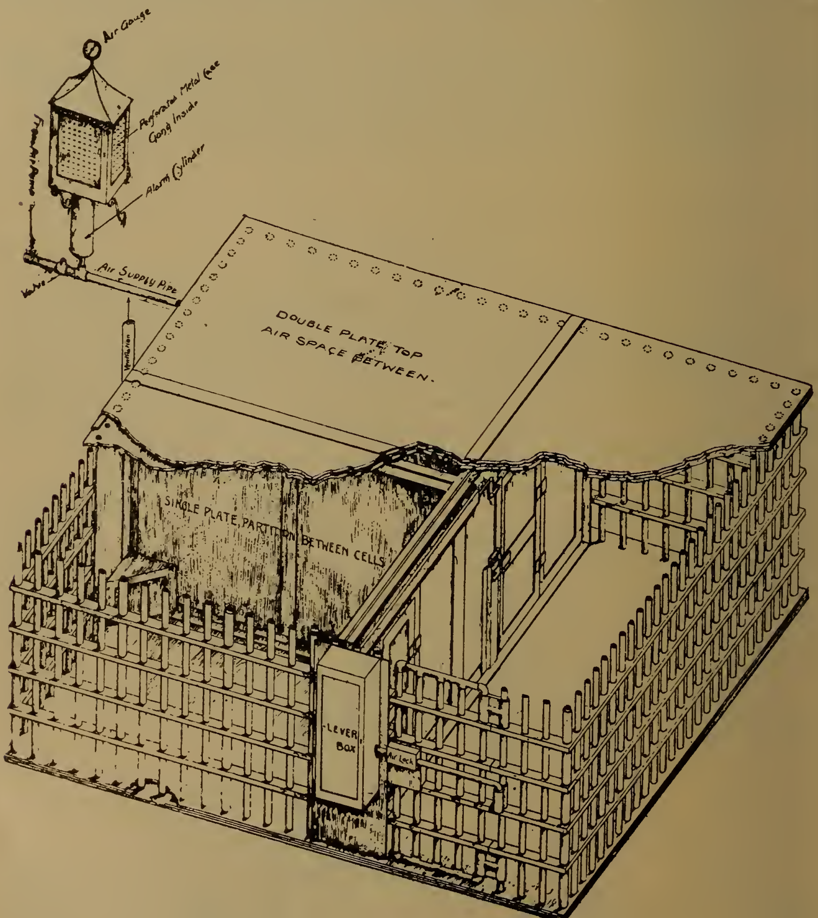

FIG. 462—JAIL CELL PNEUMATICALLY PROTECTED.

building, the supply pipe connecting it with the air spaces of the cell being built in the walls of the building or otherwise protected. In small jails the pump is operated by hand and in large ones by electric or water motor or other available power. An automatic alarm, set to ring when the pressure fails to say 5 lbs., gives timely warning when any of the air spaces are pierced or connections broken. As may be readily seen the alarm can be placed at any desired point, either inside or outside the jail building, or any number of alarms may be used. It may be conveyed to any distance by electricity or by air pipe, but the objection to relying on an electric alarm is that it may be so easily tampered with. There is no tampering with compressed air. An accidental loss of pressure, an injury to the supply pipe, any defect in the system must set off the alarm. The door is built up of tubes and receives the air pressure through tubular hinges or through a union near the lock, which must be disconnected to open the door. A flat lock of the Yale pattern is used, and as an additional safeguard, it is protected by an "Air Lock," which consists of a hollow hinged bar containing air pressure swinging across the door and face of the lock. This must be removed, thereby breaking the air connection and sounding the alarm, before the lock can be gotten at. The cores of the vertical tubes spoken of above are octagonal steel about ⅞-in. diam., tempered to be as nearly tool proof as such metal can be made. They are pivoted at the ends so they can turn loosely inside the tubes. The object being to give additional strength to the tubes, and in case of the air pressure being off for any reason, to make what the inventors believe to be a jail fully as difficult to cut out of as any of the best designs now on the market. It would be almost an impossibility to saw or file through a bar built up of an exterior tube with a hardened steel core loosely fitted, that would turn with every stroke of the saw. And again, the temper of such a bar could not be drawn by any means available to a prisoner. Cases are numerous where the best so-called tool-proof bars have been softened so as to be easily cut, by what would seem to be the most simple means, unthought of by any one except a prisoner whose sole mental and physical effort is to get out, such as a blow pipe made of a common pipe stem and a candle allowed him by the leniency of the jailer, the one to read by and the other to smoke with; or piping gas across the cell to the desired point by a tube moulded of bread crumbs, etc. Shrewd criminals study the question of how to get out of jails just as the builder studies how to keep them in, and the contest is close between them. It is like the contest between builders of war ships and makers of cannon, the one with his armor-piercing projectiles and the other with projectile-proof armor. It is an undisputed fact that unless closely watched even ordinary prisoners will find means to get out of the best built so-called "tool-proof" jails. We have but to watch the daily press reports to find numerous instances. In one of the most recently built state penitentiaries which has been finished scarcely two years, at least two escapes have been reported by cutting supposed tool-proof bars. Very recently a jail escape was reported in a prominent town of one of the Eastern States that is in itself a unique example. Two prisoners cut the bars of their cells and laid in wait at night in the corridor for the one turnkey who was on duty. As he made his rounds they sprang upon him, bound him and left him helpless. Then they robbed the office safe of the jail of $2,500 belonging to various officials and prisoners, supplied themselves with revolvers and ammunition and made their escape. The manufacturers of the pneumatic safety jail believe they have introduced the only real improvement in jail building which has been made since the introduction of "Chrome" steel or of bars made up of layers of hard and soft metal rolled together. They have adopted the word "Safety" across a U. S. shield as a trade mark and believe it fully merited. Before offering to build jails for public use, they have experimented extensively to find what mechanical difficulties had to be overcome to be overcome to carry out their ideas. They have now a full size cell complete in every particular in their shops at Chattanooga. The principals involved and details of construction are fully covered by patents. Those principally interested in the enterprise are the Casey & Hedges Mfg. Co., of Chattanooga, well known manufacturers of boilers and machinery, and Linn White, an experienced civil and mechanical engineer, who will have charge of the business of the company.

DUDLEY'S AIR GUN.

It has been found that compressed air is the safest and best agent for expelling a dynamite shell.

The "Scientific American," in a recent issue, describes the Dudley gun, a gun and compressed air plant in itself. It certainly is a most ingenious arrangement, and its use of gunpowder for the purpose of compressing air opens up possibilities in the application of the principle which will be apparent to any skilled mechanic.

The Dudley gun might be called a long tube, bent upon itself so as to show three tubes side by side. These tubes lie parallel to each other. The long central tube is the firing tube, and weighs 250 pounds in a 4-inch gun.

The two side tubes might be called the air compressor, for it is in them that the air is compressed to 850 pounds to the square inch. At the forward end of the gun, the two outside tubes are connected by an air passage.

The rear end of one of the tubes is connected by a similar passage to the central or firing tube, and the rear end of the other side tube is fitted with a suitable breech mechanism to receive the powder cartridge. A glance at the diagram will show the passage of the air when the powder is ignited.

The central or firing tube has a breech mechanism similar to a breech-loading rifle. In this the projectile with its load of high explosive is placed. Then the breech piece is locked, the powder cartridge is placed in the side tube, and its breech is locked.

The powder is ignited, and the air in the tubes is compressed by the generate gases. The force of the explosion, cushioned by the two columns of air which are between the powder cartridge and the projectile, acts upon the projectile. The shell leaves the gun with little noise of explosion and no smoke whatever.

The recoil of the gun is slight, and springs are provided for taking it up. The projectiles used in the gun are brass cylinders with pointed ends. The fuse is attached to the front end and from the rear end of the shell extend vanes or rings to insure rotation. The entire shell is 52 inches long, and when fully charged weighs 32 pounds.

In the main body of the shell, which is the brass cylinder, the dynamite or nitro-glycerine is placed. In the forward end of the charge is placed a charge of gun cotton, and in the centre of the gun cotton is a case containing fulminating mercury.

It is believed that the principle of compressing air by the explosion of gunpowder, as it is done in the Dudley gun, can be employed in the useful arts, particularly in quarrying and tunnel work, where air drills are remote from the main pipe of the air compressor plant.

A NEW BOLT THREAD CUTTER.

An appliance for cutting bolts and threads has been invented by Mr. J. H. Ferguson, Asst. M. M. of the Meadow Shops, P. R. R., Jersey City, N. J.

The inventor claims that his device is to provide an automatic attachment for the feed portion of a bolt machine, by which the bolts to be threaded are delivered, and when the threads are cut, removed from the "die holder" of the ordinary type of bolt threading machine, automatically, and much more rapidly than the usual method. The attachment also automatically opens and closes the dies, it being only required of the operator to lift the bolt out when it is cut, and replace it with one to be cut, thereby greatly simplifying his labor, and necessary skill.

The means for accomplishing this result are, first, compressed air acting in a cylinder fitted with a piston and piston rod; second, a valve and connection for automatically controlling the admission of air to either end of the cylinder; third, a rigid bed, secured to the original bed of the machine, and to which the cylinder is fastened; fourth, a sliding plate, having a longitudinal motion, on the bed parallel to the axis of the die shaft, and being rigidly connected to the piston rod; fifth, a round turret or monitor, revolving on the slide plate, being so revolved (when the slide plate is moved by the action of the compressed air in the cylinder) by means of a latch, engaging in pins which are set in a disc on the under side of the side plate, the disc, through the medium of a square bolt, revolving the turret; sixth, a locking device for securing the turret in a certain position during the cutting of the bolt, yet permitting it to turn when the latch engages the pins; seventh, the bolt holders in the turret, for securely holding the bolts in a proper position for cutting the threads, and allowing them to be easily removed and replaced; eighth, the substitution of a vise for holding work too long for the turret, the turret being removed.

When the compressed air is turned on, it starts the machine, the die holders revolving as usual; the air entering the back of the cylinder, acting against the piston, forces the slide forward, and presses the bolt (held in the turret) against the dies which begin to cut the thread. As the thread is being cut, the valve plug is gradually turned until air is admitted to the opposite end of the cylinder, and tends to pull back on the slide; therefore, when the die holder opens, the slide moves back, the lock pin is withdrawn, the turret turned, until a new bolt is brought into line, the die is closed, and the valve plug again admitting air to the back of the cylinder, a fresh bolt is forced to the die, the bolt just cut is then lifted out and another substituted, and there are always five uncut bolts in the turret.

FIRE ALARM WHISTLE.

Suburban towns that use fire alarms will be interested to know that the Compressed Air Whistle is the most effective means of proclaiming fire tidings that there is; and also that it is economical and automatic, and easy to install. Our correspondent, Capt. W. B. Sayre, says: "We have had a compressed air whistle in operation now about a year and find it a great success and eminently fitted for use in suburban villages, inasmuch as the cost is less than that of purchasing and mounting a heavy bell, and the alarm is a hundred times more effective for the simple reason that the ear becomes accustomed to the sound of a bell owing to adjacent church or school bells, and if a person living some distance from the engine house is sleeping soundly with windows closed and wind blowing outside, he probably will not be awakened, but the hideous screaming of our siren will almost wake the dead, as under ordinary circumstances, when the wind is not very high, it can be heard a distance of from five to eight miles distinctly, while it is doubtful if a two thousand pound bell would carry that far. Our plant consists of a boiler, an iron cylinder, eight feet long and forty-two inches in diameter, and capable of carrying one hundred and fifty pounds pressure. It is placed on the second floor of our engine house so as to be near the whistle and thus avoid unnecessary piping and probable leaks. It is fitted with pressure gauge and safety valve, as well as pet-cock at the bottom for drawing off water which condenses. Our whistle is an ordinary "Siren," such as is used on steam vessels and some few factories. It is 4½ inches in diameter, and the "chimer" is actuated by a drum and weight arrangement. This whistle is placed ten feet above the house so as to carry sound over adjacent buildings and is connected with the cylinder by inch piping; the chain which opens the valve in the whistle, trips at the same time the pall on the drum which operates the chimer and thus starts all off together. Our pressure is put on by a double action air compressor which is operated by an electric motor. These compressors can be had at most any price according to their capacity, from that capable of being run by main power—which would take, possibly a whole day to charge a tank the size of ours—down to the combination double action compressor, capable of putting 100 lbs. pressure on it in an hour but requiring five horse-power to operate it. Our plant as it is, is a decided success. We carry 100 lbs. on our cylinder constantly and this will run our whistle about 90 seconds. It seems hours. When an alarm comes in, should it be at night, the driver as he slides down the pole from the sleeping quarters pulls the whistle chain and puts it on a hook and goes on about his business, and the whistle blows until exhausted or is released. It can also be used, after giving a long blast to awaken the firemen, to give the number of the box called by short blasts."

FIRE ALARM WHISTLE.

A compressed air fire alarm whistle has been invented by F. E. Whitney, of Boston, Mass., and is said to be a most satisfactory one. Towns that have no available steam for steam alarm whistles will get good results by taking water for pumping the air direct from the street mains It is now in use at Arlington, N. J., and is being investigated by a large number of fire chiefs who look upon it as a simple and economical method of alarm, in connection with Gamewell or other systems.

THE RUTH PNEUMATIC CAR FURNISHINGS.

The private car of the vice-president of the Pittsburg and Lake Erie Railroad is equipped with the Ruth pneumatic mattresses and chair seats. These ap- ances are contained in one compartment of the car, and consist of four sec-

FIG. 463—INTERIOR OF SLEEPING CAR.

ions, or eight single beds, furnished with eight heavy duck and rubber mattresses that can be inflated with air from the engine by simply turning the air- ock provided near each bed.

When not in use, and the compartment is being used as a parlor, they are ntirely out of the way and one would not even suspect them of being a part of the furnishings of the car. When not inflated they shut up like an accordion, being formed in pleated folds, and fit into the side of the car and are covered from sight by the piece forming the side of the beds.

The partitions dividing the berths are fitted closely to the inside wall of the car, the portions of the partition that would cover the car windows being cut away. These partitions are fitted with shutter windows sliding vertically, and can be opened or closed as desired. If closed, they cannot be opened by the occupant of the berth. When opened in either the lower or upper section the two sections have free communication, and this arrangement is desirable in case of sickness or for families with children. The operation for transforming the parlor to a sleeping compartment is simple and easy. The porter by turning the same air valve that inflates, siphons the air from the seats of the chairs and then turns their backs down, making them low enough to fit under the bottom berths.

PNEUMATIC HORSE-COLLARS.

The bicycle craze and the numerous fads of the day have not entirely done away with the love for that noblest of animals, the horse, and while its devotees are considerably fewer than a few years ago, there are still many who cling to the thoroughbred and are constant in their search for inventions which may be of use to a horse or conducive toward the lightening of its work.

An Albany, N. Y., gentleman, touring in Europe not long ago, came across a new invention in the shape of a pneumatic horse-collar. It was in Milan, Italy, that the Albanian saw the new kind of collar, and, charmed with its qualities, he ordered two of them made and sent to his home.

These collars arrived in Albany a few weeks ago, and were placed on exhibition at George L. Russell's stable, No. 362 State street, where they were examined by a number of well-known lovers of horse-flesh and heartily approved. Both collars are pneumatic, and one is finished in black, while the other is in russet. They are the only collars of the kind in the country. The collars, in appearance, are similar to the ordinary horse-collar, of superior workmanship, but instead of the usual packing of horsehair and straw, there are pneumatic tubes which are blown up and made to fit the horse's neck, much the same as the tire on a bicycle. The collars are of the finest workmanship, and took the first prize offered by the Society for the Prevention of Cruelty to Animals at the exhibition held in Milan during 1895.

The principal features of the collar are its velvet-like surface and extreme lightness. No horse wearing this collar will be troubled with galling or chafing, for the make-up of the collar prevents both.—*Blacksmith and Wheelwright.*

A PNEUMATIC LETTER COPY BOOK.

A London stationery firm has brought out a novel invention in the shape of a letter copy book, which is compressed pneumatically. The device is intended principally for travelers, wherever it is impracticable to make use of a press. The book is similar to an ordinary copying book, in general appearance, but is provided with clasps to hold the covers firmly and furnish resistance to internal air pressure. Within the book there is a thin inflatable rubber bag connected with an air bulb which can be detached. When it is desired to copy a letter the leaves are moistened or a damp cloth is applied in the usual way, the book is closed and clasped and the air bag is pumped up by means of the bulb. It is said that the pressure is even and that good copies are obtained. The book is on sale in the London stores.—*Railway and Engineering Review,* Sept. 23, 1899.

A PNEUMATIC BELT SHIFTER.

One of the latest useful applications of compressed air in machine shops is reported in the April *Locomotive Engineering.*

The device is applied to countershafting, for the purpose of shifting a belt from the loose to the tight pulleys, and the reverse. It consists of a small air cylinder with a piston travel, such as will give a belt the proper throw; the cylinder is piped from each end to a two way cock, the plug of which has a bar with a looped cord within reach of the operator. Attached to the piston is an arm which extends down to the bar carrying the shifting forks—air does the rest.

A PNEUMATIC ELEVATOR SAFETY.

The statement has been made on good authority that the elevators in New York City carry more passengers than the surface cars. Whether this is true or not, it must be admitted that there are grounds for the claim. In other cities, with the exception of perhaps Chicago, we question whether the proportion would be more than 25 per cent. In any case, the statement serves as food for thought, and suggests a comparison of other features.

Two fundamental differences exist between the two forms of transportation. First, the elevator travels in a vertical plane, while the tram moves in a horizontal plane. Again the tram car, with the exception of the cable road, is always independent. The elevator car, from the nature of things, cannot be self-propelling and must always depend upon the lifting cables.

Also, since there is only one car in the case of the elevator it is ordinarily possible to stop or start the entire operating apparatus when it is desirable to stop or start the car. There are, however, occasions when brakes or some means of quickly and surely stopping are of vital importance.

Generally speaking, the present forms of elevator brake must of necessity differ from a tram brake, as they cannot be applied on the up trip without the greatest risk and the action on the down trip is mostly a matter of uncertainty.

In railroad practice the prime requisites of a brake are reliability, absolute control on the part of the engineer, and sufficient power for all possible demands.

It would seem that the same conditions are quite as essential for an elevator brake, certainly absolute control on the part of the operation is the only one

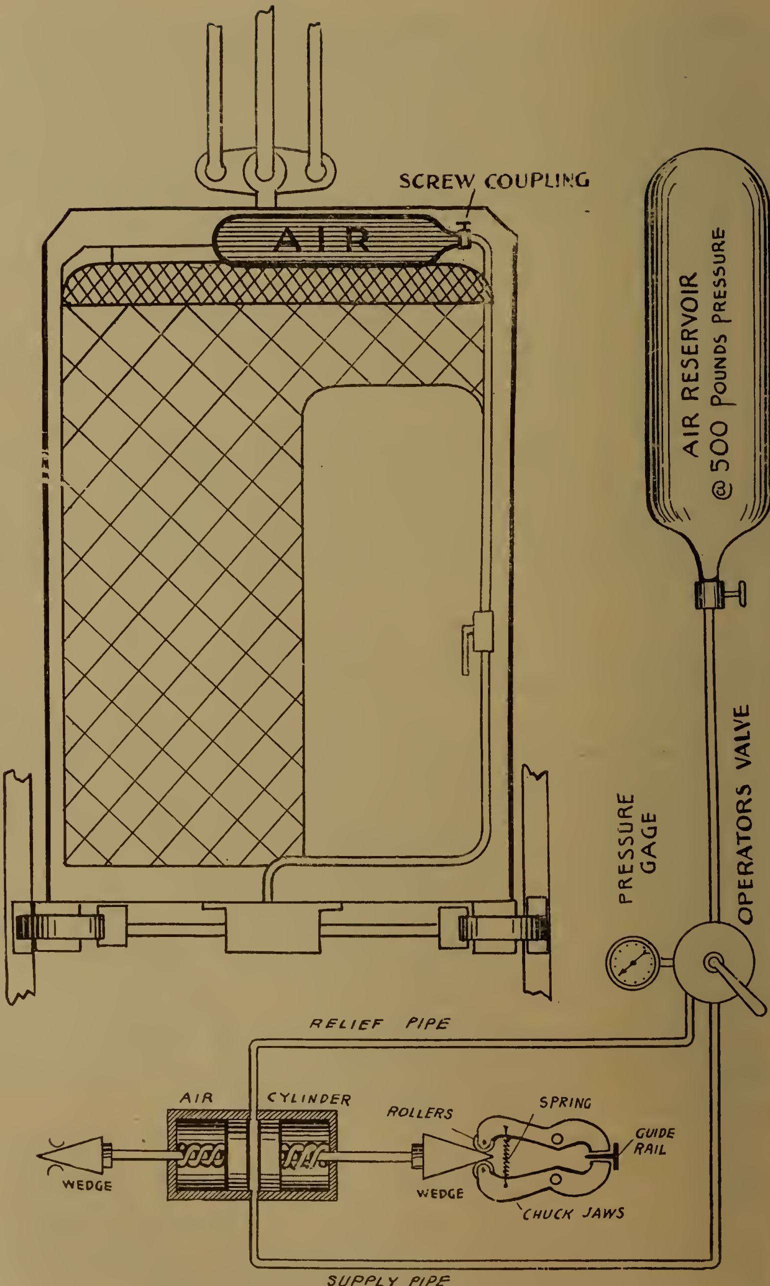

FIG. 464 PNEUMATIC ELEVATOR SAFETY.

which can be questioned. With present forms control by the operator is inadvisable and we may say impossible. The only reasons for this statement are that the operators may become confused and present clutches, catches and safeties, all depend upon springs or wedges which are driven in by the falling of the car, and there is no way to adjust these with the necessary nicety that is possible with street or tram cars.

In answer to the first of these objections, it may be stated as a general proposition that a given operator would be less rattled with a braking device over which he has control, than one over which he has no control.

Further, if he had the perfect confidence which frequent handling and test-

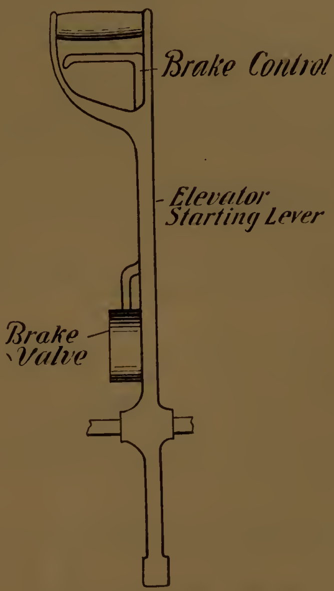

FIG. 465—ELEVATOR BRAKE.

ing inspires, the probabilities are that he would be no more confused than the engineer of a train or the average motorman.

The second proposition can only be answered by suggesting some form of brake which will admit of an adjustment by the elevator operator.

A review of the conditions outlined causes one to wonder why the air brake, which has proved so satisfactory in the case of horizontal vehicular traffic, has not been applied to those moving in a vertical direction. To better illustrate this idea, the accompanying sketch has been prepared. It shows an elevator car equipped with an air brake and ilustrates in a general way the principle involved.

The car is provided with two companion clamp jaws for each guide rail, and these jaws may in addition to their function of brakes serve as guides. These jaws are ordinarily held apart by some form of spring and thus permit a free movement of the car up or down. Centrally placed between the clamps is a cylinder with two pistons as shown. In some accessible place, either on top or at the bottom of the car, is a steel bottle or reservoir, designed for a pressure of 500 lbs. pressure. This is connected through a suitable system of piping to the brake cylinder, and an engineer's valve placed beside the operator or, if necessary, forming part of the elevator starting lever. A small gauge just in front of him shows the pressure in the reservoir, so that a positive indication is always given of the working condition of the system.

The brake handle, which is always in the hand of the operator, has two positions, "Slip" and "Fall," which are indicated by stop notches like those of the engineer's brake on a locomotive. The first of these would be used when the elevator speed increased more or less gradually, and the second for a sheer fall.

The safety could be actually and instantly tested once a day or once a week by the elevator operator by one movement of the same lever with which he continually stops or starts the elevator. This practice would make him so familiar with the apparatus that he would not get rattled in case of a fall. Reservoirs could be replenished each night from a small compressor in basement, using a hose to connect with the tank on the car; or new cylinders could be slipped into place when the pressure gauge indicated an insufficient pressure; or a flexible hose could be connected with a compressor in the basement and allowed to trail after the car.

Another plan would be to have a little compressor on the bottom of the car, which would be driven by a small hemp rope, running from top to bottom of the shaft.

Probably the best way would be to have closed bottles with air under high pressure, say 2,000 lbs., which could be placed on the car once a month or two months, or even at longer intervals. A suitable reducing valve would then drop the pressure to 500 lbs. or whatever working pressure was decided upon.

The following abbreviated calculation will show the operation of such a system.

Assume car and passengers to weigh 5,000 lbs.

In case of accident this must be carried on two clamps, or 2,500 lbs. each.

Assume coefficient of sliding friction* to be .04, which is conservative for a speed of 50 miles per hour. ($50 \times 5{,}280 = 214{,}000$ ft. per hour, 3,560 ft. per minute or 59.3 ft. per second.)

Assume brakes applied at the end of a two-second fall, the distance fallen would be

$$s = \tfrac{1}{2}\,gt.^2 = 16.2 \times 2^2 = 64.8$$

Therefore the clamping pressure necessary on each jaw to hold the load imposed by falling at the rate mentioned would be

$$\frac{2{,}500}{.04} = 62{,}500 \text{ lbs.}$$

Allowing a factor of safety of 4 to cover any uncertainty in the character of the friction between the clamps and the guide rail we have

$$4 \times 62.500 = 250{,}000 \text{ lbs.}$$

or the amount each pair of jaws must clamp.

* "Kent," page 928.

Assume the clamp jaws to have a short arm of 2½ ins. and a long arm of 12½ ins. or a ratio of 1 to 5

$$\frac{250,000}{5} = 50,000 \text{ lbs.}$$

or the amount which must be applied at end of the long arm.

Let the wedge angle equal 10° total, or 5° on each side of the axis, then

$$\text{Cos } 10^\circ \times 50,000 = .98481 \times 50,000 = 49,240 \text{ lbs. normal.}$$

$$49,240 \times \sin 10^\circ = 49,240 \times .1736 = 8,547 \text{ lbs.,}$$

which is the thrust the piston must receive to force the wedge between the long arms of the clamp levers.

Assume a working pressure of 100 lbs. per sq. in.

$$\frac{8,547}{100} = 85.47 \text{ square inches.}$$

A circle 10½ ins. in diameter has an area 86.59 sq. ins., so the working cylinder would require a diameter of 10½ ins.

With 500 lbs. working pressure the cylinder diameter would be about 5 7-32 ins.

If we allow ⅛ in. clearance between jaws and ⅛ in. for lost motion there will result ¼ in. movement for the short arms of the clamp.

¼ × 5 = 1¼ ins. for the long arm, or we will assume 1 in. With a wedge ratio of 10 to 1 each piston must move 10 ins., in opposite directions, or a total of 20 ins.

85 sq. ins. × 20 = 1,700 cu. ins. or about 1 cu. ft. per application of the safety.

A tank 9 ins. in diameter and 4 ft. long = 63 × 48 = 3,024 cu. ins. or about 2 cu. ft.

At 500 lbs. this tank would be capable of about 10 actual applications of the safety, something which would require about as many years, if past experience is considered.

With a pump on the car driven by a rope, as described, with a cylinder having an area of 1 sq. in. and a 4 in. stroke making 40 strokes per minute the tank could be filled with air at 100 lbs. pressure in about two hours, or if allowed to run continually the safety could be given a working test twice per day and at the same time always be ready for emergency.

J. J. S.

MACHINE FOR FITTING VEHICLE SPRINGS.

A novel machine for the fitting of vehicle, locomotive and car springs, also other springs of similar construction, has been patented by A. A. Landon, formerly with the Kalamazoo Spring and Axle Co., Kalamazoo, Mich.

This tool is operated by compressed air by means of a hose connection and a 3-way valve, and an ingenious arrangement of rollers connected to the end of piston rod and on frame of machine. In operation, after the two plates have been put together over the "Jack" pin on fitting horse, the machine is engaged by slip ping plates through lower opening of frame and turning to an upright position;

the air being turned on, the upper wheels engage the hot plate on top and lower wheels the under side of cold plate, in practically the same manner as in hand fitting. The crank, or handle, is then revolved, causing the machine to travel over every part of the hot plate, causing the hot plate to take in every sweep and curve of the cold plate in a more perfect manner than can be done by hand. It has the advantage of not necessitating the changing of the spring fitting horse or tempering tub, but is used in connection with same, it being only necessary to bring an air pipe down over the tub. A peculiar feature of the spring business is that it is impossible to make a stock of goods ahead, very nearly all orders differing in some respects.

The advantage of this machine over the old style spring fitting machine is that it needs no adjustment and is always ready to fit an order of any size, it not being necessary to adjust same as with the old style machine, it pinches the two

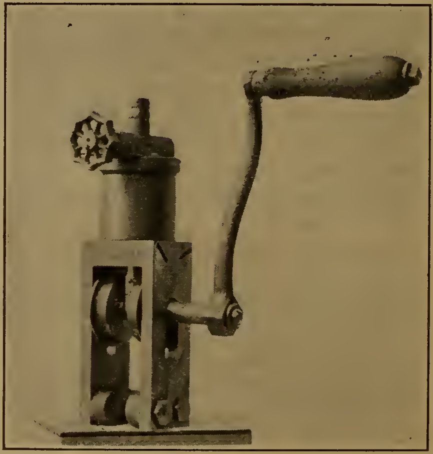

FIG. 466—MACHINE FOR FITTING VEHICLE SPRINGS.

plates together in the same way as hand fitting, and is adapted to any width of a spring. A small order can be fitted in the time necessary to set the old style machine and will give a correspondingly better economy on large orders and when operated in connection with the main plate bent in bankbending machine will make a saving of from 30 to 50 per cent. over hand fitting on vehicle springs and should do better than 50 per cent. on locomotive or other heavy springs. It is operated by unskilled labor and is adapted to either oil or water temper, and is at present in successful operation in one of our largest spring shops.

This machine marks the introduction of compressed air in the spring industry, and we are certain it will lead to the use of compressed air appliances in the more progressive concerns of the country.

Mr. A. A. Landon is at present connected with the American Radiator Co., manager of the Titusville Plant, Titusville, Pa., and will gladly give any further information that may be desired by interested parties.

ORDE'S LIQUID FUEL BURNER.

Mr. Orde, chief engineer to Messrs. Sir W. G. Armstrong, Whitworth & Co., of England, have recently introduced an oil burner which is of such design as to attract attention.

This burner, Fig. 467, together with the apparatus shown in Fig. 468, has, after considerable attention and expense, been brought to a very high degree

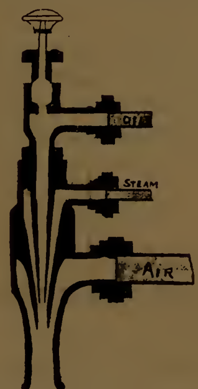

FIG. 467—SECTION OF OIL BURNER.

of perfection, and is now being used on several large steamships. It will be seen from the drawings that the system upon which this apparatus works is that of heating the oil before it reaches the burner. The air which is used is also pre-heated, and is carried into the furnace in such a manner that complete combustion of the fuel results. From experiments recently made, it appears that about 15

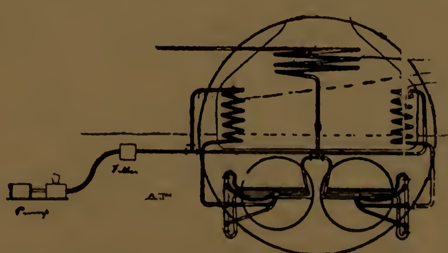

FIG. 468—ARRANGEMENT FOR BURNING OIL FUEL APPLIED TO BOILERS.

lbs. of water were evaporated from and at 212 degrees per lb. of oil consumed, and that about 16 lbs. of air was used per lb. of oil.

The analyses of the combustion gases show that a perfect combustion of the oil took place, there being no traces found of hydrocarbons. A further point is the regulation of the supply of air, which is so perfect that practically no excess of air is admitted into the furnace. The table also indicates that no carbonic oxide escapes into the chimney. In addition to this, a very important point brought out in the analysis is that only 3 per cent. of the steam produced was used for pulverizing purposes, which is a result which may be regarded as ideal. In other methods 12, 15 and even 20 per cent. of the steam produced has been utilized for the purpose of vaporizing the oil, and this has to a great extent prevented the adoption of liquid fuel on steamers.

Various experiments have been made, and, as a rule, unsuccessfully, to substitute air, compressed or otherwise, for steam.

The burner itself is of the simplest construction, and will, therefore, be very easy to manipulate. Although the invention has only recently been completed, it has been introduced in the passenger steamer "Saxonia," a passenger vessel trading between Hamburg and China. The Hamburg-American Line has also placed an order for seven steamers to be fitted with this burner. The steamship "Arista,' belonging to the Raas Company, has also been fitted.

MEGAPHONES IN FOG SIGNALING.

Lighthouse Board Experimenting With New System for Benefit of Mariners.

The Government Lighthouse Board is making experiments with a new system of fog signaling at Falkner's Island, in the Sound, near the Thimble Islands, beyond New Haven, Conn.

The principle of the new invention was tested last year and found correct, and this year the complete apparatus has been put up. It consists of eight megaphones, ten feet long, each directed to a different point of the compass. The small ends of these eight megaphones meet in a ring, inside which is a revolving cowl, which turns on the top of a siren. The siren is kept constantly spinning at the rate of two thousand revolutions a minute, and when compressed air is admitted to it it gives forth a very penetrating and far-reaching sound about C in the middle octave.

Compressed air is supplied to a large reservoir by an oil engine which runs at high speed. From this reservoir the air is taken to the siren through an oddly constructed valve by means of which a current of air at a pressure of two hundred pounds, passing through a two-inch pipe, can be controlled by a touch of the finger. This valve is operated by a series of teeth on a signal wheel, which revolves slowly, producing different signals as each of the different magaphones comes into range of the revolving cowl.

These signals consist of long and short blasts, the long ones being three seconds each and the short ones one second each. The eight points of the compass are distinguished by the difference in these signals. Opposite points have exactly opposite signals, that for north, for instance,. being one long blast and for south one short blast. For east it is one long and one short, and for west one short and one long. For southeast it is one long and two short, and for northwest two short and one long. For southwest it is two short, and for northeast two long.

These signals announce to the mariner the direction from which the sound comes, so that if a vessel was passing Falkner's Island and heard two short blasts it would know that Falkner's Island must be southwest of it. It could not hear any other signal but the one pointed toward it, because the megaphones send the other sounds in a different direction; but if the vessel were to keep on its course until Falkner's bore due west it would then be unable to hear any signal but the short and long blast which signifies west.

These signals were suggested by Col. D. P. Heap, engineer of the Third Lighthouse District, at Tompkinsville. The principle of the invention, which consists in sending sounds in a certain direction to the exclusion of other directions and the apparatus by which the signals are worked are the invention of R. F. Foster, of New York.—*New York Herald.*

THE SARGENT GAS ENGINE OILER.

The proper lubrication of the cylinder and piston of a gas or oil engine in which the average temperature during inflammation is not far from 2,000 deg. Fahrenheit, is one of the essential conditions of successful operation.

In order to obtain the best results, a constant feed commensurate with the piston speed is absolutely necessary, as too much oil will cause smoke and too little a cutting of the cylinder or piston.

Then, with a variable speed, as in automobile engines, the amount of oil should be in proportion to the revolutions and should stop when the engine stops, and to attain such results the feed must depend on some factor of the speed such as the induction strokes of the engine.

Fig. 469 illustrates an oiler which has many excellent features. This oiler was designed especially for lubricating the cylinders of gas or oil engines, vacuum pumps or air compressors in which the pressure during the induction stroke is slightly below atmospheric pressure, which is always true of such machines, for if the pressure within were not less than without, the cylinders would never fill. The essential features are a glass reservoir which is filled through a hole in the top normally covered by the slide A.; B., a needle valve which adjusts the feed into the air-tight bullseye, as shown; and D., a check valve held to its seat by a spring, the compression of which is adjusted by the nut C, which can be turned with a screwdriver.

While this is essentially a cylinder-oiler, by removing all compression from the spring, it may be used in place of the ordinary sight feed oiler on any other part of the engine.

When this oiler is used for admitting oil to the cylinder of a gas engine or air compressor, the check valve spring is so adjusted that the valve seats when the air pressure above and below the check is the same, but if the air pressure below the check valve is rarefied or slightly reduced, the check will open and allow the air in the bullseye enclosure to pass into the cylinder, whereupon the atmospheric pressure on the oil in the reservoir will force it down through the needle valve to the bullseye chamber, from which it will pass into the cylinder every time the check valve opens.

When the engine stops, rarefaction in the cylinder ceases, the check valve remains seated and the oil stops feeding through the needle valve, because oil cannot drop into the bullseye chamber if air and oil are not drawn out.

When compression begins in the cylinder, the check valve shuts and no

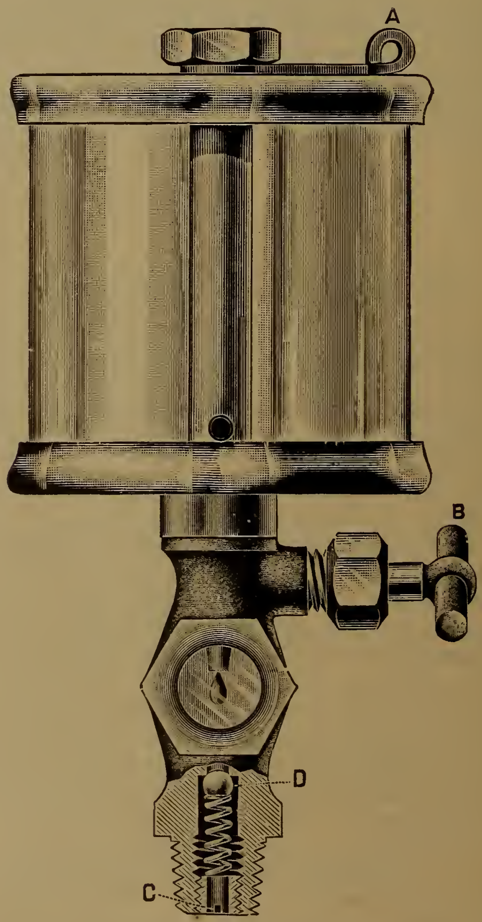

FIG. 469—GAS ENGINE OILER.

smoke or pressure from the explosion passes into the bullseye chamber or reservoir.

The reservoir can be filled while the engine is stopped or running without opening or closing a valve or changing the adjustment of feed.

The quantity of oil is always in sight; the amount feeding can always be seen; the oiler stops with the engine and begins when the engine is started again, and as no pressure accumulates in the glass reservoir, there is no danger of the oil cup exploding.

This oiler is the invention of Mr. C. E. Sargent, and is manufactured in several sizes by the Michigan Lubricator Co., 266 Beaubien Street, Detroit, Michigan.

AIR SURFACE CONDENSER.

A very interesting pamphlet has recently been issued by Mr. Fred Fouche, of Paris, who exhibited an apparatus showing a new method of condensation

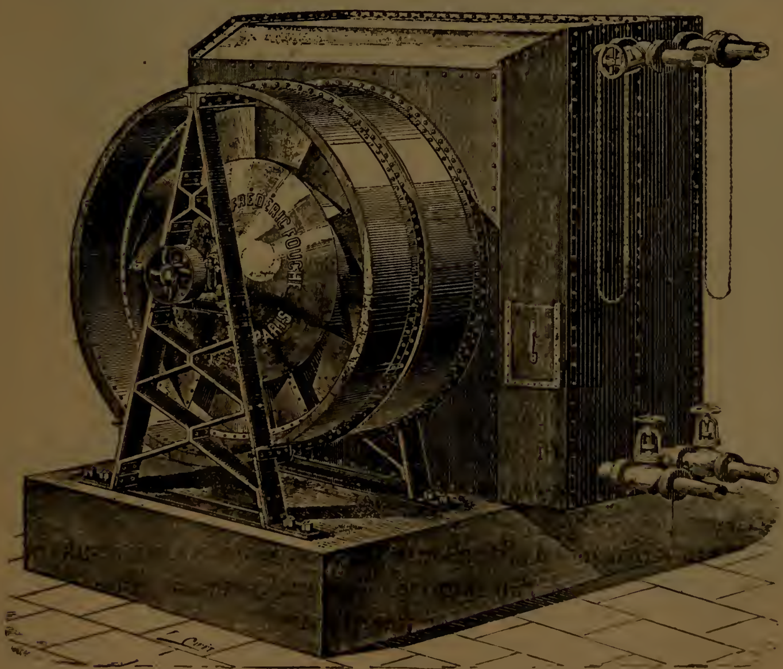

FIG. 470—AIR SURFACE CONDENSER.

for creating a vacuum in the exhaust of steam engines, the condensation being practically on the same principles as is now, and has been, effected in surface condensers, with the exception that instead of using cold water for condensation purposes cold air takes the place of same.

Mr. Fouche had one of these installations at constant work at the Paris Exposition, and claims that his apparatus would be of great value if adopted in places where fuel is expensive, where water for condensation cannot be obtained, or in case condensation water would contain lime or other foreign material which would be detrimental to the effectiveness of a surface condenser.

The apparatus which Mr. Fouche is placing on the market consists of a surface condenser consisting of narrow exhaust steam spaces between corrugated iron or steel plates, having a great condensation surface, instead of tubes, as generally used in surface condensers. He claims that by adapting this method he can obtain a greater condensing surface with a lighter weight and lesser cost.

In addition to the above apparatus, a motor, or engine, and a fan are required to transmit a current of cold air between the different sections of corrugated plates containing the exhaust steam of the engine, or engines, this current of air to be sufficient for condensing the exhaust steam from the main engine.

From tests made by the inventor, he does not claim to obtain as high an efficiency as that of surface or jet condensers, but he claims to come to within 3 to 5 per cent. of the actual efficiency now obtained by the above, and maintains that such a new departure in the line of condensers for stationary engines or locomotives should be seriously looked into by investors, who desire economy and dividends accruing therefrom.

It is a well-known fact that a locomotive consumes from 5 to 7½ lbs. of combustible per horse power per hour, and if a condenser could be adapted to same and create a vacuum of only 20 inches per sq. in., a benefit of saving in fuel and water consumption, varying from 15 to 25 per cent., would be effected.

Taking the above data into consideration, Mr. Fouche makes the statement that the weight of an air surface condenser, with its fan and engine, will equal about the weight of water and coal saved in a two hours' run of an ordinary passenger train running at a speed of 40 miles an hour, and, in addition to that, make a saving of an average of 20 per cent. of the amount of coal used for the engine.

Taking as a basis that a locomotive develops on an average only 500 H. P., which is low, as the Empire Express develops at times as much as 1,400 H. P., and rating the coal consumption at six pounds per horse power per hour, we figure that a saving of 600 pounds of coal per hour could be effected, not counting the saving in water consumption.

The reader will understand, of course, that for adaptation on railroads, the condensing apparatus would have to be placed on a special auxiliary tender.

This matter, we think, should be of interest to any railroad company, as the question of fuel is so important at the present time that it cannot be overlooked.

The inventor, in his pamphlet, omits to mention the weight of the condenser to suit a certain horse power, nor does he give the number of sq. ft. of cooling surface he would suggest per pound of exhaust steam at atmospheric pressure.

Should any reader be interested in the subject, we will be pleased to obtain any information we can in the matter.

SHEEP SHEARING IN AUSTRALIA.

Many attempts to perfect a mechanical device which would lighten the work for the shearer, prevent the wool from being injured by second cuts and

FIG. 471—SHEARING SHEEP BY COMPRESSED AIR.

guarantee the neat fleece to be even in length, or "wool topped" have in the past twenty years been made.

A machine such as we illustrate was invented, and is simple and easy to handle. The simplicity of the construction dispenses with the necessity of skilled labor in setting up, adjusting or running the machine.

The use of this machine reduces the time of shearing from an average of 70 sheep by hand to about 100 per day of ten hours, or in other words one machine can accomplish in one day as much work as it formerly required three men to turn out.

Another point in favor of this invention is that by its use the animals are never mutilated, and the wool brings a better price in the market, on account of the length of its fibres.

In Australia, the foremost country for sheep raising in the World, this machine has been introduced and is being used on a large scale with most satisfactory results.

COMPRESSED AIR DRY DOCK.

We illustrate herewith a dry dock, the invention of August Geiger, engineer, of Portland, Oregon, operated by compressed air. The dry dock is of the floating type, but unlike ordinary floating dry docks, it *has no bottom,* so that the water can flow in and out with perfect freedom. This dry dock has no pump-

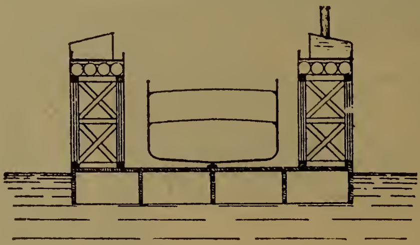

FIG. 472—DRY DOCK.

ing machinery; in its place an air compressor is used. The compressor is located upon an elevated platform, running parallel with the long sides of the dock, and is connected by pipes to the different water-tight compartments into which the dry dock is divided.

In order to lower the dock, valves near the compressor are opened, air rushes out, and water flows in from underneath, causing the dock to sink. When the dock is to be raised, the compressor is started up, air is forced into the compartments, the water is driven out and the dock rises to the surface.

Suppose a vessel of 25 ft. draught (about the greatest draught steamers have) was to be docked. It would be necessary to sink the dock about 28 ft., and in order to raise it, air pressure of about 14 pounds to the square inch would be required. The higher the dock is raised, the less pressure is needed.

Assuming a dock of 300 ft. length, 80 ft. width and 7 ft. depth, we have a large box of 300 x 80 x 7 ft., = 168,000 c. ft. This amount of compressed air is necessary when the dock is out of the water, but as the water displaced has only 7 ft. depth, = 84 in., the pressure required is only 84 in. ÷ 28 = 3 lbs. per square inch. As the lifting capacity of a dock is equal to the weight of displaced water, it would be in this case, if in a river, 168,000 c. ft. x 62 lbs., = 10,416,000 lbs., = 5,208 tons, less the weight of the dock itself.

One great advantage of such a dock would be the bottomless construction which in a dry dock of 300 x 80 ft. means a saving of 24,000 sq. ft. of water-tight flooring and caulking, which is quite an item; and with this system, a cheaper dock can be built than with the old-style pumping machinery.

Another point in favor of this style of dry dock is, that the lifting power acts under the upper side of the big box, which makes it steadier and less liable to topple over than with the ordinary dry dock, where the lifting power acts under the under side of the big box.

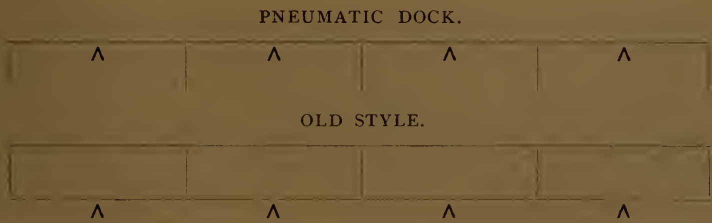

FIG. 473—OLD AND NEW METHOD OF APPLYING LIFTING POWER.

Mr. Geiger thinks that compressed air could be more quickly furnished to raise the docks than it would be possible to pump water out by the old system. The pipe connection would be smaller, and in general less machinery would be required.

NEW CANAL LOCKS.

A pneumatic canal lock, designed for use in the Erie Canal at Lockport, N. Y., is attracting attention of canal builders and engineers. By its introduction the greatest simplicity will be obtained and many of the difficulties experienced in operating locks will be obviated. It is estimated that one pneumatic lock will take the place of the sixteen locks now used at Cohoes.

The principle upon which the Dutton Lock works is described in the New York *Sun* in this way:

"If you were to take two tumblers and fasten them together, bottom to bottom, you would have the equivalent of one section of the new lock. Partly fill the upper tumbler with water and put them both in a tank of water, with the open mouth of the lower tumbler downward. With a straw blow the air into the lower tumbler until it rises almost clear of the water. Now take another pair of tumblers and arrange them in the same way beside the others. Put a U-shaped tube under the two tumblers, connecting the air spaces of each. Balanced upon the compressed air, both sets of tumblers would rise or fall in unison. If you depress one, the other will rise."

The inventor, Mr. Dutton, has developed a wide range of ingenuity in the devices used in the construction of the new lock. When it was first proposed to use air to operate the lock, the size of the pipes and the valves which would be required were looked upon as a settling argument against the method. Nobody thought of making a valve to fit a ten-foot pipe. Mr. Dutton got around the trouble by using for a water seal a U-shaped pipe such as is used for cutting off sewer gas in house plumbing. A 4-inch water cock controls this, and enables a 10-foot pipe to be opened or closed to the air almost as quickly as if a big metal valve were used.

AIR AS A LUBRICANT.

Ordinary air is now being used with good results for illustrating the action of a lubricant in a journal bearing in a machine designed by A. Kingsbury. The machine consists of a steel piston or short shaft to be rotated and a cast-iron ring or cylinder which acts as a bearing for the shaft, the whole being supported on rollers mounted on a suitable frame. The shaft weighs 50½ pounds, is 6¼ inches long and 6 inches in diameter, and its weight constitutes the total downward pressure on the bearing. The diameter of the cylinder is slightly less than 1-2000 of an inch larger than the shaft—a fairly loose fit. Both cylinder and shaft are ground exactly parallel.

The cylinder is set horizontally, the shaft inserted (both being perfectly clean and dry) and rotated with the band by the handle at the end. It can be turned with difficulty at first, and the harsh, grating sound of metal rubbing on metal will be heard. With an increase of speed, however, this grating ceases, and the force required to turn the shaft is materially decreased until, after a few revolutions, the shaft becomes entirely free from the cylinder and rotates on the film of air between. Set rotating at, say 500 revolutions per minute, it will continue to rotate four or five minutes. If allowed to run, the speed gradually decreases from the start until suddenly the piston breaks through the intervening layer of air, and a few more revolutions suffice to bring it to a sudden stop.

If a more conclusive proof is required that the shaft is entirely separated from the cylinder, an electric bell may be included in a circuit of which the shaft is made one terminal and the cylinder the other, when it will be found that the bell is silent as long as the shaft rotates at any considerable speed.

AN ACCOUNT OF THE ATTEMPTS TO INTRODUCE COMPRESSED AIR FOR STEERING VESSELS.

The first application of compressed air for steering vessels was made about fifteen years ago; by permission of the Government, on the U. S. Steamship "Tallapoosa," an old vessel which was sent to the South American coast. As a system it proved satisfactory, according to the reports officially made to the Bureau of Navigation, but some mechanical defects were needed to be remedied which could not be done at that distance. The vessel was afterwards condemned and sold. The principle of compressed air for steering was fully endorsed, and the cost of the test was allowed to the interested parties. The next application was made on the old Dominion S. S. "Seneca," and the reports of its captain were very satisfactory. I quote from the reports of Capt. Geo. M. Walker, 1887:

"After using it for six months during which time it cost nothing for repairs, giving the most complete and perfect confidence in controlling the ship in storm and fogs, dark nights and through fleets of vessels. It must when properly known come into general use." It was used for two years with gratifying results. The gear on the S. S. "Seneca" afterwards became the property of the Pneumatic Steering Gear and Mfg. Co., of New York, who obtained control of the patents.

While trying to improve some mechanical defects, it was ordered off the vessel as it was ascertained by the influence of a steam steering company who afterwards put their own steering gear on board.

The reports to the Government made in 1887 recommended the system to the favorable consideration of the Navy Department, by the members of the Pneumatic Gun Carriage Co., of Washington, D. C. In the meanwhile the Pneumatic Steering Gear Co. allowed experiments to be made, mechanically different, for the Staten Island Ferry Boat, which proved to be worthless. After spending considerable money on the experiment, that gear with the one taken from the "Seneca" was sent to the Morgan Iron Works of New York for the purpose of being made mechanically useful, and as far as possible perfect, but owing to lack of means at the time to carry out their purpose, the Company have virtually done nothing since. Later permission was given to the Pneumatic Gun Carriage Co., of Washington, D. C., to use their devices, the company having made a contract with the Government for the entire system, on the U S. monitor "Terror." Both companies are now waiting for a full endorsement of the system with order for other vessels, for which recommendations have been made and resolutions offered in Congress.

The benefits of the system are: A firmer and greater impression on the valves forming a cushion to the rudder head. It also ventilates the entire ship. It is noiseless and does away with odors and hot steam pipes, and the danger from their bursting. There is no possibility of freezing from condensation, and the exhaust reduces the temperature. Engineer T. W. Kinkaid, of the U. S. Navy, in an article in the Journal of the American Society of Naval Engineers (Vol. IV., No. 1), says: The pneumatic system is simple and powerful and possesses advantages over the hydraulic and electric systems. There is no burning out of fuses, as with electricity, and no danger from burns or electric shocks, nor from drenching, as with the hydraulic system. There is no increase of temperature, and the exhaust improves the ventilation, all of which things are advantages over steam and hydraulic and electric systems.

On the trial trip of the monitor "Terror," the rudder was turned from hard-a-port to hard-a-starboard in six (6) seconds 68 degrees. The area of the rudder is eighty-two sq. feet, the pressure of 125 lbs. per sq. inch is maintained by one air compressor. A pressure was maintained not below 30 lbs. and not above 60 lbs. for steering.

Air leakage has been entirely overcome by a process which has been tried successfully by the Cramps, of Philadelphia, Pa.

The final report further says that the system is quick and accurate, and the engine does not get out of order, and the engine room is free from noise, dust, heat, moisture and shock.

The system has been endorsed by Commodore G. W. Melville, Engineer-in-Chief, U. S. N. The Naval Board endorses it as being superior to all others, using the word excellent. Rear-Admiral Mathews endorses it, and Chief Constructor Hickborn reiterates all that has been said and recommends it.

Interested parties, with the experience of the past few years, are preparing for further superiority in the use of compressed air for steering vessels in the formation of a new company, controlling all improvements for the purpose.

The system is attracting much attention in England.

Jos. C. Walcott, President,
Pneumatic Steering Gear and Mfg. Co.

Editor Compressed Air:

A copy of your monthly publication has been given me lately; being interested in pneumatic appliances, but more especially in its use for steering vessels. It has been tried and approved of for ten years past, but has not come into universal recognition for this purpose yet. While formerly tried on a U. S. vessel and a coast steamer with success, its last application is in the U. S. monitor Terror, which did some good work during the late war, and proved effective, with many other uses to which it was put on board, but more especially in its use for steering. The slow progress in its adoption has come from other systems more strongly backed, and owing to too much red tape at Washington. Senator Chandler, on Dec. 6th, 1898, brought the subject forward in a resolution, asking why the pneumatic system is so overlooked, when it has proved so effective. It is gaining ground every day for everything, here and abroad.

The *Scientific American* of March 20th, 1897, and March 7th, 1898, has an article on the pneumatic system on the U. S. monitor Terror, with illustrations. To corroborate what I write, I can refer you to many reports of the Navy Department and others, endorsing the system for the Navy.

The elevated road has talked of using compressed air, but there is a pressure to have electricity adopted.

I have been much interested in Mr. R. P. Whitelaw's article you publish.

Joseph C. Walcott.

Stamford, Conn., Feb. 20th, 1899.

CLEANING CAR CUSHIONS BY COMPRESSED AIR.

The illustration on page 1109, Fig. 474, represents another useful application of compressed air. The picture was taken at the Pullman platform in the N. J. Central yards in Jersey City, N. J. Cushions, carpets, bedding, curtains and rugs are taken from the cars and arranged conveniently on a platform, the operator takes the hose with its spray nozzle and holds it directly over the article to be cleaned, air is turned on and the accumulations of dust of one trip is in-

FIG. 474—CLEANING CAR SEATS WITH AIR.

stantly dissipated. It takes less than a minute to thoroughly cleanse a car cushion. Besides removing the dirt, the upholstery is purified by the vigorous airing it has received. The hose is taken inside the car and the stationary upholstery and hangings are renovated.

Few dwellings receive the refreshing application of air that these cars receive. In no other way can healthfulness and purity of atmosphere be assured in railway carriages. Its use should be extended to every railroad.

CARS DUMPED BY AIR.

The Thacher Compressed Air Dumping Car is being placed on the market by the Thacher Car and Construction Co., New York. It is claimed that with this car much time is saved, and that loads can be discharged by trainmen of the construction train, the engineer operating it from the engine, and the ordinary air pump supplying the air.

The mode of operation of the dumping device is as follows:

The body of the car being pivoted centrally will dump to either side, or to one side only, according to its construction.

This is done by means of a cylinder mounted on the truck frame, the piston of which is coupled directly to the car body; another smaller cylinder called the "latch cylinder," fitted with piston rod and slide valve, positively and automatically operates the latches which lock the car body in its horizontal or normal position, and also regulates the distribution of the air to the large or dumping cylinder as required, moving its piston up and down, thus dumping the body and returning it again to its horizontal position.

An independent reservoir which each car carries contains an ample supply of air for the purpose of supplying the movements of the dumping cylinder, and is filled and kept at the necessary pressure by the engineer at any convenient

FIG. 475—PNEUMATIC DUMPING CARS.

time, a check valve preventing its escape until needed. This reservoir is filled by the regular train pipe, which is also utilized as the air brake pipe and does not interfere with the latter's action.

A LOCOMOTIVE FIRE KINDLER.

The Ferguson locomotive fire kindler, which is being introduced to the market by Leach & Simpson, Old Colony Building, Chicago, and which is illustrated herewith, consists essentially of a tank to contain oil, a hose coupling for connection with the compressed air system or with the main reservoir of the engine, a hose terminating in a nozzle for spraying the mingled oil and air and a valve for controlling the relative proportions of oil and air. The tank is most conveniently mounted on a truck, by which it may be easily removed from one part of the roundhouse to another.

The valve is the principal feature of novelty. Turning the cock regulates the proportions of air and oil admitted into the tube. Turned one way, air alone passes through and oil adhering to the inside of the hose is removed.

The tank holds twenty-five gallons. This is sufficient to kindle fires in forty engines, on an average. The time required is about forty-five minutes with a cold engine and perhaps twenty-five minutes when the engine is still warm—more or less, according to the temperature. This means getting up sufficient heat to remove the engine under its own steam.

The portability of this kindler and the intense heat generated by its flame make it very convenient to operate. When the connections are made a handful of oily waste is lighted and thrown into the ashpan to start the flame. The nozzle, which is at the end of a long tube, is thrust into the ashpan and the flame passes up through the fuel until the latter is wholly ignited. The fire door, being kept closed, prevents the admission of cold air and causes the draft to pass up through the fuel. This is claimed to be a decided improvement over the old method of blowing through the fire door with the jet of flame striking the firebox sheets. By the use of this burner it is said that less injury is done to the inner sheets than is done by a wood fire for kindling.

The same apparatus is also used as a blow pipe for heating tires, straightening frames, or any other bent work that may require removal and which ordinarily has to be sent to the smith shop to be straightened up. For such purposes the heat may be applied to the exact points required without affecting adjacent parts

An important point claimed for the Ferguson locomotive fire kindler is the fact that its use does not require the presence of a compressed air plant. If engineers are instructed to leave their engines with a supply of air in the main reservoir, the kindler may be attached directly to it, and the fire rekindled by the use of air from this source alone. The apparatus may therefore be used at the most unimportant roundhouse with the same satisfactory results as at the plant which possesses the most complete air equipment.

TOOLS FOR STONE WORKING.

The pneumatic tool used in stone cutting is one of great importance, and is likely to take precedence of every other device in shaping natural stone into whatever forms the architect or designer may specify. The skilled operator of this tool will do more work in a given time than ten ordinary cutters could in the old way. Its general use will bring about a larger demand for ornamental stone work in building and more monuments of better grade will be erected. The increased consumption will compensate for the reduction of the force of stone cutters, inasmuch as the output will need to be greater and the manufacture of the tools will employ large numbers of men. Such labor saving devices are not always the means of robbing the mechanic or artisan of employment, but rather broadens the field and increases their usefulness. The natural result is then that a less number of men are not employed, but simply the transposition of talents from one activity to another, and mankind in general is the beneficiary.

Compressed air is the power utilized to operate this tool, and in skilled hands it marks out lines of beauty and symmetrical figures equal in finish to the clear cut work of the master in the art of chiselry.

With it the noblest conceptions of the sculptor are quickly wrought into enduring form.

Where power is available the cost of plants may easily be borne by even smaller yard owners.

STONE-CUTTING BY AIR TOOLS.

Perhaps the most marked improvement in the stonecutter's art since the stone age has been the introduction of the use of compressed air. For centuries the hard, unyielding stone had been fashioned into shape by the ceaseless efforts of the hammer and chisel; and while other trades adopted newer and cheaper methods of manufacture in rapid succession, no means could be devised to hasten the tedious processes of stonecutting.

The arm of the carver could only deliver a comparatively small number of blows per minute, but by the use of pneumatic carving tools this number was multiplied to such an extent that the blows following each other in rapid succession are in effect one continuous blow.

As the cutting power is always ready, the carver had merely to guide the machine and chisel. He can thus give his whole attention to his work, and the result is shown in the increased amount of work accomplished, and the work is done much better.

These tools were crude at first, being complicated and liable to injury, and the continual breakdowns were a constant source of annoyance. They have been greatly improved and simplified until the latest and best types are but very simple in their make up, i. e., the cylinder or case, and plug for same, and the hammer or piston that delivers approximately 20,000 blows per minute on the chisel. The first tools introduced were operated at 15 to 20 pounds air pressure, as a higher pressure caused them to vibrate or "kick" to such an extent that the operator could not hold them. Now, however, 80 pounds pressure is easily handled, as the disagreeable "kick" has been overcome by the introduction of an air cushion which stops the hammer from striking the cylinder head on the up stroke. The machines do not run continuously as formerly, and now only use air while actually employed in cutting, and automatically stop the instant the chisel is removed from the stone. Soon after hand tools became widely used, a need was felt for a machine to surface granite, and a large and powerful pneumatic tool mounted on a radial arm, which is in turn supported on a vertical column or post, met the needs of the cutter. These powerful machines eat away granite at an astonishing rate, and have no difficulty in surfacing 60 or more square feet per day.

With the introduction of compressed air into the stone-cutting establishment, other uses were soon found for such a tractable servant, and now compressed air operates the overhead traveling cranes and hoists, pumps, sand and water for gang saws, blows the blacksmith's fires, and operates the quarryman's rock drills, gadders, channelers, etc.

No doubt in the future still other uses will be found for compressed air, and any one putting in an air plant would be wise in making ample provision for future needs.

GRANITE SURFACING MACHINE.

Fig. 476 shows a granite surfacer which is being adopted in quarries and by bridge builders and for general construction where compressed air is used.

FIG. 476—GRANITE SURFACING MACHINE.

It will be seen that an ordinary 2¾" rock drill is mounted on a swinging frame. It is operated by one man, who begins his work on the undressed block of granite at the highest parts of the uneven surface. The stroke is regulated by the feed screw as in ordinary drilling, and as the surfacer is being swung around over its work it may be regulated by the throttle so as to avoid striking low places, thus evening up the surface as desired. The machine shown is now used by the Pochuck Granite Co., B. J. Mallon, superintendent, Goshen, N. Y., and has made an excellent record. One machine will surface as much as ten men. A test showed that in 25 minutes it would do as much surfacing as a good stonecutter could do in ten hours.

The exhaust air can be used for keeping the dust away from the work, and this makes it much pleasanter for the operator.

CARVING AND DRESSING STONE.

Fig. 477, given below, is an excellent picture of the interior of a stone manufacturing plant that is operated by compressed air. The view was taken in the shop of L. L. Manning & Son, of Plainfield, N. J., and it illustrates what is being done in this important line by pneumatic tools and other improved apparatus. For

FIG. 477—AIR POWER IN GRANITE CARVING.

dressing and carving granite, marble or other material used as monuments and grave decorations, there is nothing so effective for the purpose, and experience proves that it reduces the cost of producing handsome designs so that the purchase of suitable gravestones is within the reach of all.

The plant of Manning & Son consist of one vertical boiler and Baxter engine, a 6-in. x 6-in. Class "E" Ingersoll-Sergeant Compressor, one polishing machine, and a set of pneumatic tools of the Keller pattern. The whole outfit was supplied by the C. H. Haeseler Co., of Philadelphia, Pa. The arrangement of the plant was planned by the owners, and for economy of space, convenience, and in general appearance, it appears to be admirable.

The compressor is run by belt. It takes 60 pounds of steam to run the entire plant, and about 40 pounds of air pressure to run the pneumatic tools on heavy work.

With the polishing machine, a piece of granite, 6 ft. x 6 ft., can be dressed and polished in two and one-half days. By hand it is said that it would take at least one month to do it.

One pneumatic tool in the hands of a competent operator will do as much as three men, and do it much better. It can trace and cut letters, and do all sorts of fancy work. A stone-worker having such a plant as the one described has every chance of success, and can certainly distance competitors in time and cost.

EXPERIENCES WITH COMPRESSED AIR IN SHIPBUILDING AND SHIP-YARD WORK.*

Of late years great advances have been made in the use of compressed air as a motive power for small tools, and it is already considered on an equality, and for many operations, superior to steam, electricity or hydraulic power.

Practically all the large railroad and ship-building plants in the country have adopted this form of power in a greater or less degree. It is possible to convey it from point to point with great facility and practically no drop in the pressure, though the pipes may be very long. For example, at the Jeddo Tunnel, in Pennsylvania, air at 60 lbs. pressure was carried 10,860 feet, and the gauges at both ends of the pipe showed no difference in pressure. There are many other instances of this kind, where it would be practically impossible to convey steam, and consequently a small boiler with fireman would be necessary at the scene of operations. Other advantages are that it lends itself for use in all kinds of holes and corners. There is very little, if any danger from frost, if the pipes are properly laid, protected and drained. There is no chance of short circuits or unforeseen shocks; no solenoids or delicate armatures to get out of order and no heavy mass of iron and copper to transport in the shape of an electric motor, for the purpose for instance, of drilling a ¾-in. hole. There are no leaky joints as in hydraulic motors, and no trouble from condensation and lack of positive movement as in steam.

Its economy is equal, if not superior, to any of the existing prime movers, if used with judgment and due regard for its capabilities and for the right tools; that is, for those various small tools that are located at a considerable distance from the source of power, operating in many different places in a short interval of time.

It is the general opinion that air, water and steam are pre-eminently suited for pressure operations or where blows are to be delivered, and electricity for rotary motion. Experience, however, has taught that for hand tools, both rotary

* Marine Engineering.

and reciprocating, the air engine has most advantages in establishments where light and easily handled tools are a necessity.

The fact that an ordinary mechanic can repair and adjust air motors, while it requires an expert electrician to repair an electric motor, would seem to make it preferable to use the former method, as ordinary mechanics are more numerous in a shipyard than expert electricians.

Compressed air should be used and not abused. Small leaks are very prevalent in the piping, valves and loose couplings, and worn out motors often consume an excessive quantity of air. These are very small matters in themselves, but taken collectively in a large plant, have a very depressing effect upon the coal pile and an elevating one on the expense account. Treat the air plant with

FIG. 478—PNEUMATIC DRILL, IN SHIP-YARD WORK.

the same care that is manifested in the insulation of electric wires or lagging of steam pipes and there will be less grumbling heard concerning the wastefulness of the system. A committee of the Master Mechanics of the principal railroads of this country reported at the last meeting, 1897, that the use of compressed air, with suitable apparatus, gave an average economy of from 25 to 50 per cent. over the ordinary former practice, in their shops, on the following work:

Tapping out stay bolt holes, reaming and drilling holes, chipping and caulking, removing tires, beading flues, air hoists, vertical and horizontal car jacks, tinware presses, shears erected outside shop for shearing off test coupons, tank riveters, shears at scrap pile, shears for light sheet iron work, small Pelton wheels for operating emery wheels, blast for blacksmith forges, applied to mixing paint in large quantities by putting a pipe in bottom of mixing barrel, used in all kinds of motors for boring cylinders and facing valves, cleaning cushions inside and out of cars, blowing out cylinders before inserting packing, rolling flues, swedging flues, testing brakes and numberless other minor purposes.

The following particulars were given of a shop turning out sixty engines per year, viz: One compressor with 15-in. steam, 14-in. air cylinders and 18-in. common stroke, five elevators, one hoist for driving wheel lathe, six hoists for lathes and planers, two Brotherhood engines, three motors, one sand elevator, one fire kindler and one flue cleaner. The cost of this compressor, including foundations and pipe connections, was $1,260.50. Pipe lines, hose, valves, reservoirs, motors, hoists, elevators, cost $1,189.50. A total of $2,450.

On a test run of eight hours it required 313 lbs. of coal per hour or 2,508 lbs. for the run. Pressure was raised from zero to 120 lbs. in 5 minutes, 40

FIG. 479—PNEUMATIC PORTABLE RIVETER, IN SHIP-YARD WORK.

seconds. The compressor made 858 revolutions and compressed 2,681.6 cu. ft. of free air to 193.9 cu. ft. of air at 120 lbs. It required with this compressor 20.4 lbs. coal to compress 1,000 cu. ft. of free air to 120 lbs., equaling 60 per cent. of its theoretical capacity. The packing of this engine had not been overhauled for eighteen months, thus accounting for some of the deficiency.

It is during the building of a ship that the advantage of these power tools are best exemplified. A hull is full of odd corners and nearly inaccessible nooks that must be as well riveted and caulked as the most accessible part of the vessel; perhaps better as it is more difficult to overhaul and examine these places.

It is not so long ago that the best yards in the country depended upon the racket drill and hand riveting, the work having to be done in such inconvenient places and uncomfortable attitudes upon the part of the workmen as to preclude the possibility of a first-class job. Now from the driving of the first rivet in the keel to the launch of the vessel the continuous clatter of air riveters, caulking tools and the whirring of rotary drills are sure indications of rapid progress toward completion.

Probably one of the largest and best equipped air plants for the use of small tools is located at the works of the Newport News Shipbuilding and Dry Dock Co. Comparatively new, this air plant now furnishes the power for the majority of the tools used on the outside work of the various naval and merchant vessels building there, to the exclusion, almost, of steam and electricity.

The original plant consisted of a small Rand compressor and a few tools; then a couple of Pedrick and Ayer compressors and more tools were added. Now,

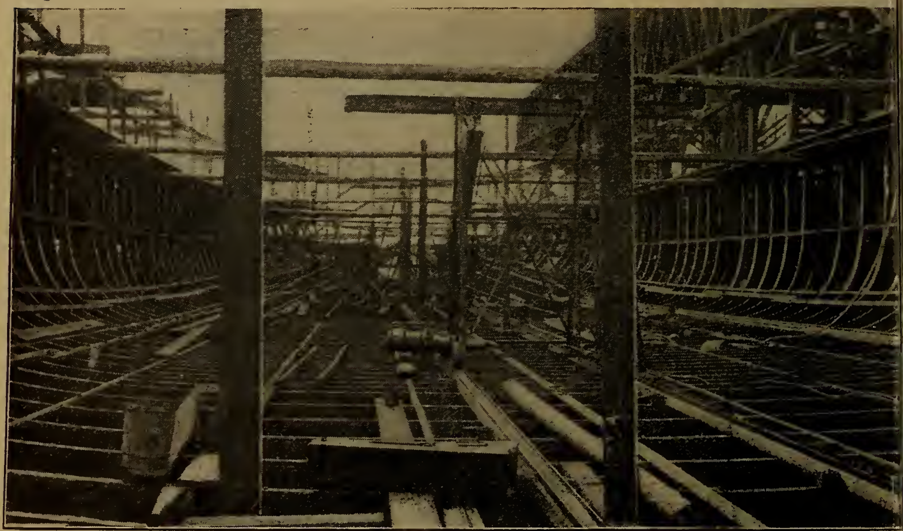

FIG. 480—PORTABLE RIVETER IN OPERATION.

hardly more than three years since the starting of the initial plant, there are in operation two large Ingersoll-Sergeant compressors, viz:

One class G, duplex compound compressor with 20-in. steam cylinders, 20¼-in. high pressure air cylinder and 32¼-in. low pressure air cylinder and 24-in. common stroke. This engine has a receiver inter-cooler 36-in. diameter by 9 ft. 6 in. long, and discharges 2,200 cubic feet free air per minute at 100 lbs. pressure.

One class G, duplex compressor, with 20-in. diameter steam and 20¼-in. diameter air cylinders and 24-in. common stroke, with a capacity of 1,600 cu. ft. of free air per minute and 100 lbs. pressure at discharge.

These compressors are all made with the piston inlet air cylinders, are water jacketed and are furnished with a governor automatic pressure regulator. The compressed air is discharged into a storage tank common to all at about 90 lbs. pressure.

The storage tanks are a necessity and should be of such size as to enable the engines, after once filling them, to run at a moderate speed during working hours.

The tanks are usually provided with pop safety valves, ample drainage, and from the first tank a small pipe is led back to the automatic regulator on the engine. From this main tank the air is carried by mains to smaller storage tanks located at different points in the yard, nearest the centres of work.

By constructing the storage tanks with a baffle plate down the center, the air entering at the top impinges upon the plate, delivering the entrained water

FIG. 481—CHIPPING, CAULKING AND RIVETING WITH PNEUMATIC TOOLS.

into the bottom of the tank, from whence it is drained at intervals. The air then passes under the baffle plate and out again at the top of the tank. The air pipes should always enter and leave the storage tanks at the top.

The yard is piped throughout. The main air pipe is about 1,500 feet long, of cast iron, with leaded joints, 8 in. inside diameter and reduced at intervals to 6-in. and then to 5-in. At the end it enters a reheater similar to a surface condenser about 27-in. diameter and 6 feet long, with wrought iron tubes 1¼-in diameter, and is there heated by the exhaust steam, from one of the shop engines. This reheated air is employed to run a regular type Atlas horizontal steam engine keel to the launch of the vessel the continuous clatter of air riveters, caulking tools and the whirring of rotary drills are sure indications of rapid progress toward completion.

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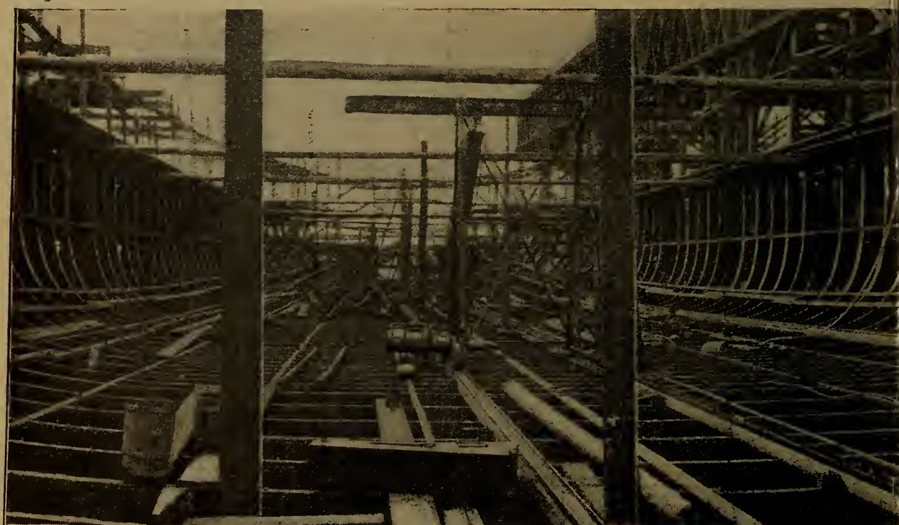

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At any point in this system the pressure gauge will register the same as at the main tank, and even under the most unfavorable circumstances, there is but little appreciable drop. There are four other mains leading from the storage tank, two 4-in., one 3-in. and one 2½-in., all wrought iron pipe with screwed joints. All pipes used in connection with this plant are buried in trenches below the frost line.

The 2½-in. main has supplied power sufficient for twenty-eight No. 2 Boyer hammers and four drills, but this was the full working limit of the pipe; about two-thirds this number would be a preferable load. The hammer supply nozzle is ¼-in. and the drills ⅜-in. pipe taps. The yard has used nearly every type of pneumatic machine that is manufactured and even now have many different types in use.

Some of the different operations performed by the tools are shown in the pictures given herewith. In everyday use many of the tools work more satisfactorily than others, in the matters of economy, in the use of air, freedom from breakdown and the not least important absence of vibration. Indeed, some tools which work satisfactorily in the first two named respects, are very severe on the workmen. They are all liable to break in one part or another, but the manufacturers are constantly improving and strengthening the weak parts as they are taught by experience.

The pneumatic riveters are a little larger than the hammers or caulkers, with a head that fits the head of the rivet. The work of driving the rivet is done by a large number of comparatively light blows instead of a single squeeze as in a hydraulic machine. This permits of the use of a very light frame for holding the riveter. The latest type is that patented by the Detroit Dry Dock Company, and is made of 2½-in. W. I gas pipe, bent to a U shape, with a gap of about 60 in. This frame enables the workman to reach rivets that are absolutely unapproachable otherwise than by hand riveting. Nearly all makes of pneumatic drills are practical; some are more powerful than others for the same weight. Their great difference is in their economy. All are extremely liable to breakage in some minor points, and a small repair shop is a necessity where many pneumatic tools are used. The drills are made in three types, the movable cylinder, the movable piston and the rotary, similar to the rotary pump; these last are great consumers of air and are not to be recommended where economy is a feature. The movable cylinder type, at the present date, seems to be the most economical and is at the repair shop the least often, considering the amount of work done by it.

It is necessary that care be taken to keep these machines clean, well oiled and in good working order. Proper lubrication is an essential requirement, both as to quality of oil and frequency in applying it. The best winter strained lard oil or valvoline sewing machine oil are recommended. Should it become necessary to clean the machine, admit kerosene and turn slowly while the grease is dissolving and when all is dissolved admit air through the throttle. Thoroughly lubricate again before using.

As these machines are made interchangeable, the parts most liable to break should be duplicated in store. These cost but little and afford a most excellent insurance against stoppage from breakdowns.

For work in the frame sheds, on bulkheads and reverse frames the Caskey or single squeeze pneumatic riveter is used. This is a very good and efficient tool; it is usually slung from a jib crane with a long jib, by a chain twist, and thus commands a large area.

The larger illustration on page 1118 shows this riveter at work on the double bottom of a battle ship. A track was laid down the center of the inner bottom. This was for the crane carriage. The riveter, as shown, is held by a pneumatic hoist. This was found to be a poor arrangement, as the elasticity of the air in the pneumatic hoist prevented a rapid setting of the hammer on the rivet. A Weston chain hoist was afterward used with success.

For general work about the yard a seesaw arrangement was devised, consisting of a beam, supporting the riveter at one end, with a counter balance at the other. The beam rested on an A frame carriage. This allowed a great latitude of movement and was eminently successful. It is shown on page 1117.

The amount of work done by these pneumatic machines is greatly dependent upon the workman, and the men must be picked by actual trial to secure the best results.

William Burlingham.

HYDRAULIC AIR COMPRESSION.

The development in the method of hydraulic air compression, which has advanced materially within the past few years, has an interesting and important history. Our files are replete with information on this subject. The principles involved were first substantially shown in the "Trompe" or hydraulic blower or forge blast, which is a very simple, effective and strikingly ingenious method, and is understood to have been invented in Italy in 1640. The fundamental principle is that falling water is utilized for the compression and conveyance of air into suitable reservoirs in which it accumulates, and from which it is drawn and applied as a power. Under certain conditions, the system of hydraulic air compression has advantages over mechanical forms, and these conditions arise when water power is present or adjacent. It can be used at any point where there is a sufficient fall to give the desired pressure. There are sources of loss inherent in the use of mechanism, such as the loss arising from the development of heat, friction, etc., that are largely obviated in the hydraulic compressing system.

The principles of the "Trompe" seem to pervade every patent or device that appears on this subject. The only fault in the early "Trompe" which has been overcome by the latter devices, is in low pressures and efficiency. In the "Trompe" blower forges only from 1½ to 4 ins. of water pressure were needed, and the "Trompe" remained as an air compressor suited to the wants of a forge at the low efficiency of from 10 to 15 per cent.

The "Trompe" shown in Fig. 482 is a large cistern, which is supplied with a constant stream of water and connected with another cistern vertically underneath it by means of wooden pipes, each measuring some 20 ft. in length. The length of these vertical pipes is not a constant quantity, but 20 ft. is a fair average. This lower cistern has two openings, one at the top, by which air gets away through the tuyere into the furnace, and another on one side near the bottom through which the water can get away. The openings of the vertical wooden pipes connecting the two cisterns are in the upper cistern partially closed by a kind of wooden funnel which causes the water to descend in the middle of the pipes instead of clinging to the sides, as might otherwise be the case. In the upright pipes, and a little below the upper cistern in an inclined direction, are several small openings, their inclination being downward. The flow of water into

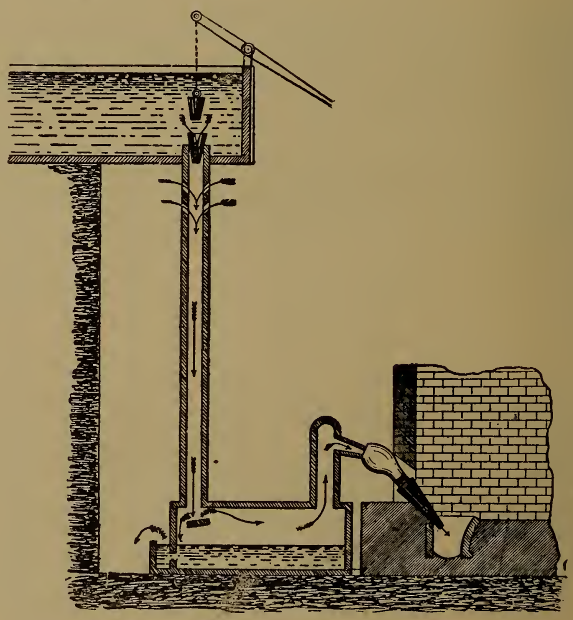

FIG. 482—THE "TROMPE," OR HYDRAULIC BLOWER.

the upright pipes is regulated by plugs, one of which is shown. The water descending is directed into the center of the pipes by the wooden funnel. The descending water produces an "induced current" under the influence of which air is drawn into the pipes through the small inclined apertures, and passes on in considerable quantity along with the water down the pipes. In the lower cistern immediately below the vertical pipes is a board on which the water and air dash, and in doing so separate, the water going to the bottom of the cistern, and the air making its way through the tuyere into the furnace. This simple construction provides for the compression of air at a very low pressure.

The first experiments leading to high air pressures were made by J. P. Frizell, of Boston, Mass., in 1877. An account of his invention, on which a patent was granted Jan. 29th, 1878, was published about that time. This patent seems to claim all of the essential features of the patents which have been granted since on similar methods. Patents have been also granted to C. H. Taylor, Adolph F. Du Faur, the late Col. George E. Waring and others, covering the features practically the same as in the original "Trompe," with the arrangement and construction of parts designed to bring the efficiency of the system up to a practical point. The patent granted to Col. Waring adds a stroke to nature by using a blower or compressor for adding more air to the water descending the shaft.

Frizell's patent indicated a mode of transforming the power of a waterfall into compressed air by the arrangement suggested in Fig. 483. At a point above the dam a vertical shaft is sunk to a depth corresponding to the pressure required. For a pressure of 100 lbs. per square inch the clear depth would be 231 feet. Thence a horizontal tunnel extends to a point below the dam, meeting another vertical shaft which reaches the surface. The top of the tunnel is not exactly horizontal, but rises slightly from both ends toward the middle, at which

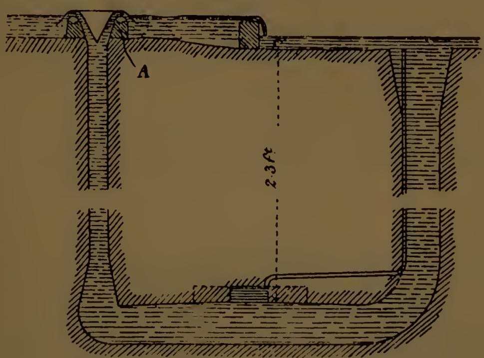

FIG. 483.

point a chamber of sufficient capacity is excavated in the rock, whence the air is drawn off through a pipe. The whole forms thus an inverted siphon, through which the water flows with a velocity depending on the effective head. The length of the tunnel will be controlled by the necessity of placing the entrance to the chamber far enough from the descending branch to admit of the complete escape of the air bubbles. The effective head will depend on the hydrostatic differences of ingress and egress of the water in the inverted siphon, and regulates the quantity of air carried by the descending branch. This can be regulated at will, and furnishes the means of controlling the velocity. Fig. 483 shows the method proposed for inducing the air bubbles into the descending column, though it is probable that a simpler method would disclose itself in the practical operation of the apparatus. The entrance to the vertical shaft is surrounded by a bulkhead of masonry. Over this bulkhead the water is led in a covered channel whose bottom rises a little above the highest level of the water in the pond, forming a siphon. The arched space below the siphon and above the masonry forms an accessible gallery, drained by a pipe which discharges below the dam. This gallery contains the cocks for regulating the admission of air. They are shown at A on the descending branch of the siphon channel, where its direction is nearly vertical. At this point the pressure within the siphon is less than that of the external air, and it will flow in through any opening.

The Frizell experiments cover broader ground than his patent claims. They suggest a good study of other forms for introducing air into the falling water tubes that may prove useful and lead to a higher efficiency. The efficiency in Frizell's early experiments was 26 per cent. Later by a larger apparatus he obtained an efficiency of 52 per cent. with a head of 5 feet.

The Taylor system has received considerable attention from the engineering press, and is familiar to the readers of COMPRESSED AIR, as a description of the plant at Magog, Quebec, and at Ainsworth, B. C., has been given in these columns. The efficiency of the Taylor compressor is said to be 62 4-10 per cent. at 52 lbs. pressure, the compressor furnishing one cubic foot of free air compressed to 52 lbs. by a fall of 4 cubic feet of water 22 feet.

It is claimed that the air compressed by the hydraulic system has some advantages over air compressed in a cylinder, in that the air delivered will be drier than the external atmosphere and of the same temperature as the water which compresses it. This claim appears to be well taken. Persons without experience with compressed air naturally infer that air compressed hydraulically and in contact with water will be moist. In mechanical compression we have the "dry" and the "wet" system. The dry system is that where compression takes place without water contact, cooling being effected by jackets; and the wet system is that where cooling is effected by a spray of water introduced within the cylinder.

At times it has been noticed that air from the dry system has given more trouble from freezing than that from the wet system. This is due to the fact that in the latter when water is introduced in the cylinder in sufficient quantities and at low temperatures a condensation of moisture takes place, the cold water acting like a condenser and absorbing some of the moisture that was in the air before it entered the compressor. This is strictly in keeping with the laws that govern condensation of moisture in atmospheric air. There are certain hydraulic systems of compression which add moisture to the air; among them is the hydraulic piston compressor. This is because the compression takes place rapidly. Heat is generated, and there are not sufficient points of contact of air and water to reduce the temperature of the air below the dew point. The "Trompe" system appears to be admirably adapted for furnishing dry air. The compression takes place slowly, and in air bubbles separated probably one from the other and distributed through the water column. It has been called the Pohle pump reversed, and we know that in pumping water by the Pohle system compressed air admitted at a higher temperature than that of the water is discharged at a lower temperature; in other words, the air is cool by thorough contact with water.

The "Trompe" system does not, as some suppose, require much head of water; on the contrary, a few feet of head are sufficient for ordinary purposes. What it requires is large water volume and a deep well. Nor is this system a competitor of the mechanical system of compression. The best engineering is that where a result is accomplished in the most economical manner. Where plenty of water exists and there is a chance to get a few feet of head, where the water does not cost much to use, and where a shaft or well may be sunk at reasonable expense, a "Trompe" air compressing system should be recommended. At the present time the Taylor system appears to be the most efficient for this purpose, and may be recommended as the best. Experience will probably still further improve the efficiency by increasing the volume of air compressed by a certain volume of water. A combination system might also in some cases be recommended. By this we mean a plant which compresses the air to low pressures hydraulically, the compressed air being then drawn into an air compressor and recompressed mechanically. We believe that there are large possibilities in this connection, as it is difficult by mechanical means to abstract the heat of compression during the early stages in the stroke of the machine. The temperature rises rapidly and in greater proportion to the pressure during the first half than during the second half of the stroke of an air compressor, and the percentage of increased power required to effect compression is thus greater. The "Trompe" system affords a means by which cold and dry compressed air at low temperatures may be compressed by air compressors with economy. Such a combined plant need not require excessive depth of shaft or well, and should be recommended in places where sinking is difficult.

A REMARKABLE CHIP.

The illustration shows the reproduction of a chip taken from a piece of steel by a No. 2 Boyer Pneumatic Hammer. It was taken off by a workman in

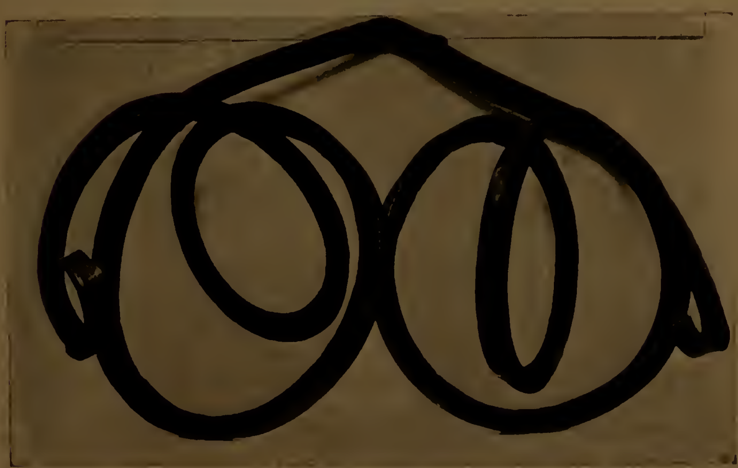

FIG. 484—CHIP OF STEEL TAKEN OFF BY A BOYER PNEUMATIC HAMMER.

Cramps shipbuilding yard at Philadelphia. The chip is 3'-9" long, ⅝" thick—width. It was removed at the rate of one foot every four minutes. One man with this hammer chipped as much in two minutes as two men did in six minutes. The hammer only weighs eight pounds. The piston has a 4½" stroke and strikes

1,800 strokes per minute. The Chicago Pneumatic Tool Co., makers of the above tool, has a number of sizes of chippers and hammers which are reported to make equally good records in the class of work for which intended.

DEATHS AMONG CAISSON WORKERS.

Deaths among caisson workers have been investigated by Drs. R. Heller, Wilhelm Meyer and Hermann von Shrotter, and the results are contained in a paper in the *Centralblatt der Bauverwaltung*, for Dec. 18, 1897, written by Mr. L. Brenecke. In 129 deaths among workers in compressed air, 38 men were divers and 91 caisson workers. These doctors agree with the theory of Paul Bert, of Paris, that the danger lies, not in the high pressure, but in a too rapid reduction of pressure. This is shown by the fact that a sudden reduction from + 0.3 atmosphere to the normal has caused death; while a pressure of + 5.4 atmospheres was followed by no evil results when 3 hours 3 minutes were consumed in reducing this pressure. They agree that in all except exceptional cases, no deaths will occur if 2 minutes are allowed in reduction, for every 6.1 atmosphere in excess of the normal pressure. They also propose a hospital air-lock where pressure of more than + 1.5 atmospheres are to be used, so that the sick may be treated under pressure. Workmen should be housed in barracks where they can be kept under medical control.—*Engineering News.*

AIR ON WAR SHIPS.

Several war ships and other vessels have been provided with a system for closing bulkhead doors in case of a leak or accident. The most approved system is one that uses compressed air. The "Long Arm" system is used on the U. S. protected cruiser Chicago, and by its application in an instant the doors of the bulkhead can be closed. A central station for compressing the air may be placed in any convenient location and usually consists of a small three stage air compressor, operated by steam or electric motor, with an air receiver consisting of the required number of storage flasks for the desired emergency capacity. Air is kept in the receiver at about 1,000 lbs. pressure and it is used at 150 lbs. pressure, and there is always enough power stored to operate all of the doors without having to wait until the air is compressed. The pipe line runs to all points where the closing mechanism is located, and is controlled from an emergency station automatically. The door slides vertically between two guides. A cylinder is attached to the door and a piston moves it up or down. In case of need the pipe line is opened and the pressure exerted on the piston head forces the door down and closes it. Some interesting experiments have been tried with this system. In one instance a pile of wet coal lying 30 in. deep above the sill obstructed the closing door, but the water swept it away and the door closed against the water pressure. In another case the door closed down upon the coal and was locked in that position. From the progress being made by the "Long Arm" System Co., of Cleveland, Ohio, it is likely that they will succeed in extending their system to every branch of marine service.

TILDEN PNEUMATIC HAMMER.

The cut herewith shows that type of pneumatic engines in which the reciprocating piston constitutes a hammer, adapted to deliver a series of rapidly recurring blows to a chipping, caulking, beading, riveting or other tools, the shank of which is located in the path of such impact piston, and constitutes an end closure for the lower piston chamber.

The objects of the present improvements are: First, to provide a simple and efficient sectional formation and arrangement of the main cylinder for the impact piston, and the valve block and housing for the reversing valve, which permits of a ready and convenient detachment of the parts for cleaning, etc. Also to provide means for connecting the handle, main cylinder and valve block

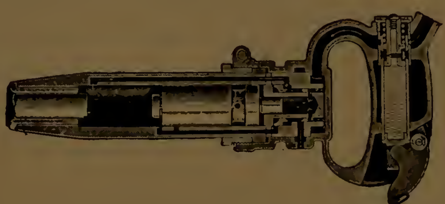

FIG. 485—TILDEN PNEUMATIC HAMMER.

and housing together in a rigid and substantial manner. To provide means, self-contained within the hammer, for automatic lubrication of the hammer parts while in operation. To overcome recoil and dispense with the vibration or jar (so objectionable in most hammers) which enables the operator to accomplish greater results with less fatigue. In this hammer there are but two moving parts, the piston and valve, which, by the arrangement of the air passages, control each other.

The sectional view herewith gives an idea of its construction and operation. Starting with the parts in the position as illustrated, the motive fluid or compressed air from the main chamber passes through ports into the valve block chamber to press upon the upper end extension of the impact piston, and acting against the decreased area thereof imparts a light initial movement to the piston, which from practical experience is found to be very efficient in reducing the amount of jar or vibration.

Letters patent were issued Oct. 24, 1899, to Robert Burns and B. E. Tilden, and the manufacture of same will be immediately commenced by the International Pneumatic Tool Co., of 1209 Monadnock Block, Chicago, Ill., under the mangement of B. E. Tilden and C. J. Fellows. To designate this from other hammers it is called "The Tilden."

At the shops of John Mohr & Sons in Chicago, they reported that an inexperienced man with one of these hammers accomplished the same amount of riveting in 30 hours for which their experienced riveters had previously required 80 hours, and that all was first class and steam-tight when tested under pressure.

They are so well adapted to all classes of work that orders are coming in practically unsolicited. They mark a great advance in pneumatic hammers.

COL. BEAUMONT, R. E.

Col. Beaumont, R. E., of England, who died in London recently, was an engineer of experience and much ability, especially in pneumatics. In 1880 a system of pneumatic traction, designed by Col. Beaumont, was put into experimental use at the Woolwich Arsenal, London. The interesting point about this experiment is the fact that compressed air was used at high pressure and the engine was so constructed that it might utilize the entire power stored in the air, no matter how high the initial power might be. One thousand pounds per square inch was the pressure which Col. Beaumont thought best for this purpose. The air was admitted into successive cylinders, having different areas, commencing first with the smallest, and compounding as the pressure was reduced.

Provision was made for a larger consumption of air as the pressure fell in the reservoir. It is easy from our point of view to-day to anticipate difficulties, which might arise in such a system as this. In the first place, the condensation of the moisture in the air would naturally cause an accumulation of water in the cylinders, and would result in freezing and interference with the machinery. This was at a time, too, when the Mannesmann steel tube had not been constructed and it was difficult to maintain air at high pressure in safe storage vessels. Like most pneumatic tram car experiments, this one was not continued to a successful issue for the lack of funds, but it is of special interest, in that it was a high pressure system, as distinguished from the low pressure systems which followed it, and which were approved by engineers up to recent years. Col. Beaumont was a firm believer in the high pressure system and held his views on this subject to the last. He believed in storing the air at high pressure on the cars, and in accomplishing pneumatic traction by the storage system, as distinguished from that which picks the air up at intervals along the line. Of the latter system, the Mekarski, Popp-Conti, Hughes & Lancaster, and Jarvis are conspicuous examples. The two systems now in operation, known as the Hoadley-Knight and the Hardie, are those of high pressure, and follow the Beaumont idea, which is now made practicable by the use of the reheater, and the Mannesmann tube. By means of the reheater the temperature of the air is raised so high, that freezing, even in compound cylinders, does not take place, and the Mannesmann tube furnishes a means by which air at high pressures may be safely stored in small areas.

BRUNEL.

Facing the Thames embankment in London is a statue of Brunel, the great English engineer. Brunel was prominent in many things, but it must not be forgotten that he was the first man to practically apply compressed air for commercial service. Compressed air, though as old as the hills, dating back to the time of Hero of Alexandria, was of little use to the world except for experimental purposes until Brunel used it in sinking caissons while building bridges over the Thames. Its importance for caisson service cannot be overestimated, as without it, it is doubtful that we should have built such piers as those at the Brooklyn Bridge, the St. Louis Bridge, and many others, where deep foundations are necessary. The use of compressed air in caisson service led to its use in diving bells, which were at one time of great importance in excavating under water. Of late years the diving bell has been replaced by the diving suit, and this is also an important use of compressed air.

DEATH OF THOMAS DOANE.

Thomas Doane, of Charlestown, Mass., the well-known civil engineer, died October 22. He was born at Orleans, Cape Cod, in 1821, and after attending the Andover Academy he entered the office of Samuel L. Felton, a noted engineer. After remaining with him for three years he became engineer of a division of the Vermont Central Railroad. Mr. Doane was connected at one time and another with all the railroads running out of Boston. In 1863, he was appointed chief engineer of the Hoosac tunnel. He located the line of the tunnel and built the dam in the Deerfield River to furnish water power. In this work he introduced nitro-glycerine and electric blasting for the first time in this country. In February, 1875, he ran the first locomotive through the tunnel. In 1869 he went to Nebraska, and built 240 miles of railroad on the extension of the C. B. & Q. R. R. He made the question of grades a special study, and so perfect were those on the extension that one engine could haul as many cars to the Missouri River as five engines could haul across Iowa. When in Nebraska he took a leading part in the agitation of the question of establishing a college in that State, and in recognition of his services the institution was named Doane College.

It is in his connection with the Hoosac Tunnel that Mr. Doane devoted himself to the perfecting of compressed air machinery. He introduced compressed air and invented and patented machinery for it, and had a large share in inventing the pneumatic drill and their carriages used there.

track return of electric street car lines. Charles A. Stone and Howard C. Forbes discuss the same subject, as it occurred in Boston, with practically the same conclusions in the Journal, N. E. W. Association in 1894. The results of electrolysis and its corrosive action is described by Inspector Stewart, of St. Joseph, Missouri, the same year. It is so evident, that the American Water Works Association appointed a committee to recommend preventive measures, and received its report at their meeting in 1894. A writer in *Cassier's Magazine,* April, 1895, discussed the legal aspects of electrolysis, and determined that electric railways should furnish whatever is necessary to minimize electric corrosion, and would probably be held liable for damage.

The subject has received treatment from city engineers and others who are connected with public works, and who have the responsibility of such matters on their hands in all parts of the world.

Electric traction has proved a dangerous element in municipal underground work. It is a silent destroyer of pipes, and a menace to public health, through the escapement of gas and sewage.

NOTES.

A novel application of compressed air has recently been patented on a "Compressed Aid Mechanism for Vehicles and Other Devices." With this simple device the inventor, F. Schumacher, of 148 Sackett street, Brooklyn, N. Y., proposes to reduce the friction on the axles of heavy rolling stock, by confining

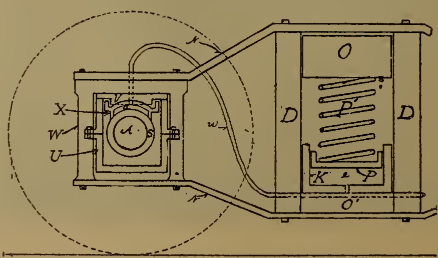

FIG. 488—AIR LUBRICATED BEARING.

a volume of compressed air in a system of pistons and chambers in such a manner so as to enable the axles of a vehicle to rotate against the air pressure without friction.

The illustration shows the principle of the invention as it is applied to a freight railway truck. Every detail of the operation of the device is automatic, simple and positive. The arrangement consists of a pressure accumulator, air chambers for the axles, and a pressure regulating mechanism. A pump and a small storage tank constitute the automatic pressure accumulator, and maintains the necessary pressure. It may well be compared to the inflation of a pneumatic tire; once filled, it lasts for a long time. From the storage tank the pressure is regulated by a governor, admitting and expelling the air to and from the chamber "a" and the space "e" below piston "P" in pot "K," chamber "a" and space "e" being connected by a pipe "w." The adjustment of the governor is such that the pressure in these spaces is maintained proportional to the load to be maintained by the air. The pot "K," with piston "P," serves to regulate the pressure under load vibrations, reducing or increasing the volume in "a," "w" and "e," without admitting or expelling any air to or from said air spaces. The load resting on bolster "O," spring "P" and piston "P," enables the air in "e" to exert an anti-vibrational influence upon the same, absorbing all trembling vibrations of the vehicle not absorbed by the spring.

The fittings on the axle consist of a collar "S," easily removable; a bearing-block "X," with its piston-shaped lid "V," a box or casing "U," for the axle, and a frame "W," for casing "U."

The bearing-block "X," has a cylindrical top for "V" and a recessed surface for an air space "a." It being fitted air tight to "V" and "S" no air can escape, and "S" can rotate with axle "A" against the pressure in "a."

Any number of air-chambers on the axles may be connected to one pot, "K," it being only necessary to properly proportion the combined lifting areas between the chambers of the axles and the lifting area of the air in pot "K."

The pressure in the storage tank is at all times greater than the pressure in the chambers of the axles and connections, it being in the latter spaces at a maximum of 175 lbs. on railing cars, and considerably less for lighter vehicles. The advantage claimed in the application of this device to heavy rolling stock is the following:

Frictional reduction of over 90 per cent.
A longer life of the bearing.
The saving of over 75 per cent. of oil.
A positive prevention of hot bearings.
Increased safety for the rolling stock.
Increased speed of fast trains.
Better comforts for the traveling public.
Smaller coal bills.
Smaller motors.
Decreased expenses in street railway equipment.

There has been considerable demand for a light, durable and easily handled breast drill, and the Empire Engine and Motor Co., of 26 Cortlandt street, New York City, has just brought out a machine to meet it. We show cut here of their No. 0 Pneumatic Breast Drill, a machine that has created the most favorable impression wherever it has gone. It weighs but 10½ pounds, with 60 to 70 pounds pressure, and with a 5-16 drill will go through 2 inches of ordinary cast iron in a minute. This is an invaluable tool for doing all classes of light drilling in fitting work, and driving test holes in columns in bridge and architectural iron works; driving test holes in stay bolts and running a burr drill for stay bolt holes in locomotive and railroad shops; boring for lag screws and running them in car building shops; running augers and driving in screws for general wood work; boring for name plates and drilling and tapping for putting on lagging.

We have enumerated a few of the uses to which this handy little tool can be put and for which it is well adapted. It is exceedingly compact and well made,

FIG. 489—PNEUMATIC BREAST DRILL.

as a glance at the cut will show, and easily operated, a simple turn of the wrist being all that is required to start or stop it. The motor is of the rotary piston type, with the gearing all enclosed in the case. It is very durable, there being nothing to cause excessive wear and nothing to get out of order.

The purifying of alcoholic liquors is accomplished by compressed air through the Cushing process, which has been in vogue for many years. The liquor is placed in receptacles for the purpose and air, after it has been washed and purified by Prof. Tyndall's well-known method, is compressed and forced through perforated pipes entering the liquor in minute streams. The liquid is violently agitated and the air permeates every portion of it. The air being warm, oxidizes the fusel oil and at the same time volatizes and expels into the open air the light poisonous ethers, leaving the liquors thoroughly pure and free from aldehydes. It is claimed that by this process new liquor for medicinal purposes is made practically as good as old and that the drinking of liquor treated thus does not cause stupefaction, headaches and other disagreeable results.

We show herewith a rather novel application of the pneumatic hammer. On the end of the piston rod of the machine is placed a saw blade which is recip-

FIG. 490—A PNEUMATIC HAMMER-SAW.

rocated rapidly, approximately to 1,000 strokes per minute, and in this way a pneumatic saw of very handy construction and rapid work is made available. Here is a portable hand saw, which may be placed in any position and which, without exertion on the part of the operator, is capable of doing very rapid and economical work. This saw can be operated by a boy when used for common work. It should be useful in pattern shops, for cabinet work and for wood carving. We have been informed that this machine is in practical operation in a packing house in Chicago, and that it is used there for the purpose of sawing ham bones.

The Standard Railway Equipment Co., of Chicagô and St. Louis, are introducing a new design of pneumatic wood drill, which is known as their Monarch No. 2. This drill is provided with ball bearings throughout. It is formed with ball bearings throughout. It is formed with a solid three point crank of tool steel hardened where the bearings of the various ball races are. Each bearing has two

FIG. 491—MONARCH DRILL.

sets of balls. The spindle is on one side of the working part of the machine, making the engine entirely independent and in that way any undue strain put on the spindle cannot affect the engine part in any manner. The drill is reversible, having the reversing and throttle valve made in one piece, so that by simply turning same to one side or the other will give the machine a forward or backward motion.

Another feature found in this drill is that the exhaust is provided with a muffler, so that the machine is practically noiseless while being operated. It is claimed that this drill is very economical in the consumption of air and will bore any size hole up to two and one-half inches in diameter in any kind of wood.

Weight of drill is but seventeen pounds, which makes it very desirable around car shops. The accompanying cut shows this machine in operation boring side plates in car repair yard.

The accompanying illustrations show the Quick Acting Stop Coupling for Air Hose made from a design of Mr. E. B. Gallaher, engineer of the Pneumatic Supply & Equipment Co., N. Y.

This coupling is designed especially for use in connection with pneumatic tools. It is both a union and a stop cock combined, and its use is desirable where

FIG. 492—QUICK ACTING STOP COUPLING FOR AIR HOSE, UNCOUPLED.

ompressed air tools or appliances are used. The operation is extremely simple —it may be locked or unlocked by a quarter turn and when locked it is absoutely air-tight under any working pressure. It is claimed that a saving of com-

FIG. 493—QUICK ACTING STOP COUPLING FOR AIR HOSE, COUPLED.

ressed air is effected and the necessity of shutting off the air supply at the eceiver or main supply pipe is avoided. The use of this coupling permits one ool to be detached and another one to be connected to the air hose instananeously and the annoyance of twisted hose is entirely obviated.

FIG. 494—HENRIKSON'S FLUE CUTTER.

The Henrikson Flue Cutter for 4½" flues, is shown in the accompanyi cut. This is a newly patented article and has been found very successful operation that is now being manufactured and sold by the Chicago Pneuma Tool Co. It is made in any size to suit requirements, and has been adopted standard on the Chicago and N. W. R. R. The cutting wheel is fed against t flue by the cylinder and piston arrangement, shown about the middle of the machine, the air pressure passing through the motor to operate the piston, and the air motor revolving the cutter at the same time. The machine will cut off the flues either inside or outside the flue sheet and on 4½" flues it has been found very efficient, cutting them off in about 20 seconds, and in much less time on locomotive flues.

Any railroad mechanical man will very quickly appreciate the advantage of this tool, on account of the great saving effected in that the machine cuts off the flues close to the sheet, thus making but very little waste on the flues.

There has recently been placed on the market by the Standard Pneumatic Tool Co., a new pneumatic tool, designated as the "Little Giant" Pneumatic Reversible Boring Machine No. 5, designed especially for work around railroad

FIG. 495—LITTLE GIANT DRILL.

car shops. Being very compact and light in weight, which permits of its being easily handled and operated, and very efficient in all classes of boring into wood. It is made of steel throughout, and can be operated in a bath of oil, as exhaust does not come in contact with working parts.

One of the principal features of this machine is that it is reversible, as by a slight turn of the handle it can be reversed running at full speed, withdrawing the auger instantly. The advantages of this is apparent, particularly when boring holes in cars. It is geared to run at a high rate of speed, and is so constructed that it will last for a long time without getting out of repair. It has double-balanced piston valves which cut off at ⅝ of full stroke, consequently is very economical in the use of air. The weight of this machine is 12 pounds, and is capable of boring into wood up to 3½ inches in diameter to any depth. An effort has been made to make this a superior pneumatic boring machine, and at the present time the claim is made that the success obtained under exhaustive tests and comparisons proves everything claimed for it.

When a firm takes pleasure in sending machines on trial to any one desiring to test its efficiency, and will pay the express charges both ways if it fails to meet with their approval, and also guarantee the same against repair for one year, it is quite certain that the claims can be substantiated, and this the above company will do.

The Gabriel Stay Bolt chuck is arranged to grasp any size stay bolt, and will turn them without the necessity of squaring up the ends. In operation with

FIG. 496—GABRIEL STAY BOLT CHUCK.

the air motor, as shown, it is very rapid and efficient and effects a great saving of labor in turning in stay bolts.

This is a small machine but great in its labor-saving qualities, and will certainly interest all users of such devices. It is an entirely new device, just patented, and will commend itself at a glance to all practical men.

The above illustration shows an apparatus which is used in the candy manufactory of Croft & Allen, Philadelphia, Pa. Its purpose is to remove candy from the tops of tables where it has been spread in thin layers to harden. These tables are provided with rollers for easily running about the place. When the candy has become of proper consistency the table is shoved over under the apparatus. It is clamped firmly to the bar A shown underneath. The blade B, which is then at the end opposite (C) to where it is in the picture, is forced forward by means of a piston attached to the blade driving it the entire length of

FIG. 497—PNEUMATIC CANDY MACHINE.

stroke. The blade skims the top of the table, scooping the candy which has adhered very firmly. The result is a great saving of labor. It is all done in a few seconds, whereas before the apparatus was designed, several men were employed to remove the candy. Many tables were required and the limited room was in continued confusion. The apparatus was designed by Mr. Howard A. Pedrick, of the firm of Pedrick & Ayer, Philadelphia, and while it is a special appliance, it is none the less interesting.

A combined compressed air churn and butter worker has been invented by Mr. R. R. Stone, a butter dealer of New York. The churn itself is wooden, cylinder shaped, like a barrel, and in it are revolving paddles, which are worked by a crank, either by hand or power. Legs support the cylinder and make it stationary, and consequently can be well ventilated. The churn is open at the top. Air is compressed and cooled, then conveyed through a small copper tube with small perforations through the bottom of the churn and escaping at the top, permeating all parts of the cream. Because of the cooling properties of compressed air no ice is required, even in warm climates. Churning may be commenced with warm cream and cooled as rapidly as desired. By the thorough distribution of cold, streaks in the butter are avoided.

The latest device for economizing fuel in steam furnaces has been brought forward by Professor Linde, the first man to put the industry of cold storage on a commercial basis. Professor Linde has lately been giving his attention to the industrial production of liquid air, in which he has been fairly successful. The liquid air can be supplied in any required quantity, but the uses to which it can be profitably applied have not developed in the same proportion. Professor Linde now proposes to employ liquid air in conjunction with coke or inferior fuel in steam boiler furnaces. It is stated that after giving off the nitrogen, a gas remains that consists of 50 per cent. of oxygen, that can be profitably used in boiler furnaces at the present high price of fuel. The idea is distinctly novel; and probably, but for the distinction attached to Professor Linde's name, would attract little attention.

For obtaining an exact idea as to liquid air there is a very simple method, in the opinion of M. Robert Pitaval, who makes this observation in *L'Aluminum,* and that is to consider it as the extreme limit of compressed air, when one can easily conceive that it may be employed as a refrigerating agent, as motive power, and as explosive force. Again, its composition sufficiently indicates that it may be a source of oxygen which, as is well known, has many uses; but the success of all these applications depends upon a principal factor, which is the sale price, and consequently the cost price of liquid air. This substance may, in fact, serve to afford liquid oxygen owing to the differences of volatility in the two elements which compose it. By evaporating one-half a given mass of liquid air as a concentration of oxygen to 85 per cent. is obtained, and, on pushing the evaporation further, nearly all the nitrogen may be eliminated.

To supply compressed air for the construction of one section of the New York tunnel or subway, a steam plant has been erected at the north end of Union Square on Seventeenth street at a cost of nearly $100,000, including the air piping to the rock drills and other machinery along the section. The plant which is erected in one side of the street proper will contain five boilers in batteries of two and three. The boilers are of multi-tubular type, 60 inches by 16 feet, set in permanent brick settings with two steel smokestacks about 70 feet high. The plant also comprises two large air compressors, a blacksmith shop, small machine shop and storehouse for various tools. It is rather surprising to see a power plant erected in such a permanent manner right in the street of a large city, and for an apparently ephemeral job, but as the construction of this section may require two or three years, the expenditure for power purposes will undoubtedly be a good investment, as compared with the cost of power generated by small portable boilers generally used in work of this character. To avoid smoke and cinders coke is used instead of coal.

John B. Smith & Sons, Toronto, have installed an equipment of compressed air hoists in their saw mills and lumber yards, ranging in capacity from ½-ton up to 4 tons. So far as can be ascertained this is the first application of this mode of handling lumber in Canada. Since its inception a great saving has been effected. For example, an ordinary load of lumber can be loaded or unloaded by two men in from 20 to 40 minutes less time than formerly. In handling the heavy lumber arriving in their yards by trains, less men are required, and a system of overhead tracks permits the lumber to be put right alongside the machinery in the mill, with the one handling. In a plant of this kind the fuel being so plentiful the first cost is almost all to be considered. The air is compressed in the ordinary way, and is stored in a central tank, and distributed to auxiliary reservoirs. The rubber hose used is coupled at convenient points with automatic valve couplings, which permit of the hose being detached, and as soon as this is done the valve prevents any loss of air, thereby the hoist retains its load for any length of time necessary for its removal to other parts of the yard or building by the trolley overhead.

Raising sand from the ground floor to an overhead bin by compressed air is done at a great many railroad engine houses, but blowing it upstairs with a fan blower is not very extensively practiced.

At the Pennsylvania Railroad engine house, in Louisville, Ky., General Foreman Foster uses an old 40-inch fan blower for this work. A smaller blower would do the work, but as he had this one on hand, it was installed. A 6-inch galvanized-iron pipe leads from the fan in engine room through the sand house to an elevated bin about 30 feet high. The sand flows from the bin under the sifting platform through a 1¼-inch pipe into the 6-inch air pipe, where the current of air takes it up the pipe, which lies at an incline of about 30 degrees, into the bin. The end of the sand pipe is curved to point the same way the current of air is traveling, so that the air does not blow up through the sand into the sifting bin.

At the top of the storage bin there is a pipe, 8 feet high, 12 inches in diameter, through which the air escapes. All the sand drops in the bin, while the loam and dust are carried out the ventilating pipe. Something over a ton an hour can be handled by this method. It is a continuous operation as long as the sand is running into the air pipe.

The fan is run only while the sand is being sifted into the lower bin, and it will not run into the air pipe unless the fan is running. The current of air seems to draw it through the curved nozzle.

Sand is taken from the elevated bin into the engine sand boxes through a pipe, the usual way.—*Locomotive Engineering.*

Compressed air baths are the latest things in health restorers.

One step further, and the fashionable cure will be taken in the Greathead compressed air shield at the "working face" of the newest Thames tunnel, wherever it happens to be.

It is at Reichenhall, in the Bavarian highlands, that this newest invention is being applied to the cure of asthma, bronchial catarrh, and numerous other forms of disease. The bath is constructed on very similar lines to the diving bell. The pneumatic chamber is built to accommodate from three to twenty persons, and can be either round or oval. The outside resembles more than anything else the turret of a modern man-of-war. Small windows with very thick glass panes let in the light, and the heavy iron door when closed is completely air-tight. The air admitted under pressure passed into a hollow space underneath the chamber and up through the carpet, which is placed over a perforated metal plate. This prevents any draught being felt, even when the pressure is at its greatest. The foul air is carried away by means of two pipes with openings immediately below the cover of the chamber. The inside is furnished with cane armchairs and a table, and the patients pass the time either in reading or writing, or very often in sleeping.

Each sitting lasts about an hour and forty-five minutes; and during the first twenty-five minutes the pressure of the air is gradually raised by means of pumps till it attains 30 centimetres. This is maintained for forty-five minutes, and then the normal pressure is gradually restored. The chief sensation during the sitting (says the *Times* in describing the process) is a slight pain and discomfort in the ears, but this soon passes off, and can, moreover, be greatly diminished by filling the ears with cotton wool. For a beneficial and lasting result at least 30 sittings are required, and then a complete cure is very often effected.

The idea was tried as long ago as 1832, but they did not succeed then in maintaining the purity of the air under pressure.

After cleaning the iron work of the New York Viaduct at 155th street, as described and illustrated in the "Cyclopedia of Compressed Air," the engineers in charge conducted a test of painting the cleaned surfaces by a compressed air painting machine. It is necessary to paint the cleaned spaces very quickly on account of the rapidity with which the fresh surfaces oxidize. The Bryce Pneumatic Paint Machine was given a trial in which it was demonstrated that in twenty minutes it could cover 285 square feet, while it would require between three and four hours for one man to cover the same space by hand. The control of the machine was so good that the paint was distributed in the interior parts difficult to reach by hand, equally as well as the exposed surfaces. The overhead plates were painted without any dropping of the paint. One overhead opening between adjacent plates was about half an inch wide and extended upward about two inches. This had to be painted formerly by means of a swab, but the interior surfaces were coated by the air-blast without any trouble by moving the nozzle in front of the opening and about two feet from it. The construction of the paint distributor is very simple. The air and paint are conducted through separate passages to the base of the nozzle. The air passage ends in a small injector nozzle, adjustable longitudinally, which atomizes and sprays the paint into the main fan-shaped nozzle, and is discharged to the surfaces to be painted; the operator at all times being able to regulate the quantity of paint discharged.

An apparatus by means of which a railway guard can shut and lock all the doors in a train, by moving a lever in his van, has recently been tried on a train on the Metropolitan District Railway. This invention, which, we understand, has been at work successfully in Australia, and is known as the Fraser railway door controller, is actuated by compressed air, which can be supplied to cylinders fixed under the carriages. By a combination of pistons, rods, levers, and springs the doors can be made to shut, and this can all be done by the guard from his van, without his touching a single door. The action is said to be so gentle that, even if people's fingers get in the doors, these are only prevented from closing, and no injury results to the fingers. The apparatus, it is said, can be worked either by means of the air in the air-brake pipes, or by means of a separate air pump, or with modifications in connection with the vacuum brake.

The employment of compressed air in finishing silk ribbon is a branch of compressed air application which has received little or no attention from compressed air authorities, but nevertheless air has been used quite extensively for this purpose and has proven of considerable value to the ribbon manufacturers. Compressed air is superior to steam for spraying the finishing material upon the ribbon, because its exhaust into the atmosphere is not offensive to the operator; it does not scatter the particles of finishing material, but concentrates the entire force of the spray upon the ribbon. Ribbons finished with the compressed air spray possess a better lustre than those finished by the steam spray, because the steam condensation dilutes and weakens the finishing material. The air is heated before it reaches the spraying nozzles, in order to produce the desired effect.

Experiments have recently been made with compressed air and compressed oxygen to purify the air in a long tunnel near Geneva, through which 200 trains pass every day. The compressed air is liberated from the cylinders on the engine. The pure air blew back the smoke and clarified the atmosphere. The oxygen was allowed to escape into the fires of the engines, causing complete combustion and preventing the formation of dangerous gases, as well as making the air more wholesome by the addition of the oxygen. The compressed air was adopted because a cheaper method. This experiment suggests the feasibility of similar methods in running tunnels and possibly in the shafts and level workings of the mines.

We present herewith the picture of a pneumatic hoist in use on the 1,400 level of the Gwin mine, Calaveras County, Cal. This hoist has a drum with capacity to carry several hundred feet of suitable rope. The drum is operated by a small hand-wheel fastened to the centre of the shaft. The motor for oper-

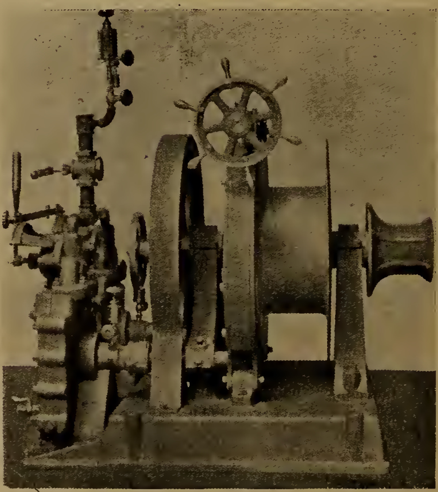

FIG. 498—PNEUMATIC HOIST IN USE ON THE 1,400 LEVEL OF THE GWIN MINE, CALAVERAS CO., CAL.

ating this hoist consists of two Dake engines of the reciprocating type and is operated by compressed air. It is portable and made so that it can be readily run through a drift on a flat car.

The application of compressed air for mechanical purposes in Paris has developed to wonderful proportions. It is said that it now takes 24,000 horse power to operate all the appliances. These embrace printing presses, saws, pumps, grindstone lathes, sewing machines, tin-smith shears, ventilators, and enters into almost every industry. In 1892 they compressed 6,887 millions of cubic feet of air, with a system of 105 miles of compressed air pipe laid under the street, 41 miles of which is used for pneumatic clock service, and about 64 miles for other appliances.

At the Altoona shops of the Pennsylvania Railroad the problem of handling ashes from locomotives has been satisfactorily solved by the erection of several pneumatic ash-hoists. An iron frame resembling a gallows extends across three tracks. Under it there is an ash pit. The bottom of this pit has a narrow-gauge track on which small trucks run and carry what may be called bifurcated buckets to receive the ashes as they are removed from the ash-pans of the engines. The ashes are raked out of the ash-pan into these buckets. The buckets are then attached to the suspended hoist and run upon a trolley the length of the frame and dumped into a car.

At the Globe Iron Works, Cleveland, O., a No. 5 Phœnix drill is being used for expanding the flues of a large marine boiler. This work is done by using the machine to drive an ordinary taper pin expander, and an idea of the rapidity with which the work can be accomplished by the use of the machine as stated may be had from the statement that on one boiler 280 3½″ flues were expanded in ten hours; this time included all delays. The seams of the boiler are caulked with the Keller 1¾″ tool, built by C. H. Haeseler & Co., Philadelphia.

Instead of blackening dry sand moulds by hand with a swab a compressed air sprayer is now used. It is easily handled and by its use the blackening is thrown into the pores of the sand and into the pockets and corners almost inaccessible with the swab. It is much quicker than the swab and the coating is more uniform.

A correspondent of the *National Engineer* asks the following question:

"Can you give me a rule to find the size of air compressor and pipes to operate an air lift to raise about 2,500 gals. of water per hour from a depth of 300 ft.; the hole is 6-in. diam. and it is 100 ft. to the surface of the water; the water is lowered 25 ft. by pumping at the rate mentioned. J. T. B."

This is the reply:

"This well would require a 5-in. casing and should be piped to twice the depth of the surface of the water from the top of the well when the water is at its lowest point, that is at twice 125, or 250 ft. The air pipe should be 1-in. diam in the well and the pipe between reservoir and well should be 1¼-in. to 1½-in Steady pumping will depend on the air pipe and the casing being properly proportioned, for if the air pipe be too small, or the casing too large, the well will blow. It will be well to have ample reservoir capacity. Air supply to compressor should be as cold as can be obtained, for then the compressor capacity will be greater than with warmer air supply. The reservoir pressure should be about 100 lbs. (250 × .434). The compressor should have a capacity of about one cubic foot of atmospheric air for each gallon of water to be raised."

A discussion took place recently at the International Mining Congress at Brussels as to the limits of safety to which work can be carried on under compressed air. The Austrian doctors declared that men under twenty and over fifty years of age should not be allowed to work where the air pressure was high, and in all cases medical certificates should be forthcoming as to the soundness of the heart, lungs and the vascular system. An ear affection, a cold or gastric attack should be sufficient for prohibition. The limit of pressure should be seventy-five pounds, which would enable the work to be carried on under water at 170 feet from the surface, but in such cases special precautions would be necessary in returning from the high pressure to the normal condition. The minimum would be 100 minutes, but the men may continue to work for any period. It is one of the peculiarities of working under high air pressure that healthy men might almost live in the pressure chamber, but the change from high to lower pressure should take one minute for every one and one-half pounds of pressure. Men acustomed to the work might take only ten minutes for a pressure of twenty-two pounds, fifteen minutes for thirty-seven pounds, or thirty minutes for a seventy-five-pound pressure. It is suggested that the men in passing through the changes of pressure should suck sugar; not that sugar possesses any particular virtue, but it insures the swallowing of the saliva and prevents the tympanum from being injured. As to the ventilation of the working chamber, the air should be renewed at the rate of 700 cubic feet per head per hour.—*Ex.*

A correspondent asks:

"It is desired to raise water from a well by the "Air-lift" process, the casing of same being 6″ in diameter, and surface of water 80 feet below the ground. We wish to know if an ordinary 8″ air brake pump can be used to accomplish this, it being necessary to convey the air a distance of 1,500 feet from the pump to the well. I presume it will be necessary to place a smaller pipe inside the casing for the purpose of raising the water.

I should like very much to know what is the method of calculation for determining what amount of water, a given amount of compressed air, at a given pressure is capable of raising."

The amount of water pumped by an Air Lift Pump depends upon the number of cubic feet of free air per minute, the height to which the water is raised above its surface and many other conditions under which the Air Lift Pump may operate.

If your Air Brake Pump has 8″ x 8″ cylinders and runs 120 strokes per minute, the volume of free air compressed would be of course the product of the piston speed by the area of the cylinder from which should be deducted perhaps 20 per cent. for clearance and leakage with this style of pump. This will give 28 —20 per cent., say 22 cubic feet of free air per minute.

The formula commonly used for determining the amount of water raised with a given amount of free air is as follows:

$$\frac{G-125A}{L}$$

where G equals the number of gallons per minute A equals cubic feet of free air and L equals the lift in feet from the surface of the water to the point of discharge. This would be for your case $\frac{125 \times 22}{80}$ equals about 34 gallons per minute. This applies only when the submergence equals one and one-half times the lift, or for your case 120 feet of water when lifting 80 feet above the water level, or to the surface of the ground only. As this water level will probably fall somewhat when pumping, the lift will be increased and the amount of water pumped decreased accordingly.

For a 1″ pipe line 1,500 feet long carrying about 22 cubic feet of free air per minute, the loss of pressure by friction will be about 5 pounds—not an excessive amount. The water discharge pipe should be 2″ and the air pipe ¾″ or 1″. The air pressure will be about half a pound for each foot of submergence, being dependent upon the submergence and not upon the lift.

While you can operate an Air Lift Pump by the use of an Air Brake Pump it is not an economical process. This style of pump uses from 150 to 250 pounds of steam per 1 horse power per hour, where an inexpensive belt driven Air Compressor would run on 40 pounds, and the saving in fuel would pay for the air compressor in a few months. It was recently brought out at a meeting of railroad officials, that if air brake pumps were to be had for nothing, it would pay better to buy air compressors at an extravagantly high price on account of the fuel saving.—Ed.

A correspondent writes:

1. How can I determine the amount of power that may be realized from a reservoir of known dimensions, charged with air at 225 pounds pressure?

2. How can I determine the amount of power that it requires to compress this air?

3. Why does heat accumulate in a compressed air reservoir?

4. Is there any book published which treats of the above subject in a simple way? and if so, give title and publisher.

[1. First determine the cubical contents of Receiver (cu. ft.) and multiply by

$$\frac{(225 + 15)}{15} = 16$$

Product will be = cu. ft. of free air in reservoir.

All depends upon the manner in which you are going to use the air. If used in a motor, the cut-off is an important factor; and if air is reheated, the quantity consumed for a given power will be proportionately diminished.

We refer you to Table, page 117, COMPRESSED AIR, No. 8, Vol I., which will give you the consumption in free air for varying cut-off and for pressures up to 150 lbs. For pressures up to 225 see general formula, page 69, COMPRESSED AIR, No. 5, Vol. I.

2. We refer you to any treatise on thermodynamics for a mathematical formula; or you will find in "Kent's" or "Haswell's" (64th edition) Pocket Books, a table of mean effective pressures for pressures up to 200 lbs., from which you can compute the horse power for any given case.

3. The heat that accumulates in a compressed air reservoir is due to the heat of compression in the air cylinder—due to work done upon the air in compression. See COMPRESSED AIR, No. 3, Vol. I., page 14.

4. Refer to Frank Richards' book.—ED.]

A correspondent writes:

The following shows a simple method of calculating volumes of free air. It entirely obviates the tedious division by 14.7, and is correct.

I shall be pleased if it is of any use, or worthy of a corner in your most interesting journal.

To find the equivalent volume of free air corresponding to a given volume of compressed air under any pressure—one atmosphere being = 14.7 lbs. per square inch.

$$\left.\begin{matrix}\text{Volume}\\\text{free air}\end{matrix}\right\} = \left.\begin{matrix}\text{Volume}\\\text{comp. air}\end{matrix}\right\} \times (0.068\ p + 1)$$

p being the gauge pressure in lbs. per sq. inch.

EXAMPLE.

Find the equivalent in free air of 78 cu. ft. compressed air at 2,500 lbs. pressure per sq. inch.

$$\begin{aligned}\text{Free air} &= 78 \left\{ (0.068 \times 2500) + 1 \right\} \\ &= 78 \quad (170 + 1) \\ &= 13338 \text{ cubic feet.}\end{aligned}$$

A correspondent writes:

"Could you give me any advice or tell me if a triple expansion or a heavy duty Corliss engine can be run by compressed air the same as with steam? By answering the above, you will confer a favor."

An engine operated by steam can be operated advantageously by compressed air, if such power is available. However, certain points must be taken into consideration. If a single cylinder engine is operated by compressed air, it is always advisable to reheat the air, say to 300 degrees at least, before utilizing the same. For a compound engine of any type, a reheater will be required to reheat the air before entering the high pressure cylinder, and as the air will lose a considerable amount of heat, on account of expansion in the high pressure cylinder, this loss of heat being proportional to the degree of expansion, a second reheater will be required between the high and low pressure cylinders, not only to increase the volume of air exhausted by the high pressure cylinder, but also in order to raise its temperature, as the final temperature of low pressure cylinders of compound engines, in many cases, would be below zero, and under such conditions proper lubricating could not be obtained. It would in no case be advisable to operate triple expansion steam engines by compressed air, as the low pressure cylinder of a triple expansion engine derives its power almost entirely from the vacuum of the condenser, the mean effective pressure of a low pressure cylinder of a triple expansion engine being generally two or three pounds below the atmosphere, vacuum not taken into consideration. However, special triple expansion engines could be built to operate by compressed air, but a special ratio of cylinders would have to be established, and the initial air pressure to operate such an engine would have to be at least 300 pounds to the square inch, while no gain in economy would be obtained over the compound engine worked by air, provided the compound engine cylinders would be of such proportion as to obtain an atmospheric terminal pressure in low pressure cylinder.

A correspondent writes:

I desire to submit the following questions to be answered through the columns of Compressed Air:

First.—Is there any difficulty in transmitting compressed air and reheating it for power purposes?

Second.—Does the back pressure from expansion in the reheater interfere with the flow of the air through the pipe leading to the reheater?

Third.—Can compressed air be forced through a reheater at as low a pressure as from 30 to 45 pounds per square inch?

Question I.—Compressed air may easily be transmitted and reheated at the end of the line or at any point along the line for power purposes. This has been done for years past on large scales in Paris. Another case on a large scale is the transmission plant at the Chapin Mines, Quinnesec Falls, Mich.

Another case is that of Jerome Park, N. Y., where a central plant is located and air transmitted in different directions and used for driving rock drills, pumps, etc.

The difficulty in transmitting compressed air long distances arises only when large volumes of air are transmitted. In these cases the size of pipe and the nature of the country over which the pipe is to be laid must receive attention, and careful figuring only can determine whether it is best under certain conditions to transmit pneumatically or electrically. Electric transmission long distances and in large power units may be more easily and more economically installed where the nature of the country is rough and mountainous, and where the distance is great, say from five to ten miles or more. In such cases it is usual to transmit electrically at high pressure, thus calling for a conduit of moderate dimensions and comparing favorably with the large compressed air pipes. The high-pressure electric current is reduced to low-pressure at the work. Compressed air, too, may be transmitted at high pressures and used, but this calls for extra heavy pipes and careful protection against leakages through expansion and contraction. Each case should be considered by itself, and a comparison of figures made, based on the conditions as they exist.

Question II.—There is no back pressure due to reheating at the end of a pipe line. The reheater expands the air and causes a reduction in the velocity of flow from the compressor to the reheater. Each pipe line is proportioned in diameter of conduit to the velocity of flow, which is dependent on the volume and the pressure, thus a reheater used on the end of a line may admit of a smaller diameter of conduit because it thins out the compressed air, reducing its density, and as the pressure remains the same it practically enables the user to do more work with a definite given volume of compressed air at normal temperature.

Question III.—Compressed air is not necessarily forced through a reheater; it passes through naturally, and at a velocity dependent on its pressure and upon the construction of the heater. These heaters as commonly constructed might do good work with compressed air at a pressure as low as ten pounds per square inch.

A very practical and simple method of determining the quantity of air used by various pneumatic tools is followed by the United States Metallic Packing Company, of Philadelphia, Pa. A belt compressor is run at a fixed speed and as many tools of each size are connected on the compressor as it would maintain under the pressure shown in the column; then taking the total capacity of the compressor and dividing by the number of tools attached to it, the result is obtained. The following table will show the result of a test recently made:

NAME OF HAMMER.	Size of Piston.	Pressure.	Cub. ft. of free air per minute.	H. P. required.
	Inches.			
A. V	1 3-16	80 lbs.	13	1.70
B. S	1⅛	35-40 lbs.	8	.75
C. S	1	35-40 lbs.	4	.3748
D. S	⅞	35-40 lbs.	3.57	.3345
Other tool about capacity of A. V		80 lbs.	26	3.40

ALPHABETICAL LIST OF INVENTIONS.

APPLIANCE.	NAME OF INVENTOR.	DATE OF ISSUE.	NO.
Air Bath	S. M. Laudis	May 14, 1867	64,677
Air Blast Engine	J. Grimm	Oct. 26, 1869	96,223
Air Blower	L. Chase	Aug. 12, 1873	141,762
" "	L. Chase	Sept. 30, 1873	143,329
" "	J. Griffin	Mar. 1, 1859	23,084
Air Brake	Andrews	June 26, 1888	385,224
"	Barber	April 4, 1893	494,772
"	Barnes et al.	Oct. 27, 1891	462,193
"	Bass	Feb. 17, 1885	312,245
"	Bass	Feb. 22, 1887	358,142
"	Bayley	Feb. 17, 1891	Reissue 11,145
"	Bayley	Nov. 6, 1894	528,712
"	Beemer	July 28, 1896	564,863
"	Beery	May 12, 1891	452,334
"	Beery	Nov. 1, 1892	485,365
"	Bentley	Jan. 5, 1897	574,656
"	Bishop	Dec. 25, 1894	531,584
"	Boluss	May 15, 1888	382,749
"	Boluss	Feb. 19, 1889	398,310
"	Boluss	Oct. 29, 1889	414,138
"	Boluss	Sept. 2, 1890	435,791
"	Borbridge et al.	Sept. 18, 1894	526,178
"	Bothwell	July 21, 1891	456,247
"	Boyden	May 25, 1897	583,278
"	Boyden	May 25, 1897	583,279
"	Bragg et al.	Nov. 9, 1897	593,531
"	Brockway et al.	Sept. 19, 1882	264,617
"	Brookmire	April 21, 1896	558,670
"	Brown	May 22, 1894	520,391
"	Buckpitt	Sept. 14, 1897	589,957
"	Burbank et al.	May 20, 1890	428,299
"	Carpenter	Mar. 22, 1887	359,953
"	Carpenter	Feb. 28, 1888	378,657
"	Carpenter	July 26, 1892	479,736
"	Catlett	Jan. 25, 1898	598,814
"	Chadwick	Aug. 1, 1876	180,460
"	Champion	Feb. 3, 1874	147,225
"	Christensen	Feb. 26, 1895	534,813
"	Clark	July 10, 1894	522,825
"	Clarke	Nov. 12, 1895	549,703
"	Clifton	Dec. 18, 1894	531,100
"	Clowry	June 7, 1898	605,394
"	Coates	Feb. 2, 1892	467,920
"	Coates	Feb. 2, 1892	467,921
"	Collins	April 2, 1889	400,638
"	Collins	April 2, 1889	400,639
"	Conness	June 4, 1895	540,539
"	Conness	Aug. 3, 1897	587,519
"	Corporan	Oct. 4, 1892	483,802
"	Corrington	Nov. 30, 1897	594,464
"	Custer	Jan. 21, 1896	553,481

APPLIANCE.	NAME OF INVENTOR.	DATE OF ISSUE.	NO.
Air Brake........................	Custer	Jan. 21, 1896	553,482
"	Daellenbach	Nov. 12, 1889	415,162
"	Daellenbach	Dec. 2, 1890	442,019
"	Dean	Dec. 19, 1893	511,071
"	L. H. Develley.....	Nov. 28, 1865	51,158
"	Dickson	Oct. 7, 1884	306,140
"	Dixon	May 1, 1888	382,031
"	Dixon	Sept. 18, 1888	389,643
"	Dixon	April 30, 1889	402,418
"	Dixon	Oct. 1, 1889	412,168
"	Dixon	Dec. 31, 1889	418,506
"	Dodd	Nov. 10, 1891	462,966
"	Dunn	April 19, 1892	473,302
"	Dunn	Jan. 10, 1893	489,527
"	Dunn	Sept. 17, 1895	546,510
"	Dunn	Jan. 28, 1896	553,517
"	Dunn	Sept. 1, 1896	56[illegible]24
"	Dunn	Feb. 23, 1897	57[illegible]425
"	Duval	Nov. 22, 1892	486,703
"	Duval	Dec. 12, 1893	510,635
"	Duval	Dec. 12, 1893	510,870
"	Dwelly	Nov. 28, 1865	51,158
"	Eames	May 10, 1881	241,323
"	Eames	May 10, 1881	241,325
"	Easton	Dec. 7, 1886	354,014
"	Edwards	Oct. 23, 1894	527,838
"	Eldridge	Oct. 9, 1894	527,327
"	Erdody	Dec. 12, 1893	510,594
"	Fahrney	Nov. 1, 1892	485,182
"	Feruley et al......	Jan. 21, 1896	553,498
"	Fish	Nov. 23, 1897	593,996
"	Flad	April 8, 1884	296,546
"	Flad	Nov. 4, 1884	307,535
"	Flad	Nov. 4, 1884	307,536
"	Fogelberg	May 28, 1872	127,332
"	C. Fogelberg......	May 28, 1872	1[illegible]7,332
"	Ford	Oct. 31, 1882	[illegible]06,684
"	Ford	Mar. 27, 1883	Reiss[illegible]
"	Fox	Dec. 18, 1894	
"	Fox	Dec. 18, 1894	1.70
"	Fox	Dec. 18, 1894	.75
"	French	Jan. 29, 189[illegible]	.3748
"	Genett	Mar. 24, 189[illegible]	.3345
"	Glass	Oct. 20, 189[illegible]	3.40
"	Glenn	Nov. 9, 188[illegible]	
"	Goode	Nov. 30, 18[illegible]	
"	Graebing	Oct. 20, 18[illegible]	
"	Gray	Feb. 22, 18[illegible]	
"	Green et al........	Dec. 11, 18[illegible]	
"	Green	Dec. 30, 1[illegible]	
"	Guels	June 19, 1[illegible]	
"	Guels	June 19, [illegible]	
"	Guels	April 15, [illegible]	
"	Guillemet	Sept. 30, [illegible]	

APPLIANCE.	NAME OF INVENTOR.	DATE OF ISSUE.	NO.
Air Brake......................	Guillemet	Sept. 6, 1892	482,040
"	Guillemet	Nov. 10, 1896	571,115
"	Guillemet	Nov. 10, 1896	571,116
"	Gunckel	May 11, 1897	582,391
"	Gunckel	Mar. 29, 1898	601,253
"	Haberkorn	Feb. 2, 1886	335,446
"	Haberkorn	Mar. 5, 1889	398,829
"	Haberkorn	Oct. 22, 1889	413,253
"	Haberkorn	Dec. 18, 1894	531,181
"	Hall	Aug. 17, 1880	231,311
"	Hall	Dec. 29, 1896	574,062
"	Hamar et al.......	Mar. 15, 1898	600,641
"	Hanney	June 14, 1892	476,880
"	Hanscom	Oct. 10, 1882	265,671
"	Hanscom	Sept. 22, 1885	326,646
"	Hanscom	Aug. 30, 1887	369,057
"	Harris	Dec. 16, 1890	442,621
"	Harris	April 5, 1892	472,190
"	Harris	Feb. 20, 1894	515,220
"	Harris	Mar. 13, 1894	516,202
"	Harris	Aug. 6, 1895	544,253
"	Harris	Oct. 1, 1895	547,253
"	Harris	Nov. 17, 1896	571,662
"	Harvey	Feb. 21, 1888	378,365
"	Hayden	Aug. 30, 1892	481,651
"	Hayden	Dec. 5, 1893	509,898
"	Herbert	Nov. 24, 1896	572,009
"	Herder	April 14, 1896	558,174
"	Higgins	Aug. 8, 1893	503,083
"	High	Mar. 3, 1896	555,809
"	Hinckley	Nov. 14, 1893	508,421
"	Hogan	July 29, 1890	433,127
"	Hogan	Aug. 5, 1890	433,594
"	Hogan	Aug. 5, 1890	433,595
"	Hogan	Mar. 3, 1891	447,731
"	Hogan	April 26, 1892	473,839
"	Hogan	Sept. 6, 1892	482,058
"	Hogan	Sept. 17, 1895	546,448
"	Hogan	Sept. 17, 1895	546,449
"	Hogan	Dec. 17, 1895	551,440
"	Hogan	Dec. 24, 1895	551,767
"	Hogan	Jan. 5, 1897	574,866
"	Holleman	June 25, 1889	405,705
"	Hollerith	Jan. 12, 1886	334,020
"	Hollerith	Jan. 12, 1886	334,021
"	Hollerith	Jan. 12, 1886	334,022
"	Hopper	July 14, 1885	321,971
"	Hopper	June 10, 1890	430,024
"	Hopper	Sept. 1, 1891	458,626
"	Howe et al........	Sept. 8, 1896	567,476
"	Humbert et al.....	May 21, 1895	539,430
"	Hunt	Nov. 13, 1894	529,270
"	Hunt	Aug. 27, 1895	545,295
"	Hunt	May 4, 1897	581,912
"	James	July 6, 1875	165,235
"	James	Feb. 24, 1891	447,236

APPLIANCE.	NAME OF INVENTOR.	DATE OF ISSUE.	NO.
Air Brake	James	Oct. 13, 1891	461,243
"	James	Aug. 21, 1894	524,990
"	Jeffries	Jan. 23, 1894	513,267
"	Jeffries	Nov. 26, 1895	550,346
"	Jones	Aug. 3, 1875	166,386
"	Juul	Nov. 3, 1896	570,483
"	Keywood	July 4, 1893	500,910
"	Kholodkowski	Mar. 15, 1898	600,537
"	Knapp	June 4, 1878	204,440
"	Kneeland	Oct. 26, 1886	351,383
"	Knudsen	Feb. 9, 1892	468,387
"	Knudsen	Sept. 4, 1894	525,686
"	Ladd	July 6, 1875	165,337
"	Lansberg	July 24, 1888	386,640
"	Lansberg	Nov. 13, 1888	392,872
"	Lansberg	Nov. 19, 1889	415,513
"	Lansberg	Nov. 19, 1889	415,514
"	Lansberg	Nov. 19, 1889	415,515
"	Lansberg	Nov. 19, 1889	415,516
"	Lansberg	Nov. 19, 1889	415,517
"	Lansberg	Oct. 28, 1890	439,528
"	Lansberg	Feb. 3, 1891	445,899
"	Lansberg	Mar. 20, 1894	516,936
"	Lapish	Mar. 12, 1889	399,420
"	Lee	Mar. 31, 1896	557,511
"	Lee	Mar. 31, 1896	557,512
"	Lee	Mar. 31, 1896	557,513
"	Lee	Mar. 31, 1896	557,514
"	Lee	Mar. 31, 1896	557,515
"	Lehy	April 17, 1888	381,392
"	Lencke et al	April 10, 1894	517,954
"	Lencke	April 10, 1894	517,955
"	Lewis	May 29, 1888	383,819
"	Lewis	Sept. 3, 1889	410,288
"	Lindsey	June 9, 1896	561,596
"	Lorraine	Aug. 23. 1881	246,166
"	Loughridge	Nov. 9, 1880	234,134
"	Luce	Sept. 10, 1872	131,286
"	T. Luce	Sept. 10, 1872	131,286
"	Mable	Sept. 18, 1894	526,189
"	Mable	Dec. 8, 1896	572,553
"	Magowan	Feb. 12, 1884	293,481
"	Maher	Aug. 5, 1890	433,737
"	Marble	Oct. 11, 1892	484,034
"	Mark	Nov. 4, 1884	307,561
"	Marsh	Jan. 15, 1889	396,284
"	Marshall	July 21, 1891	456,199
"	Marshall	May 26, 1896	560,730
"	Martin	Sept. 30, 1890	437,218
"	Massey	Nov. 12, 1889	414,717
"	Massey	Mar. 10, 1891	447,783
"	Massey	April 28, 1891	451,409
"	Massey	July 4, 1893	501,016
"	Massey	Mar. 19, 1895	535,844
"	Massey	April 9, 1895	537,057
"	Masterman	Aug. 29, 1893	504,227

APPLIANCE.	NAME OF INVENTOR.	DATE OF ISSUE.	NO.
Air Brake	Maxwell	Aug. 20, 1878	207,126
"	Maxwell	June 25, 1889	405,968
"	McAvoy	April 29, 1873	138,339
"	H. L. McAvoy	April 29, 1873	138,339
"	McCarty	Nov. 13, 1894	529,290
"	McIntosh	Aug. 31, 1897	589,265
"	McKinney	Jan. 27, 1885	311,196
"	McNulta	Mar. 29, 1892	471,801
"	Melson	Nov. 23, 1886	352,927
"	Mills	June 7, 1892	476,546
"	Mills	April 16, 1894	537,784
"	Moschcowitz	Aug. 27, 1875	166,026
"	Nef	April 12, 1898	602,094
"	Nellis et al	Nov. 23, 1897	594,033
"	Newton	April 16, 1878	202,368
"	Norris	Oct. 22, 1889	413,205
"	Noyes	Jan. 28, 1896	553,565
"	Noyes	July 21, 1896	564,389
"	Noyes	Nov. 10, 1896	571,095
"	Noyes	Nov. 10, 1896	571,786
"	Noyes	Feb. 22, 1898	599,348
"	Noyes	Feb. 22, 1898	599,349
"	O'Hara	May 8, 1894	519,681
"	Olin	Feb. 8, 1898	598,678
"	Omick	July 7, 1896	563,612
"	Omick	Aug. 24, 1897	588,913
"	Osgood	Mar. 4, 1879	212,972
"	Paradise	Feb. 19, 1884	293,774
"	Park	June 26, 1888	385,198
"	Park	Dec. 4, 1888	393,784
"	Park	July 23, 1889	407,445
"	Park	June 9, 1896	561,811
"	Park	June 21, 1898	605,904
"	Park	June 21, 1898	605,905
"	Parke et al	Oct. 3, 1893	506,185
"	Pelton	Sept. 13, 1892	482,382
"	Perkins	July 13, 1886	345,537
"	Perkins	Feb. 8, 1898	598,887
"	Perrine	Aug. 3, 1875	166,404
"	Perrine	Aug. 3, 1875	166,405
"	Perrine	Aug. 3, 1875	166,406
"	Perrine	Nov. 2, 1875	169,575
"	Pettengell	Jan. 11, 1898	597,220
"	Pickering	Jan. 19, 1886	334,466
"	Pinkston	July 11, 1893	501,359
"	Pool et al	June 13, 1893	499,582
"	Prince	June 18, 1878	204,914
"	Pritchard et al	Mar. 5, 1889	399,157
"	Pritchard et al	Mar. 5, 1889	399,158
"	Pritchard	Sept. 10, 1889	410,922
"	Raoul	May 14, 1878	203,647
"	Redfern	June 15, 1897	584,705
"	Reilly	Dec. 18, 1883	290,269
"	Reniff	Oct. 10, 1876	183,206
"	Reyburn	Oct. 6, 1896	568,923
"	Richardson	Jan. 23, 1894	513,145

APPLIANCE.	NAME OF INVENTOR.	DATE OF ISSUE.	NO.
Air Brake	Riggs	Aug. 4, 1891	457,215
"	Roberts	July 29, 1890	433,040
"	Robinson	Oct. 7, 1890	437,800
"	Rogers et al.	Jan. 21, 1896	553,294
"	Rothschild	Feb. 27, 1894	515,616
"	Rothschild	Feb. 27, 1894	515,617
"	Rymer	Dec. 10, 1889	416,953
"	Schenck	Aug. 7, 1894	524,073
"	Schenck	Dec. 18, 1894	531,137
"	Schenck	Jan. 22, 1895	532,914
"	Schroyer	April 22, 1890	426,144
"	Schultz	Sept. 30, 1879	220,178
"	Sennett et al.	Jan. 10, 1893	489,763
"	Sennett et al.	Mar. 19, 1895	536,000
"	Shallenberger	Oct. 17, 1893	506,739
"	Shearwood	Jan. 5, 1897	574,498
"	Shortridge	Mar. 2, 1897	578,168
"	Shortt	Feb. 16, 1892	469,176
"	Shortt	Dec. 11, 1894	530,904
"	Shortt	April 30, 1895	538,544
"	Shortt et al.	April 30, 1895	538,546
"	Shortt	April 30, 1895	538,547
"	Shortt	April 30, 1895	538,549
"	Shortt	April 30, 1895	538,551
"	Silcock	Feb. 9, 1892	468,701
"	Sjogren	June 17, 1884	300,401
"	Slater	May 26, 1891	452,942
"	Sloan	Oct. 28, 1884	307,344
"	Sloan	Sept. 29, 1885	327,027
"	Sloan	Nov. 10, 1885	330,164
"	Solano	Jan. 24, 1888	376,970
"	Solano	Feb. 28, 1888	378,628
"	Solano	May 8, 1888	382,667
"	Solano	July 31, 1888	387,018
"	Solano	June 25, 1889	405,855
"	Solano	June 25, 1889	406,006
"	Steedman	July 16, 1895	542,948
"	Steger	Aug. 11, 1874	......
"	Stevens	May 29, 1877	191,261
"	Stewart	Jan. 28, 1890	420,121
"	Stewart	Mar. 27, 1894	517,250
"	Thayer et al.	Aug. 21, 1883	283,534
"	Thompson	Sept. 3, 1895	545,749
"	Thompson	Nov. 17, 1896	571,708
"	Tower et al.	April 30, 1895	538,299
"	Trapp	July 6, 1897	585,927
"	Trott	Mar. 19, 1895	536,002
"	Van Dusen	Dec. 26, 1882	269,747
"	Voorhees	Aug. 7, 1894	524,050
"	Voorhees	Sept. 11, 1894	525,876
"	Waite	Nov. 10, 1891	463,085
"	Walker	Oct. 7, 1890	438,038
"	Walker et al.	Oct. 13, 1896	569,258
"	Wands	May 17, 1898	604,244
"	Ward	Jan. 30, 1872	123,312
"	T. O. Ward	Jan. 30, 1872	123,312

APPLIANCE.	NAME OF INVENTOR.	DATE OF ISSUE.	NO.
Air Brake..........................	Wessels et al......	Oct. 22, 1895	548,335
"	Westinghouse	April 13, 1869	88,929
"	Westinghouse	Jan. 23, 1872	123,067
"	Westinghouse	Mar. 5, 1872	124,404
"	Westinghouse	Mar. 5, 1872	124,405
"	Westinghouse	Oct. 28, 1873	144,005
"	Westinghouse	Oct. 27, 1874	156,323
"	Westinghouse et al.	April 27, 1875	162,465
"	Westinghouse	April 11, 1876	175,886
"	Westinghouse	July 25, 1786	180,179
"	Westinghouse	April 22, 1879	214,603
"	Westinghouse	June 28, 1881	243,415
"	Westinghouse	Aug. 2, 1881	245,109
"	Westinghouse	Aug. 2, 1881	245,110
"	Westinghouse	Jan. 9, 1883	270,528
"	Westinghouse	Mar. 29, 1887	360,070
"	Westinghouse	Feb. 18, 1890	421,641
"	Westinghouse	Mar. 24, 1891	448,827
"	Westinghouse et al.	Oct. 20, 1891	461,779
"	Westinghouse	Mar. 31, 1896	557,464
"	Westinghouse et al.	Oct. 26, 1897	592,461
" and Signal.............	G. Westinghouse..	Jan. 23, 1872	123,067
"	G. Westinghouse..	Mar. 5, 1872	124,404
"	G. Westinghouse..	Mar. 5, 1872	124,405
"	G. Westinghouse..	Oct. 28, 1873	144,005
"	Wheeler	Sept. 24, 1895	546,835
"	White	April 23, 1895	538,002
"	Willets	June 2, 1896	561,301
"	Williams	Dec. 4, 1888	393,950
"	Williams	July 1, 1890	431,303
"	Williams	July 1, 1890	431,304
"	Williams	July 8, 1890	431,790
"	Williams	Nov. 18, 1890	Reissue 11,124
"	Williams	Nov. 25, 1890	441,526
"	Willis	Aug. 19, 1884	303,777
"	Willson	Mar. 20, 1894	516,692
"	Winters	Nov. 23, 1897	594,228
"	Wisner	Jan. 26, 1886	335,094
"	Wisner	Feb. 24, 1891	446,908
"	Zenke	Nov. 17, 1896	571,736
Air Chamber......................	R. Creuzbaur......	June 18, 1801	32,595
Air Compressor	Allen	Feb. 8, 1881	237,359
"	Allen	Feb. 8, 1881	237,360
"	Allen	May 27, 1884	299,314
"	W. Arthur........	July 25, 1865	48,886
"	Avery	Sept. 20, 1892	482,775
"	B. T. Babbitt......	May 17, 1870	103,121
"	B. T. Babbitt......	Nov. 12, 1872	133,004
"	Babbitt	Dec. 11, 1877	198,067
"	Babcock	Feb. 21, 1882	253,830
"	Babcock	July 10, 1883	280,997
"	Babcock	Oct. 23, 1883	287,358
"	Babcock	July 17, 1894	523,064
"	Bailey	Mar. 23, 1875	161,090
"	Baker	June 20, 1882	259,741

APPLIANCE.	NAME OF INVENTOR.	DATE OF ISSUE.	NO.
Air Compressor	Beck	June 7, 1892	476,723
"	Beers	Dec. 12, 1882	268,854
"	Bennett	Aug. 28, 1883	283,955
"	Bicknell	Feb. 27, 1883	273,014
"	Birner & Messing	May 29, 1894	520,405
"	Blake	Feb. 12, 1895	534,192
"	Boerner	Mar. 29, 1881	239,310
"	Bois	May 25, 1880	227,877
"	Bois	June 20, 1882	259,799
"	Bolton	Mar. 24, 1885	314,218
"	Bradley	Mar. 14, 1882	254,915
"	Brislin	Aug. 5, 1884	302,978
"	Brotherhood	Feb. 20, 1894	515,282
"	Buell	Nov. 23, 1880	234,751
"	Buell	Sept. 6, 1881	246,657
"	Carobbi & Bellini	Jan. 26, 1875	159,075
"	Chamberlain	Jan. 10, 1888	376,141
"	Champ	Jan. 30, 1894	513,556
"	Champ	Feb. 27, 1894	515,516
"	Champ	July 31, 1894	523,830
"	Champ	Aug. 13, 1895	544,456
"	Champ	Aug. 13, 1895	544,457
"	Champ	Aug. 13, 1895	544,458
"	Champ	Aug. 13, 1895	544,459
"	Champ	Oct. 15, 1895	547,768
"	Champ	Nov. 3, 1896	570,540
"	Chaquette	Oct. 29, 1895	548,800
"	Chaquette	Aug. 11, 1896	565,429
"	Chase	June 9, 1874	151,753
"	Chichester	Nov. 18, 1884	308,061
"	Chichester	Jan. 12, 1886	333,994
"	Chichester	Sept. 27, 1887	370,376
"	Clark	June 2, 1891	453,374
"	Clark	April 14, 1896	558,041
"	Clayton	Jan. 16, 1877	186,306
"	Clayton	Sept. 30, 1879	220,123
"	Clayton	Nov. 25, 1879	222,014
"	Clayton	May 24, 1881	241,930
"	Clayton	Feb. 26, 1895	534,814
"	Connor & Dods	Oct. 5, 1880	232,939
"	Corey	Jan. 20, 1885	311,106
"	Crabtree	Nov. 30, 1897	594,524
"	Crocker	May 2, 1876	176,931
"	Cullen	Nov. 4, 1884	307,442
"	Cullingworth	Oct. 23, 1883	287,104
"	Cullingworth	Dec. 28, 1886	355,002
"	Cullingworth	Feb. 7, 1888	377,481
"	Cummings	May 24, 1887	363,509
"	Cummings	Oct. 8, 1889	412,474
"	Cushier	Mar. 25, 1881	236,992
"	Davey	Aug. 27, 1889	409,773
"	Dean	Mar. 27, 1888	380,195
"	Deeds	June 30, 1874	152,468
"	DeLaval	Dec. 19, 1893	511,086
"	Depp	Jan. 5, 1886	333,613
"	Dillenburg	Aug. 30, 1892	481,850

APPLIANCE.	NAME OF INVENTOR.	DATE OF ISSUE.	NO.
Air Compressor	Doremus	Sept. 10, 1878	207,954
"	Dow	May 4, 1886	341,099
"	Dreyfus	Mar. 5, 1878	200,901
"	DuFaur	June 2, 1896	561,160
"	Duffy	Oct. 1, 1895	547,338
"	F. S. Dumont	April 27, 1869	89,390
"	Dunn	April 19, 1892	473,302
"	Durand	Nov. 19, 1895	550,163
"	Dyer	June 22, 1897	585,090
"	Eckart	Feb. 3, 1880	224,081
"	Ehlers	July 1, 1884	301,348
"	Elliott	Sept. 29, 1896	568,433
"	Ellis	Feb. 17, 1874	147,623
"	Eloheimo	Aug. 26, 1890	435,034
"	G. D. Emerson	Aug. 20, 1872	130,627
"	J. Ericsson	Dec. 30, 1873	146,055
"	Erwin	Oct. 27, 1885	329,377
"	Erwin	Dec. 29, 1885	333,208
"	Erwin	April 20, 1886	340,496
"	Erwin	May 15, 1888	382,760
"	Farrell	July 19, 1892	479,260
"	Fasoldt	Aug. 23, 1892	481,527
"	Fauntleroy	April 28, 1874	150,312
"	Fevrot	Feb. 16, 1886	336,224
"	Fitzpatrick	Mar. 1, 1881	238,374
"	Fitzpatrick	April 30, 1889	402,517
"	Flindall	July 6, 1897	585,955
"	Flood	May 8, 1894	519,383
"	Fogg	Mar. 14, 1893	493,263
"	Forster	Jan. 3, 1888	375,929
"	Forster	Jan. 17, 1888	376,589
"	Forster	June 12, 1888	384,356
"	Fox	Sept. 25, 1883	285,743
"	Fox	June 30, 1885	321,206
"	Fox	June 30, 1885	321,207
"	Freeman	Mar. 1, 1881	238,225
"	Freeman	Dec. 25, 1883	290,764
"	Frizell	Jan. 29, 1878	199,819
"	Fulton	May 16, 1876	177,495
"	Funk	Dec. 24, 1889	417,717
"	Gardner	Nov. 18, 1879	221,802
"	Garrison	Jan. 16, 1877	186,336
"	Githens	July 7, 1896	563,477
"	Griffiths et al	Dec. 4, 1894	530,335
"	Griffiths et al	Oct. 15, 1895	547,882
"	Griffiths et al	Feb. 2, 1897	576,364
"	Guillemet	Sept. 6, 1892	482,040
"	Gustafson	Nov. 21, 1893	509,220
"	Guthrie	Dec. 17, 1889	417,482
"	Guyser	May 26, 1896	560,987
"	Haines	Mar. 15, 1892	470,934
"	Haines	Aug. 2, 1892	480,193
"	Hanford	May 3, 1892	474,296
"	Hanston & Burdan	Mar. 29, 1892	471,766
"	Harrold	July 20, 1886	345,969
"	Harvey	Jan. 21, 1879	211,570

APPLIANCE.	NAME OF INVENTOR.	DATE OF ISSUE.	NO.
Air Compressor................	Henderson & Schultz	May 17, 1892	475,111
"	Hill	Jan. 4, 1876	171,805
"	Hill	July 13, 1880	229,821
"	Hill	Feb. 1, 1881	237,274
"	Hill	June 21, 1881	243,257
"	Hill	July 12, 1881	244,127
"	Hill	July 12, 1881	244,128
"	Hill	July 25, 1882	261,605
"	Hill	July 25, 1882	261,606
"	Hill	Feb. 5, 1884	292,814
"	Hill	Mar. 24, 1891	448,859
"	Hill	Nov. 4, 1891	448,876
"	Hill	May 12, 1891	452,132
"	Hill	June 23, 1891	454,590
"	Hill	Nov. 17, 1891	463,386
"	Hill	Nov. 24, 1896	571,971
"	Hill	Nov. 2, 1897	593,049
"	Honigmann	Nov. 13, 1883	288,435
"	Hudson	May 24, 1881	241,984
"	Hugentobler	June 1, 1886	342,798
"	Hunter	Nov. 13, 1888	392,611
"	Hutchinson	Aug. 16, 1892	581,143
"	Jackson	July 29, 1879	218,029
"	Johnson	Sept. 21, 1886	349,954
"	Johnston	Jan. 27, 1874	146,909
"	Johnston	Nov. 4, 1879	221,318
"	Kalthoff	Dec. 17, 1895	551,549
"	Keenan	June 12, 1888	384,529
"	Keenan	Oct. 8, 1895	547,519
"	Knight	July 13, 1897	586,100
"	Knoche	Nov. 7, 1893	508,225
"	Krutsch	July 15, 1884	302,206
"	Laurence	Jan. 25, 1876	172,751
"	Lawler	Feb. 20, 1883	272,711
"	Lawrence et al.....	April 27, 1880	226,918
"	Leavitt	June 23, 1885	320,482
"	Liming	Oct. 20, 1896	569,929
"	Livingston	May 24, 1881	242,008
"	Lowe & Guyser....	Feb. 19, 1895	534,399
"	Manning	April 11, 1882	256,232
"	Manz	May 2, 1876	176,795
"	Massey	Aug. 12, 1890	433,951
"	Mayrhofer	Jan. 18, 1881	236,713
"	Mayrhofer	July 25, 1882	261,560
"	McKim	Jan. 3, 1888	375,761
"	McLean	May 11, 1886	341,673
"	Merritt	June 23, 1896	562,475
"	Middleton	Sept. 22, 1874	155,328
"	J. B. Mignon......	Mar. 19, 1867	63,075
"	Miles	Oct. 5, 1897	591,137
"	Monson	May 16, 1882	257,885
"	Monson	Oct. 20, 1885	328,598
"	Moore	June 3, 1879	216,211
"	Moore	Sept. 18, 1883	285,297
"	Moore	Dec. 23, 1884	309,642
"	Moyer	July 2, 1895	541,979

APPLIANCE.	NAME OF INVENTOR.	DATE OF ISSUE.	NO.
Air Compressor	Nichols	Feb. 25, 1896	555,178
"	Nichols	Aug. 31, 1897	589,190
"	Noack	Nov. 26, 1895	550,352
"	Nordberg	Sept. 1, 1891	458,975
"	Norris	Dec. 30, 1884	310,148
"	North	Oct. 9, 1894	527,248
"	Nosbaume	Nov. 20, 1888	393,172
"	Noyes	July 14, 1896	563,794
"	O'Brien	June 21, 1892	477,381
"	Overton	Aug. 22, 1882	263,206
"	Overton	Aug. 22, 1882	263,207
"	R. S. Pardée	Oct. 14, 1873	143,634
"	Parkinson	April 18, 1865	47,328
"	J. S. Patric	Oct. 17, 1871	120,094
"	J. S. Patric	Mar. 2, 1880	225,151
"	Pedrick	Aug. 13, 1895	544,548
"	Pendleton	June 2, 1896	561,126
"	Perine	April 13, 1897	580,714
"	Perry	Nov. 8, 1892	485,881
"	Perry	June 6, 1893	498,989
"	Pfanne	Mar. 25, 1884	295,800
"	Phillips	May 12, 1891	452,283
"	Pitchford	May 20, 1879	215,540
"	Pitchford	Oct. 19, 1880	233,432
"	Pitt	July 10, 1888	386,028
"	Quast	July 4, 1893	501,046
"	Quinn	Jan. 11, 1881	226,455
"	Rand	Mar. 21, 1882	255,116
"	Rand & Halsey	Feb. 18, 1890	421,611
"	Reynolds	Mar. 16, 1875	160,956
"	Reynolds	Feb. 27, 1877	187,906
"	Reynolds	Aug. 1, 1882	262,119
"	Reynolds	Feb. 20, 1883	272,771
"	Reynolds	Feb. 21, 1888	378,336
"	Reynolds	Dec. 1, 1896	572,377
"	Richards	Nov. 10, 1891	462,776
"	Richmann	June 29, 1880	229,468
"	Richmann	Sept. 15, 1891	459,527
"	Richmann	Nov. 3, 1891	462,453
"	Rix	Dec. 7, 1880	235,296
"	Rix	Dec. 21, 1880	235,816
"	Roberts	Dec. 1, 1896	572,314
"	Robinson & Kiser	Oct. 11, 1881	248,218
"	Root	Oct. 16, 1877	196,253
"	Sawtell	Oct. 24, 1876	183,596
"	Schutzinger	Nov. 7, 1893	508,150
"	Schutz & Henderson	April 3, 1894	517,628
"	Seal	Mar. 14, 1876	174,860
"	Seal	Sept. 19, 1876	182,333
"	Sergeant	Nov. 2, 1880	233,881
"	Sergeant	Sept. 19, 1882	264,775
"	Sergeant	Nov. 26, 1889	415,822
"	Sergeant	Mar. 10, 1891	447,910
"	Sergeant	July 21, 1891	456,165
"	Sergeant	Feb. 13, 1894	514,839
"	Sergeant	Dec. 11, 1894	530,662

APPLIANCE.	NAME OF INVENTOR.	DATE OF ISSUE.	NO.
Air Compressor	Sergeant	Oct. 6, 1896	568,804
"	Sergeant	Mar. 30, 1897	579,775
"	Shaw	Jan. 7, 1896	552,590
"	Shedlock	July 20, 1897	586,669
"	Sherman	May 17, 1892	475,251
"	Smith	Dec. 26, 1882	269,730
"	Smith	Dec. 1, 1896	572,383
"	Spencer	April 15, 1879	214,465
"	Spencer	Aug. 17, 1897	588,296
"	Springer	Dec. 17, 1878	211,062
"	Stambaugh	Oct. 22, 1895	548,399
"	Stockman	Nov. 23, 1880	234,733
"	Strange	Nov. 15, 1887	373,419
"	Sturgeon	Aug. 8, 1876	180,958
"	Sturgeon	April 17, 1883	275,959
"	Swartz	May 18, 1886	342,310
"	Tallman	April 11, 1876	176,096
"	Tatham	Dec. 23, 1879	222,802
"	Taylor	July 23, 1895	543,410
"	Taylor	July 23, 1895	543,411
"	Taylor	July 23, 1895	543,412
"	Teal	May 3, 1892	474,034
"	Thomas	July 22, 1879	217,834
"	Thomas	Mar. 2, 1886	337,209
"	Toennes	Feb. 9, 1897	576,920
"	Treat	Oct. 28, 1879	221,126
"	Underwood	April 14, 1896	558,125
"	Walker	Feb. 7, 1893	491,232
"	Wang	Mar. 21, 1882	255,222
"	Wang	April 4, 1882	255,901
"	Wang	Aug. 1, 1882	262,157
"	J. B. Waring	July 16, 1872	129,631
Air Condenser	H. J. Bailey	Jan. 14, 1868	73,283
"	J. Cochrane	July 23, 1872	129,791
"	H. Moore	Mar. 3, 1868	75,042
"	J. S. Patric	Oct. 17, 1871	120,095
Air Cooler and Ice Manufacturer	E. H. Grant	Feb. 16, 1869	87,041
"	T. D. Kingan	July 1, 1873	140,375
"	J. Kraffert	Dec. 27, 1870	110,573
"	N. S. Shaler	May 30, 1865	47,991
"	F. Villard	May 29, 1866	55,180
Air Cushion	J. W. Wetmore	Sept. 2, 1873	142,540
Air Draft	S. Randall	Mar. 12, 1811	no No.
Air Engine	Allen	July 31, 1877	193,631
"	W. Alworth	May 28, 1872	127,137
"	Anderson	April 16, 1895	537,517
"	And'son&Ericksson	Mar. 30, 1897	579,670
"	J. B. Atwater	Mar. 13, 1866	53,097
"	Babcock	Jan. 12, 1886	334,152
"	Babcock	Jan. 12, 1886	334,153
"	Babcock	Jan. 12, 1886	334,154
"	Bair	Sept. 4, 1888	389,045
"	Baldwin	Jan. 22, 1884	292,400
"	Baldwin	June 11, 1889	404,818
"	Baldwin & Bradford	Jan. 4, 1887	355,633
"	Barbour & Hansen	Oct. 12, 1897	591,584

APPLIANCE.	NAME OF INVENTOR.	DATE OF ISSUE.	NO.
Air Engine	Bausman	May 27, 1884	299,325
“	Bausman	Mar. 10, 1885	313,646
“	Beaumont	Sept. 21, 1880	232,438
“	Benster	Nov. 10, 1891	463,092
“	Bercher	April 21, 1896	558,475
“	Bergman	Nov. 10, 1891	463,025
“	Berry	May 11, 1897	582,257
“	D. Bickford	June 6, 1865	48,043
“	Bole	Oct. 26, 1897	592,688
“	Bolton	Mar. 24, 1885	314,218
“	Boynton	Dec. 11, 1883	289,967
“	Bramwell	July 30, 1895	543,462
“	Brock	Aug. 19, 1890	434,422
“	J. R. Cameron	Nov. 12, 1867	70,800
“	Chapman	Feb. 24, 1891	447,066
“	P. Chick	Dec. 18, 1866	60,474
“	Clark	July 24, 1888	386,454
“	Close	July 12, 1887	366,204
“	Coffield	July 21, 1885	322,796
“	Colman	May 5, 1885	317,093
“	Colman	May 12, 1885	317,628
“	Connolly	June 22, 1875	164,809
“	Cook	Jan. 23, 1883	271,040
“	Cook	Feb. 20, 1883	272,656
“	Coon	Mar. 10, 1896	555,929
“	Corey	Jan. 20, 1885	311,106
“	Cramer	Mar. 4, 1884	294,369
“	Davey	Jan. 9, 1877	186,119
“	Denney	April 23, 1895	538,068
“	Depp	June 19, 1894	521,762
“	W. Deukmann	Dec. 16, 1862	37,155
“	Durand	May 9, 1893	497,048
“	Eastman	Dec. 30, 1890	443,641
“	Eckart	June 17, 1879	216,563
“	Eimecke	Jan. 2, 1883	270,036
“	P. A. Ensign	Oct. 2, 1866	58,397
“	Ericsson	Mar. 30, 1880	226,052
“	Ericsson	July 8, 1890	431,729
“	J. Ericsson	Nov. 4, 1851	8,481
“	J. Ericsson	July 31, 1855	13,348
“	J. Ericsson	April 15, 1856	14,690
“	J. Ericsson	Dec. 14, 1858	22,287
“	J. Ericsson	Oct. 9, 1860	30,306
“	Eteve & DeBraan	Dec. 30, 1884	309,835
“	Field	Oct. 10, 1893	506,486
“	Fletcher&Huggings	Oct. 8, 1895	547,718
“	Genty	July 31, 1888	387,063
“	Gibbs	Oct. 26, 1897	592,246
“	Goth	April 13, 1897	580,600
“	Good	May 26, 1896	560,707
“	Good & Marichal	April 28, 1896	558,944
“	Graham	July 22, 1884	302,246
“	Griswold	June 30, 1891	455,201
“	Hall	Aug. 4, 1891	457,272
“	Hall	Aug. 4, 1891	457,273
“	Hanover	Jan. 6, 1885	310,419

APPLIANCE.	NAME OF INVENTOR.	DATE OF ISSUE.	NO.
Air Engine	Hanser & Whittaker	Jan. 3, 1893	489,148
"	Hardie & James	June 17, 1879	216,611
"	Harder	Oct. 14, 1890	438,251
"	Hill	July 13, 1880	229,821
"	O. M. Hillman	June 26, 1860	28,910
"	O. M. Hillman	June 26, 1860	28,911
"	Hock & Martin	May 8, 1877	190,490
"	Humes	April 2, 1889	400,850
"	Hurd	Sept. 8, 1885	325,805
"	Jefferson	Dec. 1, 1891	464,364
"	E. Langen	Aug. 13, 1867	67,659
"	F. J. Laubereau	April 10, 1849	6,301
"	Leavitt	Oct. 28, 1884	307,312
"	Leavitt	July 14, 1885	321,985
"	J. J. Lenoir	Mar. 19, 1861	31,722
"	Limpus	Nov. 10, 1885	329,914
"	Lochmann	Jan. 5, 1886	333,644
"	R. Lord	Sept. 17, 1861	33,308
"	Lyman	Jan. 25, 1881	236,954
"	A. S. Lyman	Feb. 28, 1854	10,576
"	Martin	June 27, 1893	500,340
"	Matthes	April 8, 1879	214,050
"	Maxim	Feb. 5, 1884	293,185
"	McCalla	Feb. 4, 1890	420,824
"	McDonough	May 29, 1883	278,446
"	T. McDonough	Sept. 23, 1856	15,771
"	McKinley	July 30, 1878	206,597
"	McKinley	Jan. 18, 1887	356,146
"	McKinley	Jan. 18, 1887	356,147
"	J. McLeish	Dec. 10, 1872	133,713
"	McTighe	July 7, 1885	321,739
"	McTighe	June 3, 1890	429,281
"	McTighe	June 3, 1890	429,282
"	McTighe	June 3, 1890	429,283
"	H. Messer	Jan. 6, 1863	37,299
"	Metzing	Nov. 18, 1890	441,103
"	Middleton	Sept. 22, 1874	155,328
"	Mihsb'ch & Groeschel	Sept. 1, 1896	566,785
"	Musselman	Aug. 8, 1893	502,860
"	D. Myers	Nov. 15, 1870	109,338
"	J. R. Napier	Sept. 19, 1854	11,696
"	Nash	May 22, 1883	278,257
"	H. Norman	Feb. 25, 1873	136,259
"	H. M. Paine	Nov. 30, 1858	22,219
"	Parke	Dec. 7, 1897	594,901
"	Parsons	Nov. 12, 1895	549,741
"	J. R. Peters	Nov. 18, 1862	36,964
"	Philpott	Mar. 15, 1887	359,282
"	Pollock	April 28, 1885	316,656
"	Presbrey	Aug. 24, 1880	231,446
"	Reynolds	Aug. 1, 1882	262,119
"	B. F. Rice	April 5, 1859	23,495
"	Rider	Jan. 5, 1875	158,525
"	Rider	Sept. 7, 1875	167,568
"	Rider	July 23, 1878	206,356
"	Rider	Oct. 7, 1879	220,309

APPLIANCE.	NAME OF INVENTOR.	DATE OF ISSUE.	NO.
Air Engine	Rider	July 13, 1886	345,450
"	Rider	Nov. 23, 1886	353,004
"	Rider	Nov. 27, 1888	393,663
"	Rider	Nov. 27, 1888	393,723
"	A. K. Rider	Jan. 17, 1871	111,088
"	A. K. Rider	Oct. 24, 1871	120,325
"	Riley	June 29, 1875	165,027
"	Robinson	Dec. 9, 1884	309,163
"	Robinson	Feb. 3, 1891	445,904
"	Roediger	Mar. 30, 1897	579,654
"	Rogers	May 13, 1890	427,911
"	Rogers	Jan. 2, 1894	511,969
"	Rusk	Aug. 18, 1891	458,070
"	Schmid & Beckfeld	May 14, 1889	403,294
"	Schmid & Beckfeld	Feb. 18, 1890	421,525
"	Schnake	Nov. 28, 1876	184,913
"	Schou	Nov. 21, 1893	508,990
"	Serdinko	Feb. 2, 1886	335,388
"	P. Shaw	May 2, 1854	10,868
"	Sherman	Mar. 12, 1895	535,602
"	Sherrill	April 1, 1879	213,783
"	Shilling	June 16, 1885	320,182
"	Smith	Feb. 14, 1893	491,859
"	Stevens	Sept. 16, 1884	305,114
"	Stevens	Oct. 29, 1889	414,173
"	Stewart	May 15, 1894	519,977
"	Tasker	June 7, 1887	364,451
"	Thuemmler	Sept. 28, 1880	232,660
"	Thuemmler	Oct. 12, 1880	233,125
"	Vivian	Sept. 30, 1890	437,320
"	Walling	Aug. 4, 1896	565,191
"	Ward	Jan. 1, 1878	198,827
"	Weimer	Feb. 23, 1897	577,568
"	Wilcox	Dec. 4, 1883	289,481
"	Wilcox	Dec. 4, 1883	289,482
"	Wilcox (re-issue)	June 3, 1884	10,486
"	Wilcox (re-issue)	Oct. 7, 1884	10,529
"	Wilcox	Dec. 15, 1885	332,312
"	A. O. Wilcox	July 19, 1853	9,871
"	S. Wilcox	May 3, 1859	23,876
"	S. Wilcox	Nov. 20, 1860	30,700
"	S. Wilcox	Nov. 20, 1860	30,701
"	S. Wilcox	Sept. 19, 1865	50,061
"	Winchell	April 17, 1888	381,313
"	Wood	Aug. 18, 1885	324,510
"	Woodbury et al.	June 8, 1880	228,712
"	Woodbury et al.	June 8, 1880	228,713
"	Woodbury et al.	June 8, 1880	228,714
"	Woodbury et al.	June 8, 1880	228,715
"	Woodbury et al.	June 8, 1880	228,716
"	Woodbury et al.	June 8, 1880	228,717
"	Woodbury et al.	Aug. 11, 1885	324,060
"	Woodbury et al.	Aug. 11, 1885	324,061
"	Woodbury et al.	Aug. 11, 1885	324,062
"	Woodbury et al.	Sept. 1, 1885	325,640
"	Woodbury et al.	Oct. 6, 1885	327,748

APPLIA …	NAME OF INVENTOR.	DATE OF ISSUE.	NO.
Air Engine	Woodbury et al.	Dec. 1, 1885	331,359
"	Woodbury et al.	Dec. 1, 1885	331,361
"	Woodbury et al.	May 28, 1889	404,237
"	J. A. Woodbury	May 17, 1853	9,739
"	J. A. Woodbury	Oct. 4, 1853	10,081
"	Wright	Aug. 13, 1889	408,784
Air and Gas Engine	A. H. De Villeneuve	Mar. 19, 1872	124,671
" "	D. Dick	April 9, 1867	63,619
" "	J. F. Haskins	July 16, 1872	129,337
" "	O. Trossin	July 22, 1873	141,189
" "	P. Shearer	Sept. 3, 1861	33,215
Air and Liquid Cooler	D. E. Somes	Mar. 29, 1870	101,392
Air and Steam Engine	F. B. Blanchard	July 10, 1855	13,209
" " "	O. M. Hillman	Aug. 9, 1864	4,380
Air-Heating	L. C. St. John	Oct. 7, 1851	8,413
Air and Steam Jet Combustion	G. M. Copeland	Feb. 26, 1867	62,397
Air-Supply and Boilers	G. E. Hibbard	Dec. 16, 1873	145,568
Apparatus for Cooling Air	T. D. Kingan	Dec. 16, 1873	145,659
" " "	D. E. Somes	Nov. 12, 1867	70,909
Apparatus for Navigating the Air	C. McDermott	Nov. 12, 1872	133,046
" " "	W. F. Quinby	Nov. 26, 1861	33,797
" Purifying "	A. S. Lyman	Jan. 19, 1864	41,309
" Removing Dust from the Air	J. D. Whelpley	Mar. 6, 1866	53,068
" Supplying Continuous Flow of Air	B. Rouquarol	Mar. 20, 1866	53,385
" Transmitting Air Power	H. Calf	Aug. 24, 1869	93,964
" " "	H. Calf	Jan. 18, 1870	98,846
Compressed Air Bath	P. T. Ware	May 8, 1866	54,655
" Cylinder	G. M Goodwin	March 1, 1870	100,282
" Engine	D. Bickford	May 15, 1860	28,248
" "	A. Parsey	July 31, 1847	5,205
" "	A. M. Smith	Aug. 8, 1871	117,825
" "	W. M. Storm	Sept. 23, 1851	8,380
" "	W. C. Turnbull	April 17, 1860	27,938
" Heater	H. Bushnell	July 1, 1873	140,466
" Spring	L. Bissel	Oct. 11, 1841	2,307
Fresh Air Apparatus	J. McNeven	Sept. 14, 1869	94,905
Hydraulic Air Compressor	M. Hey	April 26, 1870	102,397
" "	M. Hey	July 25, 1871	117,285
" "	W. D. Leaf	June 14, 1870	104,362
" "	C. Moore	July 1, 1873	140,524
" "	W. E. Prall	Nov. 7, 1871	120,597
Method of Heating Air	A. C. Fletcher	May 19, 1863	38,637
" " "	J. Hollingsworth	June 5, 1860	28,578
Process for Mixing Air and Steam	O. M. Storm	April 5, 1853	9,654

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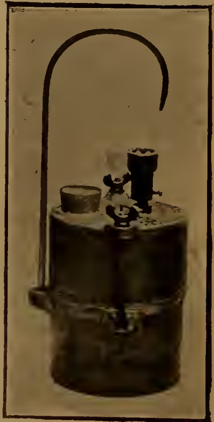

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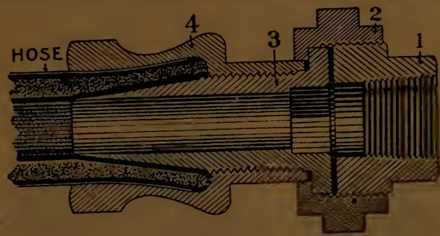

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