AMERICAN
PRODUCER GAS PRACTICE

AND

INDUSTRIAL GAS ENGINEERING

BY

NISBET LATTA

CONSULTING ENGINEER

Author of "American Gas Engineering Practice"
Member of American Gas Institute
Member of American Society of Mechanical Engineers

247 ILLUSTRATIONS

PREFACE

In placing before the American industrial world the following chapters, the author desires to make clear his position.

Where he refers to or describes processes, apparatus or inventions operating under patents or otherwise, he has done so merely to explain the predominant systems and illustrate the respective types of apparatus and appliances which are in successful operation at the present time.

He in no wise specially recommends any apparatus or instrument herein described or referred to, but places before the reader its description, method of operation, or other data for the purpose of giving information and drawing comparisons. To do so, it was necessary to select from the great variety of apparatus at present manufactured, certain examples which might reasonably be assumed as typical of the class which they respectively represent, and which, as nearly as possible, embody and emphasize the characteristics of that class.

It is with the urgent desire to maintain an impartial attitude and to narrate as accurately as possible, without prejudice or undue influence, the various features of gas engineering at present in vogue in the industrial field, that the author has written the following volume.

It has been his desire to, as nearly as possible, avoid strictly scientific and technical language, to put before his readers in simple style producer-gas engineering practice, as applied to everyday operations upon a practical and commercial basis, omitting any theorizing and laboratory results unsuited to actual commercial and manufacturing conditions.

It is his desire to make this handbook readable to the engineer, operator, and promoter, and to this end he has attempted to present in simple and elementary style the various subjects herein contained.

Trusting that the work will be accepted in the spirit here outlined, he sends it out for the consideration of the American industrial world.

<div align="right">NISBET LATTA.</div>

NEW YORK, January, 1910.

<div align="right">iii</div>

254514

CONTENTS

CHAPTER III.—WORKS DETAILS

CHAPTER IV.—PRODUCER TYPES

Chapter V.—Moving Gases

Chapter VI.—Solid Fuels

Chapter VII.—Physical Properties of Gases

Chapter VIII.—Chemical Properties of Gases

Chapter IX.—Gas Analysis

Chapter X.—Gas Power

Chapter XI.—Gas Engines

CONTENTS

Chapter XII.—Industrial Gas Applications

Chapter XIII.—Furnaces and Kilns

Chapter XIV.—Burning Lime and Cement

Chapter XV.—Pre-heating Air

Chapter XVI.—Doherty Combustion Economizer

Chapter XVII.—Combustion in Furnaces

Chapter XVIII.—Heat: Temperature, Radiation and Conduction

Chapter XIX.—Heat Measurements: Pyrometry and Calorimetry

Chapter XX.—Pipes, Flues, and Chimneys

Chapter XXI.—Materials: Fire Clay, Masonry, Weights and Rope

Chapter XXII.—Useful Tables

Appendix.—Oil Fuel Producer Gas

LIST OF ILLUSTRATIONS

PRODUCER GAS PRACTICE

CHAPTER I

PRODUCER OPERATION

The general theory of gas producers and the historical as well as typical designs have been already fully treated in other works, so that they will not be dwelt on here. Rather will the practical features of producer design and operation be enlarged upon as being more in the province of this handbook. The operation of the several pieces of apparatus employed in making producer gas will first be taken up, to be followed by descriptions of producers at present in general operation in this country.

In spite of the vast number of gas producers now in the market, and the different methods of operation, the fact remains that there is but one common factor of importance, and upon this hinges the successful operation of the producer, regardless of its other accessories, methods or attributes. This may be briefly summarized under the term of " stoking " or the maintenance of a compact fire bed.

Fuel Bed.—To complete the gasification of coal in a producer it is necessary that all the air admitted into the producer be brought into contact with incandescent carbon, and to this end the one feature to be poignantly emphasized is to *maintain the fire bed compact.*

That is to say, either by stoking, hand, mechanical or in " compressed gas shots," the condition of the bed must be maintained homogeneous and free from rivers, chimneys or channels, through which air or steam may pass undissociated to the top or bottom of the fire, depending upon the direction of draft.

To a lack of attention to this principle is due 90% of the troubles met with in the maintenance of constant service and a continuity of a fixed or uniform gas of constant value.

The fire should be barred down, stoked, coaled, or otherwise made compact at such intervals, depending upon conditions of fuel demand, capacity, etc., as will absolutely ensure this condition. For, failing in such attention, it may be assured that two things will happen. First, that the air or steam passing through incompletely dissociated will form a gas high in carbonic acid and free oxygen and of a

lean and irregular character. Second, the free oxygen passing through the fire and meeting the finished gas will produce secondary combustion on top of the fire or distillation zone and consume the gas actually manufactured within the producer, with a tremendous resultant loss in both gas and through radiation, besides having an extremely destructive effect upon the producer itself.

It may be noted, therefore, that when an up-draft producer is burning very hot on top, as indicated either by looking through the stoking-holes, side cocks, or by the use of a pyrometer, that it is an invariable sign that air is sifting through the fuel bed, which has become "honey-combed" or has had a fissure broken through, and that this air is causing combustion of the gas inside of the producer.

This is particularly frequent where an exceedingly thin fuel bed is run and also with fuels possessing large voids, such as coke and the largest size of anthracite or run of mine coal. These coals require closer attention in order to maintain uniform gas and constant conditions of operation.

Anthracite suction producers using pea or nut coal are found to run most efficiently upon a fuel bed approximating 30 inches in depth. The depth of a fuel bed must, however, necessarily increase with the size of the fuel and its consequent voids.

For bituminous fuels however a 4-ft. depth may be said to constitute a practical maximum, the best results being found at this depth, while a greater depth renders stoking extremely difficult.

Coke may get under some conditions a foot deeper by reason of its light weight and small tendency to bed or pack. For this same reason, together with its large voids, coke should be crushed to the size of a nut coal mesh before being used in the producer.

The producer fire should be examined at intervals, never exceeding one-half hour in length, for from its color and degree of temperature the condition of operation must be regulated. One of the dangers of mechanical stokers arises from the fact that there is a tendency on the part of the inspector to be too long between observations or inspections.

There can be no fixed rule for regularity of interval or periodicity in stoking of coal in producer work, especially of an arbitrary nature. The items to be observed are these:

The producer should be coaled at sufficient intervals to maintain a constant depth of fuel. This depth depending upon the size, type of machine, nature of load and load factor, and class and quality of fuel.

The stoking or poking of the producer should be at sufficient intervals to keep the fuel bed absolutely compact.

The cleaning of the producer should be at such intervals as shall remove from the fire the objectionable amount of clinker or ash, and the intervals must be determined of necessity from the character of the fuel, nature of the load, and the relative capacity of the machine.

Great care should be observed in both barring down and removing clinker, to preserve the linings from any unnecessary erosion or violence. Any carelessness in this operation will reduce the life of the lining 75% or 80%.

Where clinkers are severe they may be removed by running up the heat of

the apparatus, i.e., by increasing the draft and cutting off the endothermic agent, even where it is necessary to exhaust the resultant gas through the purge pipe.

Clinkers thus softened may be more readily barred down. Care should also be taken to slowly work the clinkers out of the ash bed, or, as this is generally termed by workmen " sneak them," for if withdrawn too rapdily or carelessly a quantity of good fuel will be drawn with them and lost.

The regulation of the producer depends more particularly upon the use and admission of the endothermic agent. Where flue or exhaust gases are used for this purpose its satisfactory balance will be found to obtain automatically; that is to say, that the proportion of exhaust gases remaining maintains an equal ratio with the demand or withdrawal from the producer, the process being that of a cycle and it is merely necessary to establish such proportion to have it automatically maintained.

For the use of steam or moisture, however, the process is more complicated and requires more constant attention. The amount increases directly with the load or demand and conversely decreases. It is the custom of the writer to admit just sufficient amount of the endothermic agent to maintain the clinkers in a tractable state and to preserve the lining of the producer from excessive heat.

This point can be determined only through experiment, and the observation of the heat, the color of which will soon be learned by the operator. In other words, it seems expedient to run a producer as hot as is possible without the formation of excessive clinker or destruction of the linings. Usually the white lights visible in the fire and around the linings at high temperature mark the danger signals, and the heat should be maintained just short of their appearance.

Heat Recovery.—Preheating of the primary air, as well as the secondary air in producer work, is of prime importance where such heat is recuperated from waste heat. It would at first appear incompatible to add sensible heat to the fire of the producer, inasmuch as the total producer reactions are so strongly exothermic as to require some endothermic agent, such as steam or CO_2 for the regulation of the fire bed temperature. Further study however will show that where this heat is added a larger portion of the endothermic agent may be used and distilled or dissociated, and this increase may be said to transform the sensible heat restored to the producer into the latent heat of a potential gas, thereby greatly increasing the volume of potential gas given off by the producer; or, in other words, increasing the manufacture of potential gas per unit of fuel, the function of the sensible heat restored through the form of primary air recuperation is almost identical with that of the sensible heat evolved from the fuel itself.

As has been stated elsewhere, one chief difficulty with water seal producers is the inability to regulate the depth of the fire bed. This difficulty varies between two extremes. First, an excess of depth, which tends to make the stoking of the fire mechanically impracticable. Second, a deficiency of depth which causes a channeling of the bed and an increase of CO_2 from (a) a combustion of CO to CO_2 within the producer on top of the fire, due to the passage of undissociated air or free oxygen through the fire in chimneys or channels; (b) lessening of the time contact in passage of gases through the fire, and hence for the consequent secondary reaction of CO_2 to CO; (c) a less distillation due to reduction of heat and a depth

of distillation zone, and moreover an intense heat localization, due to the condition (a) and a consequent destruction of the producer linings, and the fluxing of fusible ash, forming clinker.

This phenomenon is so well known that it is the practice in operating the soaking pits in many steel mills to lower the fire bed for the purpose of increasing the CO_2 and thereby obtaining an elongated and slow combustion gas flame within the furnace or soaking pit.

It will be manifest that this condition is obtained at an immense expense or waste of fuel, and where such an arrangement is necessary it is much more economical to add to the finished gas or secondary air a certain percentage of flue gas (from 3 to 12%, depending upon the temperature, a larger amount being required for higher temperatures of flue gases), and thereby obtaining the retarded or voluminous flame. The principle involved in this is described elsewhere at greater length.

The experiments of Euchene go to show that 22.3% of the heat value of the fuel is used to bring up the sensible temperature of effluent gases. In many instances a certain portion of this temperature is recuperated in the manufacture of steam and through its medium returned to the producer. In any event, however, the importance of direct connection between the producer and the furnace will be obvious, as well as the insulation of the connection which is best accomplished by lining with fire brick, the fire brick being separated from the steel shell in the manner exactly identical with the method in which the producer itself is grouted. In connection with the above Butterfield states: " The sensible heat of the effluent gases averages from 1400 to 1500° F. under ideal conditions. This sensible heat absorbs theoretically 17.2% of the total heat of the fuel liberated, or about 2500 B.T.U. per pound of carbon."

Where the sensible heat of the gas is utilized for steam generation, as is usually done by running through a tubular boiler, such admission should never be of the " down draught " type, but the gases should enter at the bottom of the boiler or water leg. This is for the reason that the hot gases, when entering at the steam chamber or dome tend to burn out the tube sheet or crown plate, whereas, when entering at the water leg, the tube sheet is protected by its water content and the gases are considerably cooled before reaching the crown sheet; moreover, the change of temperature is more gradual in the tubes themselves with less resultant movement.

Efficiency of Producers.—The thermal efficiency of producers for transformation of the latent heat of the coal into a potential gas for fuel purposes, recovering the losses through radiation, ash, jacket water, sensible heat, etc., average for multi-unit down-draft types approximately 85%. For up-draft types on bituminous or lignite coal where tar is extracted (the efficiency varying according to the tar and resinous content in coal) the efficiency is approximately 60%. For down-draft apparatus on anthracite coal approximately 80%. These figures vary widely, but give some approximation of the usual practice.

In the use of lignite and low grade fuels containing a high moisture element (approximately say 18% or above), by the heat absorption and combustion of which, together with the low flame temperature (partly due to a high neutral element), an extraneous endothermic agent is rendered unnecessary.

It must be remembered that the efficiency of the apparatus is rendered relatively lower by reason of the fact that theoretically some 17.2% (see Butterfield), and practically 22.3% (see Euchene) of the heat units of the fuel is absorbed in raising the effluent gases to their temperature of exit, together with the robbing effect of the aqueous vapor which they mechanically entrain.

Under ordinary conditions a portion of this sensible heat is recuperated, either by manufacture of steam or by the sensible temperature of the products of combustion, the heat being returned and restored through one or the other of these mediums.

Where there is no endothermic agent required, however, the sensible temperature of the effluent gases for power purposes at least are not recuperated, and such temperature becomes a total loss.

To offset to some extent this condition it will be manifest that the fuels named can be most efficiently gasified in (a) an up-draft producer, (b) a multi-unit producer in which the first unit is up-draft, and the second down-draft, the flow of gas being reversed for the following reasons:

In this arrangement, by carrying a relatively deep fuel bed the effluent gases from the combustion, dissociation, and distillation zones pass upward through the green coal and are relieved of their sensible temperature in some degree in a partial heating of the charge, the result being that such charge is gradually brought up to the point of ignition before it reaches the combustion zone and is delivered pre-dried through the agency of the sensible heat thus extracted.

As a matter of fact this is only a relatively efficient method of recuperation, inasmuch as the green charge in the producer, which is rich in moisture, abstracts from the fire a certain quantity of heat through conduction. However, the largest portion of this pre-drying or pre-heating comes from the sensible temperature of the gases passing through it on their escape from the producer.

The above, suggesting the pre-heating of fuel by the up-draft of the effluent gases, embodies to an extent the principle of " reversed currents " which is most efficient in heat transference and is extensively met with in the various conditions presented by gas manufacture.

In other words, the hottest gas is brought in contact with the hot test fuel, and vice versa, the gases being gradually cooled and the fuel being brought up by stages to the point of ignition, its distillation and drying being meanwhile secured.

It will be patent that in the use of lignite or low-grade fuel, as herein suggested, that the fuel bed should be maintained say twice the depth, otherwise carried with ordinary bituminous coal. Coking coals invariably give trouble when hopper fed by reason of their tendency to coke and " hang "; they are therefore best handled by some mechanical device.

Theoretically, in the gas producer, says Butterfield, just one-half the air is required for the theoretical combustion per pound of coal in the direct-fired furnace. This does not cover the excess actually necessary in practical operation. Pure carbon and no moisture nor hydrogen being considered, the reaction would be as follows: CO, 34.7%, and N_2, 65.3%. In the ideal producer under theoretical conditions 30.6% of the heat is liberated, that would be liberated in the direct-fired furnace.

In the experiments of Euchene one pound of coke evaporated 40% of its weight

of water, said water being from the ash pan of the producer. By this evaporation 67.6% reacted with the carbon; 32.4% escaped with this gas undissociated in the form of aqueous vapor.

The decomposition of water into its elements of hydrogen and oxygen has a total endothermic action of 3900 B.T.U. per pound. One pound of carbon plus 71.75 cu.ft. of air equals CO with a total exothermic action of 3930 B.T.U. The radiation loss in this producer, which was of the Siemen's type, as noted by Euchene, was 5.7%.

The highest theoretical efficiency in producer operation is of course only obtainable under conditions of by-product recovery, as for instance of sulphate of ammonia. This, however, is not warranted under installations of from 3000 to 4000 h.p., and then of course it is limited by the fuel available and the market demand for the product. Depreciation is extremely heavy on this class of apparatus, especially in portions where sulphuric acid is used. So heavy is its maintenance that it must be considered as one of the primary costs of operation.

The sensible heat of producer gas is of importance because 12 to 18% of the heat value of the coal may exist in this form, the loss of which is only a question of cooling the gas. It is utilized only when gases reach the furnace hot, and the hotter the gases leave the producer, the greater may be this loss.

Hotter gases result from carbonized and dry fuels, rapid driving and dry blast more than from uncarbonized and wet fuels or steam air-blast. The temperatures of escaping gases, of course, vary considerably, depending upon character of fuel and rapidity of driving.

With coke, say between 900° and 1800° F.

Soft coals, say between 600° and 1600° F.

With anthracite and steam jet blower, 1100° F. is a frequent temperature.

Where the heat from the exhaust of a gas engine is recovered, about 10% of its thermal value may be used in raising steam in exhaust boilers, where a pressure as high as 160 pounds per square inch has been attained.

Losses in Producer.—The following table shows the percentage of this loss with varying proportions of ash in the coal and varying percentages of carbon in the ash drawn from the producer:

PERCENTAGE OF TOTAL HEAT VALUE LOST

Percentage of ash in coal.....	4	7	10	13	16	20
5% carbon in ashes.........	0.22	0.40	0.60	0.80	1.00	1.30
10% " " "	0.46	0.84	1.25	1.66	2.11	2.80
15% " " "	0.74	1.33	1.98	2.64	3.36	4.40
20% " " "	1.04	1.90	2.80	3.75	4.76	6.25
30% " " "	1.80	3.20	4.80	6.40	8.16	10.70
40% " " "	2.80	5.00	7.40	10.00	12.70	16.60
50% " " "	4.16	7.50	11.10	15.00	19.00	25.00
60% " " "	6.20	11.30	16.60	22.50	28.60	37.50
80% " " "	16.60	30.00	44.40	60.00	76.00	100.00

It is found that even with sulphur as high as 3% and ash 10% it is still quite possible to make good gas without interruption, although at much reduced rate.

It is found that the total loss from all sources in the gasification of fuel in a Morgan type gas producer under fairly good conditions, when the gas is used cold or when its sensible heat is not utilized, ranges between 20% and 25%, which under very bad conditions may be increased to 50%. It is claimed that this loss, under favorable conditions, using the gas hot, is reduced to as low as 10%, which also includes the heat of the steam used in blowing. This fact can be arrived at and proven by calculation from the analysis of the gas taken in relation to the original analysis of the coal. The interested student of this subject is referred to the work of H. H. Campbell on the Manufacture of Iron and Steel, chapters VIII and IX. In his elaborate investigation all the sensible heat of the gas (namely, 14.4%) was assumed to be lost, which it always is in the Siemens regenerative furnace. There was also found to be a loss by carbon in ashes of 2.1% (which is excessive), and by radiation and conduction 5.1%, making a total of 21.6% lost. As his equipment was much inferior to the best modern practice in several respects, and as there are a great many cases where fully two-thirds of the sensible heat of the gas is utilized, it will be seen that the unavoidable loss by good practice in all heating furnaces should not exceed:

One-third of sensible heat of gas = 4.7% loss
Carbon in ash. . . . . = 0.3%
Radiation from producer. . . . . . . = 5.0%
Total amount lost. 10.0%

The total grate loss of fuel, that is to say, of the combustible charge, should not exceed $2\frac{1}{2}\%$.

American producers will average a loss through their grates of 5%, while certain badly designed producers have run as high as 32%.

It is stated by F. E. Junge that in Germany where low grade clinkering fuels are used, that is to say fuels high in fusible ash, that clinkering has been entirely eliminated by the substitution of cast-iron producers with water-cooled walls. To quote Mr. Junge: " The cooling effect of the water does not extend very far internally, only far enough to effect the layers lying at the extreme outside. The influence on the combustive process is therefore inconsiderable in such producers." The loss of heat is due to radiation from producers is much more constant than is generally supposed, and when it is taken into consideration that fire brick at white heat has the same conductivity as cast iron, Mr. Junge's conclusions may be worthy of some consideration and investigation.

Clinker.—The next in importance to consider is the subject of clinker. The formation of clinker tends to reduce the available area of the fuel bed, and not only by the space it occupies defacto, but also by acting as a deflector converts the passage of air into channels and increases the unit duty of the remaining surface of the bed. This naturally increases the heat of the fuel bed by concentrating the draft in certain defined directions and also by certain radiant heat. The result is that where a clinker is started, it tends to form other or more clinker, both along the lines aforesaid, and by the direction, reflection and concentration of a more intense heat.

It may therefore be put down as a postulate that clinker should be maintained at a minimum, if not entirely obviated (this latter being very nearly impossible), and all coals possessing a high content of fusible ash should be discarded as a producer fuel in shaft or furnace type producers, more especially where used for the generation of gas for engine combustion.

It is seen therefore that the formation of clinker, which is the accumulation of the fluxed portion of fusible ash, tends both to irregularity of gas through its agency as a deflector in the passage of the gas, and also through the intense heat resultant upon the concentration of this draft upon certain sections of the fuel bed. This and its removal form a most deteriorating influence upon the lining of the producer itself.

It naturally follows that in proper practice the effort should be to form no clinker, which may be done in one or two ways.

First, by keeping the fire compact, for the concentrated blast of certain section or area of the fuel bed, due to rivers or chimneys, has a strong tendency to flux the fusible ash, with resultant clinker.

Second, The coal selected should be as low as possible in its content of fusible ash.

Third, The fire should and must be kept as nearly as possible below the point of fluxing this fusible ash. This may be done with pressure producers by moderating the blast, but in suction producers, and pressure producers as well, the temperature may be tempered or moderated by running a fair depth of fuel and applying the proper amount of steam in the regular process, or of CO_2 in the Tait or Doherty processes.

In most or many of the lignites, producers depending upon the fusing of clinker or its removal in condensed form (such as Smith type) are usually impractical, for the following reasons, namely:

That the clinker formed by such fuels is unhomogeneous, due to the fact that while a portion of the ash is fusible, a large portion is infusible, the latter creating a diluent for the former, hence preventing cohesion and rendering it difficult to segregate it in large masses.

This inability to complete segregation prevents the formation of clinker in small groups of particles throughout the entire fuel bed and working towards the grate with considerable disadvantage to satisfactory operation.

By reason of the above conditions the extraction of clinker from the generator through segregation, with many of the lignitic fuels, is thoroughly impractical.

Temperature.—An exact mean must of course be found between this amount of steam and an excess, which tends, both through the cooling of the fire and the failure of a proper temperature for re-combination in the upper zone, and through an excess of the dissociated or free oxygen to form an excessive amount of carbon dioxide.

Gas is usually of the best quality when the top of the fuel bed (assuming an up-draft producer) is dark in color, a dull cherry or medium orange. When it assumes the color of light orange with white lights, it is almost certain that some secondary combustion is taking place, that is to say, the fire, being insufficiently compact, permits air to pass through and burn the gases within the producer.

White heats or white lights in the bright orange heats should always be avoided in producer work, being an invariable sign of too high temperatures.

It is assumed by practically all authorities on producers that the reaction of air in its passage through the producer is from O to CO_2 with a reaction of CO_2 to CO, in the following zone. Whether this is true or not the author is unable to definitely state.

It is of course impossible, however, to burn the fuel merely to CO, or in the event of the theory aforesaid, to convert all of the CO_2 to CO, but nevertheless the CO_2 can and must be maintained at a minimum.

The production of CO is accelerated by the use of fine fuel of a fair degree of depth. Large lump fuel producing greater voids must have this depth materially increased to compensate for the time factor of contact, etc., or to produce a lesser velocity in the passage of the blast.

Air over incandescent carbon is supposed to produce the minimum of CO_2 at about 1900° F., and it is therefore evident that the heat of the producer should be maintained well over this point.
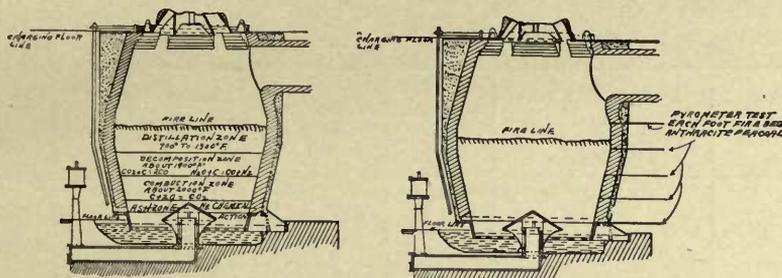
FIG. 1.—Heat Zones in Producers.

An analysis of Stockman, illustrating the hot and cold working of a producer upon an identical fuel, shows a decrease of 12% in volume of gas, with a gain of 20% in the heat value as a result of the higher temperature of combustion.

Other conditions being the same, the temperature of a producer will increase almost directly with the amount of fuel gasified in a unit of time. This of course is dependent upon the air supply and also upon the nature of the air, which, if pre-heated, is much more efficient. This however, as indicated by Stockman's experience, means increased velocity and lessened time contact.

Reactions.—The following are the chemical equations representing the principal changes which occur in the formation and combustion of producer gas.

Formation of producer gas from air and carbon:

$$C + O_2 = CO_2, \quad +97,600 \text{ calories}$$
$$CO_2 + C = 2CO, \quad -38,800 \text{ ``}$$
$$2C + O_2 = 2CO, \quad +58,800 \text{ ``}$$
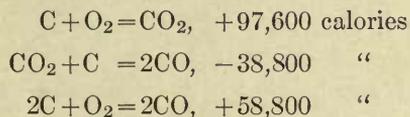
Reactions between steam and carbon:

$$H_2O + C = H_2 + CO, \quad -28,800 \text{ calories}$$
$$2H_2O + C = 2H_2 + CO_2, \quad -18,800 \text{ ``}$$
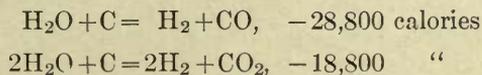
Reaction between steam and carbon monoxide:

$$H_2O + CO = CO_2 + H_2, \quad +10,000 \text{ calories}$$
$$CO_2 + H_2 = CO + H_2O, \quad -10,000 \quad ``$$
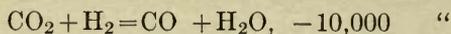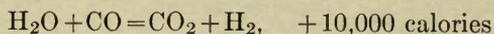
Combustion of the constituents of producer gas:

$$2CO + O_2 = 2CO_2, \quad +136,400 \text{ calories}$$
$$2H_2 + O_2 = 2H_2O, \quad +138,000 \quad ``$$
$$CH_4 + 2O_2 = CO_2, \quad +2H_2O, \quad +213,500 \text{ calories}$$
$$C_2H_4 + 3O_2 = 2CO_2, \quad +2H_2O, \quad +341,100 \quad ``$$
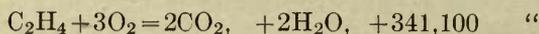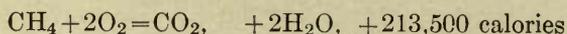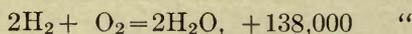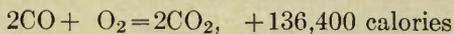
Professor Lewes says: " M. O. Boudouard has found that at 1112° F. $CO_2 + C$ yields 23% carbonic oxide, and 1832° F. $CO_2 + C$ yields 99.3% carbonic oxide, so that the proportion of carbonic acid in producer gas depends upon the temperature of the fire and the velocity of the gas through it."
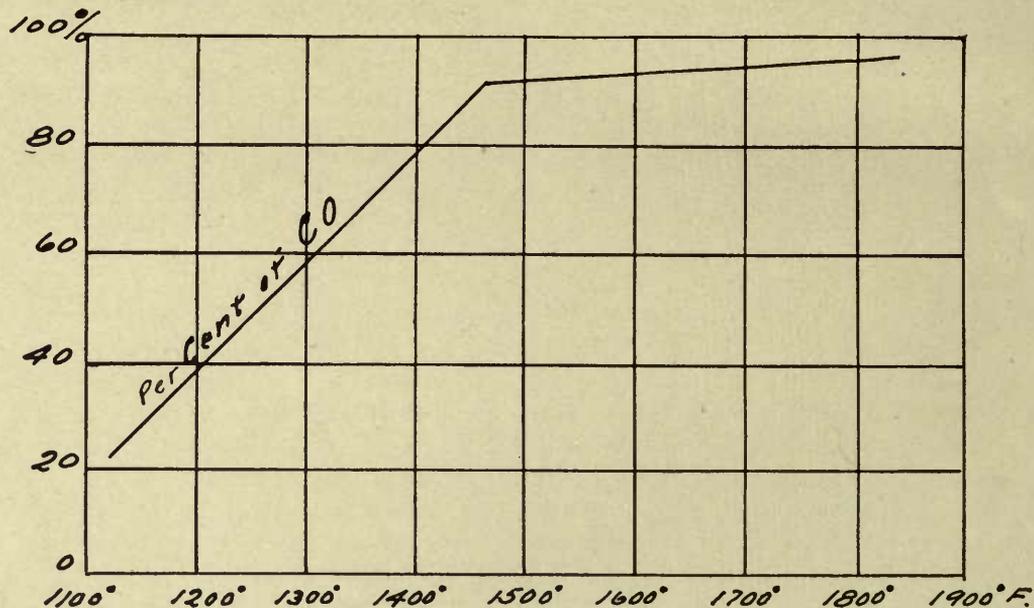
Fig. 2.—Relation of Temperature to Combustion.

In a discussion of producer designs in his work on Gas Producers (page 15) Horace Allen referred to the reaction of CO and CO_2, and the necessity of large surface contact for its efficient completion, says as follows:

"From this it would appear that the grate area should be considerably less than the area of the producer in the zone in which the reduction of CO_2 is effected. This conclusion is confirmed by blast-furnace practice, the walls of the bosh of the furnace rising from the hearth, where the blast is introduced under some pounds per square inch pressure, not being carried up vertically but at an angle of about 70°. This method of reducing the velocity of the gases rising from the fire by

increasing the area of the chamber was almost universally adopted in gas producers designed for gasifying coal for heating metallurgical furnaces, etc., and is still followed by most of the high-capacity producers of the day. However, it is a notable feature of the smaller class of producer now employed to work on the " suction " principle that the walls are generally carried up vertically above the grate. This is probably due to convenience of construction combined with the small size of the apparatus, but the producer in working corrects this, owing to the accumulation of ash and clinker round the grate."

Whether or not this is actually the case is doubtful. Certainly after cleaning periods there must be an interval in the compensation to which Mr. Allen refers, and at best the dependance upon ash and clinker as a baffling medium would seem inefficient. The question is at least well worthy of the attention of designing engineers.

The average producer shows a heat cycle about as follows:
Assuming 12 kilos of carbon.

$$C + O_2 = CO_2, \ +97{,}600 \text{ calories}$$
$$CO_2 + C \ = 2CO, \ -38{,}800 \qquad ``$$
$$2C + O_2 = 2CO, \ +58{,}800 \qquad ``$$
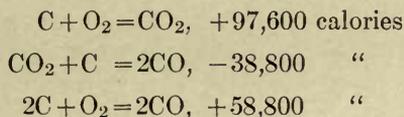
As a matter of fact probably both of these reactions occur in the shaft producer, due largely to variations in temperature, as the tendency of carbon is to act directly to CO at a temperature above 1000° C.

Again, in the use of powdered fuel it is likely that the reaction is direct to CO, the heat being greater and conditions more uniform.

Based upon the above the shaft producer shows approximately the following distribution of available heat:

> 70% latent heat in gas;
> 20% sensible heat in gas;
> 10% loss by radiation and complete combustion;
> ($C + O_2 = CO_2$) within the producer.

This also includes the heat taken from the producer and the sensible heat of the ash.

The heat cycle is analyzed by Richards' as follows:

> Heating power of the coal per unit;
> Heating power of the gas per unit of coal;
> Calorific losses in conversion.

The last item being subdivided as follows:

> Loss by unburned carbon in the ashes;
> Sensible heat of the hot gases issuing;
>
> Heat conducted to the ground;
> Heat radiated to the air.

The large amount of the total available heat, which is represented by the sensible heat of the gases, will show the great necessity of burning the gases as close as possible to the producer and at the highest possible temperature. This is of course merely applicable to the use of producer gas in furnace work, and does not apply to power where it is necessary that the gases be cooled prior to their entry into the engine.

Ingalls, in his work on "The Metallurgy of Zinc and Cadmium," page 280, states as follows: "The oxidation of carbon is a complicated process. It begins at the moderately low temperature of 400° C., carbon dioxide being formed then as the chief product, whether the supply of air be large or small, and only a very little carbon monoxide being formed therewith. The oxidation becomes more active if the temperature rises to 700° C., but the chief product is still carbon dioxide, although the air supply be deficient. Even under that circumstance, which in so far as the proportion of air to carbon is concerned, is favorable to the formation of carbon monoxide, only traces of the latter are formed. Above 700° the proportion of carbon monoxide to carbon dioxide increases rapidly until 995° is reached, where the former gas is formed exclusively. An increase of the incandescent bed of coal does not suffice to form carbon monoxide if the minimum of temperature (700° C.) be not exceeded. These observations explain why if carbon be oxidized at a lower temperature than 700°, it burns without flame, while if it be oxidized at a higher temperature the combustion is accompanied by a flame. In the first place the carbon burns directly to dioxide, an incombustible gas, and in the latter to monoxide, which at a higher temperature burns with a further part of oxygen producing the characteristic blue flame."

Endothermic Agents.—Endothermic values of various agents apparently decrease with the sensible temperature. In the case of steam this is probably caused by the lessened amount of saturation, or entrained water contained at high temperatures and the endothermic extraction of heat by such water, due to the latent heat absorbed in transformation of water vapor into steam.

This possibly accounts also for the small clinkering sometimes consequent from systems using an air blast, saturated with moisture, or "low pressure" (highly saturated) steam. Such results are often extremely noticeable. The fuel economy of such an arrangement is doubtful; this additional heat abstraction being at the expense of fuel; but undeniably it possesses advantages where the coal used contains a high percentage of fusible ash.

A condition analogous to the above just stated possibly obtains in the contention of certain water-gas engineers, who claim that the use of superheated steam (steam containing no saturation or entrained water), subtends intractable clinkers and excessive clinkering in water-gas generators. It is also a fact and a coincidence that CO_2 loses its endothermic value directly with its increase in temperature. This being due of course to its lessened density. Many lignites and some coals contain so much moisture as to require no extraneous endothermic agent. The fact would seem to have some bearing on the above.

In the use of these high moisture fuels requiring no endothermic agents, it is usually best to carry a small quantity of water in the ash pit, which performs the dual function of collecting and solidifying the finely powdered ash when falling, and

the small evaporation of which tends to cool the grate bars on up-draft apparatus. It must be remembered that the moisture in this fuel is in the form of water or steam, hence in the latent heat of combustion there is a larger heat absorption and abstraction from the fire than would otherwise be.

Unless there is an unusually large percentage of fusible ash in the fuel the writer is inclined to think that the endothermic agent is unnecessary in a fuel of a higher moisture content than 15% or certainly 18%. This would show a content of less weight of water per pound of fuel than that which would be used when artificially supplied to the producer as an endothermic agent in the form of steam. This, however, must be accounted for as follows:

First, by reason of the latent heat of absorption, as before suggested, and also by the fact that this moisture, arising in the form of aqueous vapor through the fire bed, creates a high degree of " over-ventilation " with a consequently reduced flame temperature.

This result is dual, preventing as it does a flame temperature which would dissociate the water vapor into its constituent gases; they therefore leave the producer in the form of aqueous vapor, hence maintaining it at a very low fuel bed temperature by reason of its high specific heat and the ventilation of the producer as a whole by the large masses of aqueous vapor leaving with its gases, and the high specific heat of its mixture.

Although the theoretical heat required to raise the gases to their sensible temperature of efficiency is 17.2%, Euchene showed in the particular producer in which his experiments were conducted that 22.3% of the initial thermal content of the coke was removed by the sensible heat of the influent gases. This difference of 5.1% may be accounted for by the high sensible heat or coefficient of heat absorption of the aqueous vapor, hydrocarbon, or tarry matter mechanically entrained in the gas, robbing the producer of the additional heat aforesaid.

Assuming 22.3% as an arbitrary figure for effluent temperature, 5.7% the loss of radiation, we have a total of 28%, and deducting this from the 30.6%, the theoretical portion of the heat content of the fuel liberated within the producer, we find a percentage of 2.6% or residual heat.

As a matter of fact this residual heat is much higher owing to a certain amount of complete combustion occurring within the producer as well as the combustion of hydrocarbons of the high heat value, but even under ideal conditions and with a pure fuel carbon this discrepancy would be found which it is necessary to absorb by the admission of some endothermic agent such as steam or the products of combustion.

Test Flame.—Within certain limits the operation of producers may be observed with a fair degree of accuracy through the " test light," especially if one, such as is shown in the accompanying illustration, be used. In this light, the gas is supposed to be impinged against the top of the burner and delivered to the orifice at the side at about atmospheric pressure. At this point, if it burns fully, following the entire throat or orifice with a complete annular flame, the quality of the gas may be said to be good as a rule, with a low content of CO_2.

If its emission is however irregular, burning principally in the top of the orifice and failing to follow it throughout its circumference, it is usually a sign of high

Testing Flame

Water Inlet

Gas Inlet

Pressure Guage

Water Overflow
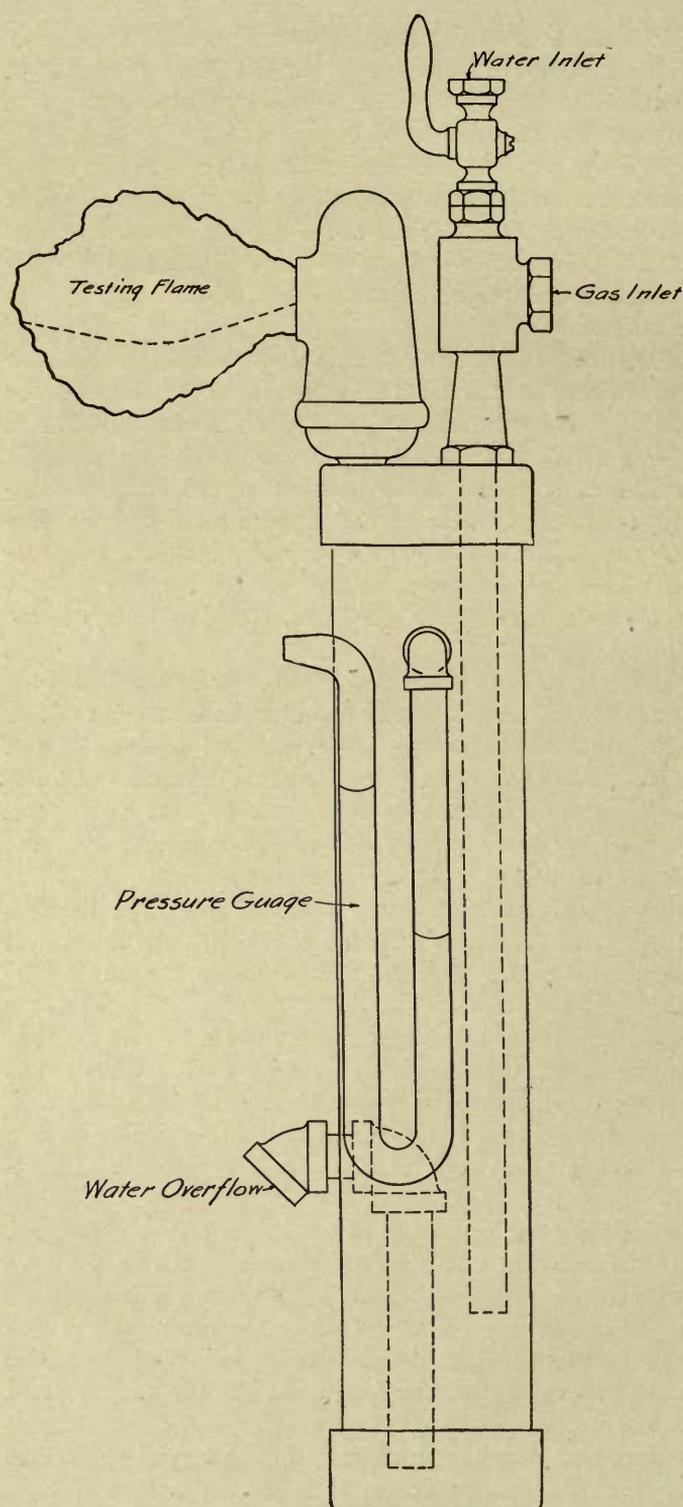
FIG. 3.—The Tait Test Flame, Burner, etc.

carbonic acid and low heat value in the gas, when the gas may be said to be "lean."

Theoretically, of course, the color of a flame is dependent upon incompleted combustion and the particles of combustible matter heated to a condition of incandescence. It will be found that various fuels vary, particularly in their color, but as a general rule the flame of the "test light" will be observed to burn from blue to red, with the increasing heat of the producer.

Hydrogen, carbonic acid, alcohol, etc., are supposed to burn when in a state of purity, with a perfectly colorless flame.

Inasmuch as it is practically impossible to burn all of the combustible or fuel of the producer to CO, some of the fuel being combined to CO_2, the curve B of Chart I does not indicate the real temperature, but by reference to the curve C, this temperature may be found in a producer where the percentage of carbon burned to CO_2 is plotted on the X axis and the temperatures upon the Y axis.

This percentage would give but 100% CO and 0% CO_2 at the Y axis, the percentage of CO decreasing and that of CO_2 increasing as the abscissa is increased

to a point where the entire amount of carbon is burned to 100% CO_2 with 0% of CO. Hence, for any analysis of flue gas produced, the actual temperature in the furnace may be determined, by reference to the curve C aforesaid, providing of course that no cooling or retarding agent has been employed and that the oxygen of combustion has been obtained from the atmosphere at a temperature approximating 60° F.

Although, under average conditions of operation, the test light may be used, manipulating the producer as aforesaid, frequent analyses of the gas should be taken, as a check and safeguard, and an empyric comparison made with general conditions of operation, the aforesaid light, etc., to form basic conditions and comparison.

Where the producer gas shows a content of CO_2 (this representing some 20% of the carbon which is burned to CO_2) the temperature is indicated by the curve C, which is approximately 2400° F.

Above this point, in most instances, a clinker mass of incombustible vitrified scoria is formed. For each fuel there is a critical temperature approximately in this neighborhood, and, as already stated, to prevent this a somewhat lower heat must be maintained. This is difficult, inasmuch as the heat above outlined given off in combustion of C to CO, considerably exceeds both the radiation of a well-built furnace and the sensible heat which may be carried off by the outgoing gas, at the specific heat which it maintains at that degree of temperature.

Steam Cooling.—It will be manifest therefore that either a portion of steam or a part of the products of combustion must be used to temper this fire.

Butterfield says (page 86): "All undecomposed steam passing through a retort-heating system (producer, furnace, etc.) *robs* that system of heat, and thereby makes the prevailing temperatures lower than they would be in the absence of undecomposed steam. The temperature at which the spent gases escape into the chimney is a measure of the *net* loss to the system as a whole, but, if the spent gases traverse regenerative passages before escaping to the chamber, the loss of heat to the producer *per se* (if recuperation is not applied to the primary as well as to the secondary air supply) may be greater than the *net* loss to the system. Hence, the passage of steam, in excess of that which the fuel can decompose through the system, usually should be felt far more seriously in the producer than elsewhere in the system. The escape of undecomposed steam from the producer implies that heat has been abstracted by this steam from the bed of fuel, the temperature of which is thereby lowered, but the lowering of the temperature of the bed of fuel renders it less competent to decompose steam and form carbonic oxide rather than carbonic acid.

"The undecomposed steam *injures* the working of the producer *indirectly* as well as *directly*. Every endeavor should therefore be made to avoid more steam traversing the bed of fuel than it can decompose, unless it can be shown that some very great collateral advantage accrues from the excessive steam. Now, the only advantages which can be reasonably claimed for a large inflow of steam to the ordinary producer, are cooling of the fire bars and avoidance of hard clinker. The practical question, therefore, is whether these advantages cannot be secured to an adequate extent without the steam supply exceeding that which the bed of fuel is competent to decompose. Actually, it would appear that this question has not been satisfactorily investigated, but it may be assumed that the answer would be different for different types of producers and different description of coke, much

depending on the area of the grate relatively to the air and steam supply and on the temperature at which the ash of the coke fluxes. Nevertheless, there is no doubt that it is very rarely that steam in excess of the quantity which will be decomposed, *is required* to keep the fire bars adequately and avoid clinker being formed to an *obstructive* extent."

As is stated above by Butterworth, the producer is "robbed" of its excess heat accumulated in the combustion of C to CO by the dissociation of the steam applied and (in practice) the thermal capacity of escaping aqueous vapor. In the processes covered by the Tait-Ellis, Eldred, and Doherty patents, this heat is absorbed in the endothermic reaction of CO_2 to CO, the intention being to create through this reaction a potential out of a neutral gas.

Otherwise, as before described, the fuel bed will get *hotter* and *hotter*, causing the ash to *fuse to clinker* and give trouble in cleaning out. Steam serves to keep the producer in good working condition, but in addition some of the steam is decomposed, so that the resulting gas will contain some carbonic acid and carbonic oxide, oxygen and some hydrogen derived from the steam.

Ingalls (page 283) states: "The use of steam in the producer presents the further advantage that, in cooling the zone of combustion, the trouble from clinkering of the ash is reduced. In many cases this is a *highly* important consideration. The effect of blowing a producer with a very large volume of steam is shown by the results of the Mond producer. The gas from that is developed at a very low temperature and is consequently high in carbon dioxide, but because of its high tenor in hydrogen it possesses a great calorific power."

Fig. 4.—Tait Producer Gas Test. (Section of Burner on Fig. 3).

In view of the theoretical and practical considerations substantiated by the authorities referred to, there can be no question as to the impracticability of operating a producer furnace without the use of some cooling agent; that is, the temperature must be reduced and maintained at a point that will restrain the rapid formation of clinkers. There is always an unavoidable loss of heat when steam is used as a cooling agent. This loss may be much reduced by means of a proper system of recuperation, but as the recuperation can never reach an efficiency of 100% the loss can never be reduced to zero.

By reference to Sheet No. 2, curve E represents the unavoidable loss in B.T.U. due to the passing of one pound of steam through the producer and furnace where the efficiency of recuperation is 65%, which is a recuperation of extremely high efficiency and seldom reached in practice, and contemplates the reduction of the products of combustion from a temperature of 2300° F. to 800° F.; but even this degree of recuperation results in a loss of 223 B.T.U.'s for every pound of steam so passed through the system. Curve F is similar to curve E, but shows the loss due to each pound of steam passing through the system with a recuperation of 46% efficiency, which

closely approximates the usual practice (see test of Calkins), and contemplates a reduction of temperature of the waste gases or products of combustion from 2300° F. to 1200° F. In this case the unavoidable loss due to the use of each pound of steam passing through the system is 592 B.T.U.'s. Curve G represents the loss with zero, or no recuperation, and amounts to 1645 B.T.U.'s per pound of steam used.

EFFECT OF STEAM ON QUALITY AND QUANTITY OF GAS

Constituents of Gas.	Air Gas by 3.			Mixed Gas by 3 and 5.			Mixed Gas by 3 and 6.		
	Vol-umes.	Cubic Feet.	Per Cent by Vol.	Vol-umes.	Cubic Feet.	Per Cent by Vol.	Vol-umes.	Cubic Feet.	Per Cent by Vol.
CO from air	2.0	715.6	34.7	2.0	715.6	25.7	2.00	715.6	23.0
CO from steam	....	.....	....	1.0	357.8	12.9			
H from steam	....	.....	....	1.0	357.8	12.9	1.96	701.2	22.5
CO_2 from steam	...	.....	....	...	.....	....	.98	350.6	11.2
N from air	3.77	1348.8	65.3	3.77	1348.8	48.5	3.77	1348.8	43.3
Volume of gas produced	5.77	2064.4	100.0	77.6	2780.0	100.0	8.70	3116.2	100.0

	Air Gas	Mixed Gas 3 and 5	Mixed Gas 3 and 6
Volume of gas per lb. C	86 cubic feet	77.2 cubic feet	87.2
Combustible in gas	34.7%	51.5%	45.5%
Calorific power per cubic foot	119 B.T.U.	176.9 B.T.U.	156.8 B.T.U.
Steam decomposed per lb. of C	None used	.5 pound	.98 pound
Air required per lb. of C	71.2 cubic feet	47.5 cubic feet	47.8

QUALITY OF GAS WITH VARYING STEAM

Gases by Volume.	Excess of Steam.		
	Moderate.	Great.	Maximum.
CO_2	5.30%	8.90%	15.00%
CO	23.50	16.40	11.50
CH_4	3.30	2.55	1.90
H	13.14	18.60	24.60
Heat value per cubic foot	151 B.T.U.	135 B.T.U.	129 B.T.U.
Temperature	1472° F.	1292° F.	932° F.

For good, average working in an ordinary producer 6% of the weight of the blast may be steam, or by volume about 10% steam and 90% air. This is equivalent to one-fifth of the C being burnt by steam and four-fifths by air. About 25% more steam sometimes may be used, and the steam may be figured as one-third to two-fifths of the coal gasified, or approximately a boiler H.P. per ton for 24 hours.

Curve "H" shows the total cooling effect, or heat absorbed by introducing one pound of steam at 212° F. to the fuel bed, wherein certain percentages of the pound of steam are decomposed, and the remaining part passes through the fuel bed

not decomposed, but merely as superheated steam. It will be seen that commencing with 330 B.T.U. absorption, representing no decomposition, the heat absorbed is merely that required to raise the steam from 212° to 1500° F., which represents the absorption of 330 B.T.U.'s. As the abscissa is increased, representing an increased percentage of decomposition, the heat-absorbing effect increases until the 100% line is reached, where the entire amount of heat absorbed by the decomposition of one pound of steam, amounts to 6060 B.T.U.'s.

It is now possible to determine the amount of steam that will be required per pound of combustible consumed, in order to maintain the temperature of the fuel
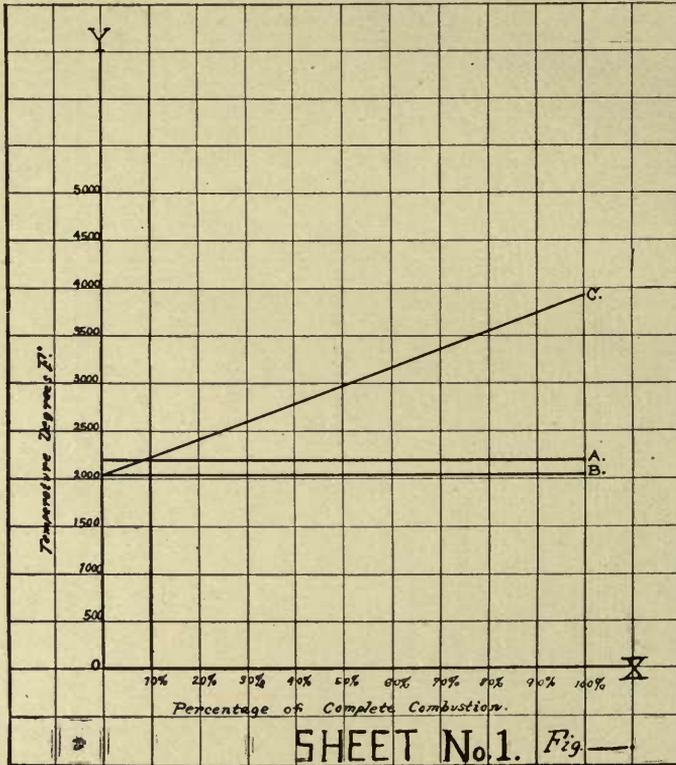
FIG. 5.—Relation of Combustion to Temperature.

in the producer at a predetermined point, provided we know the approximate proportions of each pound of steam introduced to the fuel bed that will be dissociated, which fact may be approximated by analyzing the gas issuing from the producer. As, for example, suppose it is desired to maintain the temperature of the fuel bed at approximately 1500° F. in view of the fact that one-fourth or 25% of the carbon consumed is burned to carbon dioxide (CO_2). By reference to curve C, we find that the natural temperature of the furnace, if no cooling medium be employed, would be approximately 2440° F.; therefore for each pound of combustible consumed to reduce the temperature, there would have to be the difference in the number of B.T.U.'s in 6.79 lbs. of gas at 2440° F. and the same weight of gas at 1500° F. = 3572

B.T.U. (For the specific heat of the furnace gases at this temperature see Curves, Sheet No. 5.) Therefore, there must be absorbed something in excess of 3572 B.T.U.'s; that is, for each pound of carbon burned in the producer there must be passed through the bed of fuel enough steam so that by its latent heat and heat required to cause dissociation of the steam, there will be absorbed 3572 B.T.U.'s.
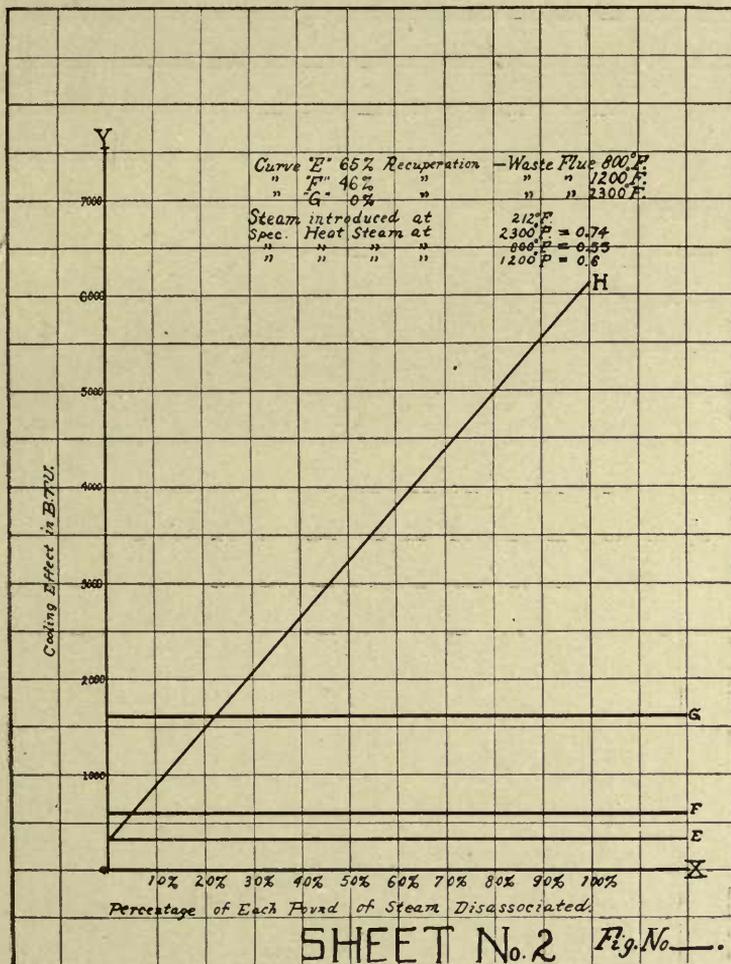
FIG. 6.—Effect of Steam on Lowering Heat of Fuel Bed.

By reference to Curve *H*, Sheet No. 2, may be determined the cooling effect produced (or heat absorbed), by the chemical dissociation of steam. It is a demonstrable fact that of all the steam introduced to a bed of incandescent fuel only a fractional part is dissociated.

Butterfield says (page 86): " It would therefore seem that Euchene's researches support the assumption, which theoretical considerations warrant, that when the water evaporated from the ash pan in a given time exceeds in quantity that which

the bed of fuel in the producer is capable of decomposing, the undecomposed steam abstracts heat from the fuel, while the decomposed steam yields practically no carbon oxide, but only hydrogen and carbonic acid."

Assuming that 70% of the steam is decomposed under these conditions, each pound of steam introduced to the furnace will absorb 4350 B.T.U.'s; therefore, for
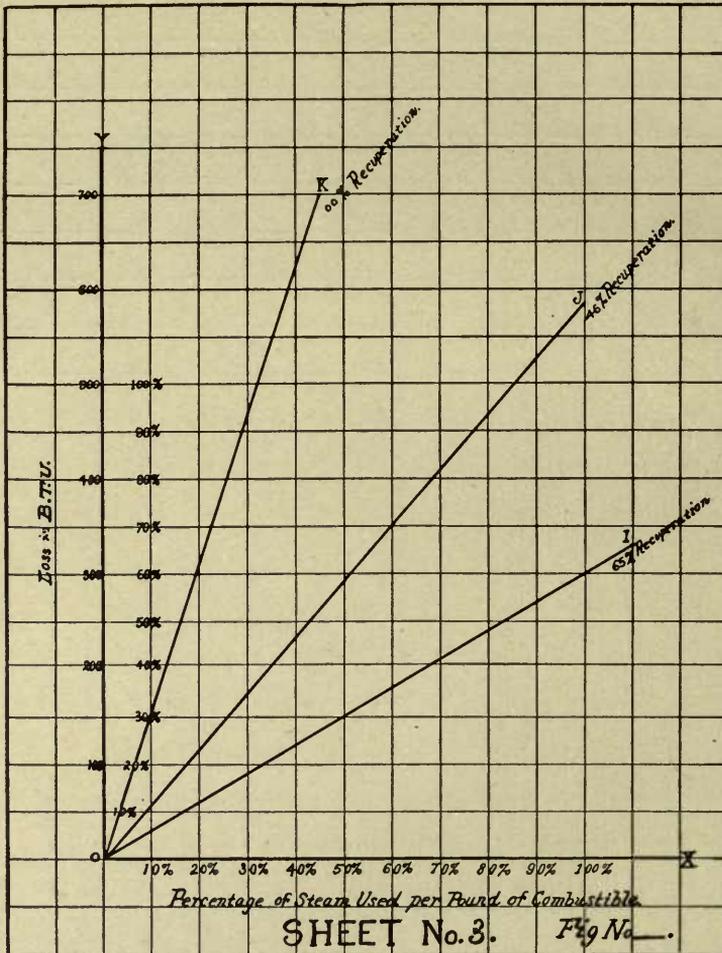
Fig. 7.—Influence of Quantity of Steam on Heat Absorbed.

each pound of combustible consumed, there would be required $\dfrac{3572}{4350} = 0.82$ lb. of steam introduced to the bed of fuel, or the ratio of steam required to that of combustible used would be 82%. By referring to Curves I, J, and K, Sheet No. 3, which curves represent various degrees of recuperation, will be shown the amount of heat (in B.T.U.'s per pound of combustible used) that is absolutely and unavoidably lost, due to the use of steam as a means of cooling the fire. Considering the

problem in hand, and with a recuperation of 65% efficiency there is lost per pound of fuel consumed 270 B.T.U.'s.; with 47% recuperation 580 B.T.U.'s, and with zero recuperation about 1600 B.T.U.'s. Thus it may be seen that for every pound of steam introduced to the bed of fuel there is always an unavoidable loss of heat, and the efficiency of steam as a cooling agent must always remain below 100%.
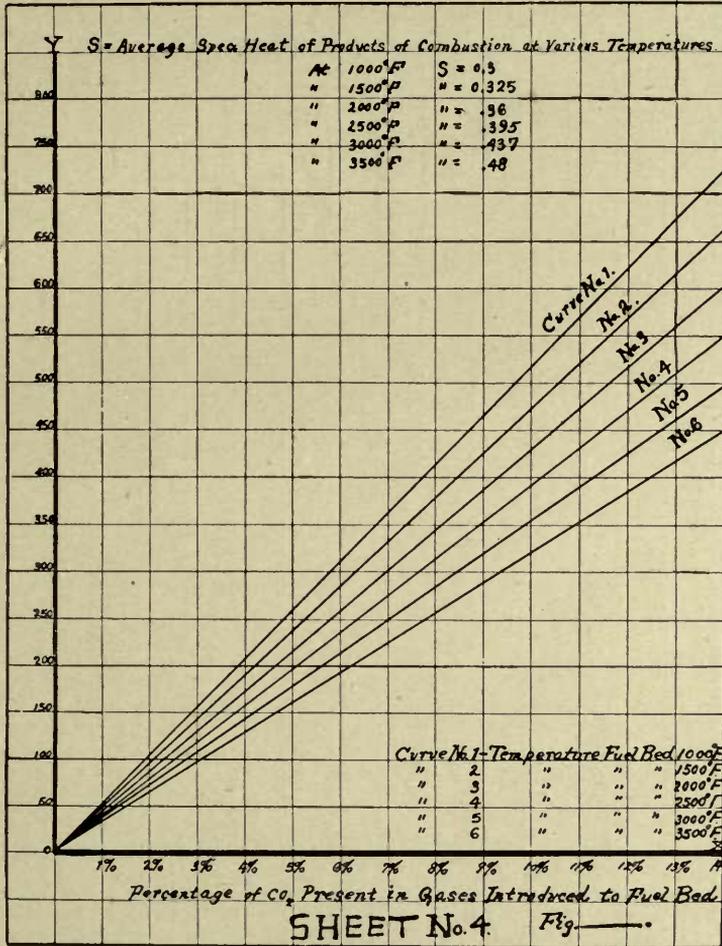
FIG. 8.—Influence of CO_2 on Temperature.

In addition to this loss of heat, there is always the direct loss required to raise water from a temperature of say 60° F. to steam at 212° F., amounting to 1118 B.T.U.'s. This heat must be supplied from some source at the expense of the combustion of fuel.

Reduction of CO_2 to CO.—Kent says (page 456): " By the decomposition of a chemical compound as much heat is absorbed, or rendered latent, as was evolved when the compound was formed. If 1 lb. of carbon is burned to CO_2, generating 14,544 B.T.U., and the CO_2 thus formed is immediately reduced to CO in the

presence of glowing carbon, by the reaction $CO_2 + C = 2CO$, the result is the same as if the 2 lbs. C had been burned directly to 2CO, generating $2 \times 4451 = 8902$ heat units; consequently $14,544 - 8902 = 5642$ heat units have disappeared or become latent, and the "unburning" of CO_2 to CO is thus a cooling operation."

By burning 1 lb. of carbon in oxygen to CO_2, there are produced $3\frac{2}{3}$ lbs. of CO_2 gas, and there are liberated about 14,544 B.T.U.; by the reduction or "unburn-
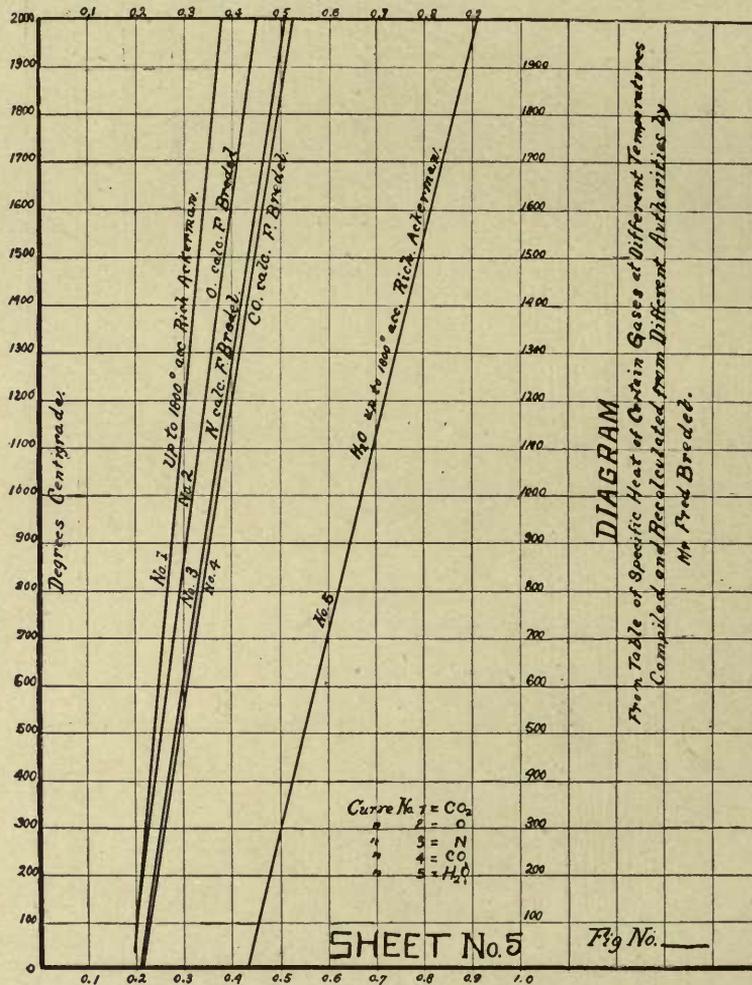
FIG. 9.—Influence of Temperature on Specific Heat.

ing" of $3\frac{2}{3}$ lbs. of CO_2 to CO there are absorbed 5642 B.T.U., therefore by the reduction of 1 lb. of CO_2 to CO, there are absorbed 5642 B.T.U. $\div 3\frac{2}{3}$ lbs., which equals 1540 B.T.U. of heat.

Consequently by the decomposition of one one-hundredth of a pound there are absorbed $1540 \div 100 = 15.4$ B.T.U.

As the average specific heat of any gaseous mixture (consisting of products

of combustion, steam and air), can be closely approximated (by reference to the curves on Sheet No. 5) the cooling effect on a fuel bed of such a mixture containing varying percentages of CO_2, by weight or volume, may be determined.

By referring to Sheet No. 4 can be seen curves which indicate the temperatures at which various mixtures of products of combustion (varying in their percentage of CO_2) must be introduced to a bed of incandescent carbon in order to cause any
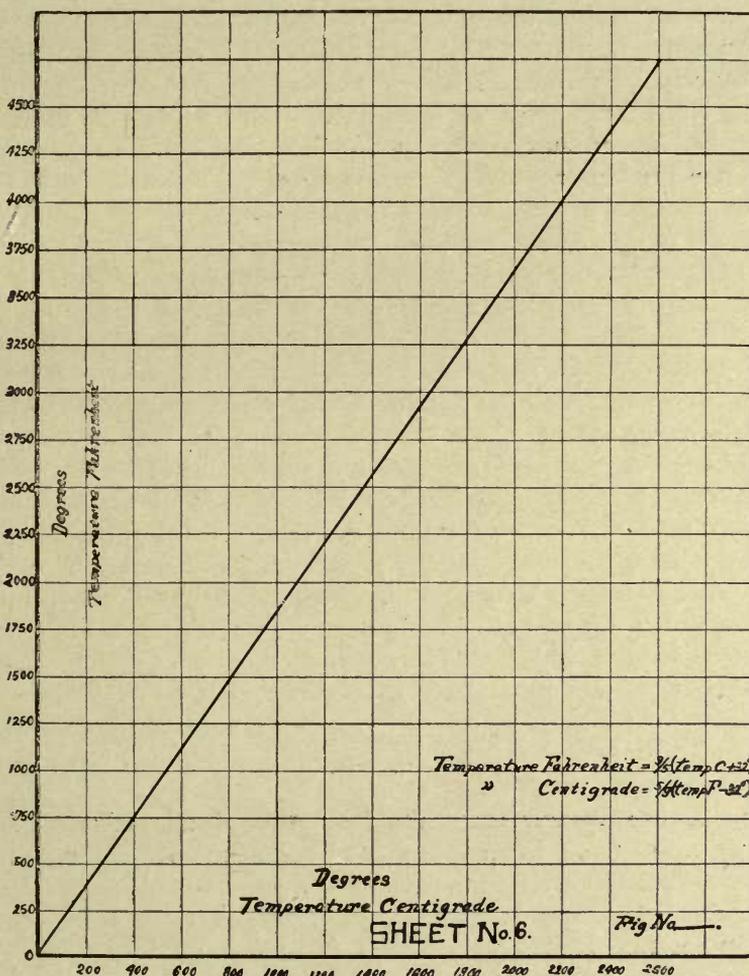
Fig. 10.—Conversion of Centigrade and Fahrenheit Degrees.

change of temperature of the fuel bed, with the understanding that all the CO_2 present is reduced to CO.

To represent these temperatures different curves are required for different temperatures of fuel beds, as the average specific heat of the gaseous mixture varies with its change of temperature. By the use of Curves Nos. 1, 2, 3, 4, 5 and 6, on Sheet No. 4, if the temperature of the fuel bed and the percentage of CO_2 present in the gaseous mixture introduced thereto be known, the fact can be determined

as to whether the net result is a heating or cooling of the fuel bed; also the temperature of the gaseous mixture can be determined at which there will be neither a cooling or heating of the fuel bed; that is, where there will be no exchange of heat between the fuel bed and the gaseous mixture. For example, if there is 8% CO_2 in the gaseous mixture introduced to the fuel bed which has an average temperature of 1500°, the gaseous mixture must have a temperature of 378° F. higher than the fuel bed in order to produce neither a heating or cooling effect (see Curve No. 2), or a total temperature of (1500° + 378°) 1878° F. If the temperature of the gaseous mixture is below 1878° F. the gases will cool the fuel bed; if above 1878° F. they will heat the fuel bed.

On Sheet No. 5 are curves representing the specific heats at varying temperatures under constant pressure (14.7 pounds absolute) of the gases, carbon dioxide, oxygen, nitrogen, carbon monoxide, and superheated steam.

On Sheet No. 6 is a curve to assist in transferring temperature readings from Fahrenheit scale to centigrade scale and vice versa.

In using suction producers of the ordinary up-draft type with the exhaust gas, or connection (CO_2 as an endothermic) during cleaning periods, it is possible by opening wide the exhaust within the producer to create an equilibration of pressure in such a manner that any, or all, doors may be temporarily opened.

This can, of course, only be maintained for a few moments by reason of the strong heat-absorbing nature of the exhaust gas and the tendency to kill the fire.

Connections.—The standard practice generally dictated is that producer outlet connections should be about one-eighth the diameter of the producer, internal diameters being taken or measurements in the clear of both producers and connections. However, it is customary among most manufacturers to make the inlet to the suction producer about one-sixth, and the outlet about one-fifth; the outlet in most suction-producer practice being about 10% greater than the inlet in the clear.

It would seem that with suction producers the connection between the producer and scrubber should be as large as possible, and should be limited only by cost of construction, for two reasons. First, there is greater freedom from friction, and second, and more important, there is less wire drawing and consequent channeling of the gases through the fuel bed.

According to one manufacturer, the flue areas of a producer should be as follows: Ample area of flue is important, and the more so in bituminous practice. In general, the diameter of the producer connection should be about one-quarter the diameter of the producer, and in a collecting flue from several producers its area in like proportion should not be less than one-sixteenth of the gas-making area of the attached producers. Thus a producer 8 feet inside diameter of lining should have a connection at least 24 inches internal diameter. As such a producer may readily gasify 600 pounds of coal hourly, the flue area is about equal to one square foot per 200 pounds of coal gasified hourly.

Sizes.—Shaft producers should not be made smaller than an internal diameter of 3 ft. 6 in. unless intended to operate with charcoal, and should not exceed in outside diameter 12 ft.

The former limit is regulated by a certain structural difficulty in the way of linings and mechanical difficulties in the removing of ash and clinker, but more

particularly, by the loss which is also applicable to gas engines and all furnaces; namely that whereas the volume or content of a furnace increases as the cube of the linear dimensions, the surface merely increases as the square.

That is to say, where a small producer may have a certain ratio of radiating surface to fuel bed, this ratio is materially lessened in the large sizes, with a corresponding increase of efficiency or decrease in the per cent of "jacket loss." The radiation increasing as the square, and the capacity as the cube of the lineal dimensions.

The latter limit is regulated by structural difficulties in the maintaining of rectitude in the linings and more especially by mechanical difficulties, the stoking of the producer, the packing of the fuel bed, and the control of the angle of repose of fuel. Also there is much greater difficulty and loss of fuel with the removal of clinker and ash which may become imbedded within the heart of the fire.

Weights.—The approximate weight of suction gas producer sets, including all apparatus and fire brick, based upon the Muenzel Suction Producer are as follows:

H.P.	Weight.	H.P.	Weight.
20	9,000	110	19,800
25	9,460	120	20,100
30	9,680	130	21,500
35	10,120	140	23,000
40	10,560	150	24,300
50	11,000	160	25,100
60	12,760	170	26,000
70	14,080	180	27,500
80	16,900	190	28,700
90	17,160	200	29,200
100	18,000	250	36,500

A 250 h.p. pressure producer complete, with holder, without fire-brick, but with connection, weighs 48,000 lbs.

The above does not include piping and auxiliaries, which usually equal 10% in addition to the sets above specified.

APPROXIMATE SPACE REQUIRED FOR SINGLE UNIT GAS POWER PLANTS

H. P.	Suction.			Pressure.*			Gas Holders.	
	Length, Feet.	Width, Feet.	Head Room, Feet.	Length, Feet.	Width, Feet.	Head Room, Feet.	Cubic Feet.	Tank Diameter.
25–50	13–14	9–11	13–15	..	..	......	1000	15 feet
50–75	14–15	10–12	14–17	..	..	......	2000	17 feet
75–100	15–19	11–14	15–20	..	..	......	2500	19 feet 6 inches
150	20–21	13–15	19–20	..	..	......	3000	21 feet 6 inches
200	22–23	15–16	22–23	32	16	22–25	4000	21 feet 6 inches
300	25–26	16–17	23–25	34	18	23–25	5000	24 feet
400	.....	.....	.....	36	20	23–26	6000	30 feet 6 inches
500	....	....	....	2 units 39	22	23–26	10000	35 feet
1000	....	.....	....	3 units 39	47	23–26	15000	43 feet

* Pressure plants exclusive of holder. Area depends of course on number and size of units for the total power given.

Producer Shell.—The writer recommends a shell of ¼-in. steel boiler plate for both producer and scrubber. This should be thoroughly riveted with the best grade of ½-in. wrought-iron rivets, the rivets being preferably pneumatically riveted and all joints having calking edges, contact being metal to metal without packing. To test the tightness of the producer shell, a fuel bed of three feet in depth is charged in the producer, and the entire bed brought to a red heat of combustion. At this point 18 inches of green coal is added to the top of the fire, and gas immediately drawn from the producer. This gas is not to show a content of more than one per cent of free oxygen, a larger amount indicating leakage of the lining or connection of the producer.

It will be manifest that the three feet of solid fire bed at a red heat is for the purpose of dissociating all air passing through the producer, and the surface of green coal is to act as a condenser to lower the resultant gas to a temperature below the ignition point for combination with free oxygen, and thereby prevent secondary combustion in the top of the producer, which would prevent its appearance in the necessary analysis.

Continuity.—Continuity of producer operation, of course, depends upon the nature of the fuel used, and the proportion of load or demand maintained to the capacity of the apparatus.

Generally speaking, on lignite or bituminous producers, the standby period of six to ten hours should be assumed per week, where the service is continuous, or twenty-four hours per day.

Several Muenzel producers running upon anthracite have made ninety days continuous run, without even a momentary intermission.

The durability or life of the lining of the producer depends much upon the conditions of operation and fuel aforementioned.

Under proper load, and with careful operation, with particular reference to preventing secondary combustions occurring in the producer through an admission of drafts, holes in the fire, etc., the durability or life should be from three and one-half to four years.

Fire-brick Linings.—Gas producers in furnaces should be lined with fire-brick and grouted, between the lining and shells or outer walls, with fire-clay, pulverized brick-dust, or asbestos, the latter being preferable by reason of its elasticity and maintenance of position after temporary strains. It is also less inclined to cleavage, fissures, cracks or chimneys. The brick should be wet before setting, the mortar being extremely thin, hardly thicker in fact in consistency than whitewash, and the bricks carefully faced. The use of a thick or putty-like mortar frequently accounts for buckling or skewbacks, by reason of having a coefficient of expansion differing from that of the brick. Leaks in producers are a source of very considerable loss through admitting of secondary air, and should be most carefully avoided.

As a wash for fire-brick in furnaces, to give the bricks a glaze and keep carbon from collecting on the walls, a correspondent of *Power* suggests one pound of salt to a pint of water, mixed with fire-clay and applied as a whitewash.

One ton of fire-clay should be sufficient to lay 3000 ordinary bricks. To secure the best results, fire-bricks should be laid in the same clay from which they are manufactured. It should be used as a thin paste, and not as mortar. The thinner the

joint the better the furnace wall. In ordering bricks the service for which they are required should be stated.

NUMBER OF FIRE-BRICK REQUIRED FOR VARIOUS CIRCLES (KENT)

Diam. of Circles Ft.	KEY BRICKS.					ARCH BRICKS.				WEDGE BRICKS.			
	No. 4	No. 3	No. 2	No. 1	Total	No. 2	No. 1	9 in.	Total.	No. 2	No. 1	9 in.	Total
1.5	25	..	..	..	25								
2.0	17	13	..	..	30	40	..	..	42				
2.5	9	25	..	..	34	31	18	..	49	60	..	..	60
3.0	..	38	..	..	38	21	36	..	57	48	20	..	68
3.5	..	32	10	..	42	10	54	..	64	36	40	..	76
4.0	..	25	21	..	46	..	72	..	72	24	59	..	83
4.5	..	19	32	..	51	..	72	8	80	12	79	..	91
5.0	..	13	42	..	55	..	72	15	87	..	98	..	98
5.5	..	6	53	..	59	..	72	23	95	..	98	8	106
6.0	..	..	63	..	63	..	72	30	102	..	98	15	113
6.5	..	..	58	9	67	..	72	38	110	..	98	23	121
7.0	..	..	52	19	71	..	72	45	117	..	98	30	128
7.5	..	..	47	29	76	..	72	53	125	..	98	38	136
8.0	..	..	42	38	80	..	72	60	132	..	98	46	144
8.5	..	..	37	47	84	..	72	68	140	..	98	53	151
9.0	..	..	31	57	88	..	72	72	147	..	98	61	159
9.5	..	..	26	66	92	..	72	83	155	..	98	68	166
10.0	..	..	21	76	97	..	72	90	162	..	98	76	174
10.5	..	..	16	85	101	..	72	98	170	..	98	83	181
11.0	..	..	11	94	105	..	72	105	177	..	98	91	189
11.5	..	..	5	104	109	..	72	113	185	..	98	98	196
12.0	..	..	..	113	113	..	72	121	193	..	98	106	204
12.5	..	..	..	113	117								

For larger circles than 12 feet diameter use 113 No. 1 Key, and as many 9-inch brick as may be needed in addition.

For further information upon fire-clay and brick, see Chapter XXI.

Repairs and Maintenance of Producers are less than that of a steam plant of the same power. After eighteen months' service of a certain plant (about 400 H.P.) the repairs were merely nominal. Producer linings are known to have stood as long as ten years, and in any case should stand several years. From 15 to 25 cents per horsepower per year may be taken as an approximate estimate for repairs of plants up to 500 H.P., so that the usual allowance of 2 to 3% of its cost is reasonably close.

Suction linings usually require repairs sooner than pressure producers, but of course depends on the grade of coal used, the quality of the brick, the workmanship in their setting, and the care given the producer in operation.

Shell Insulation.—Conditions effecting loss of heat by radiation, its calculation and measurement, are discussed in the chapter on Furnaces.

Under ordinary conditions of producer construction it is customary to have an insulation or " dead " space between the fire-brick lining and the shell varying from one to two inches in diameter. However, the former measurement is considered sufficient in general practice.

This space is filled with some non-conducting matter which serves the dual purpose of insulating the fire bed and reducing the loss by conduction and radiation to the atmosphere; and also to prevent the leakage of air and its seepage into the fire, between the brick; and the channeling of air between the lining and the shell.

In circular producers this insulation or dead space usually consists of finely powdered cinders, sand, or fire-clay, sand and asbestos, and even in some instances several thicknesses of asbestos board or wool. The highest efficiency however is obtained by a filling which remains more or less plastic and elastic; inasmuch as the taking of a " permanent set " subtends cracks and separation from the lining and shell due to expansion and contraction, and the jarring of the lining in clinkering.

While sand or powdered cinders form a fair material for circular producers, some form of grouting, as herein described, is necessary with rectangular producers, and may be advantageously used in almost any type. Regardless of the material used as a filler it is necessary that it be carefully rammed home by tamping, after the laying of every two or three courses of brick in the fire-brick lining.

Grouting.—The mixture used by the Fairbanks-Morse Co., for grouting or filling in the space between fire-brick lining and shells of producers, consists of

> 1 part coal tar;
> 2 parts sharp sand;
> 2 parts fire-clay.

Mix the sand and fire-clay throughly, and then add tar and again mix. If the weather is cold the ingredients should be pre-heated before mixing, to assure assimilation. The sand and clay should be dry and warm. The final mixture should be dry enough to be taken into the hands without sticking.

The brick to which it is applied should be smooth and lie close. They should be wet in a thin mixture of fire-clay and water, being both dipped and the mixture applied with a brush.

The bricks should be laid with a very thin joint to prevent skewing. After laying two or three courses of brick the above mixture or grouting should be poured in and tamped with an iron bar.

The tar mixture should be covered with fire-clay wherever it comes in contact with the fire, so that the tar will not burn out before hardening. After heating, however, the mixture becomes hard, and it allows for the expansion and contraction of the brickwork without cracking or setting, which faults subtend air leaks in the producer.

The grouting is both elastic and plastic.

Cements.—The following cements are in practical use:

FURNACE CEMENT

> 4 parts pulverized fire clay;
> 1 part plumbago. Iron filings or borings (free from oxidation or oil).
> 2 parts peroxide of manganese;
> $\frac{1}{2}$ part borax;
> $\frac{1}{2}$ part sea salt.

Mix in thick paste, and use immediately. Heating gradually when first using. Powder thoroughly and tamp home.

HIGH TEMPERATURE CEMENT

(Gaskets and Joints)

1 part white lead;
1 part red lead;
2 parts clean filings thoroughly mixed.

Mixture may be calked with broad-nosed tool.

FIRE CLAY PUTTY

Mixed with water to the consistency of putty.

Fiber asbestos;
Cement;
Fire-clay.

Or,

5 parts fire-clay;
5 parts broken fire-brick finely powdered.

Or,

2 parts broken fire-brick finely powdered;
2 parts fire-clay;
1 part asbestos fiber.

The Hawley Down-Draft Furnace Co. recommend the best material for patching furnaces as a mixture of four parts ganister and one part fire-clay. Also another mixture for patching of two parts fire-clay and one part silica sand.

The cements of the Johns-Manville Co. are good. Fireite is used most extensively in setting up furnaces and repairing broken joints in heating furnaces, ranges, heaters, and stoves. It adheres readily and makes a strong joint on tin or castings. It dries and sets in a few hours, and vitrifies under heat without shrinking or becoming porous. It has no odor. It is however far inferior to Vitrex.

Standard Vitrex is in general use in gas and chemical works for repairing broken clay and iron retorts and pipes, and cementing fittings, connecting pipes and flange-joints, and for cementing joints in stone, wood, and metal. It is composed of acid and fire-proof cementing materials, and can be applied with a trowel, and subjected to intense heat it vitrifies without shrinking. It is not injured by nitric or sulphuric acids nor petroleum oils, and makes an altogether satisfactory cement.

Either of the cements named above will stand all the heat ordinarily required in the places mentioned, the latter being much preferable. The writer's personal experience with the use of these materials has not gone beyond temperatures 2000°, and they will no doubt give satisfactory service up to this point and in all probability considerably beyond it.

Among the proprietary cements or dopes, one of the most satisfactory for use with gas apparatus is "Smooth On," manufactured by the Smooth On Manufacturing Co., Jersey City, U. S. A. It may be used in making permanent screw-thread joints, or under gaskets, flanges, etc., or for temporary patches. In the last connection, an efficient temporary patch for stopping a gas leak may be made by plastering the leak with Smooth On, and wrapping with cheesecloth or similar fabric, Smooth On being added to the various layers as the cloth is applied.

Rating.—The rating of a producer with American coal is most reasonable upon a basis of eight pounds per square foot of grate surface for pressure producers, and ten pounds per square foot of grate surface for suction producers. The Morgan producer, however, has been satisfactorily run, it is said, in some instances, upon a combustion of as high as fifteen pounds per square foot of grate surface. This, however, is excessive for usual practice, and cannot be generally commended.

Experiments upon the apparatus of the Loomis-Pettibone type go to show that anthracite, bituminous, lignite, coke, and even wood, have about the same thermal duty in combustion per square foot of grate surface, their inequality in calorific value being compensated by their rate of gasification.

In specifications for rating of suction gas power plant, it is customary to calculate a maximum suction on the part of the engine not exceeding $2\frac{1}{2}$ inches of vacuum. Beyond this duty the performance of the engine as a suction pump is not generally assumed to be sufficiently efficient to give it its maximum rating.

Gasification of coal increases inversely with the calorific value of the coal. (See Fernald's Tables.) For combustion of coal in the ordinary type of furnace or shaft producer, attentative rating of 10 pounds per sq.ft. of grate surface is usually an ample allowance; the horsepower resultant from this of course depending upon the heat unit content of the coal thus gasified and the efficiency of the engine used.

As has been stated, however, the increased rating of combustion on the part of low-grade coals creates a very even equilibration, so that the total number of heat units delivered by various fuels per unit of time and space, is practically identical, or at least close enough, for commercial service.

It is the custom of some engineers to allow 1.25 to 1.5 square feet of grate surface per nominal horsepower for the lower grades of bituminous coal and lignites. This, however, merely maintains the ratio of space to weight of fuel already indicated. It does not, however, include the element of time or rapidity of combustion or combination. This is most likely a mistake, especially where the low-grade fuel possesses high volatile content and high-flame propagation, when the high speed of gasification more than compensates for its thermal content per unit of weight.

It is claimed in defense of this increased area that the grate surface allowed is not co-ordinate with gasification, by reason of the total thermal liberation of heat units, or nominal horsepower supplied, but in order to accommodate the rapid increase of ash both in its rate of formation and the large bulk incident to low-grade fuels.

On the other hand, however, it must be remembered that low-grade fuel contains a large quantity of binding ash, moisture, and other neutrilent, all of these

subtending low-flame temperature. Hence where combustion occurs over a relatively large area by reason of the heat insulation and ventilation of the foreign matter, conditions of radiation, etc., the fuel bed temperature is extremely low, too low in many instances for the proper rate or temperature for gasification. Hence, in order to obtain the temperature of gasification, it is sometimes necessary to concentrate the combustion area. So it is doubtful whether the above rating should ever be exceeded. If, however, it should be, such an arrangement should only be for the disposition of the ash, when it should be remembered that many of the lignites and lower grade fuels are not necessarily richer in ash than coals of a higher grade, but that they form their ash more rapidly by reason of the high rate of combustion and the distillation of the moisture and volatile binding.

Within certain limits (with good grade fuels), fixed by the economy of construction and convenience of operation, the latter being principally stoking, the lower the gasification duty per unit of grate surface in all fuel bed producers, the less the clinker and other difficulties of operation. This is due to condition of heat propagation, blast distribution, and other contingencies. One of the most successful producers operating to-day is doing a gasification duty of only four pounds of coke per square foot of grate surface.

Load Factor.—Load factor is usually defined as the ratio of average load to maximum capacity or demand. The efficiency of suction producers varies but little upon various load factors so long as these remain below the limit of maximum capacity. Any lack of efficiency shown by a plant on low load factors is due to the low efficiency of the engine beneath its rated capacity, and not to the producer.

The operation of the producer at various load factors need not be changed as much where an exhauster is interposed as where the pumping is dependent upon the engine. It is generally expedient, however, in both cases to thin the depth of the fuel bed upon low loads, and conversely to increase the depth of fuel beds upon heavy loads. This condition has to do, however, largely with the question of time contact.

The area of the producer is not materially effected in these calculations, it being not only practical but extremely efficient to gasify at a very slow rate per unit of cross-section. It is of course necessary to gasify at a sufficient rate to maintain the proper temperature for dissociation and reaction, hence a minimum limit of from 4 to 5 pounds of coal gasified to the square foot of cross-section should be maintained, while the maximum limit for most coals should not exceed 15 pounds per square foot of cross section.

Up- and Down-draft Types.—American practice shows a division line between up- and down-draft producers, the line of demarcation being the volatile contents of coal analysis. This line appears to be about 20% of volatile matter, and above that down-draft apparatus is necessary by reason of its recovery of hydrocarbons and their fixing into a permanent gas. Below that, up-draft apparatus is sufficiently satisfactory, and offers a more simple operation and cheap construction.

Messrs. R. D. Wood & Co., who are the manufacturers of down-draft apparatus, make the following statement concerning the operation of producers of this class: " For any length of continuous operation such apparatus requires obviously a very good fuel, as coals with low sulphur and a refractory low ash. It would fail with

many ordinarily available fuels which can readily be gasified in the usual up-draft type of producer."

Suction and Pressure Types.—The advantage of suction producers over pressure producers lies under three headings:

First. There is less tendency in the suction producer to channeling distribution of gases within the producer being more uniform.

Second. The gasification of the fuel occurs more rapidly and readily below, rather than above atmospheric pressure. This is instanced in a coal gas retort and a coke oven, where the volume of gas increases rapidly in its delivery under increased suction.

Third. The production of carbon monoxide is much more rapid under conditions of suction than it is by pressure; this is probably by reason of certain conditions of mass action, notably, perhaps, that the combined gas is withdrawn rapidly and immediately upon its formation, and by its absence prevents the formation of any neucleus or obstacle to the contact and union of the uncombined elements, namely, carbon and oxygen.

In this way the rate of its union or combination remains uniform, whereas under conditions of mass action under ordinary circumstances, chemical action becomes materially slower in combination, by reason of the interposition of the combined matter already formed.

In pressure producers a constant pressure (about one-half inch of water) is maintained on the gas main, and this regulated by the small steam valve on the blower, which can be changed from a full head of gas to a complete stop, or vice versa, by a few turns of the hand. When blast is entirely off, the producer will remain hot and ready for business at a few minutes' notice, for several days, without any fuel being fed into it.

The chief distinction between suction and pressure producers may be marked by the line between power and fuel purposes. There is scarcely a doubt but that the formation of producer gas occurs more readily and rapidly below than above atmospheric pressure, and the coal is more rapidly gasified. As a matter of fact, suction producers would entirely supersede pressure producers were it not for the impossibility of handling gases at a high temperature through the medium of an exhauster.

The Brewster Engineering Company has designed an exhauster, water jacketed throughout, which is supposed to have a capacity for handling gases up to 1200° F., but even with this apparatus it would be necessary to materially lower the temperature of the gases leaving the producer before admitting them to the exhauster, and hence a considerable amount of sensible heat would be lost in any fuel operation. This of course is necessary in any event in a power plant where the gas must be both cleansed and condensed prior to its entry into the engine.

Where suction producers are used for the production of any large amount of gas they should be connected in upon a header or bus-pipe with interposing valves, so that the load upon each one could be regulated. This header acts as an equalizer and can be in turn connected with the exhauster, and the valves aforesaid may be so set as to prevent " robbing."

It is not advisable to use single suction units larger than 8 or 10 ft. inside diam-

eter, as after that the problem of hand stoking and the maintenance of the fire in proper condition becomes impractical. Two or more suction producers should never be connected to any apparatus without the intervention of the equalizing pipe and exhauster, the latter being preferably of the water-seal or blow-back type. Single suction producers may occasionally be connected direct to the suction pipe of an engine, although this arrangement is less efficient than that of an exhauster.

According to one manufacturer, the calorific power or heat value per cubic foot of suction producer gas may average 15% lower than pressure gas, having less CO and H, but requiring less air for combustion.

This observation is, however, probably due to the attenuation of the gas under suction or change of vapor tension. Understanding conditions, in the opinion of the writer, there should be little or no difference, or if any, it would be in favor of the suction apparatus; hence, where an exhaustor is interposed there would be practically equal calorific power upon the plus side.

Water-seal Producers.—The water seal producer should be differentiated from that of the grate type by reason of the following characteristics: The water-seal producer is particularly available for units of large nature and where the gas is to be used for furnace or purely fuel purposes. This is for two reasons: First, the accessibility in stoking and the easy removal of large quantities of ash. Second, because such installations are usually placed in more or less open places, where the leakage occurring through the blowing or bubbling of the seal is not objectionable.

Where the producer is installed for power purposes, however, the water seal is not advisable, for the reason that the varying content of ash, that is to say, the increase or decrease in depth of the ash bed, makes the regulation of the fire and the resultant uniformity of the gas a very difficult proposition. Hence where an absolutely uniform gas is desired, as in power propositions, the grate producer should be invariably used. Producers of the Morgan type are particularly adapted to this (water seal) character of work.

The principal advantage of a water-seal producer lies in the opportunity it affords for continuous running, it being possible to clean fires and withdraw ashes without letting down or stopping the machine.

Water-seal producers may also be operated in combination with grates, which enables a better regulation of the fuel bed.

Steam Supply.—The necessary steam pressure for operating the steam under the producer, says Sexton, necessarily depends upon the size of the producer, the nature of the fuel, the depth of the fire bed, and the kind of gas required. The pressure, however, varies between 30 and 60 pounds per square inch, the latter being most efficient for use with the air inductor, although this pressure should not be so great as to create channeling through the fire bed. Where high pressures are used, they must be offset by very considerable reduction of the orifice and the use of proper baffles within the producer.

The amount of steam used in a producer varies from $\frac{1}{3}$ lb. per pound of coal gasified, which is about the minimum, to 2.5 lbs., as exemplified by the Mond by-product recovery system. The average will probably be, in average suction or pressure producers, in commercial practice, about 0.7 lbs. to 1 lb. In the St. Louis test the weights of steam varied from 0.3 to 0.6 lbs. per pound of Pocahontas coal.

The best proportions of steam and air cannot be rigidly fixed, the more steam that is used the better, until a limit is reached, this limit depending mainly upon the amount of heat that is available for decomposing the steam without unduly cooling the producer, and this will depend on the loss of heat in the producer itself. The average proportions when a producer is working well are about 10 parts steam and 90 parts air by volume, rising sometimes to 12.5 parts of steam to 87.5 parts air, but rarely passing beyond this. Taking 10 per cent of steam by volume as being a good working proportion, this will be about 6 per cent of steam by weight, and about one-fifth of the carbon will be burned by steam and four-fifths by air.

Assuming 6 per cent of steam by weight, it is very easy to calculate the amount of fuel that will be consumed. Since 1 lb. of carbon will combine with 1.33 lbs. oxygen to form carbon monoxide, and air contains 23 per cent by weight of oxygen, the amount of air required to burn 1 lb. of carbon will be $\dfrac{1.33 \times 100}{23} = 5.8$ lbs., therefore 1 lb. of air will burn $\dfrac{1}{5.8} = 0.171$ lb. of carbon.

One pound of carbon in decomposing steam will also combine with 1.33 lbs. of oxygen, and this will be contained in 1.49 lbs. of steam; therefore 1 lb. of steam will burn $\dfrac{1}{1.49} = 0.67$ lb. of carbon, so that for 100 lbs. of the gaseous mixture

$$
\begin{array}{llll}
94 \text{ lbs. of air} & = 0.171 \times 94 = 16 \text{ lbs. of carbon burned by air.} \\
6 \text{ `` `` steam} & = 0.67 \times 6 = \underline{4} \text{ `` `` `` `` by steam.} \\
\hline
100 \text{ lbs. of steam and air} & = 20 \text{ lbs. of carbon burned by mixture.}
\end{array}
$$

If loss of heat in the producer could be guarded against, a much larger proportion of steam could be used. One engineer of large experience has stated to the author that seven per cent by weight is the maximum amount of steam which should be used in an ordinary steam-blown producer.

Assuming the proportions above given to be correct, it is easy to ascertain what amount of steam will be required to work a gas producer. In all such calculations only the fixed carbon of the fuel must be taken into account, as all volatile matter will be expelled before the residue comes under the action of the air and steam. The amount of fixed carbon in fuel, and the amount of gas given off by the fuel, should therefore always be determined. The amount of steam required will be 6 lbs. for each 20 lbs. of carbon burned, or 0.3 lb. of steam for each pound of carbon.

Assuming the coal used to yield 60 per cent of fixed carbon, $0.6 \times 0.3 = 0.18$ lb. of steam will be required for each pound of coal consumed. To be on the safe side, the boilers should be capable of supplying two or three times this amount.

Each pound of carbon will require 5.8 lbs. of air, or 1 lb. of coal of the composition assumed will require 3.48 lbs. of air. As 1 lb. of air under normal conditions of pressure and temperature occupies 12.36 cubic feet, the volume of air required will be 58.1 cubic feet for each pound of carbon, or 34.9 cubic feet for each pound of coal consumed. The steam should be supplied at a high pressure, 60 lbs. to 75 lbs. being usually used.

For the purpose of introducing into the producer the steam with air supply, the jet blower is simple, compact, and cheap, but it requires intelligent use. Its advantages are greater when the gas is much cooled before use; less with a close connection of producer and furnace, and with soft coals than with carbonized fuels. The use of steam increases the fuel by adding H to the gas, reduces the inert N, raises calorific power, lowers exit temperature of gases and retards clinkering. It does not produce more heat, simply transfers it from the generator to the furnace, where it is burned by the potential heat value of the H instead of the less efficient means of greater sensible heat in the gas.

Too much steam, however, reduces the combustible in the gas and lowers calorific power, reducing the amount of CO and increasing CO_2, and H. Jenkin reports analyses as follows:

Volume %.	EXCESS OF STEAM.	
	Moderate.	Great
CO_2	5.30	8.90
CO	23.50	16.40
CH_4	3.30	2.55
H	13.14	18.60

In gasification of coke there is often strong tendency to clinker, and use of more steam may commend itself.

Steam Temperature.—The effect of temperature on the reaction between steam and C is of fundamental importance, says Wyer, and data showing the effects of different temperatures are given. The figures were obtained from the experiments of Dr. Bunte. The table shows conclusively that it is very desirable to keep the decomposition zone at a high temperature.

EFFECTS OF TEMPERATURE ON ACTION OF STEAM

Temperature, C.	Percentage of Steam Decomposed.	COMPOSITION OF GAS BY VOLUME.		
		H	CO	CO_2
674	8.8	65.2	4.9	29.8
758	25.3	65.2	7.8	27.0
838	41.0	61.9	15.1	22.9
954	70.2	53.3	39.3	6.8
1010	94.0	48.8	49.7	1.5
1125	99.4	50.9	48.5	0.6

An investigation on the use of steam in gas-producer practice was undertaken by W. A. Bone and R. V. Wheeler, and embodied in a paper read in 1907 before the British Iron and Steel Institute. The producers selected for the trials were of the Mond type. On leaving the producers, the hot gas passed through the superheaters, around which the air and steam forming the blast traveled, in the reverse

direction, through annular space between the inner gas main and an outer jacket. No recuperation was attempted in the air heating towers. The steam used for saturating the air blast was partly exhaust steam (in the trials at 60° and 65° wholly so) and partly live steam. The efficiency is based on the net calorific values of the coal and gas. It includes the coal burned under the boiler for raising steam for the blast, plus that required for the blower engine; also the coal equivalent for any mechanical work required for cooling and washing the gas for engines. The boiler had an efficiency of 58 per cent.

Steam saturation temperature..............	60°	65°	70°	75°	80°
Mean percentage composition of gas obtained:					
Co₂...............................	5.25	6.95	9.15	11.65	13.25
CO.................................	27.30	25.40	21.70	18.35	16.05
H₂.................................	16.60	18.30	19.65	21.80	22.65
CH₄................................	3.35	3.40	3.40	3.35	3.50
N₂.................................	47.50	45.90	46.10	44.83	44.55
Total combustibles...................	47.25	47.10	44.75	43.50	42.20
Calorific value of gas (gross)...............	46.77	46.74	44.74	43.37	42.73
Calories at 32° F. (net)..................	43.60	43.32	41.14	39.65	38.69
Yield of gas, cubic feet per ton.............	138,250	134,400	141,450	145,800	147,500
Pounds of steam in blast per pound of coal gasified................................	0.45	0.55	0.80	1.10	1.55
Percentage of steam decomposed...........	87.4	80.0	61.4	52.0	40.0
Cubic feet of air at 32° F. and 30″ in blast per pound carbon gasified..............	36.95	34.9	36.8	36.9	37.1
Ammonia in gas as pound of NH₄SO₄ per ton of coal............................	39.0	44.7	51.4	65.25	71.8
Efficiencies:					
(1) Including steam for blower engine....	0.778	0.750	0.727	0.701	0.665
(2) Including steam for blower engine and washers........................	0.715	0.687	0.660	0.640	0.604

St. John Recording Steam Meter.—The principle on which the meter operates is that with a uniform difference of pressure on two sides of an orifice through which steam is flowing, the quantity of steam passing bears a direct relation to the size of the orifice. In this meter steam enters at the bottom, and following the direction of the arrows leaves at the top. In the section shown S is a brass bushing screwed into the portion of the casting which separates the spaces A and B. A brass valve V is shown with tapered shank or plug supported at top and bottom, running in guides in the castings. This valve operates in such manner that when in its lowest position the top of the tapered plug fits closely within the brass bushing or seat, and the lip of the valve rests on the seat and no steam can flow. When the valve is raised, the space between the tapered plug and the seat increases from zero to a maximum when the valve is in its highest position and the rate of increase depends upon the taper of the plug.

The space between the tapered plug and the seat S is, then, the orifice through which the steam flows and the size of the orifice varies as the plug rises or falls, which occurs with the increase or decrease in the quantity of steam flowing. The weight of the plug is such that the pressure beneath the plug in space A must be about two pounds greater than in space B in order to raise the valve or

keep it raised off the seat and floating in the current of steam. The weight of the valve remaining the same at all times, the difference in pressure on the two sides of the orifice of about two pounds per square inch will remain the same no matter what position the valve may occupy.

The means by which the size of the orifice varies automatically with the
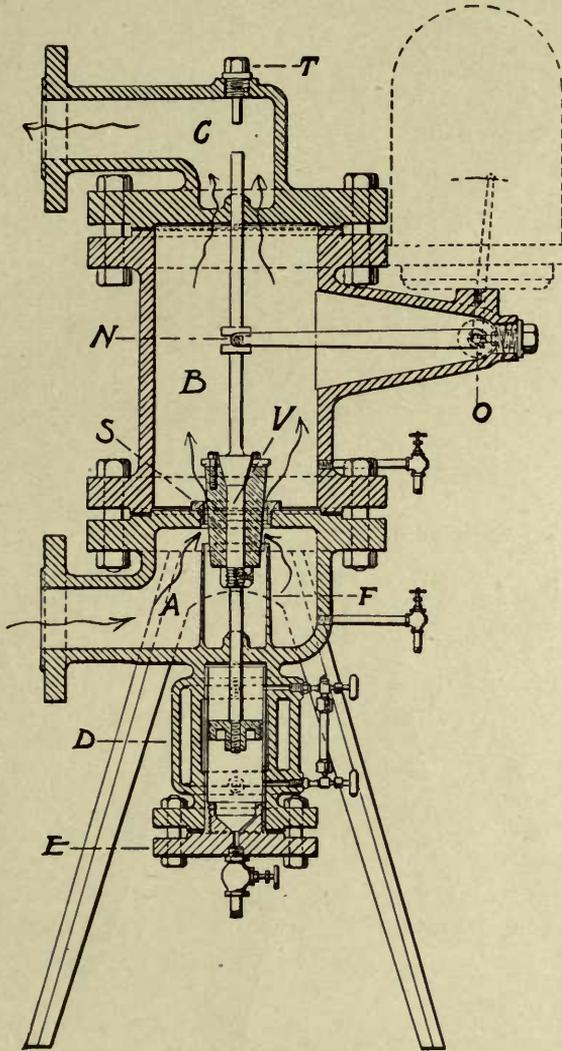
FIG. 11.—Section of the St. John Steam Meter.

draft of steam through the meter, and the means by which a uniform difference of pressure is maintained at all times on the two sides of the orifice, is thus shown.

The taper of the plug is such that the amount of steam passing through the orifice per hour is directly proportional to the rise of the valve. That is, if 1000 pounds of steam will pass in one hour when the valve is raised one inch, then when

the valve is raised two inches 2000 pounds will pass, and with a raise of one-half inch 500 pounds per hour will pass. Thus the rise of the valve is a direct indication of the quantity of steam flowing through the meter per hour.
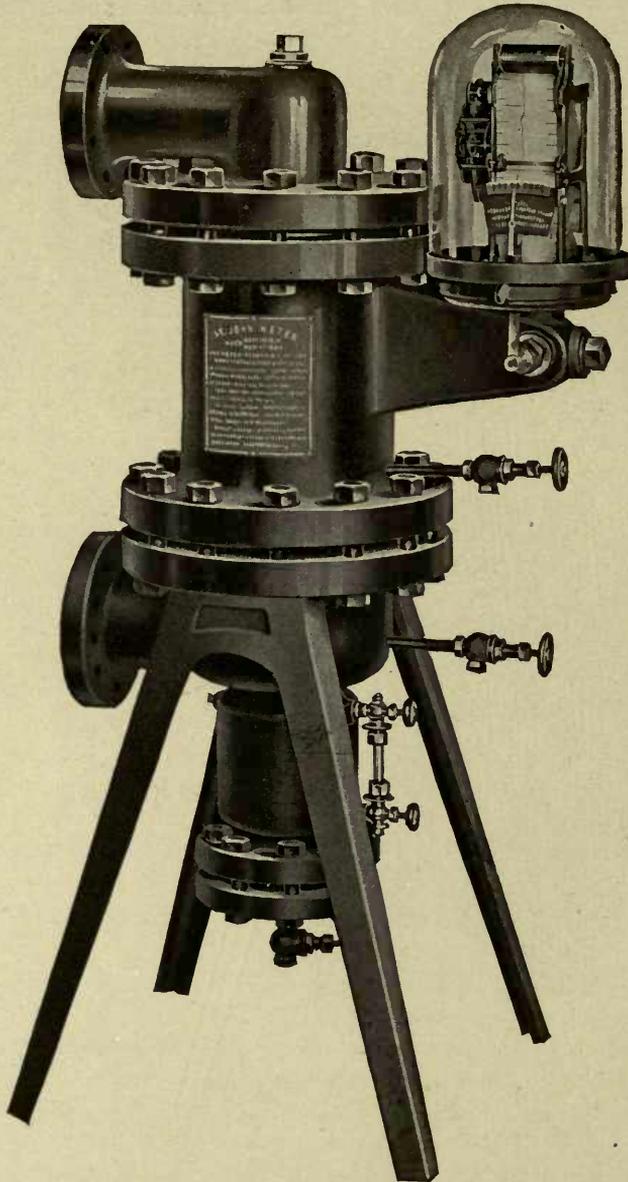
FIG. 12.—View of the St. John Steam Meter.

To transfer this motion to the pencil-arm outside of the meter casing, which carries the pencil and pointer, a lever arm inside the casing is supported at the center of rotation by a spindle, and is connected in proper manner to the upper

valve spindle at N. The horizontal spindle at O projects through the meter casing to support the pencil-arm, and is provided with a small stuffing box to prevent leakage of steam. The pencil-arm is set at such an angle with relation to the inside lever arm that when the valve is on its seat the pointer will be over the zero of the dial scale. Above the pencil held by the pencil-arm is a second pencil in a holder attached to the register frame, which may be adjusted horizontally and which should be set so that it is directly above the moving pencil and so that the lines drawn by the two pencils will coincide when the valve is on its seat and the pointer at zero. This line drawn by the stationary pencil is called the base line.

The vertical movement of the valve thus produces a horizontal movement of the pointer over the dial and of the pencil over the paper chart. With a proper scale engraved upon the brass dial in accordance with the calibration of the meter, the rate of flow of steam through the meter, either in pounds per hour or in horse-power, may be read from the dial at any instant. At the same time, with a proper scale of equal divisions marked upon the length of the chart to represent hours, and a uniform vertical movement of the chart upward under the pencil at such a rate that hour divisions marked on the paper will pass under the pencil at hourly intervals of time, the pencil will face a line the distance of which from the base-line will remain as a record of the rise of the valve and hence of the rate of flow of steam at all times throughout the day. This line, drawn by the moving pencil, is called the steam line. The motion of the chart is produced by two brass rollers held against each other by springs, between which the chart passes, and which are operated by clockwork.

Every meter is calibrated under working conditions, the steam after passing through the meter being condensed by means of a surface condenser and the water weighed in a tank on scales. The brass indicator scale is cut after the meter is calibrated and the rate of the meter determined.

Sargent Steam or Compressed Air Meter.—The demand for a device which would accurately record or indicate the quantity of steam passing through a pipe has long been recognized by engineers. There are numerous ways of calculating the rate of flow of steam through orifices and pipes, but the conditions are usually such that these calculations do not conform with reason. Variations in the moisture contained in steam, different degrees of superheat, and the skin friction of the pipe, are factors which introduce errors in calculations. The most reliable method of determining the quantity of steam passing through a pipe is, of course, to condense the steam and weigh the condensate.

In view of the above mentioned demand, the Sargent steam and compressed air meter was designed and placed upon the market. The device indicates the quantity of steam flowing through a pipe, irrespective of the pressure, and is said to be accurate within 2%.

The valve of the meter is cone shaped in order to attain a large movement for complete opening of the valve. The raising and lowering of the valve indicates volume, and a Bourdon spring, carried by a valve stem in the lower part of the meter, carries a needle which is given vertical movement by the valve opening, and lateral motion by the pressure produced on the Bourdon spring. This needle moves before a dial which has been calculated and laid out from actual test.
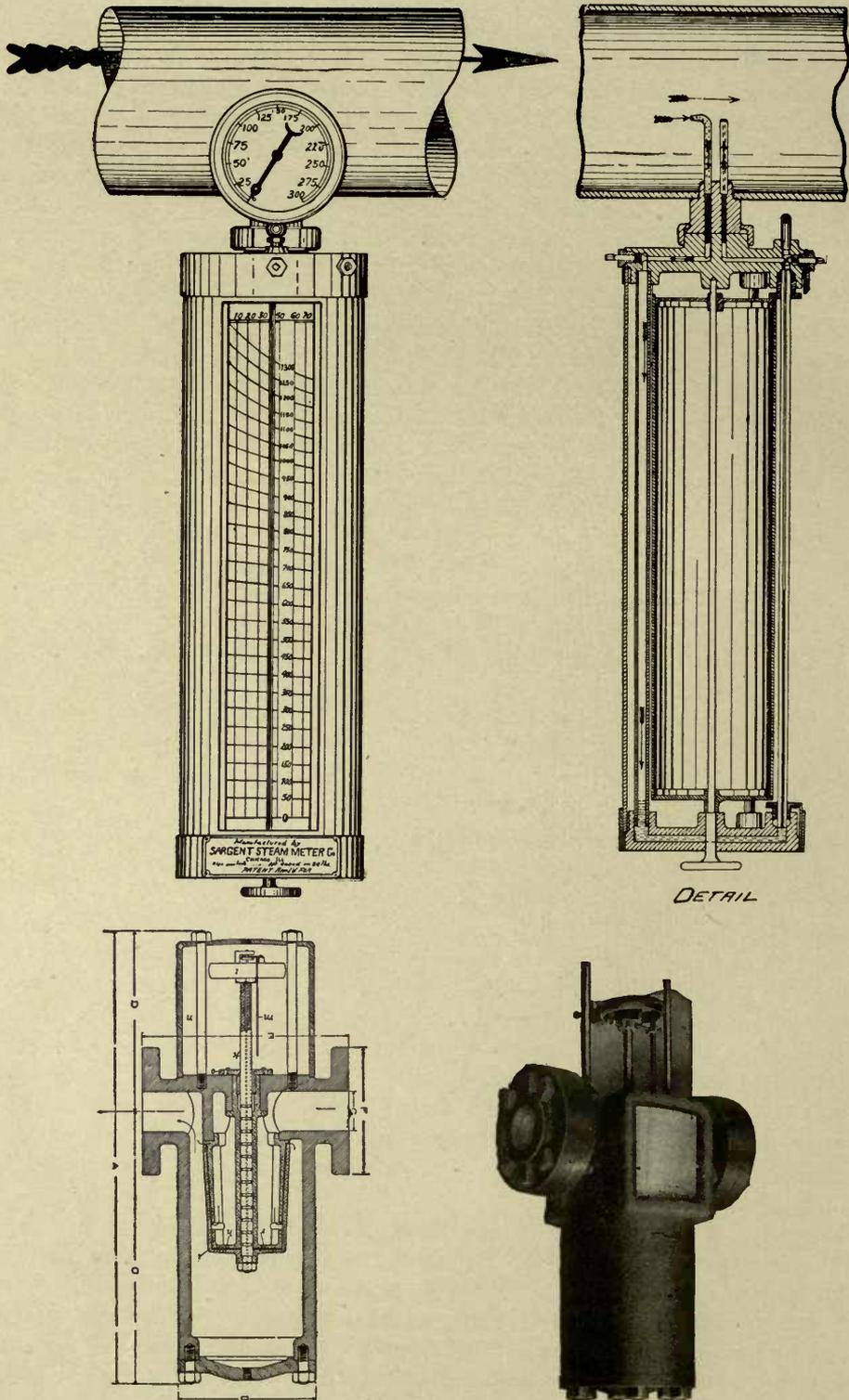
Fig. 13.—The Sargent Steam Meters.

In testing, the meter is placed on a steam line which leads to a 3000 h.p. condenser close by. The per cent of moisture in the steam is determined by a throttling steam calorimeter, and is usually found to be about 2%. Several tests with various valve openings and pressures are taken, and after a complete log is taken, a dial based on the test log is laid out. When such means are adopted for testing the device, its accuracy can be fully relied upon.

It is used for testing engines where surface condensers are not available for testing the capacity of boilers and for measuring the amount of steam used in each department of industrial plants. It is used by many who sell steam, and by others who buy steam. By placing it on the steam pipe to your engine you can tell at a glance the horsepower the engine is developing or the pounds of steam required to carry your load.

If the meter is located in a steam header and the coal is weighed, the pounds of water evaporated per pound can be determined by simple inspection, and the cost of evaporating a pound of water with different grades of coal is readily determined without the expense of elaborate tests.

The Sargent steam meter indicates the quantity of steam, or horsepower, flowing through just as a steam gauge indicates the pressure on the boiler, and if the steam from the meter is condensed and weighed, the indications will check irrespective of the pressure. Each meter is calibrated separately, and the dial is made from the results obtained.

The meters are tested with commercially dry steam and when used to measure steam of the same quality are always reliable. A very wet steam or slugs of water have no injurious effect upon the workings of the meter and cannot derange the working parts.

The location of the meter may be anywhere in the steam line, preferably close to the boilers, where the flow is uniform. If placed near an engine, a tank or drum holding two or three times the capacity of the cylinder should be inserted between the meter and the engine. In a long run of pipe, where there is liable to be considerable condensation, a separator before the meter should be inserted if very accurate results are desired.

Grates.—Grates for producers may be classified in general under two heads. *A*. Those depending upon the natural angle of repose of the fuel. *B*. Those of the grid type, either cast as in the Herringbone and shaking grates, or straight bars of steel. Their respective merits and disadvantages stated briefly are as follows:

Probably the best universal grate, and that most generally adapted to the widest range of fuels, consists of a number of simple wedge-shaped cast-iron or steel bars (the former being most cheaply replaced), these bars being loosely laid on two or more girders intersecting the diameter of the producer.

Square bars may also be used. The ease and cheapness with which the bars may be replaced form their chief advantage, in addition to which they are fairly efficient in their distribution of draft. Distance blocks may or may not be used for keeping them in place, as conditions require.

The admission of steam, with blast beneath the grate bars, creates, of course, a material saving in their life. This is also the case where water is maintained in the ash pit. It should be borne in mind, however, that when water is carried to
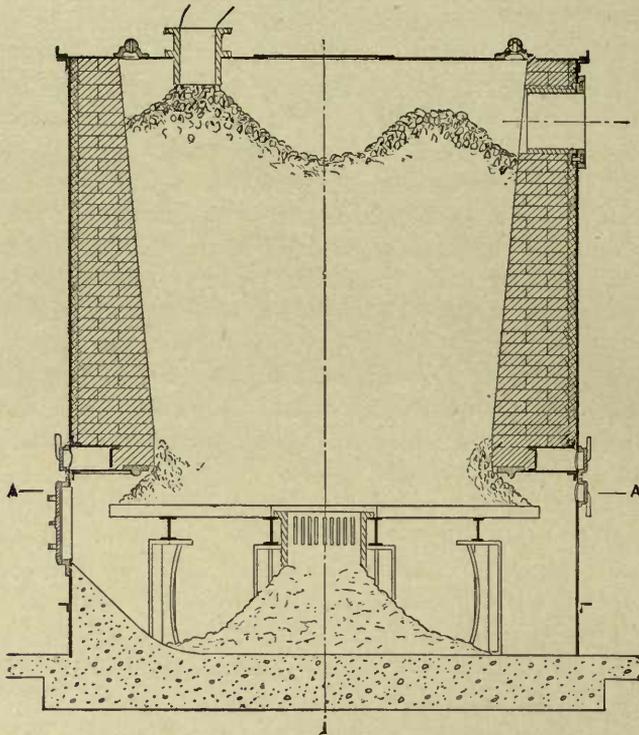
Fig. 14.—Grid Type Grate for Air Producer.
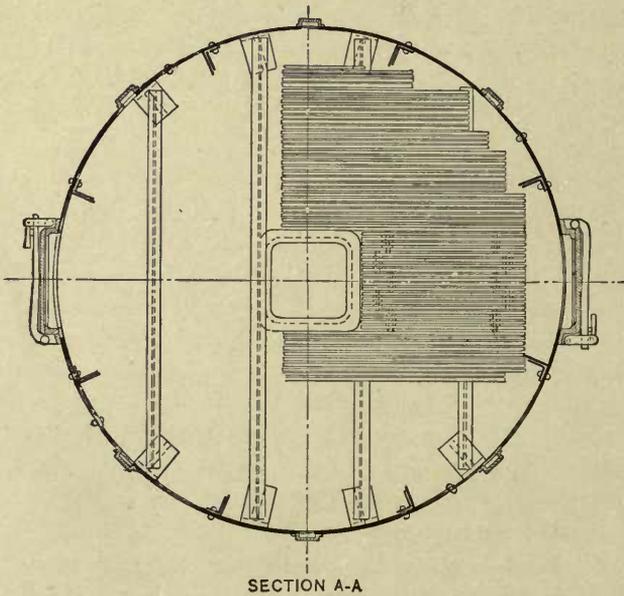
SECTION A-A

Fig. 15.—Top View of Grate.
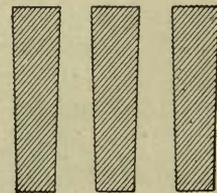
Fig. 16.—Section of Grate Bars.

the ash pit, the endothermic agent is materially increased, the evaporation becoming as high as 0.3 lb. of water per pound of coal, gasified, where the heats carried are high.

Angle of Repose Grates. The angle of repose grates, under which class come not only the bar grates interspaced, but the step grates, ring grates, conical grates, and inverted grates, which are used more especially in Germany in connection with low grade fuels. They have a single advantage of not clogging easily, and being, when properly designed, more accessible and readily cleaned. This constitutes a material factor where the fuel used is of a fluxing, fining, or highly resinous nature, wherein the voids of an ordinary grate tend to plug or clog, while in the first and last classes the grates are clogged by the viscous matter, in the case of some fuels not dissimilar to molten asphalt.

As a disadvantage, however, the repose grate is exceedingly uneconomical, the leakage of fuel through them being excessive, especially if not manipulated with the greatest care. This tends to make them impractical, except with a more or less resinous or coking fuel, which tends to bridge or arch over their spacing and retain the coal from " running."

Another questionable disadvantage is the fact that the repose grates blank a large surface of the active area of the producer; also it converges or baffles to some extent the incoming air, and it is therefore a question whether, on the up-draft producer, its diffusion is as complete or thorough as that of the grid type.

Grid-Type Grates. The grid grates, especially the better design, have a more universal and uniform distribution of voids over the total cross-section of the producer. Theoretically they are unquestionably satisfactory, but practically these grates stop up by reason of the small size of their apertures and voids, and in actual practice, particularly where the fuel is either resinous or fines (in other words, in any other than a coking coal), a large percentage of the voids are continually stopped, and hence a considerable portion of the active grate surface is blanked.

So far is this true that there are several grate manufacturers supplying boiler furnaces who make guarantees of non-clinkering on the simple fact that they are able to keep the voids in their grates open, and that where the voids are clear and the draft equal and uniform in pressure and volume throughout the entire active surface of the furnace, no clinker will result.

As a matter of fact, we are aware that inequality in temperature is the primal cause of clinkering in any furnace or producer, and moreover we know that such inequality is subtended by unequal draft and the resultant combustion area.

However, the maintaining of these voids in a clear and free condition in grates of the grid type is theoretically a satisfactory arrangement, but practically is extremely difficult.

Shaking Grates. An illustration of the shaking grate is the one manufactured by the New England Roller Grate Co., of Springfield, Massachusetts, such as has been used with some degree of satisfaction by the writer. The special claim of this grate reverts to its freedom from blanks or dead spots and the equality of its draft distribution.

As a general consideration, however, the character of the grate must depend upon the class of fuel used, the size of the voids of course depending upon its nature,

a memorandum of which has been given elsewhere. Where fuel of a resinous or clogging nature is to be used, especially fuels containing high quantities of sulphur and bituminous matter, which has a tendency to flux or run, it will probably be
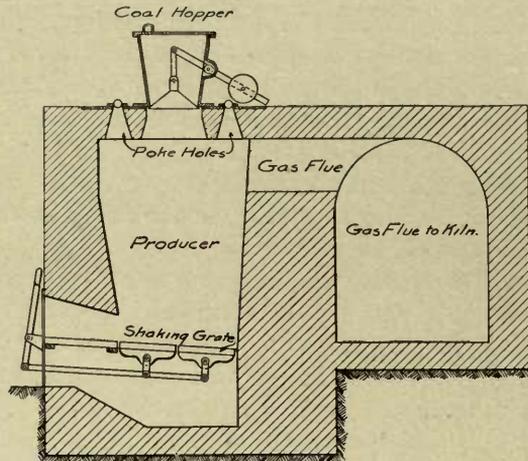
FIG. 17.—Shaking Grates Applied to Gas Producer.

found expedient to use the grates of the repose type, even at the expense of wasted fuel.

Down-Draft Grates. The grates used in the apparatus of the Loomis-Pettibone type are of fire-brick and are somewhat difficult of cleaning and ash removal.
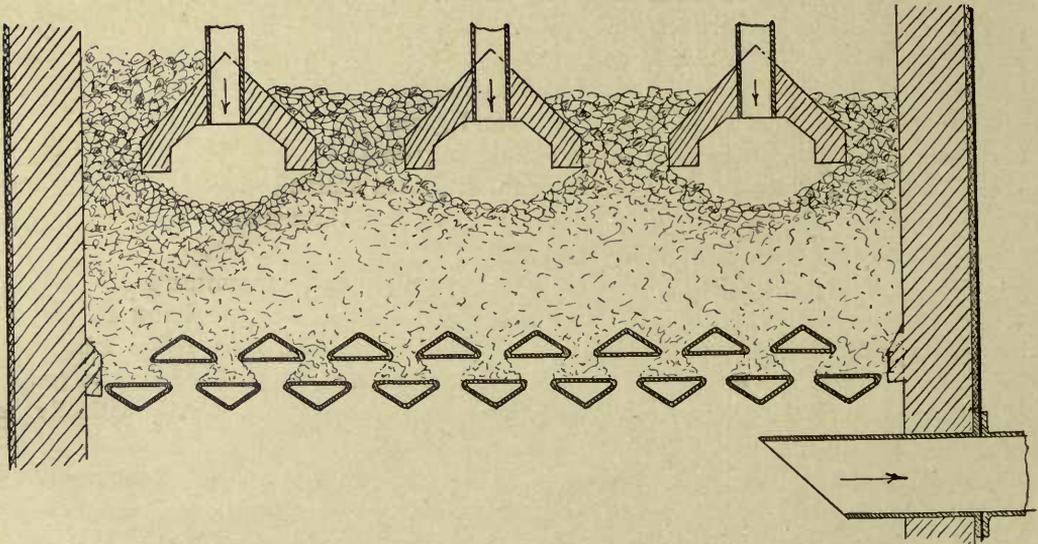
FIG. 18.—Water-cooled Repose Grates.

There is no particular disadvantage in water-cooled grates (only necessary in down-draft), where the gas is used for power purposes, if a fairly heavy ash bed is interposed between the grates and the combustion area, preventing undue heat

transference between same. The water cooling of the grates does not rob the fire of an unreasonable amount of heat, and serves as a first stage of condensing or cooling of the sensible heat of the outgoing gases.

Size of Bars. With regard to the specifications of grates, these should be invariably designed with reference to the fuel to be used. For anthracite coal the bars in the grate should be of the following diameter approximately: rice $\frac{1}{4}$-inch; pea $\frac{3}{8}$-inch; nut $\frac{1}{2}$-inch; egg $\frac{5}{8}$-inch.

Where a mixed fuel is used, that is to say a fuel of mixed sizes, the size of the bars should be in correspondence with that of the smaller fuel used. Bituminous coal, run of mine, requires bars from $\frac{3}{8}$ to $\frac{1}{2}$-inch; slack $\frac{1}{4}$-inch.

For a clinker anthracite coal, dumping grates should be invariably used, while with a non-clinkering bituminous coal shaking grates are usually satisfactory. For
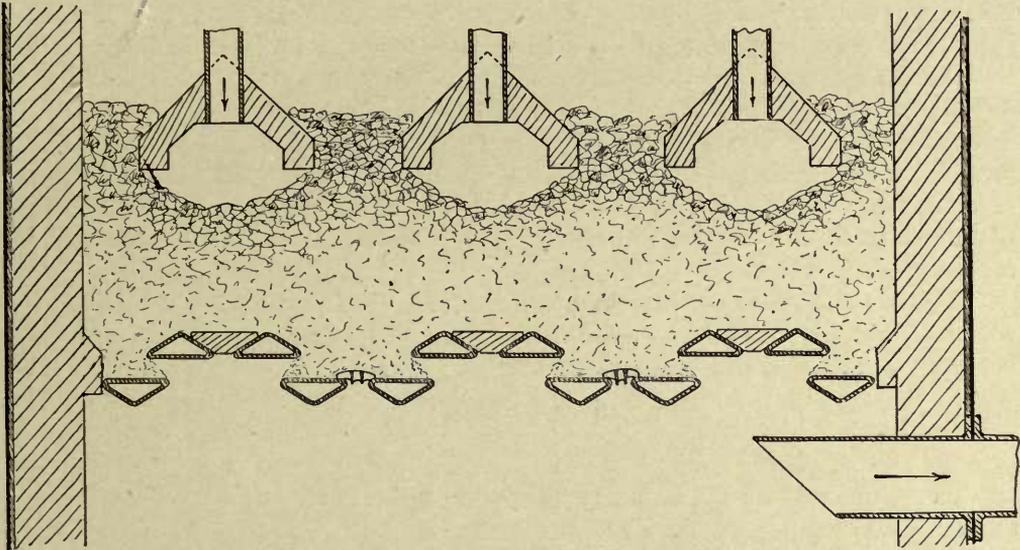
Fig. 19.—Water-cooled Repose Grates, Area Reduced by Blanks.

non-clinkering anthracite or bituminous, ordinary grate bars may be used, but for all around purposes a combination of shaking and dumping grate will be found to give the best results.

Repose Grates. Repose grates are designed with special reference to ease of stoking and cleaning, distribution of circulation, and for use with down-draft apparatus, though not limited to that type. The grate consists of a number of triangular bars which are water cooled with water circulation occurring through a header upon one side of the producer. These bars are so introduced as to create certain angles of repose of the ash bed within their voids, the effect being to accelerate and distribute the flow of the air or gases through the total area at equal pressure.

Another arrangement shows a combination of the bars for blanking certain portions of the cross-section of the producer, where, by reason of adjacency to the tuyeres or otherwise, there may have been an undue short-circuiting of the gas or

air, and it is by retarding this tendency, or by baffling or diverting, to disseminate the flow more generally throughout the cross-section, diminishing, channeling, wire drawing, or localization of draft.

Besides the mere chemical advantage of general distribution the blanking of the grate permits the drawing away of the hydrocarbon products of the distillation zone from any combustion vortex and a consequent reduction of secondary combustion within the producer.

These grates may also be pivoted and used as rocking and dumping grates, the upper and lower tiers being operated seriatim. In no instance, however, is their fuel efficiency very high. Where used in down-draft apparatus a relatively high ash bed should be carried, both to prevent waste of fuel and to insulate the combustion zone from the grates, hence diminishing the heat transference and "robbing" of the jacket water. The water cooling then tends merely to cool and condense the effluent gases, instead of abstracting useful heat from the fire at the expense of fuel. Repose grates are most satisfactory, and their fuel loss reduced to a minimum in the use of coking coal.

Grates for Lignites. Where lignites or low-grade fuels are used it is sometimes necessary to insert a secondary or upper grate in the shaft of the producer for the purpose of supporting the upper section of the fuel charge and the maintenance of an incandescent or dissociation zone. This is to prevent or equalize the excessive rapidity in the drop of the charge at a critical point of temperature or stage of combustion, which the writer will term the point of "ashification."

This critical point in the combustion of low-grade fuels occurs by reason of the distilling out of the high moisture and volatile content, which acts as a binder between the carbon and the diluent elements of the fuel.

In the case of low-grade fuels this distillation of the binding elements (principally moisture and hydrogen) is very rapid, and results in the sudden "fining" or precipitation on the part of the fuel, the high ash content serving to choke the draft, and through its insulating properties to prevent chemical reaction necessary for gas formation.

A condition analogous to this is found in lime burning, where the paradox exists that the softer or less refractory the lime stone ($CaCO_3$) the more difficult it is to burn. This is by reason of certain mass action; that is to say, that prior to calcination (reaction to CaO) at an early period of the process, and at a relatively low temperature, the stone disintegrates or fines, creating a precipitation of finely powdered, closely packed limestone, forming a dense mass almost impenetrable to the passage of air or gases, and presenting a poor heat conductor necessary to the final calcination.

The interposition of the second grate aforesaid supports the fire but prevents packing consequent to the conditions named. Though but little used in America they have had long and successful operation abroad. The fact that a 10 per cent ash content in using coal is at present the American limit of low-grade fuel utilization, while the German practice has run as high as 40 per cent moisture and 20 per cent ash, is an attest to the efficiency of the arrangement. In Germany the Jahns-Ring producer has been successfully run upon fuels containing only 20 per cent of combustible matter.
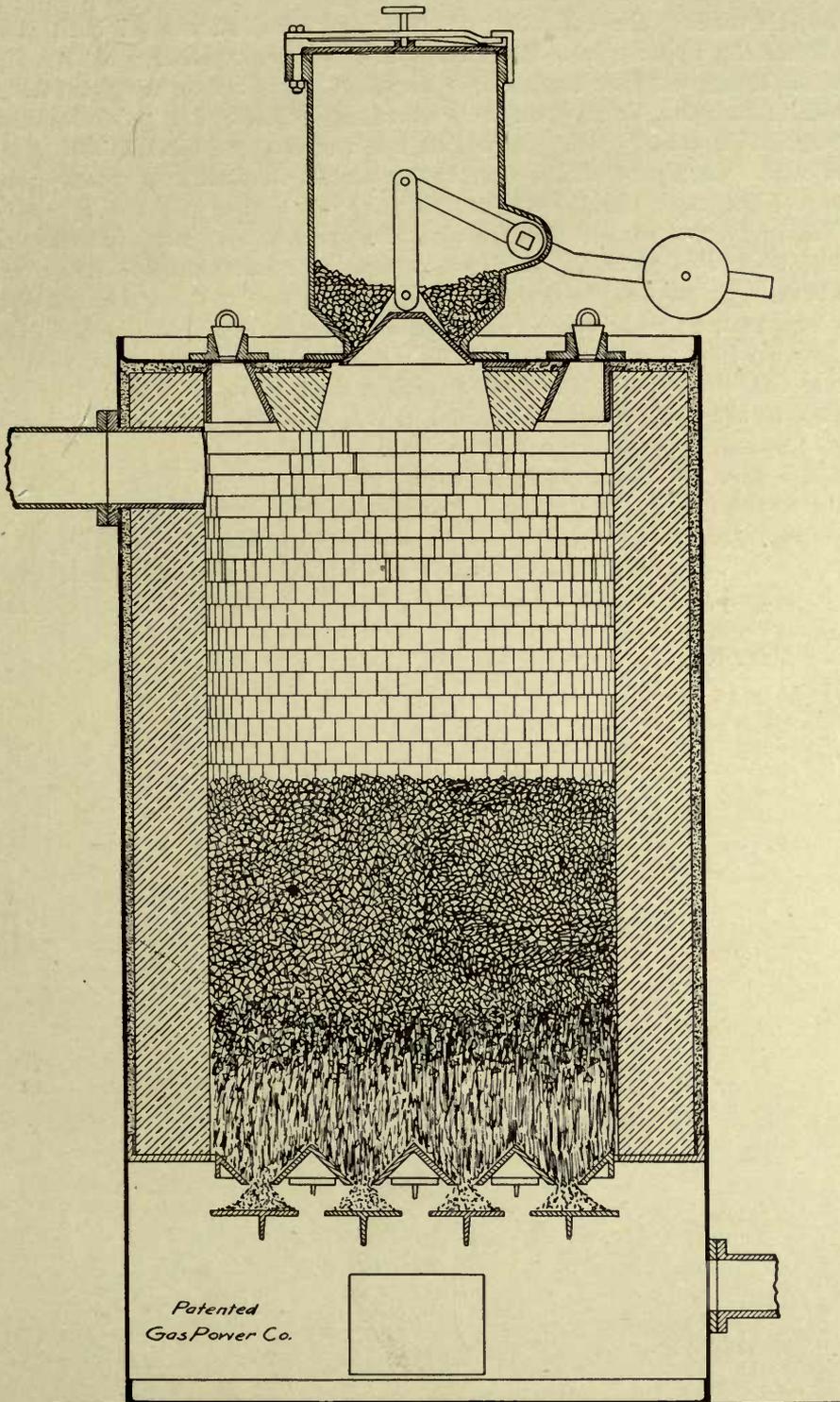
FIG. 20.—Repose Grates for Lignite Fuel.

In this country the utilization of such poor fuels has not yet been attempted, nor should the writer advise its attempt in any type of shaft producer. The use of the double grate herein suggested is advisable for fuels approximating 20 per cent or more of moisture, or in those fuels where the " ashification " is extremely rapid.

The auxiliary or upper grate is best made of heavy fire-brick, cored, and reinforced with iron piping, which may be supported in various manners—the piping or core of the grate being water cooled.

The iron cores are for strengthening the grate and making it more solid and durable, while this water is cooling a precaution against over-heating. The fire-brick covering is essential to the grate, in order that the center of the fuel bed, where it reposes, shall be robbed of the minimum heat.

Burning Out. Franz Walter, of the Vienna Gas Works, notes that the fire bars or grate bars have the appearance of being melted, when such cannot in reality be the case, as the temperature maintained at this location in the furnace is below the point of fusion, nor are the bars sulphided.

Mr. Walter attributes the result to the slagging of the iron with silica and ash content of the fuel in the presence of the moist and heated air. The slag becomes more and more basic, finally attaining the composition of $2FeOSiO_2$, which has the power of dissolving large quantities of iron oxide, Fe_2O_3. Consequently bars may be found with absolutely no metallic iron in them.

These changes occur of course only in high temperatures, and to prevent this action tubular bars or air-cooled bars are necessary, or at least interspersed between solid bars in the proportion of two tubular bars to one solid one.

CHAPTER II

CLEANING THE GAS

General Conditions.—In considering the necessary conditions of cleaning gas, two elements must be thoroughly understood; first, the nature of the impurities to be removed, and second, the conditions under which these impurities are removed.

To all present purposes under the first head, the impurities in gas consist of three classes, namely, dry, liquid, and semi-liquid. Under the first we may include lampblack, metallic dust, and small portions of ash. Under the second, moisture, steam, and aqueous vapor. Under the third, tar, and also an emulsion containing all or several of the foregoing ingredients in various proportions.

The condition, under which gas precipitates its impurities are, generally speaking, as follows:

a. Cooling. This condition primarily effects a change of volume, a change of density, a change of vapor tension, and a consequent dew point.

b. Change of volume. This condition of precipitation of impurities occurs largely through a change of vapor tension.

c. Change of pressure. It is well known that an increase of pressure tends to compress out any supersaturation of gases, probably due to the change of volume, as noted in *b*.

d. Impingement. The impingement of a gas upon any baffling substance tends to remove its impurities, probably because of the strong capillary and cohesive attraction of these impurities themselves.

e. Centrifugal action. The centrifugal action by which gas, when revolved about any axis, tends to rid itself of any impurities, is easily understood, and this is due of course to the greater density of those impurities.

f. Reversion of direction. Any gas whose direction or flow is reversed or diverted tends to deposit its saturation of impurities. It is likely that this phenomenon, however, is caused by certain centrifugal action, as suggested in *e*.

g. Velocity. Another function of gas is to deposit its saturation, or rather supersaturation, at whatever point its velocity of flow may be caused to lessen.

h. Filtration. Passing through screens or beds of porous material.

i. Washing. Efforts are being made by a number of manufacturers of apparatus to purify producer gas through filtration, the line upon which many of them are working being to bubble the gas from a number of orifices through a seal or lute of oil beneath which the gas has been submerged. This oil is periodically filtered and renewed. The system is said to be fairly efficacious for the removal of dust and lampblack.

Bearing these functions in mind, the purification of gas should be done about as follows:

It may be sufficient, where gas is used merely for furnace or boiler firing, to remove the dust or dry impurities, such impurity, especially in the instance of blast furnace gas, tending to clog the mains, choke up flues and linings, and create further objectionable difficulties.

It should be remembered, however, that a reduction in the sensible temperature of a gas means a resultant deduction or subtraction from the resultant flame temperature of combustion. This purification must therefore be accomplished with the least possible loss of heat and the baffle separator involving the principle of impingement and reversion of direction is to be recommended.

Where gas is to be used for power, however, a complete purification is necessary, for it is the history of gas power work that almost without exception failure in successful operation is to be attributed to impure and unfiltered gas.

Moreover, it is necessary in power work to condense the heat value of a gas into its least possible compass (under ordinary conditions say at 86° F.) and to this end a cooling process must be effected.

The cooling process creates a dew point or precipitaion of all liquid or semi-liquid contents, for it is a known fact 1 cu.ft. of space at 70° F. cannot contain more than 8 gr. of water vapor, or 1 cu.ft. at 50° F. more than 4 gr., nor can 1 cu.ft. at 32° F. contain more than 2 gr.

The more quickly a gas is cooled after manufacture the sooner its volume is reduced and the more rapidly it may be handled in subsequent stages of the purification; that is to say, assuming one thousand feet of gas to leave the producer at 560° F., when this gas is reduced to 60° F. the volume would be approximately only 500 cu.ft., which from the standpoint of both pumping and cleaning can be much more economically and efficiently handled. We will therefore see that the wet scrubber for power work should be logically the first in the series.

The tar and the emulsions which have been referred to are, however, too tenacious to be removed by merely cooling and washing, the tendency of the gas moreover being to pass through the wet scrubber, even one of the film or mist type, more or less in the form of rivers or chimneys, the intermixture not being particularly intimate.

To overcome this and obtain a closer mixture, and for more thorough scrubbing, a power scrubber is next intervened, its functions being multiple, tending to (a) coagulate the tar globules (oils and moisture), (b) to break up intermixing, and finally divide gas and water, thoroughly cleansing and cooling it, and (c) to rid the gas of its impurities through centrifugal action. Where very severe scrubbing is required it is sometimes necessary to connect two or more of these rotary scrubbers in series.

Following what is usually customary, though not always necessary, to have dry scrubbers where some filtering material tends, through the above principle of baffling and impingement, to remove any impurity which has escaped the foregoing process and to take out any moisture which may have been carried over in suspense.

Following these last in series and usually made adjacent to the engine is the receiving tank, which performs the following functions: First, to have a large supply

of gas made adjacent to the engine and by its elastic volume to act as a cushion for the cutoffs of the valves, thereby preventing any "hammer," and also to act as a moisture separator, freeing the gas from any moisture carried over from the purifying system or (a more frequent evil, especially after stand-bys) condensation in the pipes.

This receiving tank may or may not contain baffle plates. In the latter case it depends upon the actions (b) and (g), that is to say, change of volume and of velocity of flow, as previously described.

Efficiency is materially increased by increasing the size of scrubbers and connections. For two reasons: First: with increased volume gas distends and presents more surface for cooling and scrubbing action; second, the velocity of passage

SECTION   FRONT ELEVATION
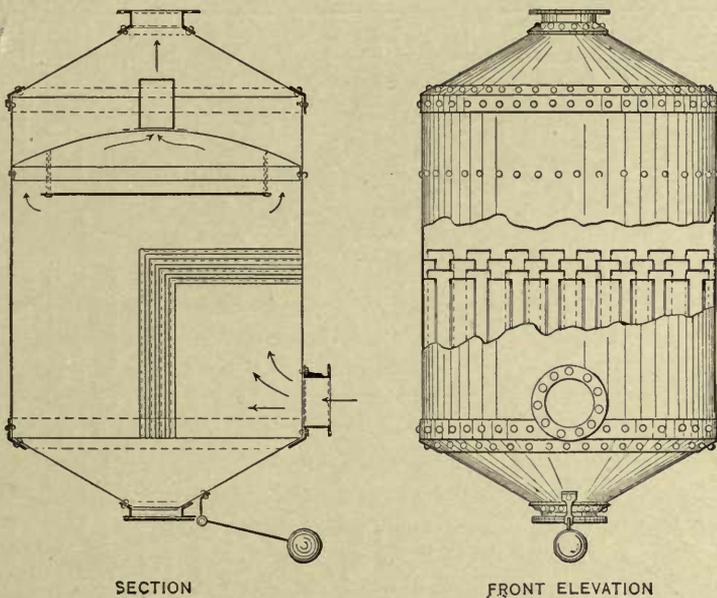
FIG. 21.—Dry Scrubber used by the Lackawanna Steel Co.

per unit of gas is decreased, with the result that the mechanical ingredients tend to settle by gravity.

Connections should be as elastic as possible, permitting as nearly as possible the temporary by-passing of any unit, as it is often possible by temporarily overloading the remaining unit, to by-pass and repair an obstruction and thereby prevent a total shut down. With the exception of the engine, practically all of the other apparatus may be momentarily overloaded to a considerable extent.

Dry Scrubbers.—Dry scrubbers and small apparatus should have hopper-shaped dumping valves to facilitate cleaning and removal of stoppages. These valves are dust sealed with automatic dust doors, held in place with levers and counter weights, serving as blow-off or safety valves in case of puffs or explosions.

The Lackawanna Steel Company purifies its blast gas down to 0.663 and to 0.524 grains of dust per 3500 cu.ft.
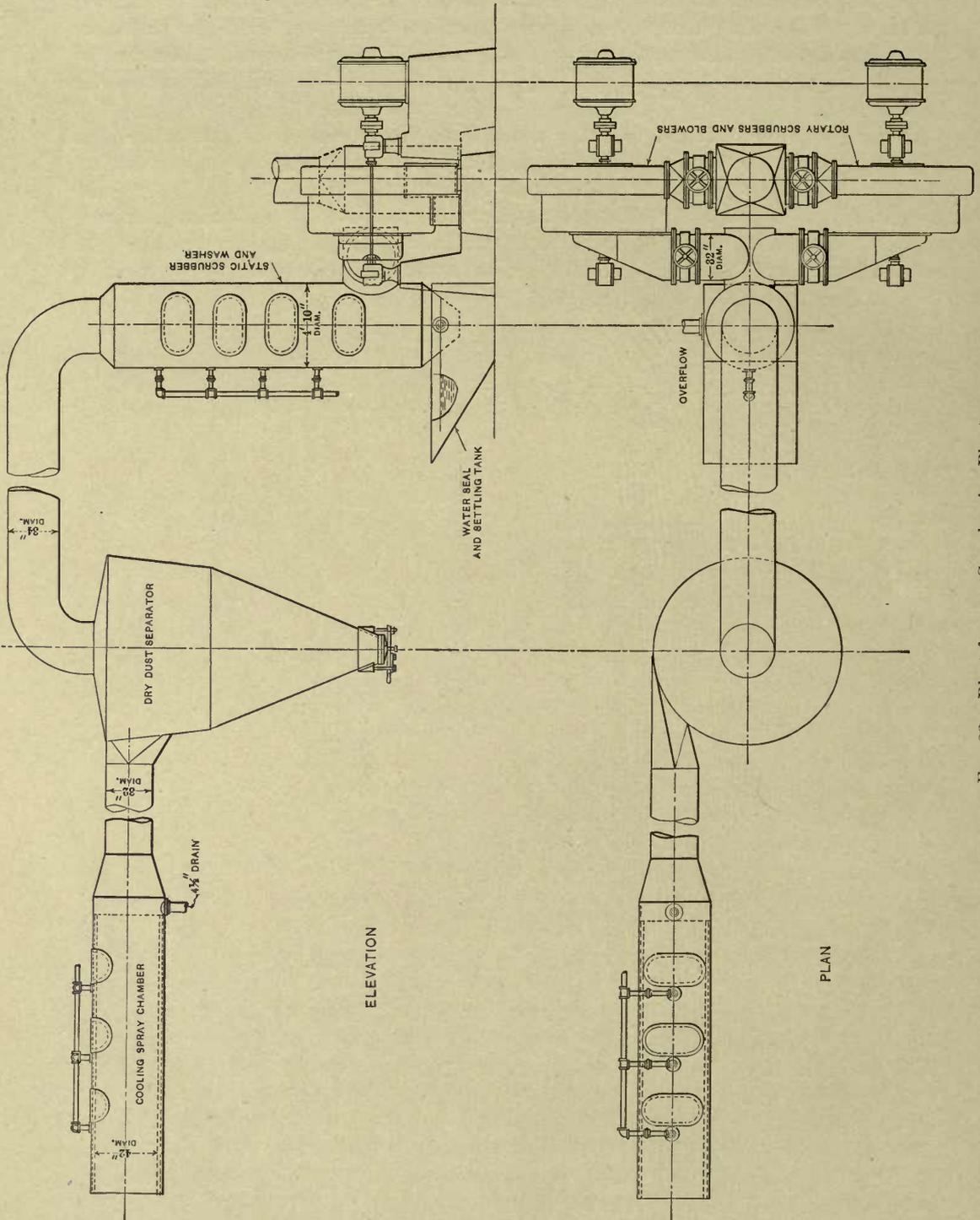
FIG. 22.—Blast-furnace Gas-cleaning Plant.

The dry scrubber is preferably designed with two compartments, so arranged that the gas may be turned in either part of the scrubber at will. The dry scrubber should be equal in area to the net in side diameter of the generator, according to the best English practice.

Oil soaked excelsior is extensively used as a scrubbing material.

Concerning filtering material to be used in scrubbers, generally speaking, broken coke in a wet scrubber is most serviceable, as after it has become fouled it may be burned. Sawdust or small shavings in the dry scrubber or coke-breeze, the latter to a depth of 30 in., may be used if the gas is perfectly dry upon reaching the dry purifier; otherwise it has a tendency to pack.

Mineral wool is one of the best substances for dry scrubbers, and very oily waste can likewise be used to advantage.

The most satisfactory filling for dry scrubbers would seem to be a mixture of sawdust and planer chips, say half-and-half. This combination possesses the scouring advantages of the sawdust, while packing is prevented by the intermixture of the shavings. The sawdust also has a tendency to fill in the voids otherwise left by the shavings.

Removing Dust from Furnace Gas.—The illustrated apparatus showing arrangement of gas cleaning apparatus covers a layout for a hundred ton blast furnace, as made by the Buffalo Forge Co., who have had perhaps the largest experience in the United States in the construction of such plants for the steel manufacturing industry. The equipment is capable of handling 10,000 cu.ft. of gas per minute. This capacity, is measured at the discharge of the rotary scrubbers, where the gas may be at a temperature of about 125° F.

Upon leaving the blast furnace the gas would pass through a 42-in. duct, which should be constructed of $\frac{5}{16}$-in. black steel, lined with fire-brick, to the cooling spray chamber. This is constructed of the same material, and equipped with three sets of spray nozzles, which injects a fine spray of water in a direction opposite to that of the flow of the gas. These nozzles require about 72 gallons of water per minute at a pressure of 25 lbs.

After passing through this chamber the gas enters the dry-dust separator as shown, where a considerable portion of the dust is deposited, and drawn out through a gate at the lower end of the separator. After leaving the separator, the gas passes through the vertical static scrubber and washer. This is equipped with four sets of nozzles, discharging the water in a direction opposite to the flow of gas. This requires 260 gallons of water per minute at a pressure of 25 lbs. per sq.in. This scrubber is arranged with a water seal at the bottom, so that the dust extracted from the gas would pass out into the settling tank below.

Upon leaving this washer the gas passes into one of the rotary scrubbers and blowers. These are shown in duplicate, only one of which is operated at a time, each having a capacity of 10,000 feet of gas per minute. In addition to this being a rotary scrubber, it also acts as an exhaust fan, giving a suction corresponding to a 4-in. water column at the inlet. This requires 120 gallons of water per minute.

The gas, upon leaving this rotary scrubber, is ready for the gas engine, and does not contain more than 0.02 grain of dust per cubic foot. This is sufficiently clean

for gas engines. As a matter of fact it has been found by test that the dust will not be more than 0.01 grain per cubic foot.

These scrubbers are really a three-stage exhauster. The gas entering the first stage is thrown against the periphery of the shell, where it comes in contact with a large number of sprays. There is also a number of sprays at the inlet. The gas being thrown against the peripheral shell at a high velocity the dust comes in contact with a sheet of water and is carried away through a water seal, while the gas passes over into the second stage which is in the same shell as the first stage, and here the gas passes inwardly to the third stage. These two wheels in the first and second stage are of approximately the same diameter, and counteract each other.

The gas entering the third stage has almost the same pressure as when it entered the first. In the third stage there are also a number of sprays giving a sheet of water around the peripheral shell, and the dust that happened to escape the water in the first stage is extracted in the third. Here the gas is discharged at the periphery, as in ordinary fans, and against a pressure determined by the speed and diameter of the blast wheel. These rotary scrubbers require a speed of 565 r.p.m. and should be directly connected to 50 h.p. motors.

The cleaning of furnace gas is becoming of great importance in the economical manufacture of iron and steel. It is necessary to clean furnace gas of practically all the solid matter, consisting of the furnace ingredients, in order to use the gas successfully in internal combustion engines, and is also found desirable and productive of economy to partially clean the gas used in the stoves and blast furnaces. The dust and dirt from uncleaned gas amounting to 12 to 30 gms. per cubic meter (5 to 13 grains per cubic foot) is gradually deposited on the heating surface of the stoves, and acting as an insulator prevents the rapid absorption of the heat by the brick work, and also makes the frequent cleaning of the stoves imperative. Higher temperatures are obtained when clean gas is used, and it has been found that the saving in coke consumption under these conditions amounts in a 100-ton furnace to about $9000 per year; this of course depending entirely upon the analysis of both the ore and fuel used.

While the large particles of ore, limestone, and coke in the gas are precipitated by gravity into the pockets of the flues, the fine and impalpable dust will remain suspended in the gas-like smoke in the atmosphere, and can only be removed by washing, filtering, and the various processes described. When furnace gas is used for fuel in the cylinder of an engine a very small amount of dust is prohibitive, as it, naturally gritty, will unite with the oil of lubrication, forming a pasty mass which produces an abrasive effect only excelled by oil and emery. As 75 per cent of the dust is metallic oxide, it, when subjected to a temperature of 3000° F., the heat of inflammation, will be precipitated as iron or steel. The impalpable dust, so light that it will be carried along with the current of gases, does not affect the furnace stoves so rapidly, and the gas used in these regenerators need not of course be as clean as the gas used in the engine cylinders. In fact, if the gas used in the furnace stoves has less than 0.5 gm. of dust per cubic meter (0.22 grains per cubic foot) the heating effect of the gas is too rapid and intense and the melting of the brick lining is liable to take place. On the other hand, gas used in internal com-

bustion engines should not have over 0.02 gm. of dust per cubic meter (0.009 grain per cubic foot) or the wearing of the engine cylinder will be excessive. When used under boilers for making steam, the freer the gas from solid matter the better. The efficiency of gas-fired boilers depends as much on the side of the tube next to the fire being clean as the side surrounded by the water.

The maximum limit of cleaning blast gas, however, should not exceed, even for boiler firing, a purity of extraction with a less limit of residual exceeding 0.2 grain of dust per cubic foot. The dust in blast furnace work varies largely, and depends of course on the quality of coal and the analysis of the ore being reduced.

Nearly all the difficulties experienced in America with blast gas for power purposes have been derived from an improper or insufficient cleaning. The dust contained in blast furnace gas largely exceeds that derived from producer gas manufacture, one reason being the high velocity of the blast and the high rate of gasification of blast furnaces, ranging all the way from 50 to 100 lbs. of fuel per square foot of cross-section.

Moreover, the dust of blast furnaces varies greatly from that of producer gas in analysis, more than three-fourths of its content being metallic ingredients derived from the ore.

By reason of its leanness or low calorific value it is necessary to condense blast furnace gas to its smallest possible compass, which entails complete condensation. This usually involves a range of temperature in its reduction of volume of from 150 to 25 or 30° C.

Constant accurate determination is an essential accessory for every steel or producer plant: in the former, for both power and hot stove work, and for the latter for all power purposes. Proper apparatus in such investigation and record must necessarily be installed.

Dust Determination.—Such an instrument must be simple, its accuracy unquestionable, and its design such that the determinations may be made hourly or as often as desired. The ordinary method of determining the dust in the air or gas is to make a filter of a glass tube filled with absorbent cotton through which the air to be filtered flows. The gas is measured through a test meter and the cotton is weighed before and after. This method might give accurate results if the cotton always has the same density throughout the tube and were not hydroscopic. The cotton may be packed in so loosely that some of the dust will work through, and unless the cotton is carefully dried over calcium chloride and weighed several times, a long and tedious process, errors will naturally arise. Experiments have shown that as two cotton-filled tubes are used in tandem, the second will increase in weight, showing that some of the impalpable dust is not retained by the first tube. The filtering medium for the apparatus herein described is simply a diaphragm of white filter paper through which the gas percolates, but on account of the minute interstices of the medium every atom of dust or dirt remains behind. The side through which the gas enters becomes the color of dust, while the other side remains uncolored. When two filters are used in tandem, the second does not increase in weight, showing that no dust permeates such a filtering medium. The velocity of the gas through the filters and a test meter which has but a one-quarter inch pipe, is not rapid, and if the instrument is erected some distance from the main

supply pipe, the deposition of dust on the way to filter will cause an appreciable error. In the apparatus described, the three-quarter inch pipe passing across the top of the filter holder allows a considerable quantity of gas, which keeps the dust stirred up to pass the opening, to filter at a fair velocity so that the amount filtered out must be indicative of the total dust in gas.

By keeping continuous records of the dust in the gas before and after cleaning, the efficiency of the cleaners can be maintained. A check on the operation of the furnace is possible and the minimum wear of the engine cylinders is insured.
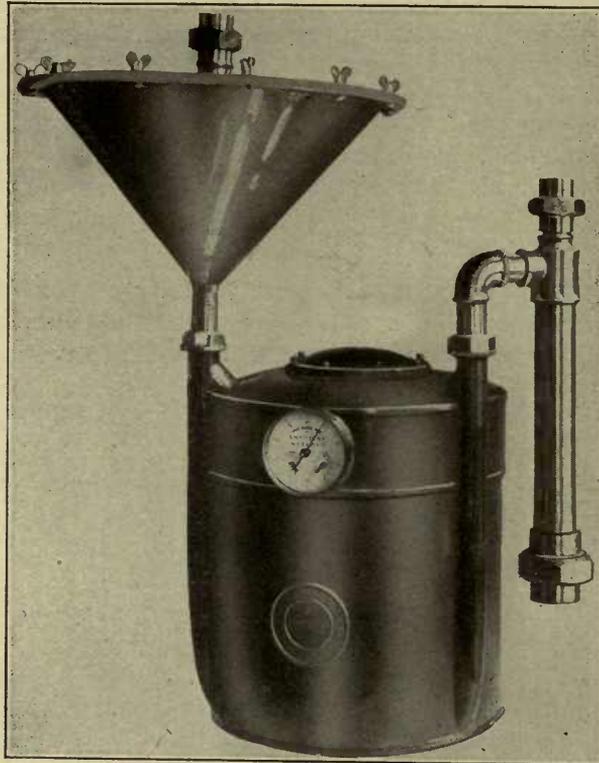
Fig. 23.—Sargent Dust Determinator, Compact form.

A record of the condition of the furnace gas is essential in its commercial use. The illustration shows the complete self-contained determinator, which consists of a portable case containing an accurate test meter, two filter holders in section, complete cross-connection three-quarter inch brass piping, so that gas to be tested may flow over the mouth of either filter, and hose connections allowing the gas passing through the filter paper to be accurately measured through the test meter. When the desired percentage of moisture in the gas is obtained, the gas is passed through a cooling coil, where most of the moisture is condensed and precipitated in a collecting bottle. After passing the cooling coil the gas is passed through three or four bottles of calcium chloride, removing effectually any further moisture in the gas before it is

metered or its calorific value is determined. When the determinations are merely for finding the percentage of dust, the cleaned gas, after leaving the meter, is mingled with the main supply and burned or wasted to the atmosphere. The cleaned dried gas may be passed through an automatic calorimeter, by which the B.T.U. are determined as well as the hydrogen in the gas. A complete record of the dust and calorific value is an indication of the internal furnace conditions described in the economical manufacture of steel. By using two filter holders continuous determination can be made. By the proper manipulation of the valves gas can be passed through either filter, while the dust collected in the other per cubic foot of gas burned is being ascertained. On account of the moisture in the gas softening up the filter paper, a wire gauze is inserted under the filtering medium which prevents the weight
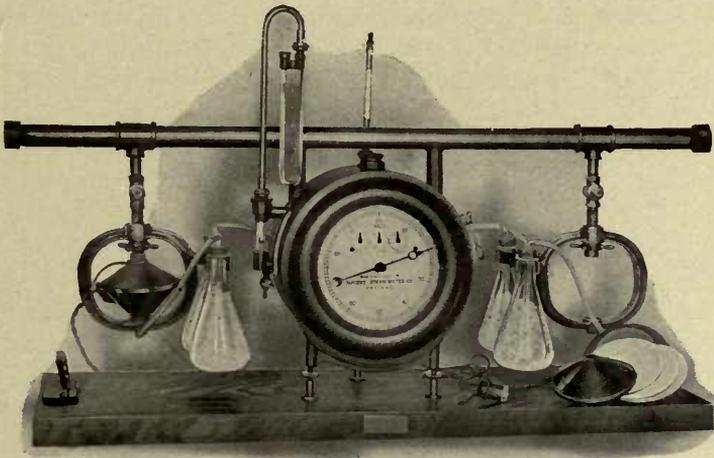
Fig. 24.—Sargent Determinator, complete.

of the dust from tearing it. As the deposited dust and filter paper remain more porous if kept warm and dry, an incandescent lamp or candle is burned under the filter holder in use. The inlet and outlet pipe for gas passes through the case, which is provided with a door and lock and may be left running for twenty-four hours if desired, though hourly readings may be obtained if the variations of the dust under different conditions are desired. The proportion of gas wasting and going through the meter is adjustable, and can be regulated to suit the conditions and location of the apparatus relative to the flue from which the sample is taken. If the burning or wasting of the gas flowing by the filter mouth is not desirable it may be piped back into the gas flue in such a way as to maintain a circulation through the shunt.

The operation of the determinator is as follows:

Locate the instrument as close to the flue containing the gas as practicable. Run a three-quarter inch pipe from flue to inlet pipe at the case. Run the waste pipe where desired. Level and fill test meter with water until it rises to the level indicated in the glass by the pointer. Place filter paper in holder and tighten thumb

screws. (This may be done in the laboratory where filter paper is weighed if desired, and holder can be connected up by union.) Note the reading of gas meter, the date and hour; write same on the filter holder being used. After a certain time, depending on the amount of dust in the gas, the meter is read and the gas by-passed through the other filter which had been previously prepared. Remove the filter holder and determine the amount of dust collected as follows: The filter paper having previously been dried and weighed should be carefully dried again by subjecting it and the dust attached to the same temperature, not less than 212° F. This will drive off the moisture, and the difference between the weight of the clean paper and the dust-covered paper will give the new amount of dust which, divided by the cubic feet of gas, will give the grains or grams per cubic foot.

To get the percentage of moisture, weigh the water precipitated in the inverted flask below condenser, and by weighing each flask of calcium chloride (the weight of each having been noted before test began), the percentage of moisture is readily obtained. In order to be sure that all moisture has been extracted, the last flask through which the gas passes should not increase in weight.
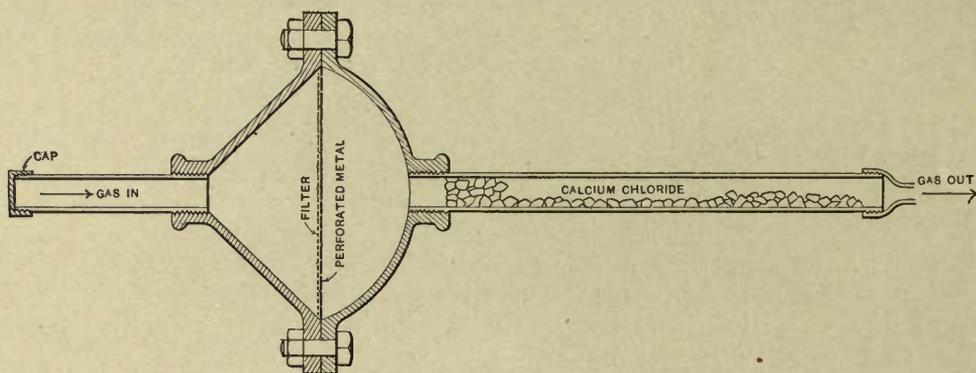
Fig. 25.—Test for Dust and Moisture.

A pressure gauge and thermometer at the meter will allow of a reduction of the meter reading to standard, should this be desired for comparison. As fifteen to twenty-five per cent of the dust in furnace gas is coke, it is not advisable to determine the total dust by incineration, though this method is used where the solid matter collected contains no combustible.

When air or gas at or below atmospheric pressure are analyzed for foreign matter, a water ejector is used to draw the air through filter and meter. If the dust or tar is desired, as well as the calorific value of the gas, the pressure of which is below atmospheric, our ejector and separator which draws gas through filters and forces it through meter into chlorimeter, is used. Separate dust determination is made by precipitating tar and by cooling gas before entering filter.

For making tar determination place a piece of absorbent cotton above the filter paper in the filter holder, running the same as in the determination of dust. Separate moisture is determined by connecting calcium chloride flasks direct to the gas supply. The above dust determinator is manufactured by the Sargent Steam Meter Co., of Chicago.

The accompanying illustration is a rough sketch of an apparatus which is used to some extent among the steel plants for the removal of dust and chemical impurities in the blast furnace. This instrument is made of brass and aluminum. It consists of a receiver containing a perforated metal shelf for the support of the filter paper, which is placed thereon, and which serves to collect tar and dust. The stem of the apparatus contains calcium chloride, from whence the moisture content is determined. It is possible to make a direct determination of the supersaturation in gas by condensing it directly by passing through a water-jacketed worm.

Influence of Dust.—In a letter under date of July 3, 1908, F. E. Junge, of Gorlitz, Germany, writes as follows:

" Dust is an inert constituent in the gas and acts similar as ash does in coal, when the latter is burned, absorbing heat and reducing thereby the maximum obtainable temperature of combustion. It also has a reducing influence on the rapidity of flame propagation, since by laboratory investigations in experimental glass tubes we have satisfied ourselves that the speed of flame travel, and the amount of heat developed per time unit grows smaller the more dust is added to the gas, the extreme result being, of course, an extinguishing of the flame. Therefore, if dust is present, less of the combustible of the gas is burned in the furnace, heat developed being postponed and valuable properties lost to the atmosphere. We cannot get around the fact that, in numerous instances, the coal bill has been decreased after a cleaning plant was added to the equipment, and we cannot but adjust our theories to the achievements of practice."

The writer believes, except in exceptional cases of blast furnace gas, where the content of entrained metallic oxides and dust is very high, that no gas should be washed for furnace or firing purposes. With gases of this kind, a large quantity of their impurities may be removed by dry cleaning, which may take the form of almost any baffling separator which removes the dust and dirt through impingement, change of volume, or change of direction, or by the brushing or scrubbing effect of its plates or contents.

If water is used, it is the belief of the writer that the loss of sensible heat (in itself a tremendous disadvantage), and a consequent reduction of flame temperature, more than offsets any loss that may accrue through the absorption of heat by the dust, or by the clogging and insulating effect within the furnace.

Except under exceptional circumstances, the dry cleaning of gas will be found sufficient, and although Mr. Junge speaks of the extinguishing of the flame as due to dust in extreme cases, these extreme results are rarely reached in practice, or even approximated. In fact, so great a portion of the impurities may be removed by dry scrubbing that the remaining entrainment is inconsiderable under working conditions and economics.

Centrifugal Rotary Separators.—To remove substances heavier than the gas, such as water and dust, centrifugal force has been utilized.

Thiesen Centrifugal Gas Washer.—The Thiesen centrifugal gas washer consists of a drum having peripheral vanes whereby the gas is rotated in presence of a water spray. The circulation being superinduced by a fan at the end of the washer.

This washer claims an efficiency of $2\frac{1}{2}$ to 1% of the power obtained by the

total gas purified, the consumption of water being from five to ten gallons per 1000 feet.
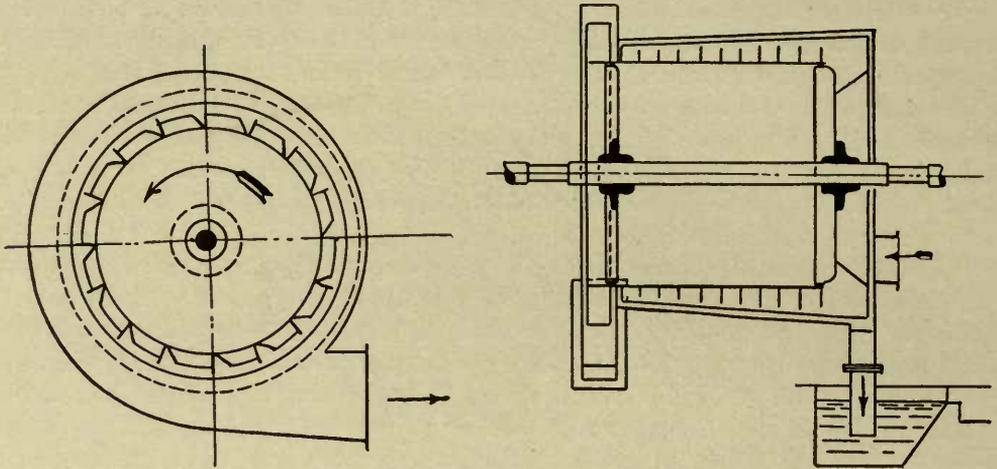
Fig. 26.—Thiesen Centrifugal Gas Washer.

Saaler Washer.—The Saaler washer is one of the centrifugal type, similar in construction and operation to the Thiesen washer. It consists of a drum with axial vanes set at irregular angles to the plane of the axis. The drum is connected with
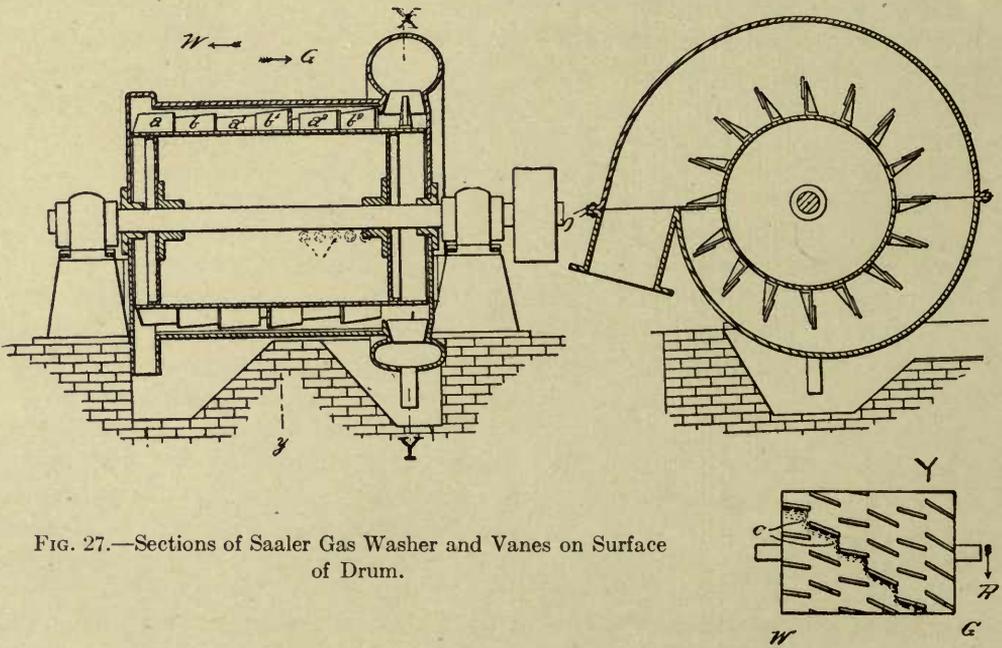
Fig. 27.—Sections of Saaler Gas Washer and Vanes on Surface of Drum.

a centrifugal fan of the paddle-wheel type. The principle of the washer is the emulsification of the impurities through churning and intermingling of the gas and water, and the expulsion of the emulsion through centrifugal force. The washer

it is claimed refines the gas to an impurity content of 0.015 grain of matter per cubic foot.

The inclined paddles churn the water to the left-hand end, and the gas pressure and fan (Section X–Y) suction forces the gas the contrary direction. The paddles are irregularly arranged, as shown in the view of the drum.

Latta Heavy-duty Separator.—The gas washer herewith shown consists of three cylinders, the first and second revolving (preferably in opposite directions), and the third being fixed within the second.

The gas entering the washer at A, together with a spray of water, or water mist, is drawn through the cylinder B, which is perforated, and the gas and water are thereby finely divided and atomized.

Through the space C and the cylinder E the water and gas mixture is drawn, being forced against and slightly repelled by the centrifugal motion of the vanes D, which are perforated in order to produce a filtering effect.

The gas is further induced through the cylinder F, where a further quantity of water mist is added through the shaft, and from whence the gas is drawn out by the peripheral fan (of the Sirocco type) G, and expelled through the outlet H.

The washer depends for its efficiency principally upon two features: First, the emulsifying of the impurities through the very close intermixture of the water and impurities. A flushing of said impurities and thorough washing of the gas, depending upon centrifugal force, upon filtration of the various sieves, vanes, and cylinders, and upon the opposition of forces. The centrifugal force of the cylinders B, E, and F, and the vanes D, tend to throw out the heavier impurities and act in an opposite direction to the fan-blower G, which forces being opposed tend to wire-draw the gas away from its impurities.

Of course there is the usual cleansing effect due to dew point, supersaturation, and the absorption of impurities due to the fineness of division and the intimacy of the intermixture obtained.

It will be noticed that cylinder E and the vanes D in sequence are suspended from cylinder B, the cylinder F to which the blower G is attached running free and independent. This permits the regulation of blower speed and consequent blower pressure through the variation of the speed of F and G, allowing elasticity of regulation in operation. It also creates a compensation through additional speed for the faster rim travel of the cylinders B and E and the vanes D, through a greater length of radius.

It also makes a slower speed necessary upon the part of the heavier moving parts, and also of the main shaft and bearing, reducing the general travel both in part and in total.

Another form, a light service tar extractor, is based upon the principles of the Latta heavy-duty gas washer. In addition to filtration, impingement, change of pressure and volume, cooling and scrubbing, the unpurified gas upon entry is brought into contact with a finely divided water spray, and by great thoroughness of agitation the impurities are emulsified or thrown into solution by contact with the water and moisture. The principal feature of the process then takes place, namely, an " intensified stratification." The heavier or more impure matter being more amenable to centrifugal action, are thrown to the periphery of the revolving sepa-

SECTION ON LINE Y-Z

OUTLET TO SEAL POT
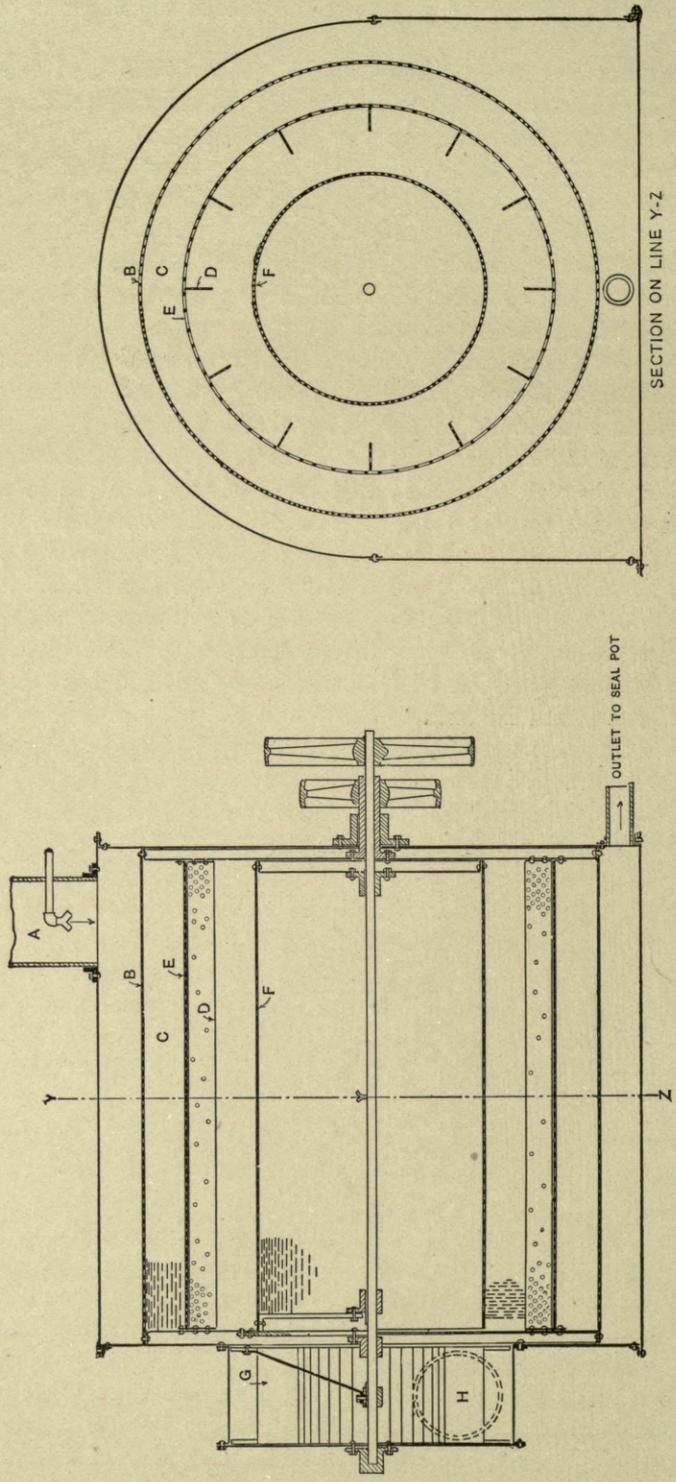
FIG. 28.—Latta Heavy Duty Washer.

rator, while the lighter or purified gases forming the inner complement are withdrawn through the suction action of the exhauster, there being thus two forces at work on the impure gas, the one tending to divert the heavier portions outward, while the suction draws away the lighter portion thus freed from the center, drawing more gas in to be separate in turn by continuous operation.

Fixed Centrifugal Separators.—The accompanying illustration shows a scrubbing tank designed to be more efficient per unit of volume and weight than the
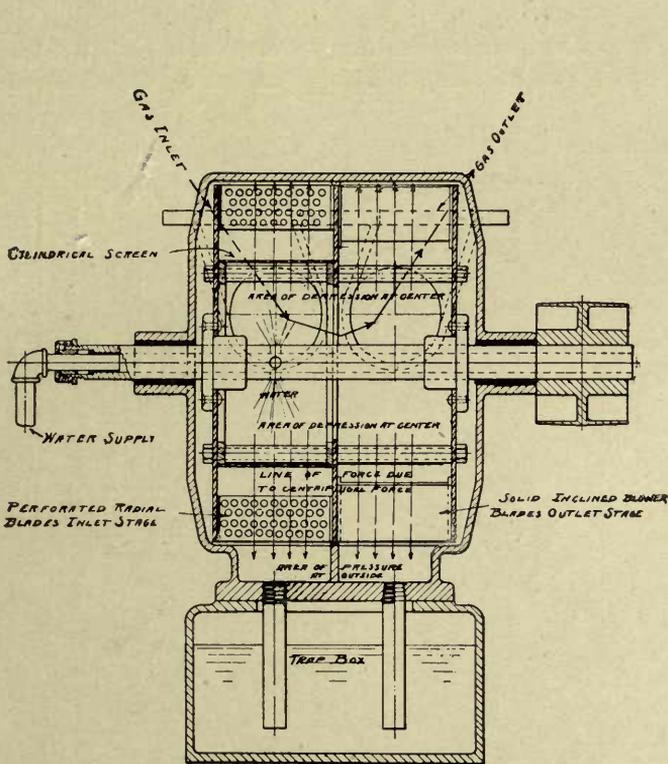
FIG. 29.—Latta Stratification Washer.   FIG. 30.—Fixed Centrifugal Separator.
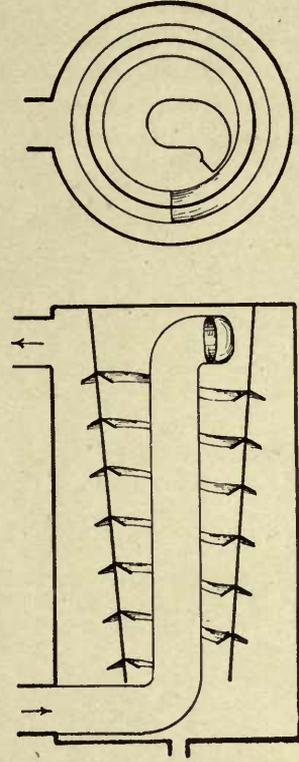
ordinary coke scrubber, therefore especially amenable to marine service. The scrubber is designed to accomplish the following functions of gas purification:

  a. Reversion of flow.
  b. Change of direction.
  c. Change of volume.
  d. Impingement.
  e. Baffling.
  f. Scrubbing.
  g. Concentration.
  h. Centrifugal action.

The gas entering the scrubber centrifugally through a central pipe is carried down through one of the spiral vanes, being met by a spray of water falling from above.

The spiral vanes have the tendency of an inverted cone to constrict or throttle the flow of the gas and concentrate it within a comparatively small area at the bottom of the cone, whence the water falling from above in this compressed or condensed form will have a peculiarly severe scrubbing action.

At this point the flow of the gas reverts upward, at first expanding into the upper tank, its spiral and upward motion maintains the gas in rotation with a consequent centrifugal action, the tendency of the gas being again to be reduced in volume and throttled towards the outlet, where a second spray falls upon it in its concentrated form.

Reversed Current.—This type of separator has many examples and is used for many purposes, where baffling plates and settling chambers are used. The following will illustrate the principle.
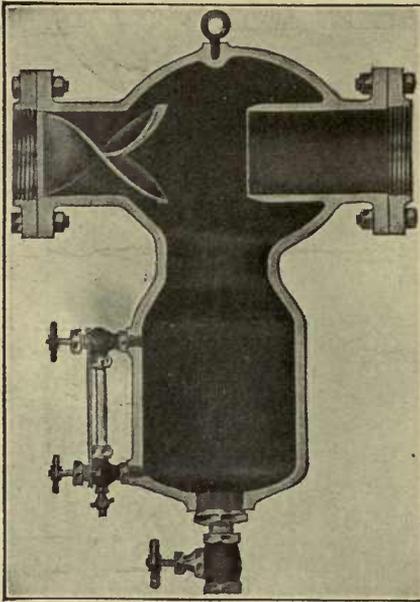
Fig. 31.—Steam Separator used as Moisture Remover.
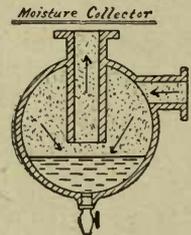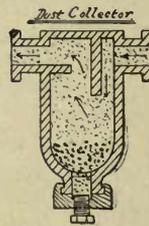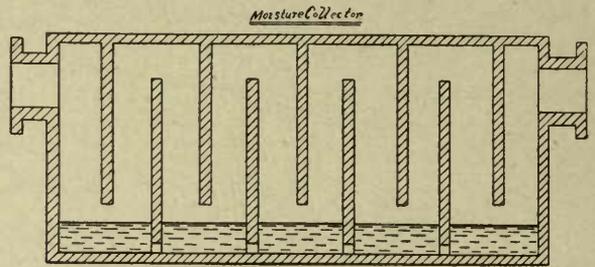
Fig. 32.—Examples of Baffling Separation, the dust or moisture being deposited by the reversal of direction of flow.

Condensing Blast Moisture.—The removal of moisture by dehydrating the air very considerably diminishes the amount ordinarily requisite. This dehydration is usually performed by refrigeration, the air being reduced to about 28° F., the reduction usually being about 80° F.

This reduction in temperature, in one instance known to the writer, lowered the moisture content from 5.66 to 1.75 grains of moisture per cubic foot. In one furnace with a capacity of 350 tons of iron per day, with a coke consumption of 2147 lbs. per ton of iron output, and using approximately 40,000 cubic feet of air per minute, two ammonia compressors working with a nominal capacity of 225 tons of ice each, constituted the equipment, but one was usually used as a relay or stand-by, except under conditions of excessive humidity.

The air condensed by a drop of temperature was reduced to 34,000 cubic feet per minute, the output increased to 450 tons of iron, with a coke consumption of 1,729 lbs. per ton output, the blower slowed from 114 to 96 revolutions per minute indicated horsepower, consequently reducing from 2700 to 2013, thereby saving 687 h.p. The refrigerating apparatus requiring 530 h.p. there was a net saving in power amounting to 157 h.p., in addition to the reduction of fuel and the increase of output. In this instance, as cited by Dr. J. H. Hart, the amount of moisture collected per day amounted to ten tons of water.

In addition to the advantages mentioned, it is well-known fact that dry blast air means dry gas or higher flame temperature. Moreover, the gas is cleaner and better in every respect for both hot stove and engine apparatus. The experiments and comparisons, both in America and abroad, have proven that the increased value and efficiency of this gas alone warrants the pre-drying of blast air for furnaces.

The principal drawback with blast furnace gas lies in its variability, its calorific value varying from 80 to 100 B.T.U., but it is rarely constant at the maximum value, and for purposes of calculation it is best estimated at the other extreme. The cause of its variation lies principally with leaks in the furnace or channels through the furnace producing over-ventilation and high CO_2; leaky tuyeres and broken water jackets, with an attendant escape of large quantities of water into the furnace, both deaden the fires and produce a large hydrogen content. It is largely due to these variations that the reliability of blast furnace gas has been so far discredited in this country.

To correct these faults there are a number of patents covering processes for the recarburation of blast gas by passing it through additional retorts or strata of incandescent fuel.

Blast furnace gas is delivered by a fan to boilers, hot stoves, furnaces, or engines usually at a pressure of from 2 to 4 inches of water.

Eckel is authority for the statement that ore-dust to the amount of 15% or more of the furnace charge (equivalent to from 25 to 50 tons per furnace per day), is sometimes carried out from a furnace by the blast.

For a plant requiring, say, 15,000,000 cu.ft. of air per twenty-four hours, a multiple or factor of same being, roughly speaking, proportional; a reduction of temperature from 85° to 26°–28°, humidity calculated at 80% saturation, there would be required an equipment consisting of two batteries of direct expansion pipe in coils, of 15,000 feet of 2-inch pipe, having separate expansion shut-offs, and other connections for use separately or in multiple, the former being, in cases of low load or during continuous operation, to permit coils to be defrosted or repaired.

Also an ammonia compressor, or compressors, to be the equivalent of a compressor cylinder 18-inch bore and 30-inch stroke, the condenser being atmospheric in six sections of 24 2-inch pipes 20 feet long.

The compressor should be driven by a 125 h.p. 220 v.d.c. motor running at 700 r.p.m., belt-connected.

The total cost of the foregoing plant, as estimated upon by several ice machinery companies, is between $20,000 and $22,000 erected complete.

Where the by-product gas from blast furnaces is used for power purposes the

quality and uniformity of the gas for such apparatus is notably improved by the dehydration of the air.

This is due to the prevention of deadening of the fire or the creation of spots, with a consequent reduction of CO_2, more even heat which subtends an advantage in both quality and quantity of the ensuent gas, and the reduction of hydrogen, which is invariably a disadvantage in this character of gas when used for power purposes.

In fact, under these conditions the gas product of the blast furnace would be an almost perfect fuel for engine purposes, were it not for the tendency of water jackets and the water-cooled tuyeres to leak, permitting the escape of water and steam into the furnace with an ensuent production of both H and CO_2.
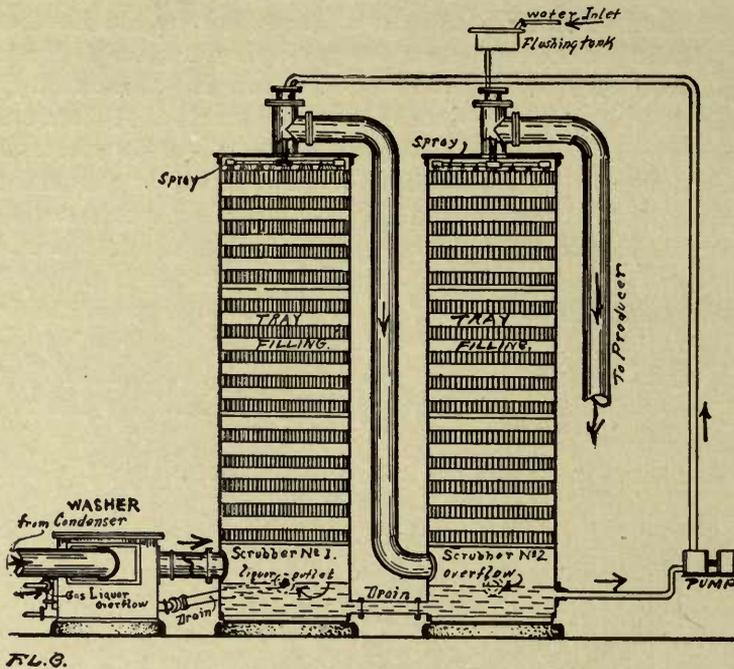
Fig. 33.—Tower Scrubbers in Series.

Tower Scrubbers.—This type of wet scrubber is already well known in coal-gas manufacture, so that extended description is not necessary. Instead of filling with coke-trays, or similar material over which the water trickles, one of the more recent producer-gas plant ideas is a number of interior water sprays or misting jets. The capacity may be increased 100% by increasing the water supply. The spray nozzles of these misting jets are an interesting development.

Bottom trays in scrubbers connected with down-draft apparatus should be metal (preferably cast iron) to resist high heat of gases upon entering and possible danger of ignition through carelessness in opening water pipes. It is also a practice of some engineers to heat up the coke or wood contents of these scrubbers by turning in gas without the use of water sprays, and flood the tower with a view to removing deposits through the overflow. The value of this method is, however, doubtful.
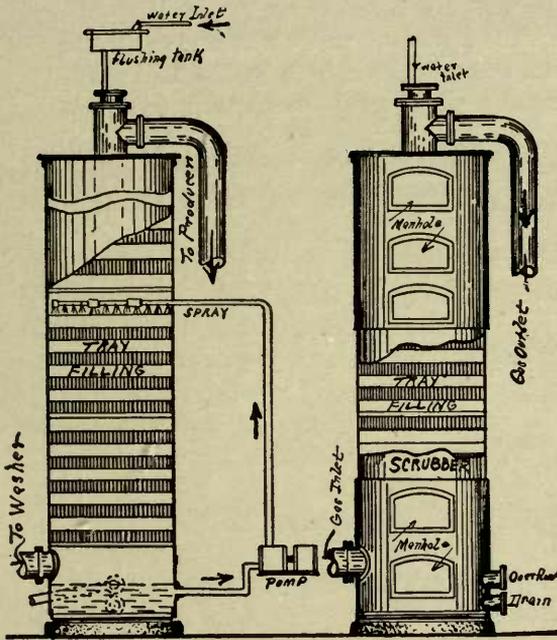
FIG. 34.—Tower Scrubbers in Part Section.
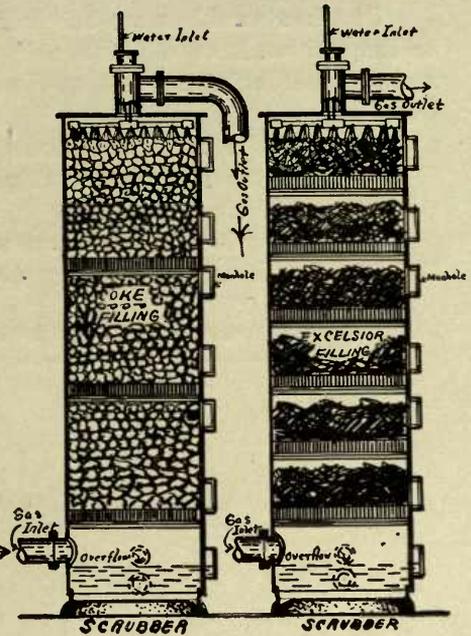
FIG. 35.—Tower Scrubbers Filled with Coke or Excelsior.
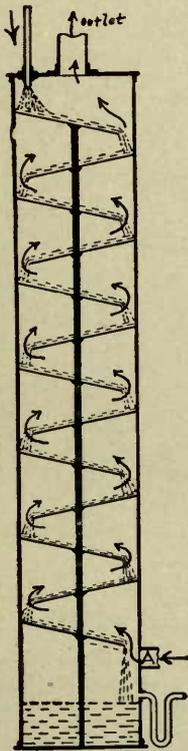
FIG. 36.—Film Tower Scrubber.
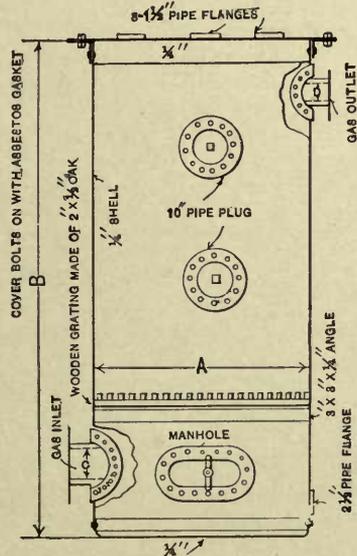
FIG. 37.—Misting Spray Scrubber.

Cast-iron scrubbers are better than steel scrubbers as they are not as susceptible to the action of the sulphuric acid when the sulphur is high in the coal. They are more advisable for use with salt water, also when scrubber water is used over and over.

Sprays.—The essential qualities for sprays consist in (*a*) uniform distribution, (*b*) freedom from stoppage or clogging, (*c*) dispersion of the water into the finest possible particles.

The reason for the first two requisites is obvious, for the second, because of the fact that there is a tendency upon the part of all gases to channel through and to be channeled through by any opposing current of gas, vapor or water, hence the more complete the vaporization the more thorough the intermingling consequent, and the more intimate the mixture.

Such intermixture has a tendency, as already described, to supersaturate and weigh down foreign matter, besides dissolving the bubbles and globules to a point where they gravitate and precipitate.

A mist spray is herewith shown,
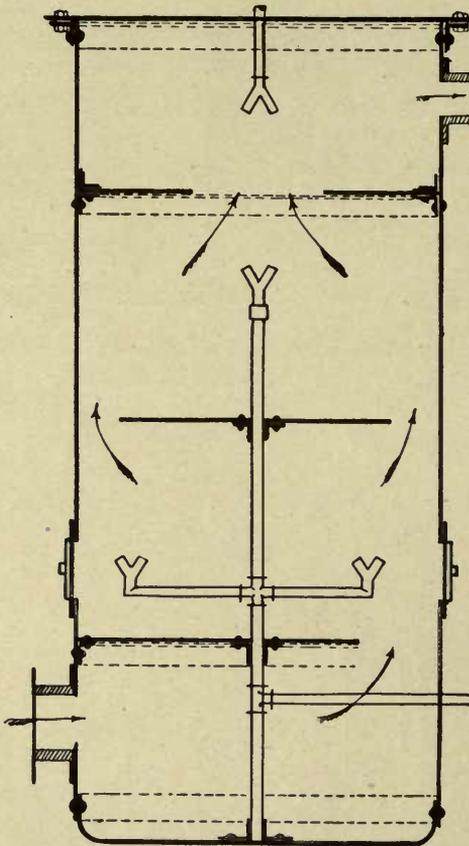
FIG. 38.—Section of Misting Spray Scrubber.
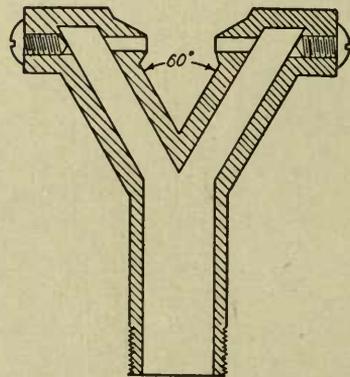
FIG. 39.—Water Misting Spray.

which gives a high degree of vaporization through the mutual impingement of the two nozzles.

The umbrella sprays are particularly free from stoppage and uniform in distribution, although their misting qualities do not compare with the impinging jets. It is designed to be made with a brass regulating baffle of the semi-spiral type, whose degree of throttling compensates for the water pressure and also the area over which the spray is delivered.

This spray has been known to give fairly good results under a water head of

Section A--A

Section B--B
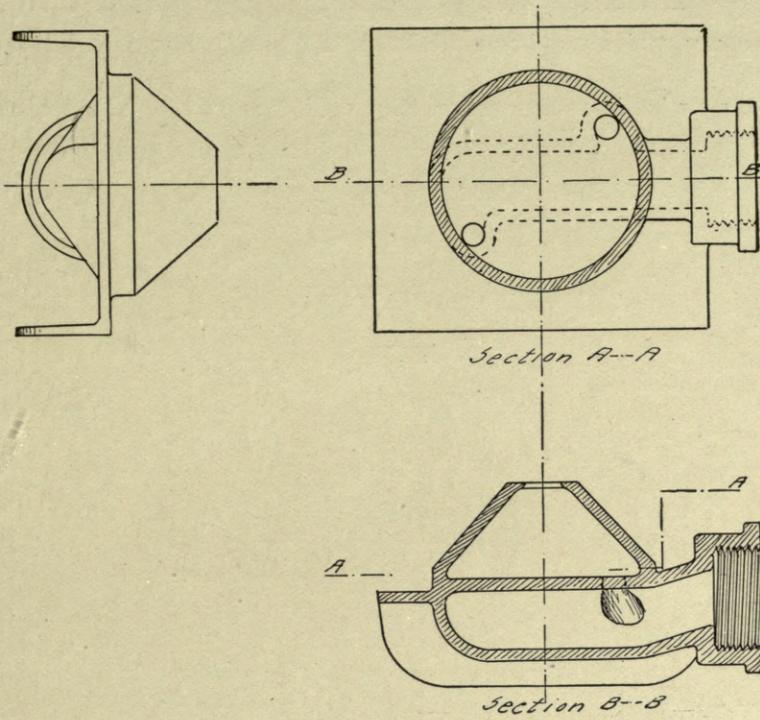
FIG. 40.—Spray Nozzle.

Section A--A

Section B--B
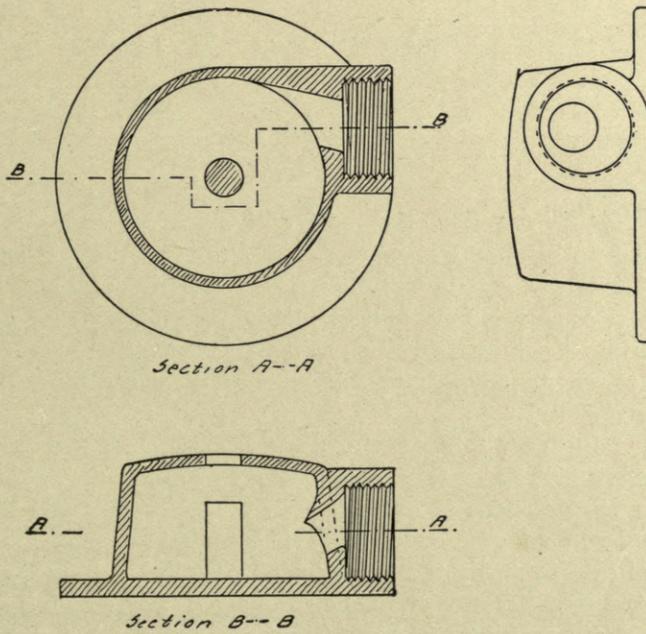
FIG. 41.—Another Form of Spray Nozzle.

5 or 6 feet, a very necessary quality under some conditions and directly opposed to the misting spray, which requires a minimum of 60 lbs. pressure, and is most effective at 100 lbs.

While the umbrella sprays are usually used for the tops of scrubbers, etc., the misting sprays are particularly effective when interposed in pipe lines and are much used in this manner in the cleaning of blast furnace gas.
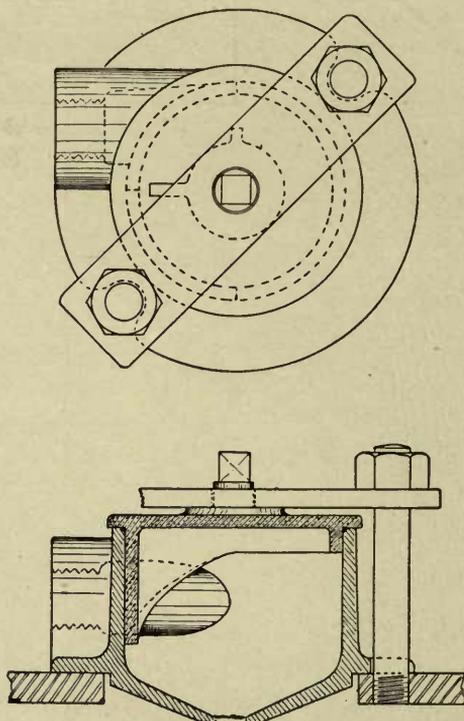
FIG. 42.—Umbrella Spray Nozzle.

Scrubber Water.—Regarding the matter of purifying water for scrubbers and condensors in the purification or cooling of producer gas, where such water comes in direct contact with the gas, it must necessarily become foul, and inasmuch as the amount of water necessary is comparatively large, the facilities for or cost of it may become an important item, so that it is necessary sometimes to recuperate or recover such water for reuse, merely using insufficient fresh water to compensate for the evaporation taking place.

Where this is the case settling tanks are advisable, in connection with which there should be used a baffle separator, as herewith illustrated. The last sections of this separator should contain, as indicated, a bed of broken coke, to which in some instances may be added a screen of jute or cotton bagging.

This will be found to purify the water for all practical purposes, either for further use or to meet the requirements of public drainage. For circulation an iron pump should be used whose packing will resist the action of the hot water and to some

extent acids and sulphurous compounds. A brass-lined ball-valve pump with large ports will be found most effective.

A careful disposal of all scrubber water or drainage water in gas apparatus should be made. In allowing it to escape in ordinary sewage systems, care should be taken of the ultimate contamination of streams, as such water is destructive to animal life, especially fish, and is also extremely detrimental to metallic substances.
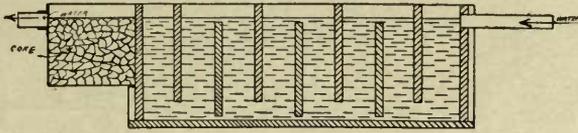
Fig. 43.—Baffling Separator.

In this connection, even a small contamination is most injurious to feed water for boilers, its corrosive action upon tubes and shells being very severe.

The amount of water per horsepower used by scrubber on a suction plant is given as follows by one of the largest American manufacturers:

" Our suction gas plant pamphlet gives this as one gallon per horsepower per hour, but we have since discovered that this is in error and will be corrected in a new issue of the pamphlet. As an answer to this question often affects the water supply that the purchaser will allow, we would state that it is advisable to tell the purchaser to provide for seven gallons for the entire use of the suction plant per b.h.p. hour, figured at a temperature of 60°. This, in our opinion, will give about twice as much water as required, but ample provision should be made in all installations to have sufficient water."

Wash Box and Seals.—The action of the wash-box or seal is largely similar to that of a check valve, to prevent the return of the gas to the apparatus. These seals are generally made with a ratio between the wash-box and the dip-pipe areas of about 25 to 1. It will therefore be obvious that if the dip-pipe dips, say 3 inches in the water of the wash-box, it will require but the rise of 3 inches of water-pressure to force the gas through the seal, while before the gas can return from the box into the dip-pipe all the water in the box would have to be forced back into the dip-pipe. Taking the area ratio of 25 to 1, as before mentioned, while it takes but three inches of pressure to force the gas into the box, it would require $3 \times 25 = 75$ inches pressure to force the gas back into the dip-pipe. These figures are only approximate. This same prin-

Fig. 44.—Water Seal.

ciple can be observed at a coal gas works in the action of the hydraulic main.
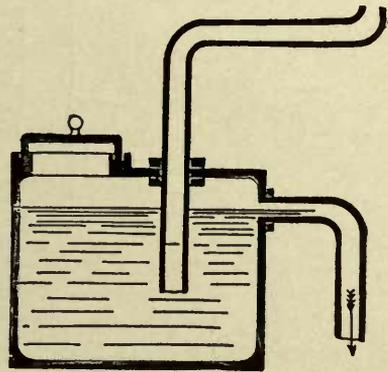
Receiver Tanks.—A receiver tank such as that herewith illustrated performs the dual function of separating the moisture mechanically entrained in the gas by

means of stratification or gravity, and also the maintenance of an ample supply of gas close to the engine and ready for its immediate demand. This arrangement is particularly advantageous on rapidly shifting loads, inasmuch as it maintains a
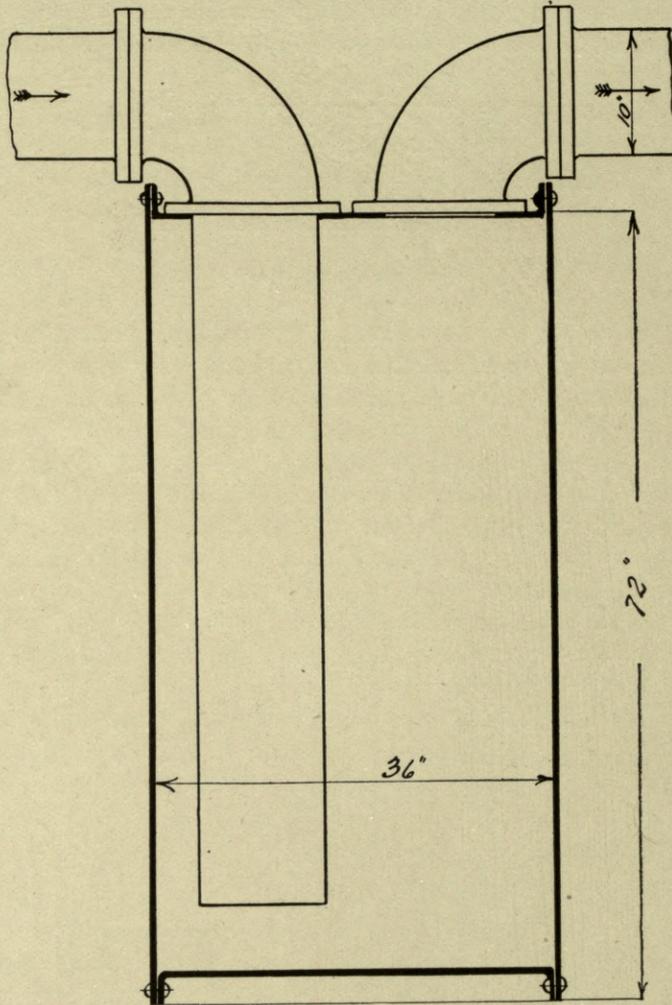
FIG. 45.—Receiver Tank and Moisture Collector.

supply ready for the momentary demand, and also tends to prevent the hammer or pulsation in the gas line due either to the cutting off of the engine valves or the rotation of the blower, there being a strong cushioning effect. In some circumstances this receiver would be found even more efficient than a dry scrubber, which in many installations it has superseded.

TAR EXTRACTORS

The tar found in producer gas is a product of the distillation zone of the producer, the hydrocarbons being distilled from the coal in most part at a low temperature, and vary very much in their gravity and nature, running all the way from the lighter illuminants to the very heaviest coal oils. The passage of this tar is a mechanical one, the gas holding it in various amounts at various temperature or various degrees of vapor tension and pressure.

Although there is a constant tendency for gas to deposit this tar, produced by mechanical friction, kinetic action, and reduction of temperature, the final precipitation of the tar seems to occur most critically at a point about or below 120° F.

Not only do these tars appear in the form of globules, but in some instances in a finely divided mist known as " tar fog." This tar fog has a tendency to entrain other foreign matter, hence stoppages along pipe lines and the mixing valves of engines occur, which are formed not only of hydrocarbon constituents, but of particles of coal ash and iron with their various oxides, and also sulphur compounds.

The methods of removing this tar from a gas may be divided into three parts, the latter two being practically identical in principle though reversed in accomplishment.

The first, by washing, has the dual purpose of cooling the gas and lowering the dew point of precipitation, and also by supersaturating the tar fog or mist with water, and increasing its specific gravity or weight to such a point that it falls through gravitation. In other words, the tar globules take up and entrain enough water to precipitate themselves by their own weight or that of the combined mass.

The second and third methods are respectively those of baffle plates or mechanical separators, the motive in each being the use of centrifugal force. That is to say, the weight of the tar being greater than that of the gas, centrifugal force tends to crowd it to the outer edges of the passage, where it impinges upon and adheres to these baffles by reason of its own weight. Moreover, the inertia of the tar being greater than that of the gas, it does not follow lines of diversion with the same rapidity, and is therefore more easily impinged upon the baffles. In the centrifugal separator, the difference in weight of the tar globule and the gas is the sole principle involved.

Comparison of Tar Extractors.—This subject is treated by R. H. Clayton and F. W. Skirrow in the London *Journal of Gas Lighting* (June 4, 1907). Although
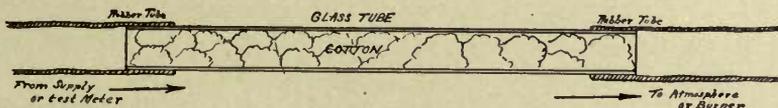
FIG. 46.—Filter used in Testing for Tar.

used primarily in connection with the removal of impurities from coal gas, yet the comparisons drawn are all of an analogous nature and useful in a general discussion of the subject.

A series of experiments was first made to obtain a satisfactory method of stimating the tar fog carried along in the gas. This was done by inserting in the

pipe a glass filtering tube $\frac{3}{4}$-inch in diameter, with a $\frac{1}{4}$-inch hole in the side facing the flow of gas. The inner end of the tube is closed, and its length is such that the hole is exactly two-thirds of the way across the main. The tube contains about 12 inches of lightly packed cotton wool, care being taken that all that part of the tube containing the cotton wool is in the main. Generally 20 to 30 feet of the gas are taken. The tar is determined by washing the cotton with carbon bisulphide and evaporating.

At the works in question a Kirkham and a Clapham washer were worked in parallel. Simultaneous determinations showed that while the average tar at the inlet was 1.5 grams per 100 cubic feet, that at the outlet of the Clapham was 1.3 grams, and at the outlet of the Kirkham washer was 1.45 grams, the temperature 60 to 74° F. Similar tests made on Livesey washers at other plants showed that at 73 to 86° F. between 84 and 88% of the tar fog was removed, showing that this is not a very perfect form of extractor.

The next type examined was a P. & A. tar extractor. This was found to remove 98% of the tar temperature ranging from 72 to 88° F. Next was tried the effect of varying the differential pressure, with the result as here shown:

Differential Pressure.	Temperature (Inlet).	Tar per 100 Cubic Feet.		Purification.
		Inlet.	Outlet.	
4.75 ins.	72.5 deg.	11.33 gr.	0.126 gr.	98.9%
4.62 "	62.0 "	15.21 "	0.133 "	99.1%
4.50 "	65.0 "	15.54 "	0.156 "	99.0%
4.75 "	81.0 "	11.72 "	0.185 "	98.4%
4.81 "	83.8 "	12.89 "	0.155 "	98.8%
2.00 "	71.2 "	15.00 "	0.421 "	97.2%
1.50 "	69.0 "	10.98 "	4.890 "	55.4%
1.50 "	68.0 "	11.05 "	3.410 "	69.2%

Below a differential of 2 inches the machine ceases to work efficiently. Since the volume of gas passed is proportional to the square root of the head, with reduced pressure, the number of holes would have to be very largely increased, and the cage would have to be raised so far out of water that the seal would be broken and the gas would be by-passed.

It would appear that the temperature did not exercise as great an influence as might have been expected, for as great an efficiency was obtained at low as at high temperatures. According to other observers, however, the temperature should be kept at about 80° F., so that the tar remains thin and the plates clear themselves. Another point to be noted is that the tar at the outlet is independent of the quantity entering the machine within the limits of the experiment.

On trying the P. & A. extractor with water gas it was found that the plates within a few days pitched up, leading to the conclusion that the present form could not give the desired result. On considering the greater difficulty presented in removing tar from water gas than from coal gas, the writers arrived at the idea that the problem was similar to that presented in operating gas engines from soft coal

producers. Inquiry brought out the fact that in all cases purification by centrifugal force had been adopted. It being impossible to learn the efficiency of this method by questions, the writers decided to test this method for themselves.

The tests were made with the ordinary fan and the Crossley fan. The first revolved at from 1500 to 2000 revolutions. The gas entered at the center, and a jet of water was introduced at the same time to the amount of 1 gallon per 80 cubic feet. The gas left the machine at an increased pressure of 2 or 3 inches.

The Crossley fan was designed for the special purpose of gas purification and does not increase the pressure. It consists of a revolving disk in a casing. The gas enters one side at the center, passes to the periphery, absorbing much power, and then flows down the opposite side to the outlet at the center on that side, returning the power absorbed. The total power is said to be but 3 or 4 h.p. per 5,000,000 cubic feet per day. One gallon of water was used in this machine per 1000 cubic feet, to flush out the tar and prevent clogging. The fan tested had a diameter of 9 feet, ran at 400 revolutions, and had a nominal capacity of 5,000,000 cubic feet per day. The power required is about the same as is required for driving gas through a P. & A. extractor.

Having no opportunity for testing this machine on water gas, the authors had to content themselves with observing its efficiency with producer gas and on but half its capacity. The results are herewith shown:

No.	Flow of Gas, 1000's cu. ft. per Hour.	Temperature, Fahrenheit.	Tar, Grams per 100 Cubic Feet.		Purification, per Cent.
			Inlet.	Outlet.	
1	60	..	3.8	0.426	89.0
2	50	75	13.8	0.458	96.7
3	50	84	26.5	0.690	97.4
4	100	83	9.36	0.570	93.9

In tests No. 2 and 3 the preliminary washers were by-passed, and in No. 4 one of the coolers was out of action.

Determinations of the tar in water gas showed from 10 to 13 grams per 100 cubic feet at the inlet of the purifier. If we assume, and there is every justification for doing so, that the fans will be as efficient as with producer gas, we should not only remove about 95% of the tar, but recover it in a salable form. The small amount left in the gas could economically be removed with a sawdust scrubber.

Mallets' rotary tar extractor, in use in some continental gas works, comprises plates built up as a revolving drum, the lower half of which dips into condensed tar in the bottom of the casing. The differential pressure is regulated by raising and lowering the tar level. The temperature giving best results is from 80° to 85° F., and at a differential of 2.5 to 3 inches, the efficiency is said to be equivalent to a reduction in the tar of from 13 to 6 grams of tar down to 0.18 to 0.04 gram per 100 cubic feet.

Stationary Tar Extractors, Centrifugal.—Although many centrifugal tar extractors require power, as they revolve and act by centrifugal force upon the tar particles,

in the invention to be described, there are no moving parts whatever, as such motion is imparted to the gas as to cause the tarry particles, globules, or vesicles which have a greater density than the gas, to be immediately forced against the interior surfaces of the apparatus, and thus be subjected to the necessary friction and impact.

Not only is it the object of the present invention to remove the tar, which in its pure state is composed entirely of a number of hydrocarbons of varying density, but also to remove any solid matter suspended in or carried by the gas in the shape of impurities.

Referring to the figure, the gas-main has inserted within its length a trap, while at the opposite sides of the trap and connected with the main are elbow-
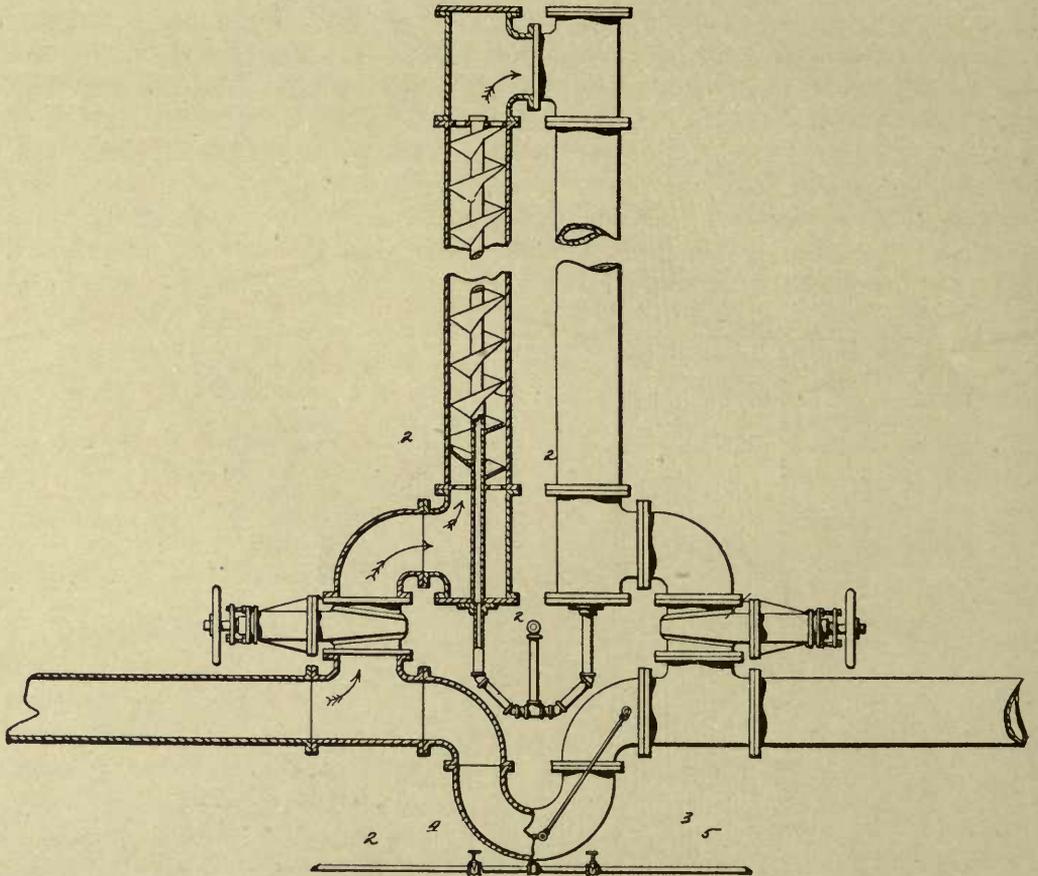
Fig. 47.—Fixed Centrifugal Tar Extractor.

couplings which are controlled by means of suitable valves. From the couplings extend branch pipes or conduits which at their outer ends are connected. By means of the valves the by-passing of the gas around the columns is controlled. Suitably secured within the ends of the pipe are spiders or skeleton frames in central sockets of which are inserted the tubular shaft of the screw. This shaft is closed at its upper end and is open at its lower end, where it communicates, by means of

branches forming a tar seal with a discharge-pipe. The screw-blade slants toward the center, forming inverted cone-shaped surfaces over which the liquid may run in all directions toward the center, and the edge of the blade is in contact with the inner cylindrical surface of the pipe or conduit. Small holes or perforations are made in the tubular shaft or axis of the screw, so that the tar which is deposited on the blade and the inside surface of the pipe or conduit may, after first flowing down to the tube, pass through the said holes or perforations and down the interior of the tube. A suitable dam is formed behind each hole for the purpose of causing the tar to dam up, and thus be forced into the holes. As there is a differential pressure in the gas between the top and bottom parts of the screw, a small amount of gas will leak into the tube through the holes or perforations at the bottom and out of the holes at the top.

The water seal referred to is provided with two water-gauge glasses, to show the different heights of the water in the seal. But one of the glasses is shown at the right-hand side of the seal. A pipe at the bottom of the water seal is connected with the same, and is provided at opposite sides of the said connection with valves. One valve is to be connected to water-supply under pressure, while the other valve is connected to waste. By opening one valve for instance, the water in the seal can be entirely withdrawn, while by closing this valve and opening the other valve the water-level in the seal can be increased. The object of the described water seal is to prevent any undue back pressure of gas in case the pipe should become stopped up, and it therefore forms an automatic by-pass.

The described apparatus can be employed either with coal-gas or water-gas plants for the removal of tar or other solid matter forming impurities.

P. & A. Baffling Extractors.—This is another form of stationary extractor. Where used in intermittent service, it must be kept as nearly as possible at a constant temperature, usually between 120 and 100° F. This is for the reason
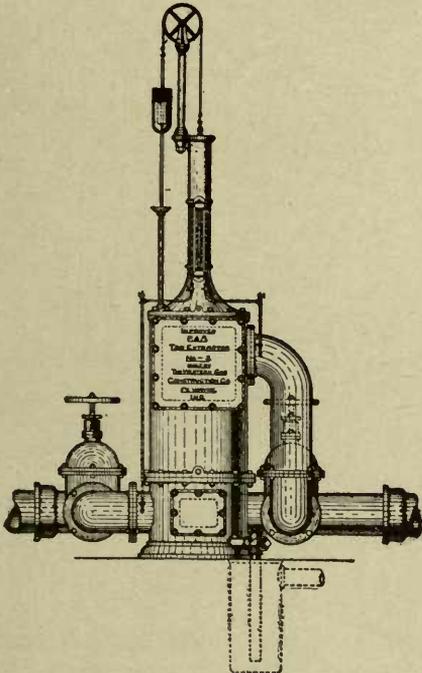
FIG. 48.—Elevation of the P. & A. Tar Extractor.
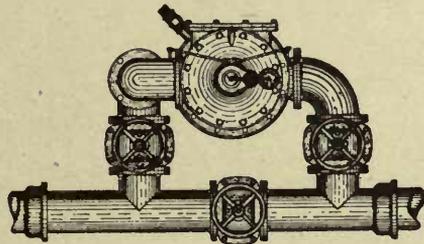
FIG. 49.—Plan of P. & A. Tar Extractor showing connections.

that during stand-by periods a certain amount of sediment upon the plates has a tendency to congeal, due to a cooling influence on the part of the separator itself and

its water seal, the result is that the plates become " gummy," and create a nucleus which, upon starting up the separator again entrains further stoppage and in a short time puts the apparatus out of commission. The temperature of the condenser should at no time get lower than 100° F. The easiest way would be to have a steam-pipe attachment and turn on a little steam into the separator during stand-by periods.

The accompanying illustration shows what this extractor looks like. The gas passes through small holes and impinges on surfaces to which the tar sticks. Gas
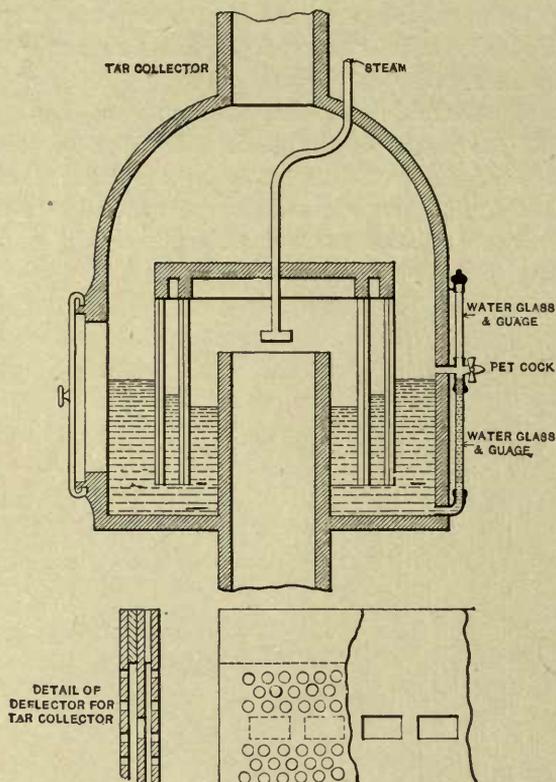
FIG. 50.—Tar Extractor.

tar remains fluid above 100 to 120° F., below which it becomes sluggish and congeals.

A form of tar collector is herewith illustrated resembling the P. & A. in principle, operating upon the idea of impinging jets. This type is advisable only in exceptional instances.

Centrifugal Tar Extractor.—Efficient gas cleaning of bituminous gas has been demonstrated in the blast furnace gas power plant of the former Carnegie Steel Co., at Pittsburg, Pa. The apparatus comprises a combination of vertical baffling washers connected in series with a centrifugal rotary scrubber. This apparatus delivers gas to the holder in a condition which may be noted as absolutely clean.

A fair estimate of the power required for a mechanical tar separator, including

friction of line shaft and other losses, may be placed at between 4 and 5% of the total horsepower of the plant.

The centrifugal tar separator fitted in the works of the Allis-Chalmers Co., at
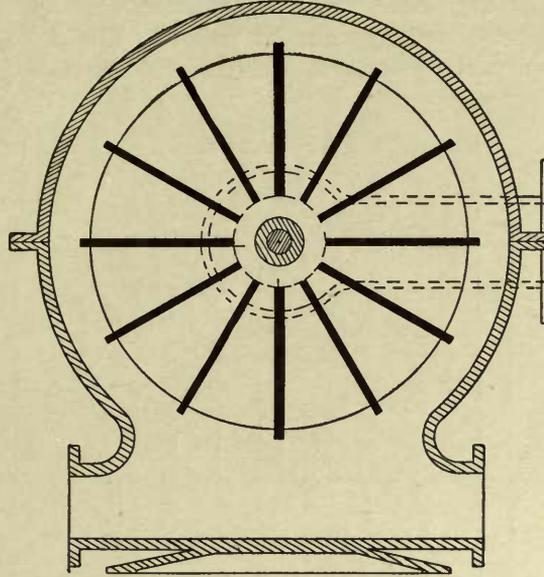
Fig. 51.—Vertical Section of Centrifugal Tar Extractor.

West Allis, Wis., has proven a duty of separating tar from producer gas at the rate of 300 lbs. of net tar per ton of coal gasified.

The accompanying section illustrates the horizontal cross-section through a centrifugal scrubber, and this illustrates very well this type of separator, useful for tar as well as moisture and wet, dust-like impurities.

The location for the tar extractor at the 300 h.p. suction producer plant of the Fort Dodge (Ia.) Light and Power Co., is shown by the accompanying drawing.

In soft-coal practice it is necessary to periodically burn out the tar and soot deposited by the gas. This is done by stopping the producer and opening suitable doors provided in the flues. Usually the soot takes fire readily, or may be ignited,

Fig. 52.—Centrifugal Tar Separator.

and the furnace stack draws the air and combustion through the flue. In some cases direct connection of the flue is made to the stack and air or steam jets used to loosen the deposits of soot, while at the accessible points it is scraped out.

Ordinarily, tar is not decomposed below a temperature of 2000° F., although moisture which it contains may, of course, be evaporated at boiling-point

Gas Engine Requirements.—The purity of gas for use in gas engines is specified by the makers of those engines which operate on producer gas, and the following are some examples:

Snow Steam Pump Co.: They have experienced little trouble from moisture, the single exceptions having been occasioned not from moisture in the gas, but from condensation in the pipes after long stand-by periods. This may, of course, be overcome by blowing out a small quantity of gas through the engine purge pipes.

FIG. 53.—Location of Tar Separator, Plan and Elevation.

A small content of tar, however, creates much trouble, occasioning crematory stoppages and attendant evils. The limit permissible should not exceed 0.01 grain per cubic foot, mineral dust must not exceed 0.02 grain per cubic foot, and the total impurities, including lamp black, should not exceed 0.05 grain per cubic foot.

Westinghouse Machine Co.: "A producer gas containing from 125 to 150 effective B.T.U., but the gas must not contain more than 170 effective B.T.U. They would like the gas to be in accordance with the following analysis: Not to contain more than,

0.01 grain of dust per cu.ft.,

0.15 grain of sulphur per cu.ft.,

0.02 grain of tar per cu.ft.,

4.00 grains of moisture per cu.ft., above point of saturation, and not to contain more than 15% of hydrogen by volume, and not less than 2% of methane by volume. In some cases we have found it impossible to get the producer manufacturer to comply with our specifications as to the quality of gas, but the above limitations are by no means impossible of attainment."

R. D. Wood & Co.: They make the following guarantee as to the gas supplied from their producer for engine service: That gas produced shall contain per cubic foot not in excess of 0.02 grain of tar; 0.01 grain of dust and 6 grains of moisture.

Junge states in his work on Power Gas: " It must be remembered that even a very small amount of dust is prohibitive in gas-engine cylinders as it, naturally gritty, will unite with the lubricating oil, forming a pasty mass which produces an abrasive effect only excelled by oil and emery. As 75% of the dust is metallic oxide, when subjected to a temperature of 300° F. (the heat of inflammation) it will be precipitated as iron and steel. The third requirement to be considered is freedom from excessive moisture. When the gas leaves the furnace (we are now speaking of blast-furnace gas) it is laden with dust, containing 8 to 15 grains per cubic meter (4 to 7 grains per cubic foot), and other negligible impurities, and is very hot (140° to 180° C.) but comparatively dry. The greater part of the dust is first removed by a dry process in the dust catcher, while the finer particles are eliminated by bringing the gas in intimate contact with water. Now this water, leaving aside its varying temperature, represents in all processes an almost constant amount compared to the quantity, temperature, and composition of the gas and its dust contents, all of which vary according to the course of the smelting process and the condition of the season. This water remains suspended in the gas after leaving the scrubbers, washers, and fans, and to secure regular and efficient combustion it must be removed again down to a very low percentage before being conveyed to heaters and engines.

" To secure maximum efficiency of combustion we must have a cool, clean, dry gas. But these requirements vary in degree, according to the manner and kind of application. For use in hot-blast stoves and under boilers the temperature of the gas may be higher than for use in gas engines. But higher temperatures enable the gas to contain a large amount of moisture, which is again harmful to the all-around efficiency. The degree of purity of the gas for heating furnaces need not necessarily be higher than 0.5 grain of dust per 1 cubic meter, or 0.2 grain per cubic foot, as it is found that the fire-brick lining of the ovens is apt to fuse when still higher temperatures are maintained. For use in engines there are no lower limits fixed for temperature or purity, but the upper limits are the more rigidly drawn, namely, temperature 25° C., and degree of purity 0.02 grain per cubic foot. The latter figure is the basis on which German manufacturers give their guarantees on gas engines. This covers the case as far as temperature and purity for various purposes are concerned."

Lackawanna Iron Co.: According to an official statement made by the Lacka-

wanna staff some time ago, the degree of purity of the gas that can be reached with this cleaning plant was shown by its content of from 0.043 to 0.934 grain (0.6663 to 0.524 grain) of dust per cubic meter (35,314 cubic feet).

Sulphur in Engine Gas.—Considerable controversy has arisen in various parts of the country regarding the influence of sulphur upon the cylinders of a gas engine, leading in some cases to the introduction of this question into important lawsuits. The engine in use at the testing plant of the United States Geological Survey has received the full charge of sulphur contained in the gas, since the establishment of the plant, and shows absolutely no signs of injurious effects, although coals have been used running as high as 8.1% sulphur.

CHAPTER III

WORKS DETAILS

Vaporizers.—The subject of the use of steam *versus* water vapor as an endothermic agent has been pretty thoroughly discussed by the writer under the head of endothermic agents. It seems logical that the heat for the creation of this steam or vapor should be recuperated heat, that is to say, should not be obtained at the expense of fuel consumption; this, as far as power plants are concerned, must logically be from the sensible heat of the effluent gases, the tendency being to condense the gas and also restore the waste heat to the fire.

With producers operated in connection with furnaces the utility of this arrangement is doubtful, and it is perhaps best to utilize direct radiant heat of the fire as in No. 4, as an absorption of the sensible heat of the gases in this connection tends to the reduction of flame temperature in final combustion.

Taking up vaporizers for power purposes further, there may be said to be three distinct types, namely, those relating to the evaporation of water from the ash pits, to which many engineers are opposed by reason of the cooling effect upon the ashes, thereby preventing the radiation of their heat during the cooling process back into the furnace. This claim, made by Mathot and other German engineers, is of doubtful value, inasmuch as recuperated heat from the cooling ash must be comparatively small when compared to the loss by conduction, also there is considerable benefit derived from the humidifying effect of vapor thus distilled upon the grate bars which are materially cooled thereby. There is also a cooling effect upon the bottom of the fire where clinker is apt to collect and fuse, or in common parlance to " slag."

The second type of vaporizers for the recuperation of sensible heat is that of the multitubular type connected with the take-off pipe of the producer through which the effluent gases pass. This type of vaporizer is very satisfactory where fuel of a non-bituminous nature is used or where the effluent gases are free from tar, lampblack or unfixed hydrocarbons.

This is the case also with down-draft apparatus where these hydrocarbons were fixed. In case of the use of this type the gas should be admitted at the bottom of the vaporizer where it comes in contact with the water leg of the tubes, as otherwise tubes and tube sheets cannot withstand the temperature.

Where this type is adopted type " B " would be found most satisfactory inasmuch as these tubes are susceptible to operation with cleannig or scurfing rings after the manner of an economizer.

For general apparatus, however, the arrangement shown in the illustrations will be found more satisfactory; these, especially Nos. 1, 2, and 3, are designed to vaporize
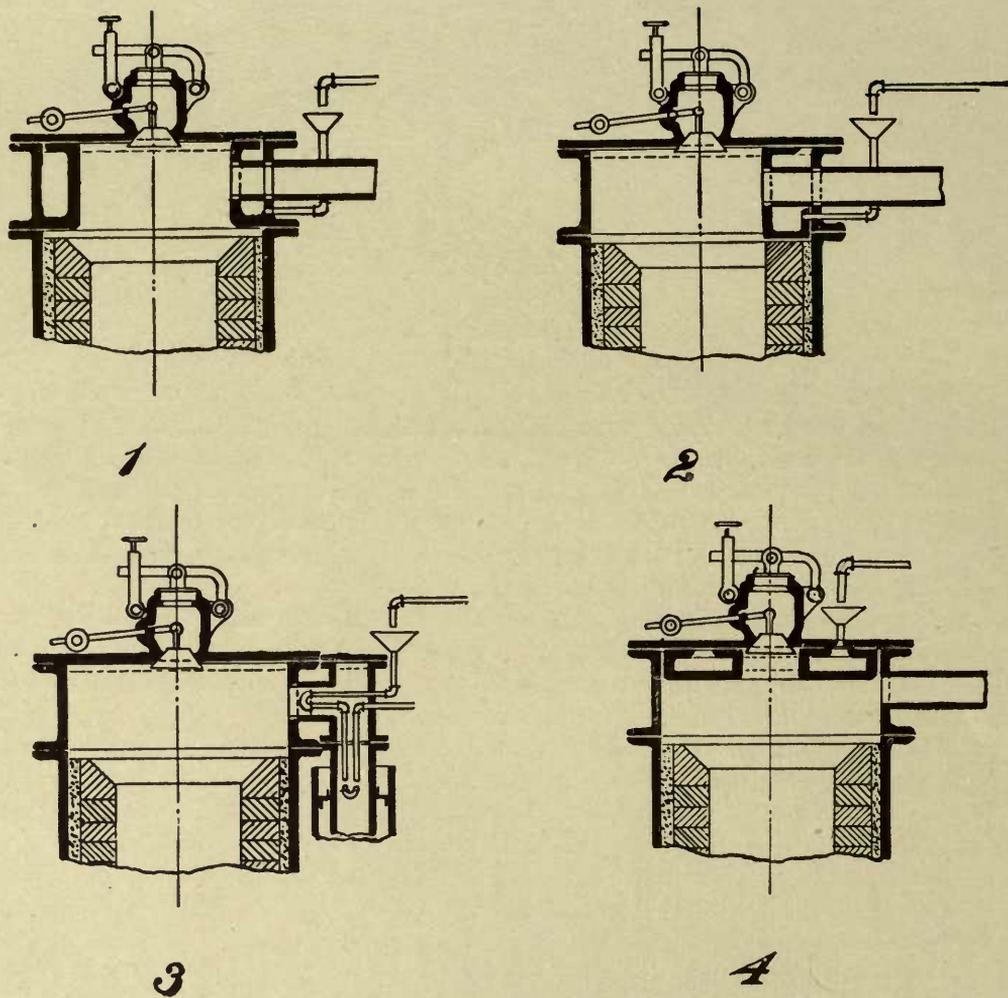
Fig. 54.—Water Vaporisers on Producer.
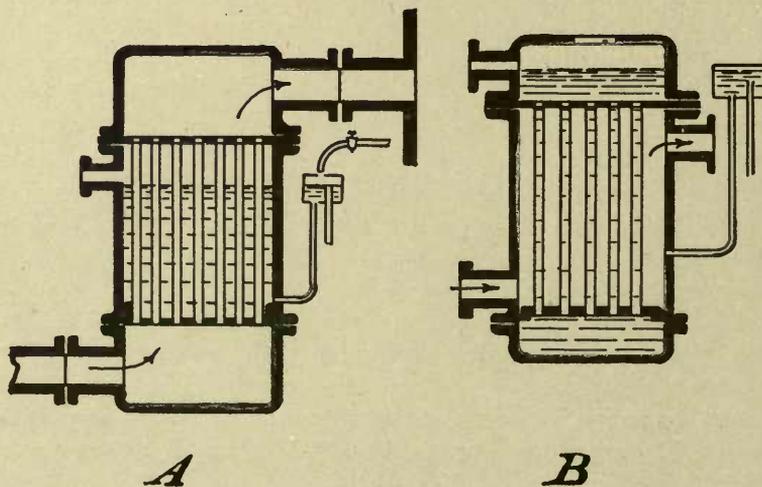
Fig. 55.—Producer Economizers.

water by the sensible heat of the effluent gases within the top of the producer, while leaving the producer through the take-off pipe.

All these producers receive a small portion of radiant heat from the fire and there may be a trifling loss of heat from the conduction of the shell. Such losses are comparatively small and the benefit to operation derived from a cool producer top and their accessibility for the removal of scale, etc., may be considered a stand-off.

It is the belief of the writer that water should always be hand regulated to producers, inasmuch as the amount of water required varies with so many conditions that it is impossible to confine its admission as a reciprocal of any one condition.
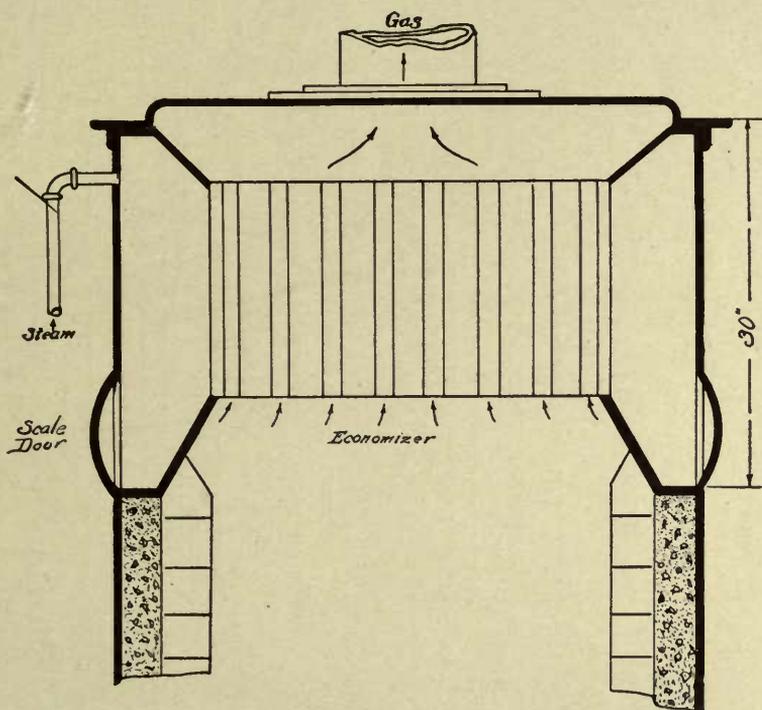
FIG. 56.—Powdered Fuel Producer Economizer.

A small water content can be constantly kept in the vaporizers herewith shown, or again the steam may be flashed by intermittent admission. The latter is an excellent arrangement.

No. 3 shows an arrangement whereby the steam is generated in a small return bend coil within the take-off pipe, a sheath or sleeve on the outside of the take-off pipe forming a pre-heater for the incoming air and absorbing the radiation from the outside of the take-off pipe as the coil absorbs the sensible heat of the gas within the pipe. This coil has the advantage of being easily removed and cleaned, and is also cheaply renewed, if it is for any reason destroyed or impaired.

Within all up-draft producers the gases collect in the take-off pipe and top of the producer, and the abstraction of heat from these will, under most conditions, make all the steam which is required.

For down-draft producers, or producers of the powdered-fuel type, completely fixing their hydrocarbons, the tubular vaporizer will doubtless be found most efficient, as shown.

Charging Producers.—One of the most convenient, economical, and simple methods of charging gas producers is by an electric storage battery locomotive coal car, running on an industrial railway, specially designed for handling coal from the
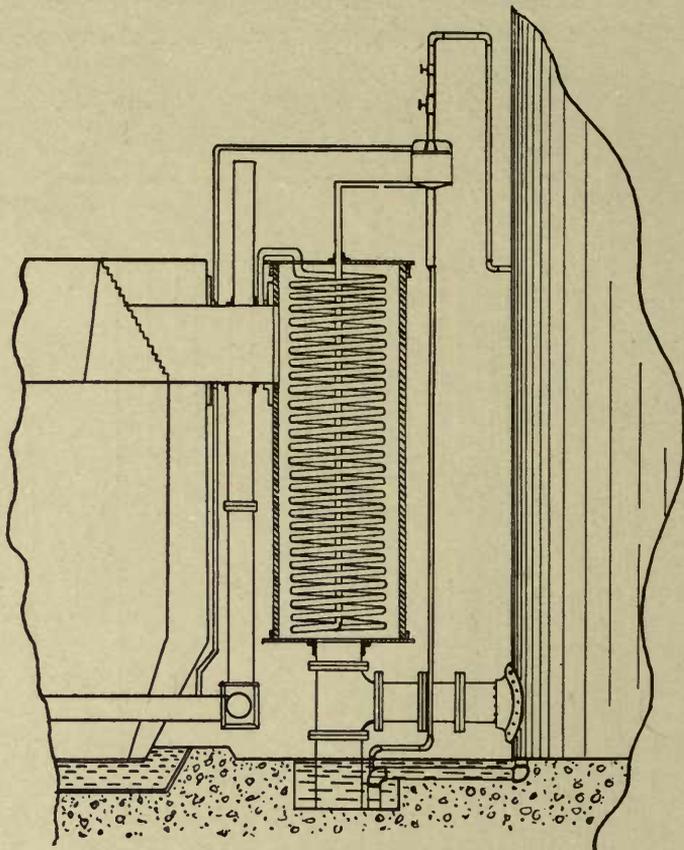
Fig. 57.—Economizer for Bituminous Producer.

storage bins to gas producers. The locomotive runs under an elevated storage bin, and coal is loaded into the larry through suitable valves. The track runs over the top of the gas producers, into which the locomotive spouts the coal direct. The coal-storage bin can be situated in any convenient position where the tracks can reach them. The entire operation of the machine requires the services of but one man.

Pressure boards, consisting of series of glass dip pipes for approximate determination of either suction or pressure at different points of the apparatus can be installed to advantage as a check on operation.

Safety Devices.—Blast pipe may be to a degree protective against the ignition of gases and " flare-backs " by the insertion of diagonal or conical screens of larger
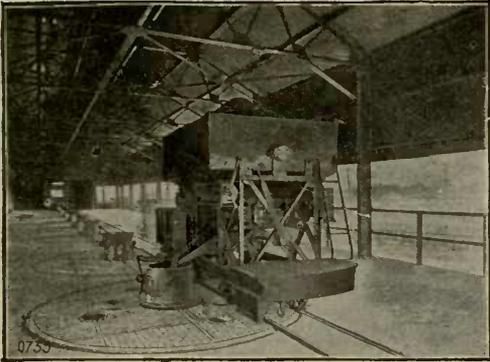
FIG. 58.—Coal Car ready for charging Producer.
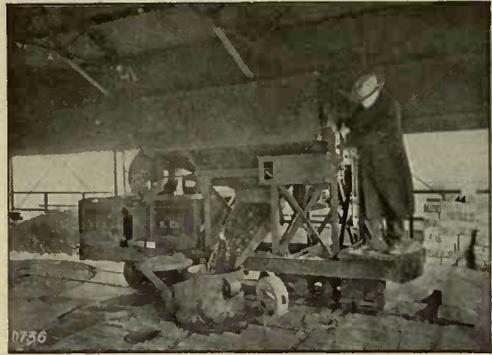
FIG. 59.—Charging a Gas Producer.
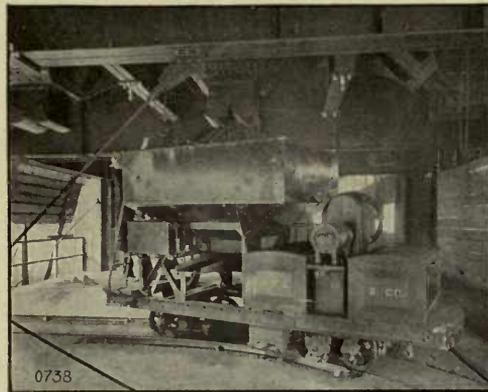
FIG. 60.—Charging a Car with Coal.
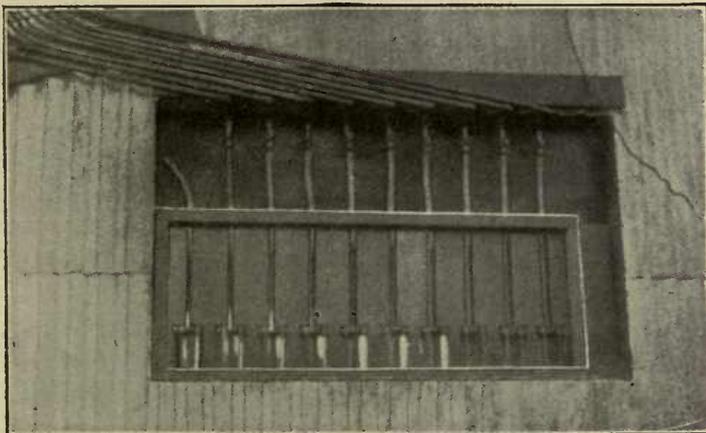
FIG. 61.—Suction Gauge Board.

area than the pipe section. The diagonal form is used, of course, to increase the area. The screen should be made of brass-wire gauze not larger than 60 mesh or its equivalent.

Wire-gauze screens or caps should cover all air-intake piping or test-light outlets, where connected with gas apparatus or appliances. Relief valves may be of three types, namely:

a. Swinging valves which are hinged and consist of blank flanges hinged upon one side and held in position by counter weights.
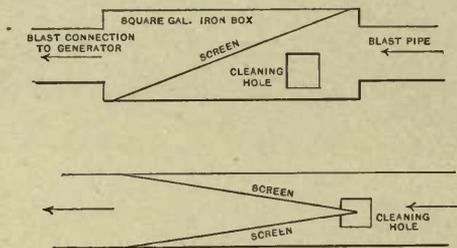
Fig. 62.—Screen Preventing Firing back.

b. Water seals consisting of dip pipes sealed in water to a depth affording a margin of safety. And

c. Thin-lead blank flanges whose rupture point should not be above some three or four pounds pressure.

It is preferable that all of these devices have air vents leading to the atmosphere, these being most important with the two last-named arrangements, inasmuch as the seal being destroyed, there is danger of gas collecting within a building in sufficient quantities to create an explosive mixture. This danger can, in some degree, be obviated in the case of the water seal by equipping it with a continuous water supply and overflow. There is, however, a factor of danger present in each of the last-named types, and the swing valve, such as is indicated in the illustration, of a blast-gas dry scrubber, is perhaps the safest arrangement, so long as the outlet of the valve is so situated that it cannot impinge during a blow off upon either the operator or any inflammable substance.

Insurance Requirements.—Underwriters require all overflow pipes to be sealed with at least twelve inches of water. Where ash pits of producers are sealed with water, the bosch must be continuously overflowing. Rule 2*e* requires the use of some form of interfering three-way valve, so that the producer is always open either to the engine or to the outside atmosphere.

Pressure Systems. All pressure systems must be located in a special building or buildings approved for the purpose, at such distance from other buildings as not to constitute an exposure thereto, excepting that approved pressure systems without gas holder, having a maximum capacity not exceeding 250 H.P., and with pressure in generator not exceeding two pounds, may be located in the building; provided that the generator and all apparatus connected therewith be located in a separate fire-proof room, well ventilated to the outside of the building. In all other respects the apparatus must comply with the requirements for suction systems.

Suction Systems. The 1908 rules of the National Board of Fire Underwriters' Engineers for suction producers are as follows:

a. A suction gas producer of approved make having a maximum capacity not exceeding 250 H.P. may be located inside the building, provided the apparatus for producing and preparing the gas is installed in a separate, enclosed, well-ventilated fire-proof room with standard fire doors at all communicating openings.

Note.—The installation of gas producers in cellars, basements, or any other places where artificial light will be necessary for their operation, is considered hazardous and will not be permitted except by special permission of the underwriters having jurisdiction.

Note.—The portions of these rules relating to the design and construction of apparatus are but a partial outline of requirements. A producer which fulfils the conditions herein outlined and no more will not be necessarily acceptable. All appliances should be submitted for examination and report before being introduced for use.

b. The smoke and vent pipe shall, where practicable, be carried above the roof of the building in which the apparatus is contained, and adjoining buildings, and when buildings are too high to make this practicable, the pipe shall end at least 10 feet from any wall. Such smoke or vent pipes shall not pass through floors, roofs, or partitions, nor shall they, under any circumstances, be connected into chimneys or flues.

c. Platforms used in connection with generators must be of metal. Metal cans must be used for ashes.

d. The producer and apparatus connected therewith shall be safely set on a solidly built foundation of brick, stone, or cement.

e. While the plant is not in operation the connection between the generator and scrubber must be closed and the connection between the producer and vent pipe opened, so that the products of combustion can be carried into the open air. This must be accomplished by means of a mechanical arrangement which will prevent one operation without the other.

f. The producer must have sufficient mechanical strength to successfully resist all strains to which it will be subjected in practice.

g. Wire gauze not larger than sixty mesh or its equivalent must be used in the test-pipe outlet in the engine room.

h. If illuminating or other pressure gas is used as an alternative supply, the connections must be so arranged as to make the mixing of the two gases or the use of both at the same time impossible.

i. Before making repairs which involves opening the gas passages to the air, the producer fire must be drawn and quenched and all combustible gas blown out of the apparatus through the vent pipe.

j. The opening for admitting fuel shall be provided with some charging device so that no considerable quantity of air can be admitted while charging.

k. The apparatus must have name plate giving the name of the device, capacity, and name of maker.

Gas Explosions.—Explosions resulting from an ordinary explosive mixture of producer gas in pipes, holders, tanks, or other apparatus, where said explosive mix-

ture is ignited without previous compression, the resulting explosive force exerted does not, in the experience of the writer, exert a maximum pressure of over 60 lbs. per sq.in. It is therefore manifest that any connections, fittings, etc., which may be subject to such explosives, should have a safe working pressure or rupturing point above this figure.

One serious explosion in the experience of the writer in connection with the gas producer power plant having a holder occurred as follows:

The fire bed of producer having been permitted to become porous, the exhauster drew through the producer, and forcing into the holder a certain portion of un-
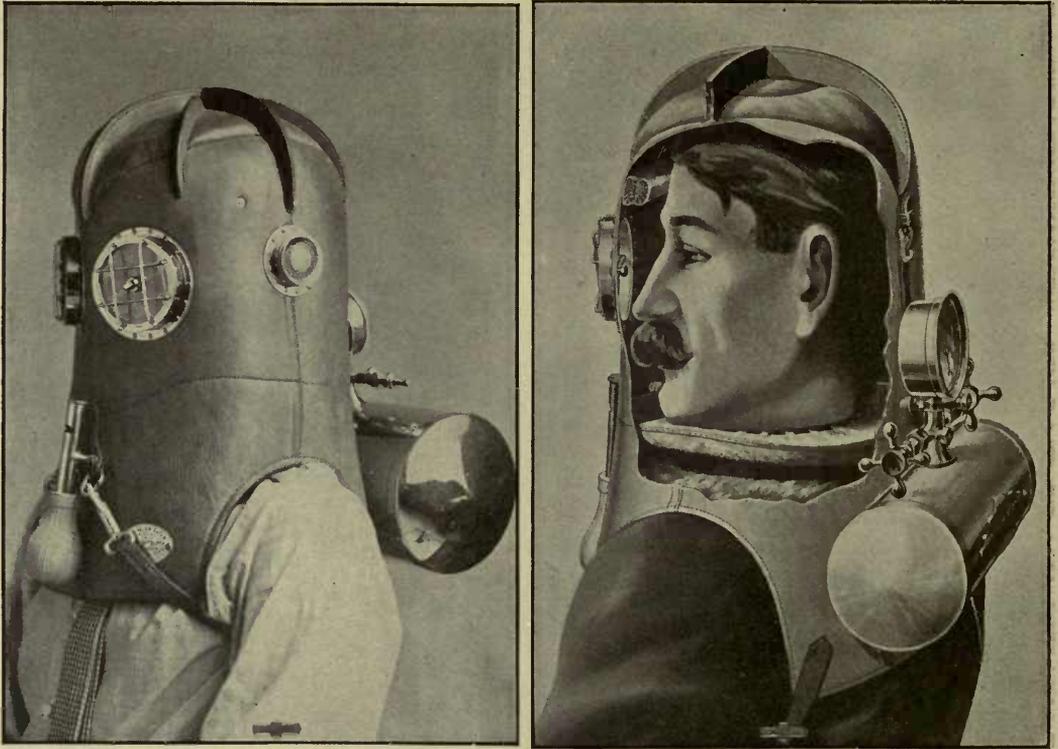
The Vajen Helmet.　　　　　　　　　　Cut-out Section of Vajen Helmet.
Fig. 63.—For Working in Asphyxiating Atmosphere.

decomposed air, thus forming an explosive mixture in the holder. As a matter of fact, prior to this the gas supplied the engine was so inferior, due to the condition of the fire bed, which contained a high percentage of CO_2, producing a very slow combustion in the engine cylinder, that a portion of the charge " hung over."

This condition of affairs caused the engine to back-fire, or fire on the admission stroke, thereby igniting the explosive mixture.

This could, of course, occur in installations without a holder, but of course there would not be the accumulated volume of gas. It is possible that its liability might be reduced to a minimum by the insertion within the pipe lines of proper wire screens between the engine and holder.

Gas Asphyxiation.—According to Dr. Haldane air containing so small a percentage as 0.2% of carbon monoxide, should be regarded as entailing risk to life. The chief danger of carbon monoxide lies in its lack of odor unless combined with sulphurous or other odorous compound.

First aid in cases of poisoning lies in the application of heat, artificial respiration, and stimulants. Muscular action should be as limited as possible.

The action of carbon monoxide as a poison consists in its combination with the hæmoglobin of the blood, which causes the corpuscle to become inert and prevents its combination or rather revivification through union with oxygen.

The illustrations show the Vajen patent helmet for use in gaseous atmosphere, in which, by reason of the fact that it can be put on in three seconds and taken off in two, is a particularly effective apparatus for rescue work, repairing gas leaks, etc. The air supply is sufficient for at least one hours' service. The reservoir may be re-charged within two minutes and will stand for months ready for service, the gauge indicating the amount of air which it contains.

Oxygen Administration.—Artificial respiration by oxygen should be administered preferably before natural respiration has entirely ceased, or after some slight respiration has been started by placing the patient in a sitting position, lifting the
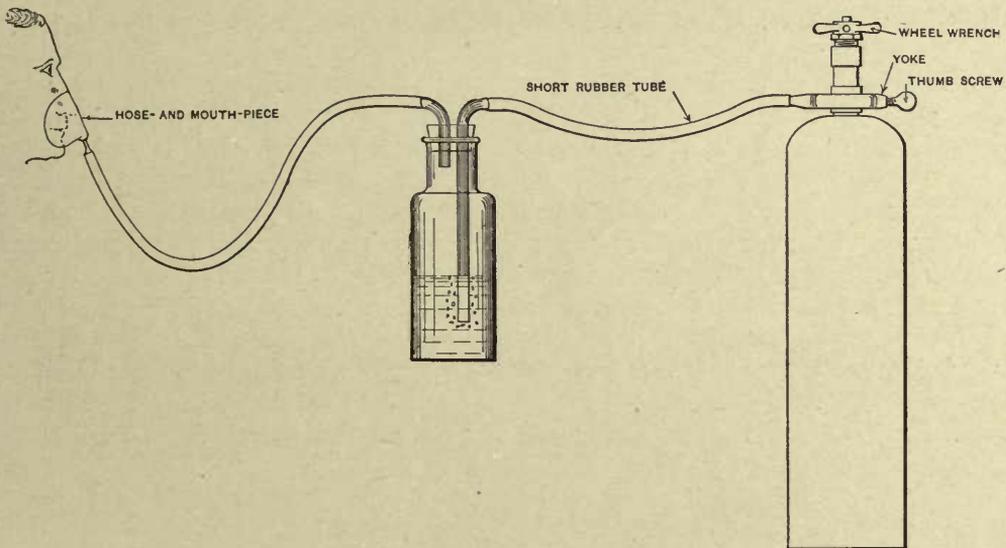
FIG. 64.—Oxygen Administration Apparatus.

arms above the head and moving them down to the sides thereby inflating and deflating the chest, by blowing in the patient's mouth, or by the use of brandy or other restoratives.

Care should be taken that the tongue of the patient has not been swallowed or contracted into the thorax, in which case it should be withdrawn with forceps and held as nearly as possible in normal condition. It may be remembered that good oxygen gas is harmless and the lungs may be completely filled without danger to the patient. The administration of oxygen may be performed in company with the

ordinary means of resuscitation, manipulating the limbs and chest, the mouth- and nose-piece being held either to the nose or mouth.   After partial resuscitation the patient may be benefited by taking deep inhalations of the oxygen from the mouth-piece.

The method of applying oxygen is shown in the illustration, and the following are the directions to be followed: Remove paper seal from opening in valve, slip yoke over so that the tubular projection on same will fit into opening of valve. Tighten thumb screw.   Fill bottle half full of warm water, put cork in bottle firmly, then connect short rubber tube attached to yoke with long glass tube in bottle. Turn the gas on very slowly with small wheel-wrench.   The volume of oxygen being given can be estimated by the flow of bubbles.   Close the valve gently but firmly.

According to Dr. J. S. Haldane effect of carbon monoxide upon man is as follows:

Percentage of Carbon Monoxide.	Effect on Men
0.05	After half an hour to two hours, giddiness on exertion.
0.1	" " " " " inability to walk.
0.2	" " " " " loss of consciousness and perhaps death.
0.4	" " " " " probable death.
1.0	" a few minutes, loss of consciousness, followed before long by death.

CHAPTER IV

PRODUCER TYPES

DOWN DRAFT PRODUCERS

THE down-draft producer has as its raison-d'être the fixing of the hydrocarbons by their passage through an incandescent fire-bed after their formation instead of passing off immediately in the gas, as is the case with the up-draft producer.

Failing in this fixing action, the down-draft apparatus would have no cause for existence. As a matter of fact, some of its features are positively objectionable, as, for instance, the double ash zones, with their ever-increasing tendency to meet, also percolation down through the fire-bed of the finer ash from the upper zone, stopping the voids and causing the back pressure so characteristic of this type of apparatus. It must be conceded that the down-draft apparatus must essentially be of the multi-unit type, for the following reasons: In order to give a longer time contact in the formation of the gas and the fixing of the hydrocarbons. The limit of fire-bed operation made practical by continued stoking is four feet, and should this fire become in the slightest degree porous or honeycombed, the time contact is not sufficient for the fixing operation necessary.

With a multi-unit arrangement, however, a reversal in flow in operation is possible, which combines the advantage of presenting fresh carbon surfaces, stirring up the ash, clearing it from the voids, breaking into the channels, equalizing combustion throughout the cross-section, reducing clinker, and gaining an all-around higher rate of efficiency.

The advantage of such operation has long been admitted in water-gas practice where it is usually customary to reverse the runs at the ratio of two up runs and one down run.

Per contra, the disadvantages of single-unit down-draft apparatus is shown by the fact that it cokes through the center of the producer with coking coals, or forms an ash zone through the center with non-coking coals (the former being merely an intermediate stage of the latter), with a result that it is almost impossible to maintain uniform conditions.

Another difficulty to be met with in down-draft units is the formation of lamp-black, especially around the grates. With some fuels it has been found necessary to admit a small quantity of secondary air at this point in order to produce sufficient combustion to gasify this lampblack. A large portion of the lampblack is, however, used in the multi-unit type of down-draft producer by re-carburation of the gas as well as the preventing of fixing and clogging on account of its physical action.

93

In a multi-unit down-draft producer the rate of flow, or rather the relative rate of flow, per unit of fuel, is somewhat reduced; hence to some extent a corresponding reduction or wire drawing of the gases through the fuel bed with attendant central coking or ashification follows.

It is with an intention to prevent this core burning that producers of the Smith type introduce a central tuyere admitting the air at the center of the fuel bed. These tuyeres, however, are more or less expensive and difficult to maintain by reason of their water cooling, also the central admission of the air reduces the time contact of its passage through the fuel, and there is not sufficient firing surface in which to bake all of the hydrocarbons. These are merely the disadvantages of an otherwise very satisfactory arrangement, and noted merely by way of general consideration.

By reason of the ash-forming conditions herein discussed, 5 to 6% of ash may be considered as a limit of content in fuel used in down-draft apparatus, and a very much smaller content should be required as a limitation, where such ash is strongly inclined to fuse or where it fuses at a relatively low temperature. The maximum volatile content permissible is usually between 20 and 30%, some manufacturers limiting it to a maximum of 15%.

THE WOOD SYSTEM

It is the intention in this work, in describing specific gas producers, to select those which are distinctive, as representing certain types and not in any way to prejudice opinion in favor of any particular make or manufacture of apparatus.

The Taylor Producer, more commonly known to the gas industry by the name of the "Wood Producer," by reason of its being manufactured by R. D. Wood & Co. of Philadelphia, is an excellent example of the simple type of pressure and suction producer, and has been especially successful in operation upon anthracite fuel, although they also manufacture producers to be used with coke, lignite, and bituminous coal.

The distinctive feature of this producer is a rotative ash table or grate, which by its rotation tends to stir the fire, or primarily to close by the tort given to the fire, or fuel bed, any air chimney or lines of cleavage which may have occurred throughout the fuel bed.

This type of producer is exceedingly simple and easily operated. It is run with a comparatively shallow fuel bed, and the results obtained are best described in the experiments performed by the Fuel Testing Section of the United States Geological Survey in St. Louis and published by the latter.

Directions for starting the R. D. Wood pressure producers are as follows: " In starting the producer a good quality of ash, with little unburned material, should be used in filling up the bosh of the producer. The ash should be brought up to a point about 6 inches above the blast hood, and should at no time approach nearer. Neglect of this precaution may cause the loss of the blast hood. At the start small pieces of clinker or broken material may be placed about the hood to keep the material from packing too tightly and obstructing the blast. On this bed a fire is built and a light blast supplied and coal added until the requisite bed of incan-

descent fuel is attained. The depth of the incandescent bed will depend on the kind and size, etc., of fuel, as elsewhere indicated. With soft coals it will range from 2 feet to 3 feet and with anthracites somewhat less; with large coke or anthracite
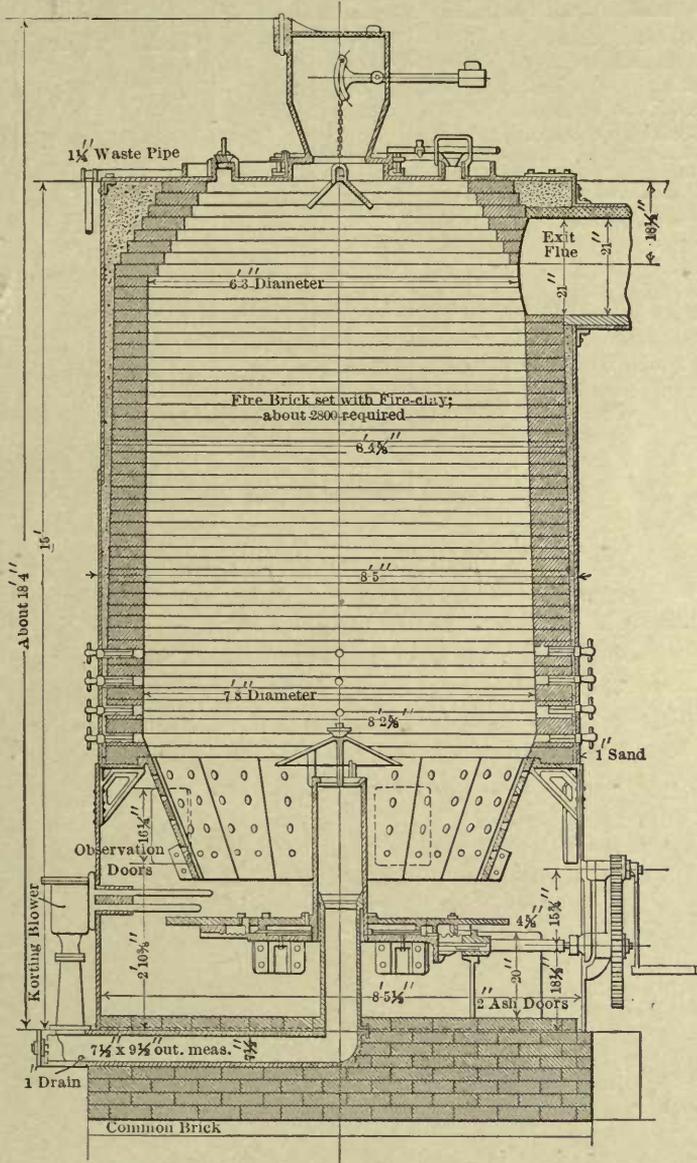
FIG. 65.—Taylor No. 7 Producer with Revolving Bottom.

perhaps 4 feet or more. It is often better to keep the fire-bed approximately near one level by occasional removal of ashes rather than to allow the fuel bed to build to a great height and then remove large quantities. This latter will seriously injure the quality of the gas and perhaps cause runs of the coal and its loss in the ashes."

AVERAGE OF NUMEROUS COAL TESTS IN R. D. WOOD PRESSURE PLANT

Composition of Fuel.	Bituminous Coal.			Lignites.			Peat No. 1.
	Average.	Max.	Min.	Average.	Max.	Min.	
Moisture	6.83	16.69	1.43	26.6	39.56	8.51	21
Volatile combustible	33.06	42.46	9.70	31.4	38.41	25.54	51.72
Fixed carbon	49.8	73.7	31.19	32.6	45.69	23.80	22.11
Ash	10.32	23.44	2.77	9.53	15.47	2.74	5.17
Sulphur	2.41	7.36	.28	1.29	4.88	.47	4.45
Composition of Gas by Volume.							
Carbon dioxide, CO_2	9.84	.....	.....	10.55	.....	.....	12.40
Oxygen, O_2	.04	.....	.....	0.16	.....	.....	.0
Ethylene, C_2H_4	.18	.....	.....	.17	.....	.....	.4
Carbon monoxide, CO	18.28	.....	.....	18.72	.....	.....	21.0
Hydrogen, H_2	12.90	23.89	11.93	13.74	25.20	13.90	18.5
Methane, CH_4	3.12	18.60	2.81	3.44	19.30	9.20	2.20
Nitrogen, N_2	55.60	.....	.....	53.22	.....	.....	45.5
B.T.U. per cubic foot	152.1	176	126.6	158.4	188.5	125.5	175
B.T.U. per lb. of coal as fired	12280	14674	8735	8350	10685	6970	8127

THE TAIT SYSTEM

This apparatus is for the manufacture of producer gas without the use of steam or water vapor. In the operation of gas engines utilizing producer gas as a fuel, considerable trouble has been experienced from variation in the gas and especially from pre-ignitions in the engine, and it was with a view to obviate these troubles that a process has recently been put upon the market for generating a gas from anthracite or bituminous fuel in the usual form of producer, but containing no hydrogen except that supplied in the fuel employed.

The producer gas usually manufactured from anthracite fuel will be found by volumetric analysis to be about as follows:

<div style="text-align:center">Volume per cent.</div>

CO_2	4.6
O_2	0.5
CO	23.8
H_2	15.5
CH_4	1.1
N	54.5

A gas of this analysis will be found to have about 139 B.T.U.'s per cu. ft., and is considered a very good producer gas.

However, in practice, where a gas is used for engine purposes, it is a well-known fact that, due to the changes in load on the engine, the analysis does not remain as above, on account of incident changes in the temperature of the fire, which determine the quantity of draft passing up through the fuel bed on various engine loads.

As the amount of draft passing up through the fuel bed determines the temperature of same, it follows that the amount of steam disassociated in the hot zone of the fire will vary with the load on the engine. In other words, only about 10% of the steam fed to a producer will dissociate at 1300° F. (this being approximately the temperature in the fuel bed when the engine is running light), while on the other hand when the producer is running at its full rated capacity the temperature in the hot zone of the fire will rise to 2000°, at which point practically complete dissociation of the steam occurs.

The effect of this variation in the steam dissociation is shown in the amount of hydrogen contained in the resultant gas; for example, analyses taken at low load will show from 5 to 8% hydrogen, while other analyses taken at full load will show 18% hydrogen, or even higher.

Now, the effect of this variable quantity in the active part of the gas necessarily affects the regulation of the engine, and this is especially true when it is remembered that the rate of combustion in a gas engine cylinder of carbon monoxide and hydrogen is about as two to one, the hydrogen being the quicker burning of the two and the element for which the ignition on the engine has been set. The effect on a gas engine operating on producer gas under these varying conditions is naturally, therefore, subject to irregularities for the following reason:

We will suppose that a plant rated at 100 h.p. is being fed with a gas made under the usual process of a steam-blasted producer. The gas fed to the engine will, due to the variation of temperature at different loads, change from 125 B.T.U. to 145, or thereabouts, and while this variation in heat units is, of course, a disadvantage, the throttle on the engine could well take care of same, provided that the *proportion of the constituents* forming the gas do not also change.

Unfortunately, while at full load the engine is operating on a gas, the active part of which consists of about 30% hydrogen (and the ignition of the engine being set so as to coincide with this hydrogen and being too late to derive the full benefit from the carbon monoxide), it will be found that when the engine is running light that the drop in temperature will affect the amount of hydrogen to such an extent as to practically reduce the same to a negligible quantity. Now, under these conditions it will be noted that the ignition of the engine is wrong, being altogether too late for the carbon monoxide which at that time forms the most important part of the gas.

To overcome this well-known defect some engine builders provide for an ignition system, the timing of which is controlled by the speed of the governor, but even this method, although tending to help matters under some conditions, falls far short of being a complete remedy.

The natural way to overcome this defect would be to make changes in the producer, not the engine, which would supply a gas having a uniform composition under all loads, or at least, if this is impossible, supplying a gas which contains only one active constituent, so as not to affect the timing on the engine under any conditions. If this is done, it will be seen that the throttle on the engine will take care of the variations in *quality* of the gas, that is to say, if at low load the gas is merely weaker, but containing the same constituents as at full load, it can readily be seen that the throttle valve of the engine will run wider open under these conditions with no result-

ant bad effect on the regulation. Such a gas can be readily generated by supplying any form of gas producer with a draft consisting of air alone, and this has often been tried.

Although this method of gas generation will supply a gas answering the requirements, another difficulty is experienced due to the fact that the fire in the producer, when fed with pure air, will soon reach such a high degree of temperature as to melt the fusible ash in the fuel, thereby forming excessive clinkers, which stick to the lining, clog up the grates and generally cause shut-downs.

Advantages of the Tait Producer.—This problem has, however, been overcome by the Combustion Utilities Company of New York, who have patented a process for supplying the air draft to a producer diluted with a certain amount of CO_2, this CO_2 being obtained from any available source, such as for example the exhaust of the engine. By admitting a fixed proportion of CO_2 under the fuel bed in the producer, the percentage of free oxygen in the draft supplied to the producer is cut down to the point where excessive temperatures in the producer are entirely prevented, while at the same time sufficient temperature is obtained to cause a conversion of the CO_2 formed in the lower layers of the fire to CO in the upper layers, and to supply a resultant gas having approximately the following analysis:

	Volume per cent.
CO_2	1.8
O_2	0.2
CO	26.2
H_2	0.4
CH_4	1.7
N	69.7

This gas, while of a very much lower total heating value than the gas formed under the usual method of producer operation, is found to generate just as much power in a gas engine with cylinders of a given size as the usual type of producer gas, while on the other hand absolute freedom from pre-ignitions is experienced, due to the absence of hydrogen, and from reasons explained above, such variations as occur in the amount of CO in the gas (and these variations are found to be very slight between no load and full load), are not such as to affect the regulation of the engine to even a small extent.

Furthermore, complete control of the temperature of the fuel bed is maintained by operating the valve supplying the CO_2 to the ash pit. In the illustration herewith is shown an elevation and partial section of a plant arranged under this process, and, as will be seen, the exhaust pipe 22 by-passes parts of the exhaust back to the producer through valve 7, from whence it goes to the ash pit. At the same time the air supply enters with it through the pipe and valve 6 in a predetermined proportion.

When operating suction producers under this process, it is usual to employ a mechanically operated exhauster (14), as shown in the illustration, the effect of same being to suck the gas from the producer and pass same into the engine at an absolutely constant pressure of about two inches water. This arrangement is particularly

1 GAS GENERATOR
2 COAL HOPPER
3 AUTOMATIC CASTIGHT HOPPER VALVE
4 POKE HOLES
5 GAS OUTLET PIPE
6 AIR INLET PIPE & VALVE
7 EXHAUST INLET PIPE & VALVE
8 THREE WAY AUTOMATIC GAS VALVE
9=9 SAFETY RELEASE WATER SEALS
10 PURGE PIPE
11 SCRUBBER
12 DRYER = PURIFIER

13 GAS OUTLET PIPE
14 AUTOMATIC EXHAUSTER & GAS REGULATOR
15 BY PASS CONNECTION TO PURGE PIPE 10
16 VALVE
17 TESTING BURNER
18 MAIN GAS PIPE TO ENGINE
19 WATER TRAP
20 AIR INLET PIPES TO ENGINE
21 GAS INLET PIPES TO ENGINE
22 EXHAUST MAIN
23 IRON WORKING PLATFORM

Fig. 66.—Diagram showing Arrangement of the Tait Producer System.

advantageous when it is desired to operate two or more engines from a suction producer, as the gas supplied to the engine is always under the uniform pressure and a test burner, as shown by the illustration, can be watched by the operator to see that his gas is of uniform character.

The apparatus (14) consists of a positive-type exhauster operated by motor or other suitable means, and which draws the gas from the producer as indicated by the arrow points, and discharges the same toward the engines and at a predetermined and absolutely fixed pressure.

This pressure regulation is very simply obtained, by the fact that the outlet of the exhauster communicates through several pipes, to a seal of water contained in the base of the apparatus, this seal of water being set to the desired point to give best results at the engines. Any excess gas over and above this pressure naturally bubbles up through this water seal, returning to the inlet side of the exhauster. This apparatus in a very simple manner takes the place of the usual gas holder and enables engines to be operated in parallel from the same suction producer.
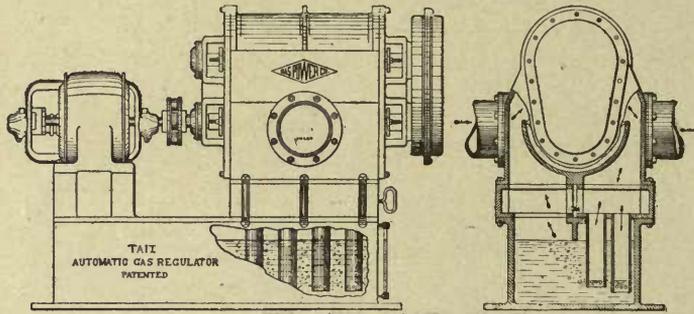
FIG. 67.—Automatic Regulation Exhauster.   (No. 14 in Diagram of System.)

This apparatus was found to greatly assist in steadying up the conditions upon which the plant operated and was absolutely necessary to close regulation when it was desired to operate more than one engine from a single suction producer.

It was found when using this process (in which the resultant gas contains no hydrogen), that very much higher compression pressures could be handled with safety in the engines employed, and it is usual to operate engines using this system at a compression pressure of 200 lbs. This, of course, greatly increases the efficiency of the engine, while, at the same time, it is usually found that the horsepower will run up about 10% beyond the point obtainable when running the same engine on regular producer gas containing hydrogen.

Numerous tests have been run with this process and have proven the superiority of this type of gas for engine work over the usual form of gas containing hydrogen, not only in point of economy, but more especially in regard to the reliability of operation, the same being on a plane with a steam-engine installation of the same size.

One of the features incidental to this process, which proves attractive to many using steam-blasted producers of the suction type, is the ability to operate the producer continuously without stopping the engine when the fires are cleaned, the reason for this being that opening the ash-pit doors for cleaning the producer has no effect

on the quality of the gas, as it does under the steam-operated conditions, for the reason that only air and exhaust gases are passing up through the fuel bed, and the steam which goes up under ordinary conditions, and which is cut off by absence of suction when the ash-pit doors are open, is eliminated at all times, and conditions are therefore the same running with the ash-pit doors open or closed, with the exception that to operate for any long period with the ash-pit doors open would cause an overheating of the fuel bed, due to too much oxygen reaching the fire.
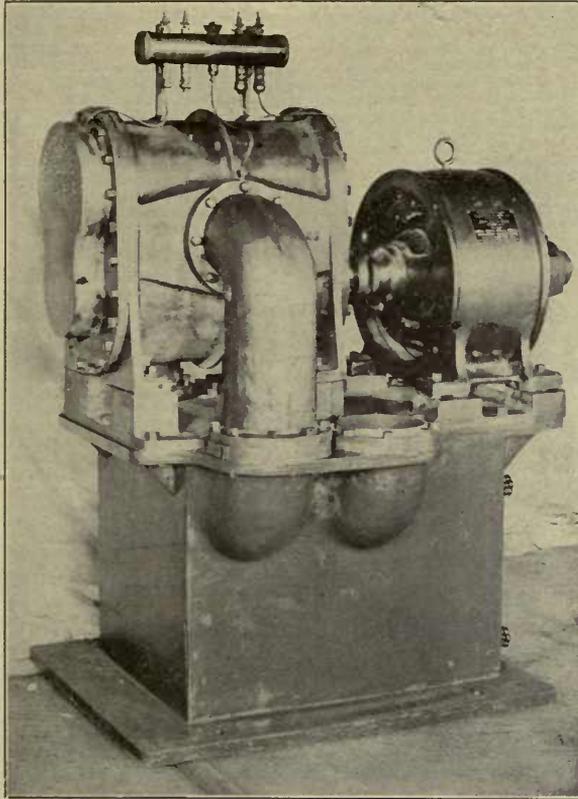
Fig. 68.—View of Previous Illustration.

Regarding the operation of a producer plant operating under this system, the services of one fireman for each 300 h.p. in small units, or for each 500 h.p. in large units will be sufficient, provided that means are at hand for delivering the coal upon the working platform, which, in the case of a producer is, as shown in the illustration, at the top of the apparatus in the form of a hopper.

The cleaning of the fire requires slightly less work on the part of the operator than the cleaning of the fires under a steam boiler of the same capacity, while on the other hand the stoking with fresh coal and the poking down of the fuel bed are about the same as that required on a steam-operated plant. It should be borne in

mind, however, that a somewhat higher degree of intelligence is required from a producer fireman than from a boiler fireman, as in the one case all he has to do is to watch his steam gauge to tell what results he is getting, and on the other hand he has to know by the color of the flame issuing from his sample burner whether the gas is satisfactory, and what to do to make it so, whether to put on fresh coal, or poke down the fire. Any man of ordinary intelligence, however, can master the running of the producer in from one to two weeks of actual experience, at the end of which time he should experience no trouble whatever.

Regarding the efficiency of a producer operating under this arrangement, this has been found to be 80%, provided that the down-take pipe from the producer is surrounded by a pre-heater jacket, for the purpose of returning to the fuel bed some of the sensible heat lost in the gas. While this efficiency is practically the same as that of a producer operated on the blast containing steam, on the other hand, the efficiency of the gas produced, when burned in a gas engine, increases the economy of same, so that an efficiency of 26% is readily obtained in the ordinary three-cylinder
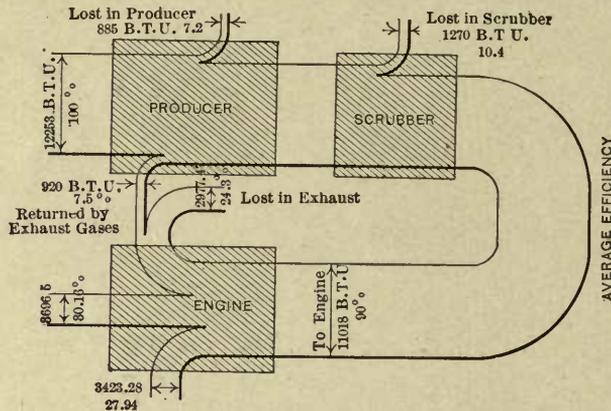
Fig. 69.—Diagram of Heat Distribution with Tait Process.

vertical type of gas engine, where the valve chambers are separated from the main cylinders, while in engines in which the valves open directly into the cylinder still higher economies can be shown.

In other words, the total efficiency of the plant reckoned from the heat supplied in the form of coal to the power actually developed by the engine will be found to be slightly over 19%. This figure being obtained in direct comparison with the same producer operating with the usual steam blast and with the same engine, in which case only developing a total efficiency for the plant of 13%, or, to carry the comparison still farther, as compared with a non-condensing steam plant of 100 h.p. (this being the size of the plant on which the gas tests were run), it will be found that the best results obtainable show less than 6% efficiency of the whole steam plant.

Regarding the floor space, etc., for a producer plant of this character, this will be found to be the same as standard producer practice, and is based upon allowing for a gasification with a maximum of 15 lbs. anthracite coal per square foot of internal diameter per hour in the case of suction producers, and 8 lbs. per sq.ft. per internal

diameter in case of pressure producers. As this is substantially the practice where producers are operated with steam blast, the point of its capacity rating and available space does not enter into the argument.

The plant shown in the accompanying illustration has a capacity of 175 h.p., and is installed in a room 50 × 20 ft. with an overhead room of 20 ft. This room contains, in addition to the entire producer plant, two engine units of 125 and 50 h.p. respectively, as well as auxiliary machinery for blasting the producer, air compressor for starting engine, electric generators, switchboards, etc., and compares very well with the necessary room required for a steam installation of the same capacity.

When operating with bituminous fuel, there is additional apparatus consisting of a rotary tar separator which would be driven from the same motor which drives the exhauster; the additional space for this apparatus would not affect the layout sufficiently to increase the over-all dimensions of the plant.
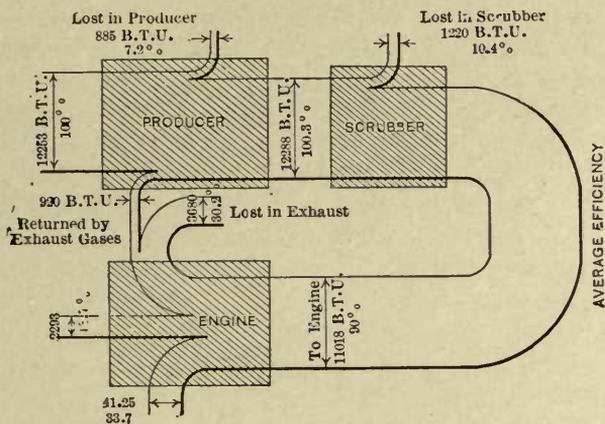
Fig. 70.—Another Example of Heat Distribution.

A heat balance of such a plant will be found to be about as follows, assuming a coal of 12,253 B.T.U. per cu.ft., and an average load on the plant of 102 h.p., for a duration of the test of 24 hours:

	B.T.U.
Total heat of combustion per pound of coal, by calorimeter....	12,253
Coal consumed per hour, lbs.	106.52
B.T.U. supplied to plant per hour.	1,305,214
Heat lost in scrubber water per hour.	145,124
Heat lost in water jackets of engine per hour.	342,719
Water jacket manifold around exhaust pipe per hour.	63,966
Heat converted into work.	267,225
Heat lost in exhaust gases, after deducting the amount returned under the producer per hour.	354,802
Estimated loss per hour from radiation from producer, etc.	131,378
Total	1,305,214

As will be noted in the foregoing table, the losses in the plant are largely occasioned by heat given off in the jacket water of the engine and the temperature of exhaust gases. This entire amount can be utilized towards heating the premises, as is done in some installations, in which case the total efficiency of the plant is raised to a corresponding degree.

Operation of the Tait Producer.—The temperature of a gas leaving the producer under the Tait System, is about 800° F. The temperature of the air and exhaust gases entering under fuel bed will approximate or average 500° F. The latter temperature will, of course, vary largely with the equipment and general conditions, especially the distance of the exhaust muffler from the inlet of the producer. Usually the exhaust gases from the engine will leave the manifold of the engine at about 845° F., this being slightly lower than the temperature found in operating under engines under the standard or steam producer gas system.

The amount of CO_2 appearing in the primary air of the producer and reflecting the acidulation of this air by the use of flue or exhaust gas, will vary from one-half to four and a half per cent, the minimum and maximum extremes reflecting the ratio between the load-factor and total capacity of the producer, a higher rate of gasification per square foot of grate surface in the producer, requiring a larger amount of the endothermic agent.

As a check upon the gas when the plant is in operation, the writer taps the line somewhere between the purifier and the engine, testing same for CO and CO_2 only, for practical purposes; it is only necessary to test for CO_2 once the plant has been put in satisfactory operation, for if the Orsat shows not over 2% CO_2 in the finished gas, everything else can be assumed to be correct, for the reason that any drop in temperature in the producer below the dissociated point in CO_2 would show a high volume of CO_2 in gas fed the engine; whereas, if the fire goes to the other extreme and becomes too hot, CO_2 in disproportionate amount will again show in the analysis, indicating blow-holes in the fire, etc.

Which of these two conditions cause the CO_2 in the gas can be readily noted by observing whether the producer appears hot or cold on the outside. If it appears quite hot and the CO_2 in the analysis shows too high, the fire is getting into a burned-out condition and requires poking down and fresh coal; if, on the other hand, the outside of producer is almost cold and the CO_2 in the gas is abnormally high, it shows that the temperature of the fire has fallen below the right point, and all that is necessary to do in this case is to close off the exhaust where it enters the ash pit, so that the fire may feed on fresh air alone; this will bring up the temperature of the fuel bed rapidly until the same has reached the right point. Analysis of the gas during this time will show a drop off of CO_2 until it gets down to about 2%, where it belonged.

The usual method of keeping track of the operation of the producer is to watch the flame issuing from the testing burner. When the gas is weak from any cause whatever, or in other words, when it is high in CO_2, the flame will assume a yellowish color, and will have a tendency to blow out, while, on the other hand, when everything is running as it should, the flame will burn steadily with a strong blue color. Any man who has operated one of these producers for a week or ten days can easily learn from practice what to do by watching this flame. As to the variation of qual-

ity of gas fed to the engine, this will not be found to vary over 5% while the engine is in operation, and the variation, as it is only in *quantity* of CO and not in *quality* (as in the case of regular producer gas containing two active constituents and where the proportion of constituents to each other varies, due to the variation of load), will not affect the operation of the engine, as the throttle governor will take care of any variations, that is to say, the throttle will run further open when the gas is "weak" and close up more when it becomes rich again.

Other things being equal and the coal of a fairly good grade and not inclined too much to clinkering, it is well to run the producer at a high temperature, so that the dissociation zone, which is the bottom 12 ins. of the fire, shall be about 2000° F.

As regards the admission of air to the producer, there is no necessity of regulating this, it only being necessary to regulate the amount of exhaust, as the one will affect the other inversely; it being understood that the more exhaust passed through the producer the lower the temperature of the fire in the producer and *vice versa*, this being entirely under the control of the operator, and being an advantage not obtained with other systems.

Starting Up.—To start plant, build fire in producer (1) of wood or charcoal, leaving purge pipe open, so as to cause a natural draft. When the kindling is thoroughly ignited, dump in sufficient coal through hopper (2) to gradually build up a bed of fuel, continually increasing the depth of fuel until same has reached the bottom of the magazine.

The fire is now in condition to be left over night with purge pipe open and one of the ash-pit doors open about one inch, which will allow sufficient draft to circulate through the producer to ignite the whole mass of coal during the night.

In the morning see that there are at least two inches of water in the seal by-pass pot (9), as shown by water column on side of same. Open the vent pipe (8) on top of this pot, then open by-pass valve (16); start up exhauster (14). The attendant should then close the purge-pipe valve on pipe at producer and also open valve in pipe leading from producer to scrubber.

As soon as this is done the exhauster (14) will produce a sucking action of the bed of the producer, discharging the gas, etc., up through the vent pipe (15).

A few minutes after starting the blower try the gas at the burner (17), and if it burns with a steady blue flame the engine may be started.

In starting the engine it is well to see that the vent-pipe valve (8) is wide open, likewise the by-pass valve (16) around at the blower. After the engine has been started the vent-pipe valve (8) should be closed and the by-pass valve (16) regulated so as to produce a pressure on water gauge of about two inches. The water gauge should show a suction of about three inches or less when the plant is running under full load.

When a marked decrease of load is put on the engine the valve (16) may be further closed, so as to keep up the pressure as shown at gauge.

When shutting down the plant all that is necessary is to cut off the gas where it enters the engine valve (21), and to open the vent-pipe valve (16), so that the gas handled by the blower may escape through pipe (15).

This is the procedure for shut-downs of a few minutes, but should it be desirable to stop the plant for several hours, such as over night, proceed as above, and then

stop blower, close valve between producer and scrubber, and open valve at the bottom of purge pipe; then the air inlet of the producer may be partially closed, so as to just admit sufficient air to keep the fuel in good condition over night.

Troubles.—Explosions in the muffler boxes and exhaust pipe are usually occasioned by MIS-FIRING of the engine, and this "mis-firing" is almost invariably caused by ignition trouble, the igniters in one cylinder failing to work and the gas igniting in the exhaust pipe of muffle by the next charge when it leaves the engine. There is no particular damage caused by this trouble beyond the loss of power which it entails, and the knowledge from the noise of the exhaust.

The remedy is to locate the igniter which is giving the trouble and to stop the engine and change the igniter. For this purpose it is always necessary to have a duplicate set of igniters handy for changing. It is well to mention here that engineers should always on taking igniters out of their engines clean and test same immediately before doing anything else, so that when they are again called upon for an igniter they can always have a supply ready and in condition to operate. Much trouble is occasioned by engineers taking out old igniters and laying them aside and forgetting to clean them, with the result that when another igniter is needed suddenly there is none available.

Back Firing.—Another trouble which may be encountered is back firing. This is usually distinguished by flame coming out through the inlet-air pipe (20), or in cases where this inlet pipe comes from the outside of the building and cannot be seen, it will be noted that the back firing by producing a back pressure on gas main (18) will splash the water in the water seals around the apparatus as it fires back towards the producer. Back firing is usually occasioned by an improper mixture at the engine or by a sudden weakening of the gas, and should never occur if the producer operator has his fire in good condition; for, long before the engine gives trouble, *the pilot flame (17) which should be kept burning all the time will get very low or blow out altogether on account of weak gas.*

The remedy for this trouble is to poke down the fire, as a blow hole through the fuel bed is probably the cause of the trouble. A small amount of coal should also be added to help matters and the trouble should not last more than two or three minutes with proper handling. Changing the mixture of air and gas at valves will also help temporarily. If back firing occurs when the gas is burning steadily with a good flame at testing burner (17), it will usually be found that one of the inlet valves on the engine is either "pitted," or does not close properly, due to the foreign matter on the valve seat. This can be taken care of when the engine is shut down after the day's run, it being unnecessary to shut down on this account, providing that the engine will run.

Pre-ignitions.—This trouble consists of explosions inside the cylinders of an engine when both the inlet and exhaust valves are closed, but occurring too early in the working cycle, with the result that an impulse is given to the combustion in the reverse way to that in which the engine is operated.

Pre-ignitions are almost invariably due to particles of carbon or other foreign matter in the cylinder becoming heated redhot, and thereby igniting the charge prematurely. They may also occur from the timer on the engine being shifted to too early a period. This is easily remedied by shifting the timer back again. In the case of prematures, which are traced to foreign substances in the cylinder, the only remedy is to shut down and clean out the affected cylinder.

The engine attendant should always watch his exhaust gases where they emerge from the building to see that they are perfectly clean, any smoke in the exhaust gas indicating a too lavish expenditure of cylinder oil, or an improper mixture of the fuel, air, and gas, either of which will be apt to cause a deposit of carbon in the gas engine cylinders and to result in the pre-ignitions already referred to.

When shutting down an engine used for power purposes the gas valve should always be shut off before cutting off the ignition circuit, thereby insuring the fact that there is no live gas left in the engine cylinders. The reason for this precaution is to obviate danger to attendants, who, when turning the engine over to its center when getting ready to start again might encounter a "kick" from an unexploded charge in one of the cylinders with disastrous results. By leaving the igniters on until the engine actually stops, every particle of combustible gas in the cylinders is exploded, and it is therefore harmless.

In operating the producer (1), it is always well to remember that a deep bed of fuel insures steady operating conditions, and further, that systematic poking every hour and a half or thereabouts, according to the amount of load on the plant, will keep the fuel bed properly packed down, prevent clinkers adhering to the lining of the producers and also obviate the risk of blow-holes burning up through the fire.

The Combustion Utilities Company's process comprises a method of controlling the temperature of the fire by the admission of exhaust gases under the fuel bed, and while the valves (7) and (6) on each plant are set by the erecting engineer at their approximate running positions before the plant is turned over to the cutomers, the operator has always under his control these valves by which he can cool down his fire when it becomes too hot, due to overload; or, on the other hand, if when starting up he wishes to heat his fire up quickly he can do so by keeping valve (7) tightly closed, and valve (6) wide open, thereby admitting pure air to the producer until such time as the fuel bed attains the desired temperature.

The operator should at all times see that the water gauges on the various parts of the apparatus are in working order, and that there is no great discrepancy between the reading of any two adjacent gauges, as such discrepancy would be due to a clogging of the apparatus with foreign substances, such as dirt or ashes, which would interfere with the running of the plant if not removed.

As long as the gas issuing from the testing burner (17) burns with a steady blue flame, the engine should run with complete saitsfaction, and any troubles encountered under these conditions are surely traceable to the engine, and should be looked for in that quarter. If, however, the flame flickers and goes out there is trouble in the producer which should be attended to immediately to avoid having trouble with the engine.

AVERAGE COMPOSITION OF ORDINARY PRODUCER GAS

	Per Cent.
Carbonic acid, CO_2	5.8
Oxygen, O_2	1.3
Carbonic oxide, CO	19.8
Hydrogen, H_2	15.1
Marsh gas, CH_4	1.3
Nitrogen, N.	56.7
B.T.U. gross per cu.ft.	136

AVERAGE COMPOSITION OF TAIT PRODUCER GAS

Main Gas Supply to Engine: Per Cent.

Carbonic acid, CO_2 .... 2.2

Oxygen, O_2 .... 1.3

Carbonic oxide, CO 25.6

B.T.U. gross per cu.ft. 103.7

Mixture of Air and Engine Exhaust Gases Entering Producer:

Carbonic acid, CO_2 .... 3.3

Oxygen, O_2 .... 18.9

Carbonic oxide, CO 0.1

Complete Analysis:

Carbonic acid, CO_2 .... 1.8

Oxygen, O_2 .... 1.2

Carbonic oxide, CO 26.2

Hydrogen, H_2 .... 0.4

Marsh gas, CH_4 .... 0.7

Nitrogen, N. 69.7

Total 100.0

GAS ANALYSIS MADE DURING TEST OF TAIT PRODUCER SYSTEM

(No Steam Used.)

B.T.U. by Calorimeter.	Time.	CO_2.	O_2.	CO.	H_2.	CH_4.	N.
110	12 Noon	2.0	1.3	26.9	0.3	0.5	69.0
105	1.45 P.M.	2.0	1.2	25.0	0.2	0.6	71.0
109	3.30 P.M.	1.75	1.2	25.85	0.4	0.8	70.0
110	5.45 P.M.	1.70	1.1	26.3	0.8	1.0	69.1
101	3.45 A.M.	1.70	1.2	25.9	0.6	0.6	70.0
105	6.30 A.M.	1.75	1.3	26.95	0.2	0.5	69.3

LOOMIS-PETTIBONE SYSTEM

Process.—The method of operating the Loomis-Pettibone gas-generating apparatus is readily understood by following the course of the air and gas currents shown by the accompanying cuts. Air is drawn down through the incandescent fuel beds in the generators by the positive exhauster and the usual chemical action takes place, the oxygen in the air combining with the carbon in the fuel to form CO_2. As this gas passes further down through the fuel bed it combines with more carbon, viz.: $CO_2 + C = 2CO$. Any water in the fuel is decomposed by the incandescent carbon liberating the hydrogen, and the oxygen combining with the carbon forms CO_2, and
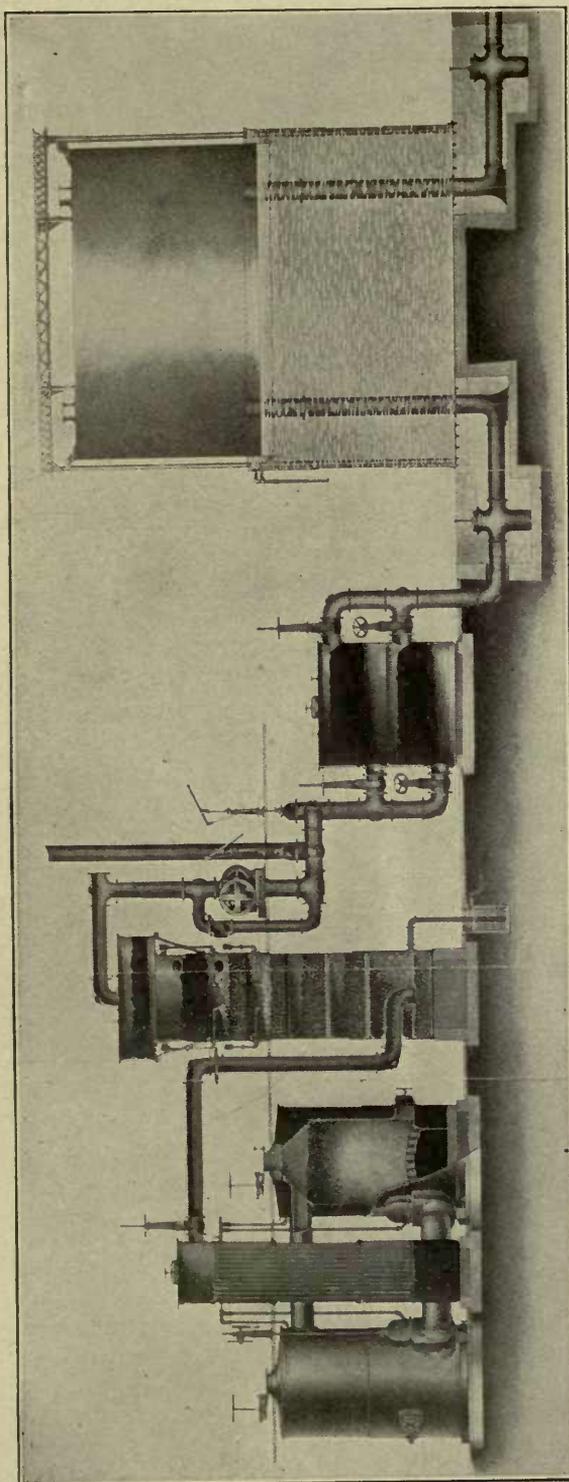
FIG. 71.—Twin Producer Plant, Loomis-Pettibone System.
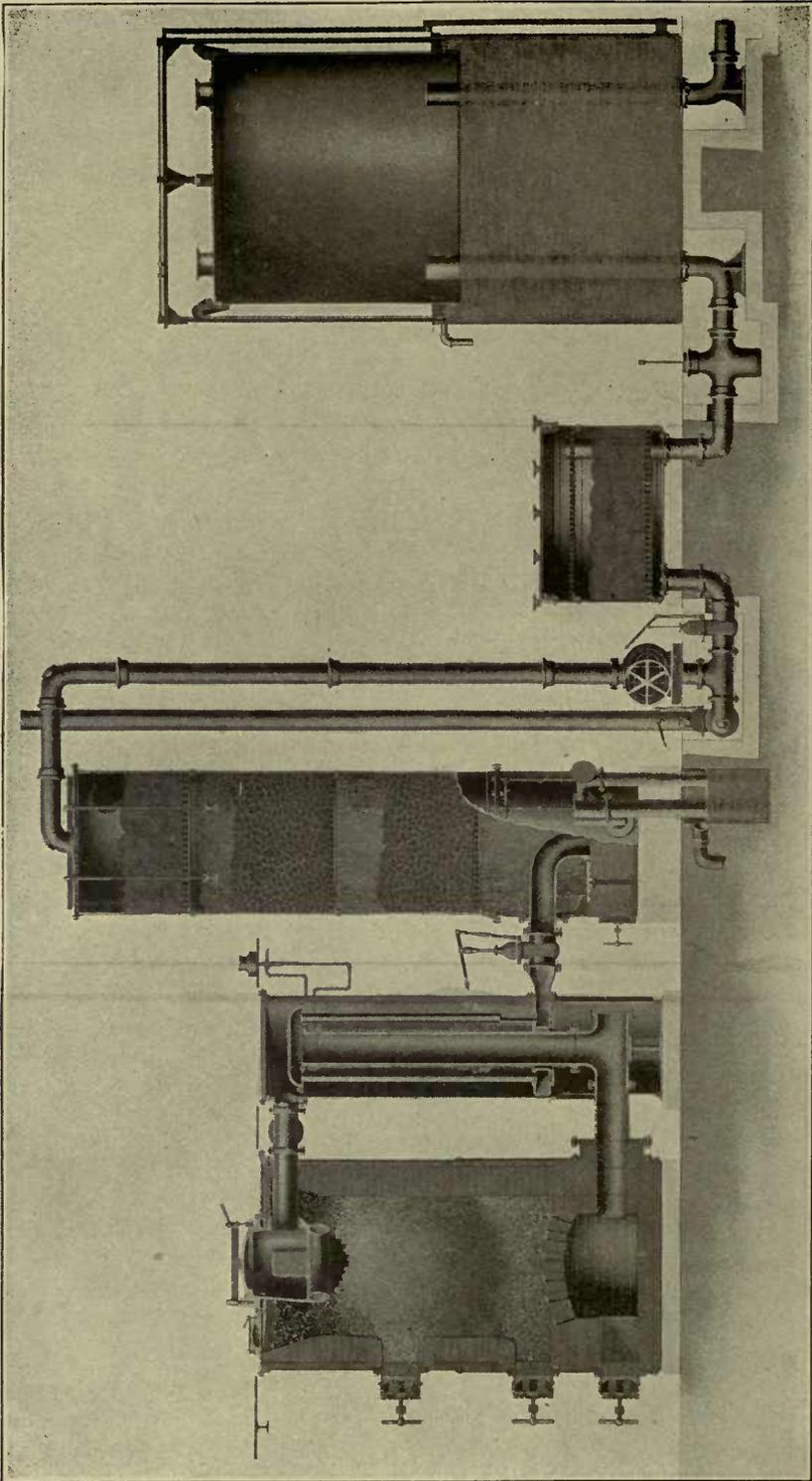
FIG. 72.—Loomis-Pettibone Gas-Producer System.

CO. The other constituents of the gas are derived from the volatile portions of the fuel. The resulting producer or blast gas passes from the bottoms of the generators through the connecting pipes and into the waste-heat boiler. In passing up through the tubes of this boiler a large percentage of the sensible heat is absorbed by the water forming steam. The gas then passes from the boiler to the bottom of the wet scrubber where it comes in contact with the water by passing under a diaphragm plate. In ascending through the scrubber it is divided by the scrubbing material and meeting counter streams of water, is cooled, and at the same time the greater portion of the impurities are removed. Thence it passes through the exhauster to the dry scrubber where the remaining dust, etc., is removed. It then passes on to the mixed-gas holder. At intervals runs of water gas made by turning steam into the bottom of one generator. The steam in passing through the incandescent fuel bed is decomposed, the hydrogen being liberated and the oxygen combining with the carbon to form CO_2, CO, etc. This gas passes from the first generator across to the second, down through it and then takes the same course as the producer gas through the rest of the apparatus. The steam is only applied for about a minute when the manufacture of producer gas is resumed. The water gas in passing up through the first fire carries with it some of the volatiles of the fuel which, in passing down through the second generator, are converted into fixed gases and the second fuel bed also serves to decompose any steam which may have passed intact through the first fire. Coal is fed into the generators through the charging doors provided in the crowns of the machines and the tops of the fires being plainly visible can be deposited to the best advantage.

Apparatus.—The apparatus consists of two cylindrical shells lined with fire-brick and having fire-brick grates. Charging doors with sliding covers are attached to the top plates of the generators and suitable brick-lined cleaning doors are bolted to the sides of the generator to give access when cleaning above and below the grates. A brick-lined pipe joins the generators, being located near the top of the shells. Brick-lined pipes connect the ash pits of the generator with the lower gas chamber of the waste-heat boiler. Steam connections are provided for introducing steam into the top or bottom of the generators. The boiler is of the vertical cylindrical multitubular fire tube, and the lower gas chamber is brick-lined. Manholes both in the upper and lower gas chambers provide openings for inspection and cleaning. Water-cooled valves are placed in the connections between the generators and boiler. A valve is located at the gas outlet on the boiler and cast-iron pipe connects the boiler with the scrubber. The scrubber is a cylindrical steel shell in the lower portion of which is placed a diaphragm plate just above the water level. This forces the gas to come in contact with the water in the bottom of the scrubber. Suitable overflows for waste water are provided. The interior of the shell is divided into sections by trays supporting the scrubbing material. The upper portion of the scrubber is enlarged to contain excelsior or other suitable material. The water is introduced below the second tray from the top and the one directly below it. The gas main then connects the top of the scrubber with the exhauster which is of the positive type and is either driven by a motor, steam engine, or other motive power. A by-pass is arranged around the exhauster to provide means of releasing the vacuum on the apparatus while making a water gas run, and beyond the exhauster are the controlling valves for directing

the gas either into purge stack of holder.   The purge stack is only used when blasting up the fires after a stand-by in order to obtain the proper temperature in the fuel beds. From the exhauster the gas passes through the dry scrubber, which is a cylindrical steel shell arranged with trays for supporting the scrubbing material.   Suitable man-holes for cleaning and charging are provided.   The gas then passes into the holder which is of the usual type.

Operation.—The operation of the apparatus can be readily followed by referring to the accompanying illustration.

Fuel is charged into the two generators to a depth of about five feet and after the exhauster has been started is kindled from above through the doors.   When it is seen that the fires have been thoroughly kindled a small quantity of steam is admitted, and mingling with the air which enters through the top doors, and is drawn down through the incandescent fuel beds by the action of the exhauster.   The producer gas thus generated passes down through the grates of the generators, both valves being open, up through the boiler valve and on to the scrubber and exhauster.   When the gas burns at the test flame by the exhauster, and valves direct the gas through the dry scrubber into the holder, the operator charges coal through the open charging doors as it is needed and he also regulates the quantity of gas made to meet the demands by altering the speed of the exhauster.   The fires are kept in a uniform condition by making runs of water gas, which is accomplished by closing the charging doors, and introducing steam.   This process is alternated by using the valves above and the steam inlets below.

If more water gas is required for metallurgical work the plant is arranged with a separate water-gas outlet, so that it can be divided from the producer gas and stored in its own holder.   The intervals between cleaning of the fires is governed by several factors, viz., hours of operation per day, load factor, quality of fuel, etc., but it is customary to remove the ashes and clinkers once every three to seven days.

The total efficiency of the apparatus is shown by the following heat balance:

<div align="center">

PRODUCER HEAT BALANCE

</div>

	B.T.U.	Per Cent.
Total heat in fuel supplied to plant.	100,000,000	100.00
Heat in gas at 60° F.	84,700,000	84.70
Heat removed by scrubber water.	8,160,000	8.16
Heat removed by water-cooled valves . . .	1,560,000	1.56
Heat lost by radiation and other losses . .	5,580,000	5.58

The points claimed for this apparatus meriting special attention are as follows:

    1. It produces a fixed clean gas of uniform quality.

    2. All varieties of fuel can be used without any modification in the construction of the apparatus.

    3. Very high efficiency over wide ranges in load.

    4. Large overload capacity.

    5. The ability to operate under sudden fluctuations in load.

    6. Stand-by loss reduced to a minimum as combustion is arrested during such periods.

7. The fires being at all times visible to the operator, the fuel can be charged to the best advantage.

8. The fires can be kindled and plant be in full operation in fifteen minutes.

9. A fuel gas of high heating value and low cost is produced.

10. Freedom from smoke or smell, due to apparatus operating under a vacuum.

11. No tar extractors required.

12. Ability to construct single units of large capacity.

13. The use of an exhauster and holder ensure a uniform pressure on the gas mains.

14. Where water is scarce or expensive the greater part of the scrubbing water is recovered and cooled by means of a cooling tower so that the water requirements for a power plant are far less than those for a boiler plant.

The thermal value of the gas varies slightly according to the conditions under which the apparatus is operated, and also differs with the fuel used. If a plant is installed the primary object of which is to generate a large proportion of water gas for metallurgical or other purposes, the producer gas will have a lower B.T.U. value than if the gas is to be used exclusively for engine or lower heating work. The following analyses are typical of the above:

LOOMIS-PETTIBONE PRODUCER GAS ANALYSES

No.	I.	II.	III.	IV.	V.	VI.	VII.
Carbon dioxide, CO_2	3.6	6.0	15.96	21.3	10.7	3.6	5.0
Oxygen, O	0.2	0.3	0.11	0.26	0.5	0.2	0.4
Illuminants	...	0.2	0.28	0.46	....	....	....
Carbon monoxide, CO	26.9	38.7	13.27	9.86	17.2	26.1	18.6
Methane, CH_4	1.1	3.4	2.61	3.45	3.1	1.0	1.2
Hydrogen, H	9.4	46.4	20.97	54.14	14.0	9.1	9.3
Nitrogen, N	58.8	5.0	46.80	10.53	54.5	60.0	65.5
B.T.U. per cu.ft. at 60° F.	129.1	315.0	140.22	246.88	132.7	125.2	101.5

I. Mixed gas using bituminous coal.
II. Water gas using bituminous coal.
III. Mixed gas using wood.
IV. Water gas using wood.
V. Mixed gas using lignite.
VI. Producer gas using bituminous coal (for gas engines).
VII. Producer gas using bituminous coal (producer gas practically a by-product from manufacture of water gas).

When operating to obtain the greatest yield of water gas the ratio of water gas to producer gas is about 1 to 3; this proportion, however, can be increased to almost any amount. The amount of water and producer gas derived from a ton of coal is influenced by the quality of coal, a poor grade of bituminous coal yielding about 35,000 to 38,000 cu.ft., whereas a good quality will produce as high as 50,000 to 55,000 cu.ft. When operating the plant to obtain a good quality of mixed gas, say for engine use, from 160,000 to 200,000 cu.ft. per ton can be reasonably expected.

The tar distilled from bituminous and lignite fuel in this apparatus and converted into a fixed gas is assumed to represent 15 to 20% of the total calorific value of the fuel. The fuel bed maintained should approximate at all times about 4 ft. in depth.

In the Loomis-Pettibone apparatus, compressed gas is used for stoking, a charge of some 90 lbs. pressure being admitted through a quick-opening valve (approximating $1\frac{1}{2}$ ins.). These "shots" are administered at intervals of 30 minutes and tend to lift the entire fuel bed, which replaces itself and compacts with a tendency to break up any chimneys or honeycombing.

The best results or high efficiency of gas obtained from this process for power purposes is found with the gas approximating 105 B.T.U. in value, this usually representing about 5% of water gas to 95% of producer gas in the total mixture. This is probably by reason of the fact that a higher heat value is reflected by the presence of a large hydrogen factor.

No difference in rating or great surface capacity is made in these producers for anthracite, wood, bituminous, or coke, the discrepancy in the heat value off these fuels being compensated by their rate of gasification. All of this apparatus is rated on the basis of an estimated six-hour 50% overload.

The apparatus is built in sizes as given below, the dimensions stated being the diameter and height of the generator shells. For convenience the various sizes are rated at so many horsepower, which is their normal capacity, but the overload output for an hour or two is 50% higher.

H.P. of plant	250	375	500	750	1000	1500	2000
Diameter of generator	5'3"	6.0"	7'0"	8'0"	9'0"	10'0"	11'0"
Height of shell	12'0"	13'0"	14'0"	14'0"	15'0"	16'0"	18'0"

The floor space and size of building required to house the above plants is shown by the following figures:
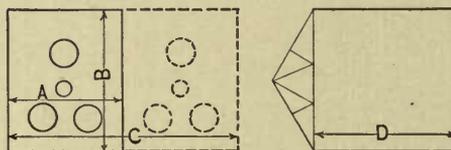
FIG. 73.—Space occupied by Plant.

	Single Unit Plants.				Double Unit Plants.			
Horsepower of Plant.	Size of both Generators.	A.	B.	D.	Horsepower of Plant.	B.	C.	D.
250	5' 3"×12'	24' 0"	28' 3"	28' 0"	500	28' 3"	44' 6"	28' 0"
375	6'×13'	25' 4"	31' 0"	28' 0"	750	31' 0"	46' 6"	28' 0"
500	7'×14'	26' 4"	38' 0"	33' 0"	1000	38' 0"	51' 6"	33' 0"
750	8'×14'	28' 6"	40' 10"	33' 0"	1500	40' 10"	55' 0"	33' 0"
1000	9'×15'	31' 10"	42' 3"	33' 0"	2000	42' 3"	59' 10"	33' 0"
1500	10'×16'	36' 0"	47' 7"	33' 0"	3000	47' 7"	64' 0"	33' 0"
2000	11'×18'	38' 0"	46' 0"	33' 0"	4000	46' 0"	72' 0"	33' 0"

In the above table the double-unit plants consist of two pair of generators with their boilers and scrubbers.

The only purification the gas is given for general use is the washing it receives in the wet scrubber, and the final cleaning is accomplished in the dry scrubber. The lower sections of the wet scrubber are usually filled with coke or stones and the upper sections, above the water, with excelsior. The dry scrubbing material usually consists of excelsior or sawdust.

In special cases where it is necessary to remove the sulphur from the water gas it is accomplished by resorting to the conventional type of purifying boxes filled with iron oxide or lime.

Uses.—This system of gas manufacture is in extensive use at the present time, water gas being utilized in a large number of manufacturing plants for processes where high temperatures are required, while the mixed and producer gases have proved their worth as fuel for lower heat work and gas engines. As water gas contains such a large percentage of hydrogen and carbon monoxide, its flame temperature is even higher than natural gas. Water gas has a high rate of combustion, resulting in its successful application to direct-fired furnaces with a minimum of combustion space, which contrasts strongly with oil-fired furnaces where considerable additional space must be provided to permit of the full development of the flame. It is unnecessary to use regenerative or recuperative furnaces to obtain the high temperatures, but by utilizing the waste heat in pre-heating the air used for combustion considerable economies are effected. Among the processes in which water gas is used are:

> Small direct-fired furnaces for welding and drop forging.
> Brass melting in crucibles.
> Steel melting in crucibles.
> Semi-regenerative pipe-welding furnaces.
> Soldering irons and furnaces.
> Blow pipes for brazing.
> Tempering watch springs.
> Singeing cloth.
> Japanning ovens.
> Hardening and tempering.
> Annealing.

Mixed gas, which consists of water gas and producer gas in any desired proportion, is utilized for lower temperature work where regenerative fire-brick checkerwork is not required, but with this feature added to furnaces, melting of various metals is readily accomplished. The work being done with this gas consists of

> Hardening and tempering saws.
> Annealing and japanning.
> Pipe-bending furnaces.
> Gas engines.

Producer gas is also used for the above work in case there is a surplus of it.

By the use of gas in furnaces a considerable saving can be effected, due to the centralization of the coal pile which obviates the necessity of carting or wheeling the fuel through the shops. Another advantage is that there is no interruption in the

output of the furnaces, as is the case where the fuel bed in a coal or coke-fired forge has to be replenished, with a consequent delay while the fresh fuel is kindling; neither is any time lost in taking out ashes or clinker. This naturally results in an increase in the output per man, which in many cases is of far greater monetary value than any saving which may be effected in the fuel. As no space has to be allowed for the
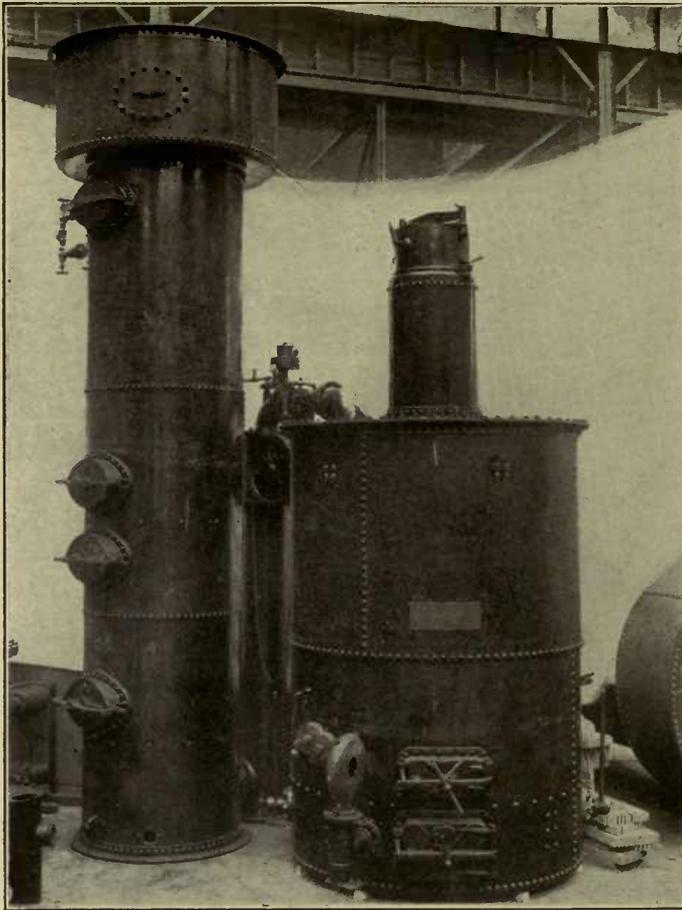
FIG. 74.—Staub Suction Gas Producer. Typical anthracite suction producer, as manufactured by the Power and Mining Machinery Company.

storage of a fuel supply around each furnace, the available floor space in a shop is either materially augmented or else in planning a new building the dimensions of the building can be reduced. Cleanliness is another good feature, dust from ashes, etc., being eliminated. Uniform temperature can be maintained, which in many manufacturing processes is a vital point. The wear and tear on such furnaces is reduced, and by using recuperators for pre-heating the air, heat which would otherwise be lost up the stack is returned to the furnace.

THE MORGAN PRODUCER

The Morgan producer, manufactured by the Morgan Company of Worcester, Mass., is perhaps the leading type of industrial producer manufacturing producer gas for metallurgical and industrial work. The producer is steam blown and is exceedingly simple and substantial in its construction.
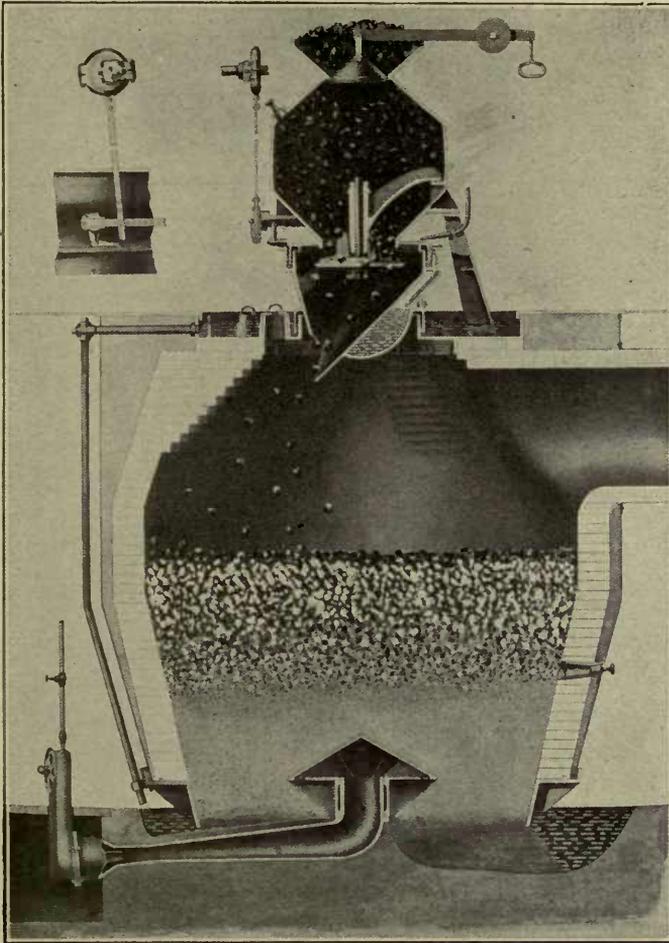
Fig. 75.—The Morgan Continuous Gas Producer with George Automatic Feed.

For its stoking it depends, in opposition to the Wood producer previously described, more upon its method of feeding the fuel than upon any agitation of the fuel bed itself, the producer being of the water-seal type and the ashes being withdrawn through the seal or lute.

The George feed, with which the Morgan producer is equipped, when supplied with a proper and uniform size of fuel, gives perhaps the most even and complete

distribution of its charge over the surface of the fuel bed which has as yet been obtained. This uniformity of charge tends to close any chimneys or lines of cleavage in the fuel bed upon the top, instead of closing such lines through the tort produced in a revolving grate or ash table.

It may be said that the Morgan producer with its George feed, stops up or covers its chimneys, where the Wood producer endeavors to close them. Again, with the uniformity of feed attained with this producer, such chimneys or lines of cleavage are less apt to occur, very seldom in fact where a fair uniformity of fuel is used.

The Morgan producer is used entirely for metallurgical or industrial work, and is not used for power; by reason of the heat of its gases and from their direct application, a very high efficiency is claimed for the producer.

WESTINGHOUSE DOUBLE ZONE BITUMINOUS GAS PRODUCER

The Westinghouse Machine Company has developed a double zone bituminous gas producer in compliance with a pre-determined standard which involves a producer design capable of (1) continuous operation, (2) producing a gas free from tar, (3) operating at such temperatures as would avoid troublesome clinker formation, (4) producing a gas of normal constituents suited to high engine compression, and (5) finally a producer that could be readily operated by a single attendant with comparatively little labor and skill. This latter qualification evidently necessitates a plant of considerable simplicity.

This apparatus is running successfully upon both high and low grades fuel, the latter including the lignites of northern Colorado, Texas, and South America. It is also satisfactorily operated upon garbage, crude meadow peat, and other waste materials. The general scheme is indicated in a sectional drawing showing a complete plant with all auxiliaries. An upper shell (A) superimposed upon lower shell (B) with cast-iron evaporator (E) between, a hollow air-cooled top (C), communicates with the evaporator through downcomer (D_1) and uptake (D_2). A third downcomer connects evaporator with lower tuyere (T). The producer is supported from four concrete foundation piers on a cast-iron mantle ring (M), the lower rim of which dips beneath the level of the water in the ash pit, forming a water seal.

In the operation of this producer, green fuel is fed through the open top (F), and during its descent to the offtake zone (O) is completely transformed into coke. During its further descent to the ash line (S), this coke is completely gasified to ash. There are, therefore, two independent fuel beds, (A) and (B). In the former tar vapors distilled from the fresh coal, are transformed into fixed gas which mixes with the straight coke gas generated in the lower zone (B).

Vaporizer.—There are two combustion zones in this producer, one at the extreme top and one at the bottom just above the tuyere. This is brought about by a double supply of vapor laden air. This air supply is drawn in from above at (G) (see plan). Circulating entirely around the hollow top, it is heated sufficiently to increase its capacity for taking up moistures, when it is again circulated over the surface of the water in the evaporator (E). This vaporizer is practically in contact with the hot fuel bed at the center of the producer, when it generates the

proper amount of vapor to carry out the endothermic reactions, for cooling the fuel bed through H_2O dissociation. This evidently does away with the necessity of an external boiler to supply steam to the producer, and, in general, conforms to the practice of suction producer design in large sizes. Entering the vaporizer at E_2, heated air divides, emerging at E_3, part ascending and part descending. Valves
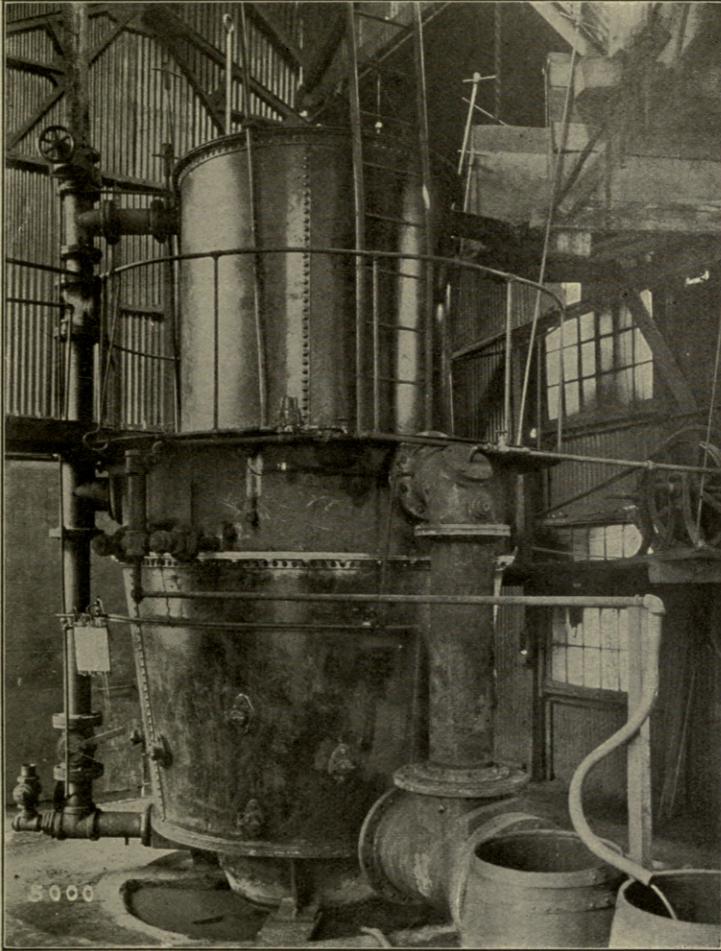
Fig. 76.—A 175 H.P. Westinghouse Double Zone Bituminous Gas Producer.

J_1 and J_2 serve to control the relative quantity of blast to the two combustion zones. This relation constitutes practically the only variable in the operation of the plant, but for any given fuel, it is only necessary to regulate these valves once. The automatic proportioning of vapor to air is otherwise provided for in the design of the producer, so that the process of gasification is automatic through the entire range of load.

With variable fuels, it is important to reduce the velocity of gas as low as possible at the offtake. On this account the gas is drawn from the fuel bed at several points communicating with the annulus (E_1).

Rotary Exhauster.—The rotary exhauster (H) serves to provide a positive and uniform suction on the fuel bed. This type seems to fulfil the requirements and incidentally avoid the uncertainties of operation encountered with the hand-regulated blower. Thus, the plant becomes virtually a double-zone suction type.

This exhauster operates at a constant speed and delivers gas to the engine always at constant pressure of a few inches of water. This regulation is accomplished by means of a butterfly valve (K) and a gasometer (I) which arrangement by-passes such part of the gas delivered by the blower as is not required by the engines, the remainder circulating through a small mixing heater overhead. In this manner the necessity for a variable speed exhaust is avoided.
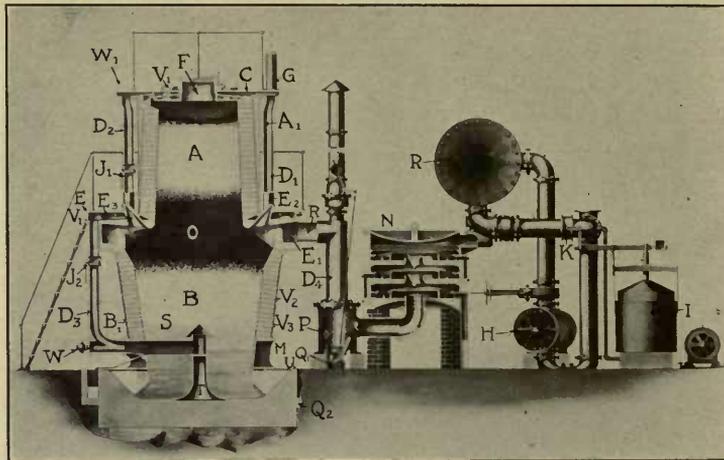
Fig. 77.—Section of Westinghouse Producer.

Holder.—It will also be noted that a large gas holder is not employed for the control of gas production as regards quality and quantity or delivery pressure, thereby effecting a material economy in installation.

Cleaning.—In the absence of tar, the problem of cleaning the gas suitably for engine use, resolves itself into the simple removal of dust and lampblack. This is accomplished by a static cellular type washer (N) in which the gas streams are spread out in a thin layer and constrained to pass over the surface of still water, during which process the foreign matter is thrown down. This reduces the quality of foreign matter to about 0.02 of a grain per cubic foot, which affords a very large margin of safety in actual operation.

Water Seals.—At (O) is a single-seated stack valve and at (P) a water seal controlled by plug (Q) which is normally left open. When the plant is shut down, the closing of valve (Q) floods the water seal (P), thus shutting off the rest of the

plant and automatically opens the stack valve (*O*). This water seal also makes it possible to work on the auxiliary while the producer is at stand-by.

In practice, a large part of the foreign matter is thrown down in the down-comer (*D*₄) by the action of a water spray (*R*), this sediment passing freely to the overflow without entering the static washer.

The water seal of the producer proper may be partially drained by a rotating valve (*U*). In its up position, this valve maintains a level as shown by the dotted line. When turned downward, the water is drained 2 inches beneath the lower rim of the mantle ring (*M*), consequently breaking the seal, and allowing free ingress of air at all points. This is effective in the starting of a new fire in which a heavy draft is desirable.

Draft.—In operation, the pressure at the top fire bed is slightly below atmosphere, so that when the charging cover (*F*) is opened, there is no tendency for smoke or gas to reach the producer room. Thus it occurs that the most important part of the fuel is always available for inspection and can be easily worked down in full view. In addition, poke holes (*V*) are provided so located that the sides of both the upper and lower linings may readily be raked by a poker bar and the ash settled down as in the normal operation of a pressure type producer. This also gives access to the fire bed—an important feature.

Labor.—The labor requirements are comparatively small, as the bed requires poking seldom more frequently than once per hour. Ashes are removed about once in twenty-four hours. Thus it occurs that with coal and ash separately handled, one man can operate at least three of these producers without difficulty. Coal may be charged at intervals of fifteen minutes to one hour, according to the load. Owing to the low temperature at which the fuel bed is maintained, the formation of large clinker is entirely prevented and this trouble has not been encountered in any of the tests. Provision is made for flushing out the vaporizer at intervals to prevent the deposit of mud in case foul water were used.

Washer.—The static washer is practically indestructible and partly self-cleaning; but in any event, the various sections are readily accessible by lifting off the cover. In the remainder of the plant there is little opportunity for deterioration, so that as a whole this type of plant presents a number of important advantages that have not been possessed by its predecessors, built and tested under similar conditions.

Operating Results.—Several weeks run on Pittsburg run-of-mine at 13,000 B.T.U. per pound, as fired, gave an average consumption of 1.24 lbs. per b.h.p. hour continuous operation.

Nature of some of the fuels which have been successfully used with the Westinghouse producer:

COMPOSITION

Runs	A.	B.	C.	D.	E.
Moisture	20.05	16.63	2.03	38.10	34.09
Volatile	34.44	33.78	34.98	40.54	30.03
Fixed carbon	30.85	42.22	56.22	17.86	26.32
Ash	14.66	7.37	6.77	3.50	9.56
B.T.U. pound as fired	8032	8599	13305	6410	6950

Efficiency.—The efficiency of the producer does not vary more than 10% from full load to no load on the engine, and approximates 77.5% on higher heat value, or 71.5% on lower. Samples of ash taken from the producer during the tests on Pittsburg run-of-mine, show for an average of six samples less than 15% ash.

Combustion Rate.—The rate of firing varied from 13 to 22.8 lbs. per square foot of fuel bed area per hour at the green fuel zone. This higher rate may be maintained indefinitely without vitiating the gas from excessive oxidation or without clinker formation. The temperature of the gas leaving the fuel bed averages about 900° F., low enough to prevent clinker. With considerably hotter gas, the heat value of the gas falls slightly. This temperature, therefore, serves as a fair index of limits in regard to fuel bed temperature.

Heat Value.—The average samples of gas taken from the engine show a heat value of about 115 B.T.U. A considerably higher value could be obtained by using more vapor.

Foreign Matter.—The average gas samples show from 0.015 to 0.025 grain of solid matter per cubic foot of standard gas. During a week's test on the auxiliary plant, twenty-five determinations showed a range of solid matter from 0.006 to 0.043. This solid matter consists entirely of dust and a little lampblack, the heavier matter having already been removed at the discharge nozzle of the producer by a water spray. These figures show ample capacity of the cleaning plant to take care of bituminous fuels.

THE HERRICK PRODUCER

In opposition to the producers before described, the essential feature of the Herrick producer is the idea of disseminating the air from the bottom through the sides and top of its patented tuyere.

A claim made for this producer is that the air is disseminated so generally as to prevent its concentration at any one point with the attendant formation of chimneys, fissures, or channels.

This producer is being extensively used on bituminous coals and lignite. It is well adapted for industrial work and particularly the operation of ceramic and metallurgical furnaces.
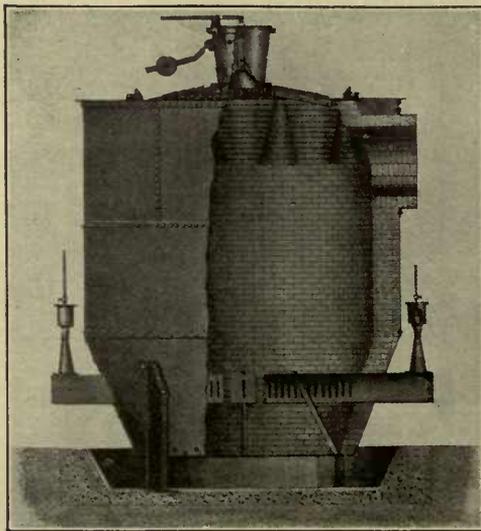
FIG. 78.—The Herrick Generator in Half Section.
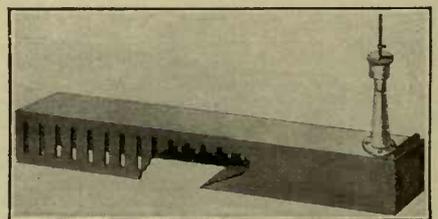
FIG. 79.—Tuyere and Steam Blower of Fig. 75.

SMITH LIGNITE PRODUCER

In addition to the bituminous producers made by the Smith Gas Producer Co., they have been particularly successful in manufacturing a producer adaptable to the use of lignite and low-grade fuels.

It is a fact that it is almost impossible to operate the average down-draft producer of ordinary construction on lignite coal, on account of the fact that these coals crumble to very small dimensions after being heated, the crumbling occurring at a certain temperature and the dissociation being very rapid and complete, with the resultant effect that a sudden dampering occurs due to the instant accumulation of a heavy ash bed. As a result the central part of the fuel bed becomes very compact, so that the fuel is driven to the lining and channeling and high drafts occur.

In the Smith lignite producer this tendency is overcome by confining the blast to the producer to a centrally located tuyere, which delivers into the heart of the fuel charged, so that in whatever direction the blast may pass it is obliged to go through a sufficient depth of fuel to insure the production of a good gas. In this way the tendency to channeling and the driving of the blast to the lining is entirely overcome.

This construction also permits of the running with a very shallow fuel bed which, when used together with a shaking grate, avoids the difficulty with a backing fire which invariably follows the use of lignite fuel.

Another feature of the producer is the handling of the ash which necessarily forms most rapidly and in greatest quantity at the point closest to the air inlet or outlet of the tuyere. In the down-draft producer this is, of course, on top of the fuel, and the presence of this large percentage of ash in the upper part of the fuel bed has been one of the chief difficulties in operating this type of apparatus.

It is obviously impossible to work this ash through the grate in the ordinary way, since if the ash is allowed to accumulate until it settles on the grate the whole fuel bed would consist of ash, and hence the producer be out of commission. If an attempt is made to force the ash down through the fuel below, there must necessarily result a great loss of carbon or good coal from the ash pit which will be entrained in its passage, and consequent reduction in the efficiency of the apparatus.

This difficulty has been avoided in the Smith producer by arranging to deliver the ash towards the center of the fuel bed or that portion which is directly under the air blast or tuyere, where the temperature of combustion is necessarily the highest. At this point the ash is fused in a large solid mass or clinker, which generally increases in size by accretions to its outside surface until it becomes of sufficient dimensions to be easily detected in a fire, and of sufficient hardness to permit the proper handling when it is withdrawn from the fire from above by means of proper tools and removed through the ash inlet pipe or tuyere, from whence it is taken out of the top of the producer.

In practice this process of handling the ash is found to be in the highest degree practical. The clinker can be withdrawn at any time when the producer is in oper-

ation without interfering with the production of gas, and the ash taken from the producer in this way contains an extremely small percentage of good fuel or carbon.

There is, of course, a certain small amount of finely divided ash which is con-

Detail of Charging Hopper.
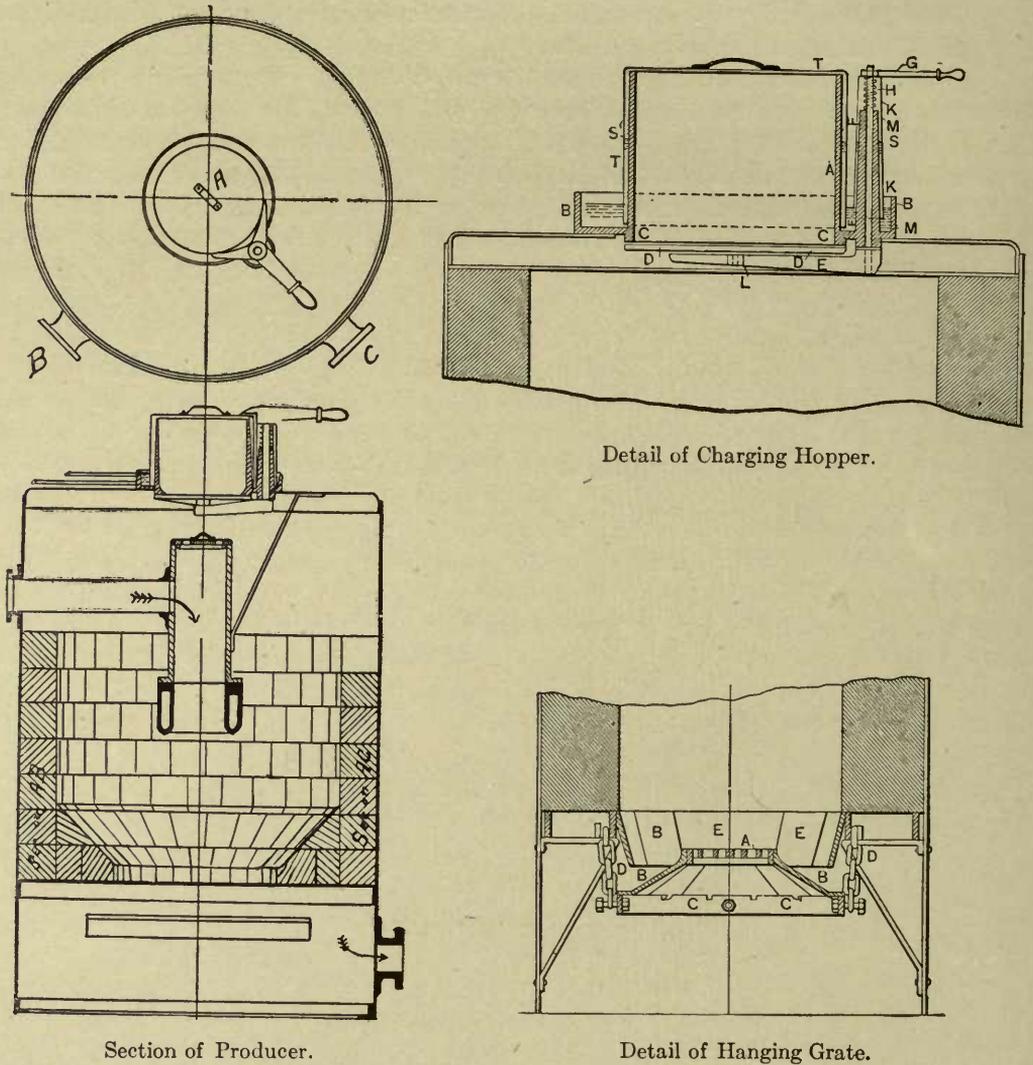
Section of Producer.

Detail of Hanging Grate.

FIG. 80.—Smith Lignite Producer.

stantly forming in the lower part of the fuel bed as a result of the decomposition of CO_2 to CO by carbon in this part of the fire. This fine ash or dust is removed from the grate by simply shaking the grate from side to side, thus agitating the fuel bed and tending to close up rivers or channels, when the down-draft of gas sweeps the fine ash from the grate into the ash pit. In this way the ash is readily handled

without undue loss of carbon and a packing of the fuel bed, consequent from the use of lignite, entirely obviated. Moreover, the percentage of tar and lampblack in the gas is reduced to a minimum and the hydrocarbons volatilized to the benefit of the resultant gas.
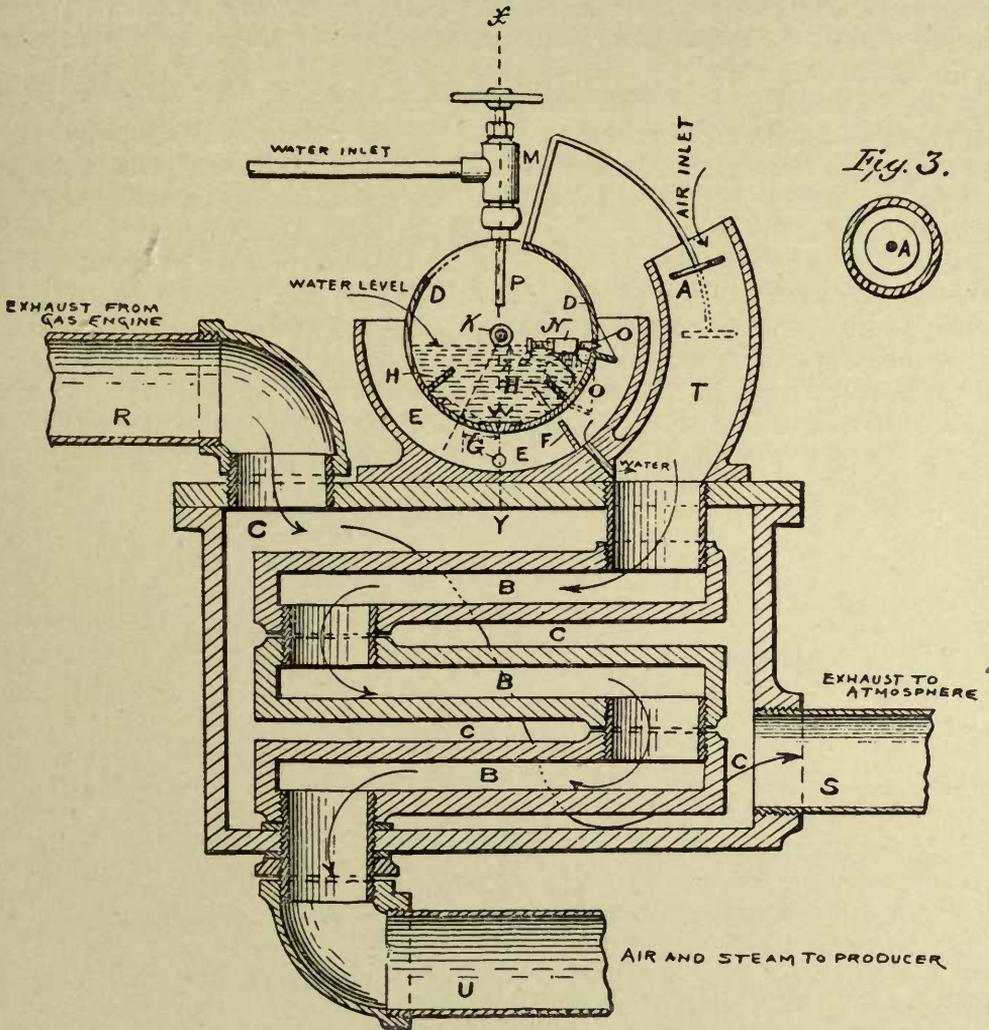
FIG. 81.—Air and Steam Pre-heater.

In the Smith apparatus the fuel magazine extends around the air-inlet tuyere and up to the top end of this tube. This part of the producer is now filled with green coal. The large diameter of this tube serves to equalize the pressure between the top of the producer and the end of the tuyere, and the fuel in the magazine becomes ignited from below, burning upward solely by natural draft, and distils off the vola-

tile hydrocarbons which pass into the upper part of the producer. Here they become slightly cooled and descend again through openings provided in the top of the central draft tube where they are mixed with air and actually burned as soon as they come in contact with the ignited fuel at the bottom end of the tuyere.

When burned these hydrocarbons become CO_2 and H_2O. These in turn are decomposed when passing through the coke in the lower part of the fuel bed and become CO and H, their endothermic action being used to moderate the temperature in the middle of the fire.

The illustration herewith shown of the steam-regulating device of the Smith gas producer has proved very superior. The balance valve or piston is regulated by the static head or amount of suction created by the incoming primary air to the producer, the amount of water admitted to the vaporizer being proportional to the volume of said air.

The passage of the air and water through the coils (B) of the recuperator tends to make a thorough mixture of all hydrate or air in a very complete manner. The heat used for the vaporization of the water, and to some extent the incoming air, is supplied by the exhaust gas of the engine.

It is, however, likely that an arrangement could be made to abstract the sensible temperature of the effluent gases on their passage through the producer to the scrubber, should the arrangement as shown be in any way inconvenient.

LIGNITE SUCTION PRODUCERS

Lignite suction producers, under the design of the Gas Power Manufacturing Co., resemble in principle and general outline the standard type of suction producer for anthracite coal, coke, and charcoal. There are, however, certain radical principles in the design made necessary by the specific conditions existing in the gasification of lignitic fuels, more particularly, by reason of the larger percentage of moisture, volatile hydrocarbons, ash which they contain, the physical structure of the lignitic fuel, temperature at which it disintegrates, and on account of extreme rapidity of the gasification or combination of elements. The lignite producer plant consists of: producer, scrubber, gas washer, and purifier. Taking up these parts in order seriatum, they may be described as follows:

The Producer.—The producer consists of a cylindrical steel shell, with firebrick lining, and has a plain bar grate, with ample cleaning doors and ash pit. Coal is charged in the top of the producers, through a double closure, or feeding hopper, and may be delivered to the hopper either by hand, from a coal hopper by gravity, or through the medium of a conveyor.

No vaporizer is necessary to produce steam for the purpose of regulating the temperature within the producer, inasmuch as lignite coals usually contain a high percentage of moisture, the evaporation of which within the producer is sufficient, under most conditions, for all tempering purposes. Where, however, this amount is inadequate and must be supplemented, a small amount of water is carried in the ash pit, which will evaporate as high as $\frac{1}{3}$ lb. of water per lb. of fuel gasified. This

feature avoids perhaps the greatest complication in producer operation, and eliminates the most expensive item of maintenance or up-keep.

The regulation of steam, which under ordinary circumstances is a complex and complicated process, requiring great skill on the part of the operator, and by bad adjustment, produces an excess of carbon dioxide, hydrogen, clinkering in the fuel, etc. To a great extent this is obviated in the lignite producer and the evils aforesaid reduced to a minimum, the operation of the apparatus being simplified to the most primitive form.

The producer works up-draft, the gases passing from the top of the producer to
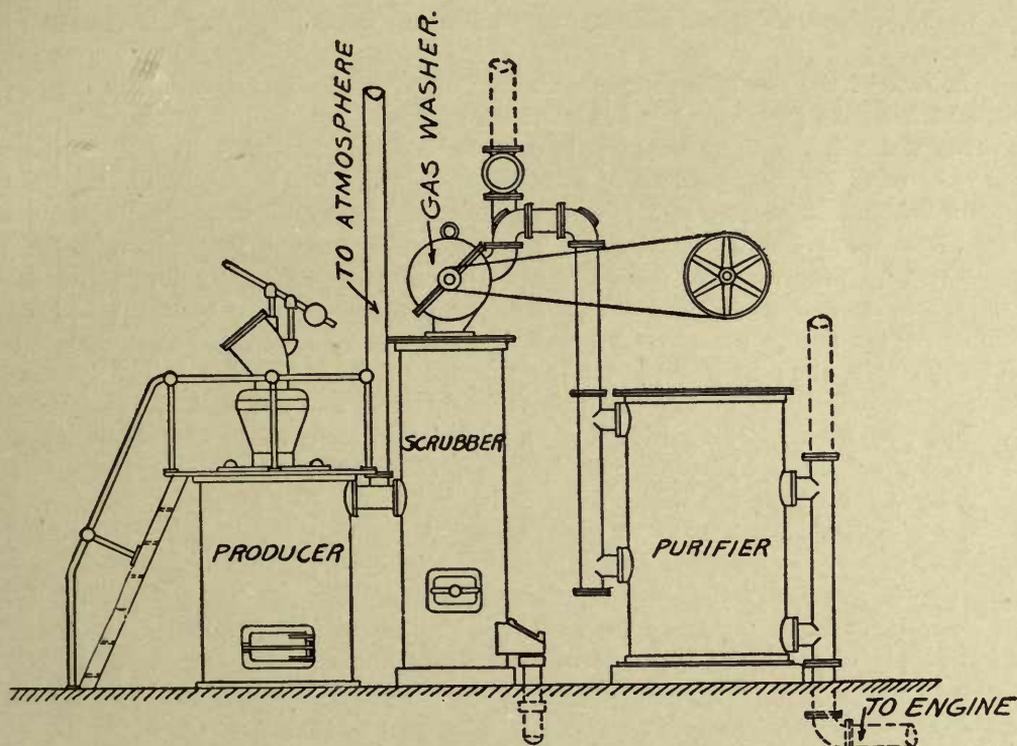
Fig. 82.—Lignite Suction Producer.

the scrubber in such a way as to penetrate the incoming charge of coal, or the "green coal" as it is known, which charge is pre-heated by the absorption of the sensible heat from the effluent gases, affording a high degree of heat recuperation, amounting in some instances to say 20% of the total heat of the fuel, and thereby conserving and restoring waste heat to the producer in a most efficient and economical manner.

The Scrubber.—The scrubber is a cylindrical steel shell containing neither coke nor checker work, as is the ordinary practice, but equipped instead with several atomizing sprayers of a peculiar device and design, which fill the volume of the tank

with water vapor at a certain tension, necessary for combination with the impurities of the crude gas.

The function of the scrubber is to cool the gas and condense the heavy hydrocarbons which are precipitated, together with a large portion of the dust and ash which they entrain, through the change of volume in condensing, change of pressure and also through super-saturation by the water vapor.

Gas Washer.—The gas washer is of centrifugal type, which separates the tar and dust from the gas by placing the unpurified product in rapid rotary motion, and at the same time subjecting it to a change of volume and pressure in the presence of a finely divided water spray. The impurities washed out of the gas in both the gas washer and scrubber are collected in a waterbox, from which they are drained to a sewer.

In case of the use of lignite, gas washers of peculiar efficiency are necessary to abstract from the gas not only what is known as "tar," but the other unfixed hydrocarbons which impregnate the gases in a most tenacious manner. These constitute not only the lighter tar and tarry vapors, but oils of the paraffine series, ranging from a light yellow viscous matter to the heavier seal brown oil tars, such as are produced from the distillation of crude oil.

The very wide range of these impurities requires a cleaning apparatus of great comprehension and scope, and only a machine especially designed for the purpose can efficiently purify the gas for practical engine service. In installations where water is scarce, the centrifugal pump is connected to the gas washer to circulate the wash water, only enough cold water being added to cool and condense the gas.

The power necessary to drive the gas washer varies from 2 to 4% of the power the engine supplies. This does not, however, change the rating of an engine or plant, inasmuch as the gas washer is so designed as to deliver the gas to the engine under atmospheric pressure, or when expedient at slight pressure. This relieves the engine of its duty as a suction pump, in which service no gas engine made is a particularly efficient apparatus. Hence, the resulting arrangement really increases the engine rating, and consequently the total efficiency of the plant, the engine receiving a full supply of gas in its cylinders at each stroke and obviating all losses through piston "slip."

Purifier.—The sawdust purifier is advisable to reduce the amount of saturation or moisture mechanically entrained in the gas in its passage to the engine. This purifier is the ordinary type and contains wooden trays covered with a mixture of sawdust and planer chips, fine coke, corn cobs, or similar material.

General Advantages.—Briefly stated, the advantages of the up-draft lignite producer over the down-draft type (as represented by the Loomis-Pettibone and Smith producers) are as follows:

a. The grate is accessible at all times for cleaning, preventing plugging, banking, and channeling, and involving a removal of clinker and ash with the minimum loss of fuel, and without slowing the engine or loss of power.

b. The sensible heat of the gases is regenerated by the passage of gas through the incoming or green fuel, which fuel absorbs the larger portion of this heat, conserving it and retaining it within the producer, at the same time pre-heating fuel and bringing it up a stage towards the heat of combustion or gasification. Moreover,

this pre-heating of the fuel drives off a large portion of the high moisture content of the lignite, which would otherwise act as a diluent, and both require a large amount of fuel consumption in its evaporation, and subtend a hydrogen content in the resultant gas, when distilled at the higher temperature of the lower producer zones. Not only is this an advantage in driving off the hygroscopic moisture in the lignite itself, but also the moisture absorbed by lignite upon its exposure to wet or rain, under which conditions its saturation is remarkably high.

c. The quality of the gas, therefore, obtained is remarkably uniform and high in heat value and low in free hydrogen, all of which are essential advantages in gas for power purposes and the natural result of the system hereinbefore described.

d. This system is peculiarly free from danger to the operator, as he is at no time exposed to the unprotected portions of the producers, or in contact with areas where explosive mixtures may be formed.

e. The fixed carbon or combustible matter in the fuel is more completely gasified than that within any other commercial system, there being less grate loss or unconsumed combustible matter withdrawn from the producer in cleaning or along with the ashes.

f. The apparatus is of much more simple construction, being more easily operated, and possessing fewer variable conditions, requiring no water-cooled grates, less skill in labor, no collecting tubes, vaporizers, or special fire tubes, and hence reducing the expense of up-keep, repairs, and maintenance.

The advantage claimed by builders of the down-draft producer consists in the fixing of a larger percentage of volatile hydrocarbon in the gas (the breaking up of tars, oils, etc., into permanent gases) and through this reduction of waste, the effecting of a greater fuel economy; or, in other words, the creating of a higher total efficiency in gasification. It is unquestionalby true that under these conditions more of the volatile and viscous hydrocarbons are fixed, but of necessity there is an insufficient supply of oxygen in the bottom of the fuel bed, this being the result of mass action in combination, as, for instance, the insulating and diluting effect of ash formation, etc.

A certain portion of the fuel escaping unburned to the ash zone is carried off in the cleaning of the grates, moreover, by reason of the lack of oxygen for complete combination, the fire dies out around the grate or in the lower extremities of the fuel bed. Hence, a certain portion of the fuel escaping unburned is lost by drawing the coal with the ash. This may be said to be an offset and more than commensurate with any possible saving in the fixing of the hydrocarbon under the down-draft process.

The following analyses show the fixed carbon loss in ash in one specific instance:

LIGNITE FROM WILSON COAL CO., CENTRALIA, WASH.

Proximate Analysis.	Per Cent.
Moisture	15.7
Volatile matter	47.0
Fixed carbon	24.0
Sulphur	0.5
Ash	12.8

Ash Withdrawn, Down-draft Producer, Wilson Dust Coal

Analysis.	Per Cent.
Moisture	17.8
Volatile matter	9.7
Fixed carbon and sulphur	48.7
Ash	23.8
Calorific value, B.T.U.	80.0
Specific gravity	1.42

Lignite from Renton Mine, Wash.

Proximate Analysis.	Per Cent.
Moisture	6.6
Volatile matter	52.3
Fixed carbon	28.0
Sulphur	0.3
Ash	12.8

Ash Withdrawn, Smith Down-draft Producer, Renton Coal

Analysis.	Per Cent.
Moisture	25.0
Volatile matter	6.6
Fixed carbon and sulphur	34.3
Ash	34.1
Calorific value, B.T.U.	7600
Specific gravity	1.61

With up-draft producers the following would be the characteristic analysis of the ash drawn:

Analysis.	Per Cent.
Moisture	25.0
Volatile matter	5.0
Fixed carbon and sulphur	15.0
Ash	55.0

The moisture content of draw is due principally to water-sealed producers. It is a matter of record that the draw from properly gasified lignite fuel contains less waste, or free carbon and volatile matter than the bituminous or anthracite coal. This may be, perhaps, by reason of its low temperature of distillation, and its extreme rapidity of heat propagation.

Lignite coals are widely distributed throughout the western and southern sections of the United States. Most lignites can be successfully used in the producer described,

probably not more than one in twenty being unacceptable. Before guaranteeing operation, it would be necessary, however, to have analyses and experimental tests of samples made, the principal points to be determined being the amount of volatile matter, the amount of fixed carbon, the moisture content, the fusibility of the ash, and the nature of the tarry oils or unfixed hydrocarbons. Brown lignites often work as well as black, although they are usually of a lower heating value and require more pounds per mechanical horsepower produced.

The amount of fuel required will range from $1\frac{3}{4}$ to 3 lbs. per b.h.p. per hour, depending, of course, upon the heating value and general characteristics of lignite used. A thermal efficiency of 60% is a safe guaranty in connection with plants of this type. That is to say, 60% of the B.T.U. contained in the original coal is delivered to the engine and mechanical power is then calculated by the number of B.T.U. required by the engine at various loads, or load factors. The usual arbitrary used in rough calculations being 10,000 B.T.U. b.h.p. per hour.

Lignite producer plants require about four gallons of water per h.p. hour, in addition to the amount required for water jacketing of the engine. The gas-cleaning water can, of course, be cooled, separated from its impurities, and re-used where proper towers, settling tanks, or separating apparatus is installed.

The quality of the gas from producers of this type is affected less by cleaning or barring the producer than the gas from anthracite producers. It also requires less time to blast up the producers, and the apparatus is more sympathetic, and has wider range in accepting load variations.

On the whole, it is operated with less labor and effort, and the quality of its service is so uniform as to make it peculiarly acceptable for variable conditions and continued service.

WOOD-FUEL SUCTION PRODUCER

Wood, planer chips, sawdust and corn cobs may be used in suction producers of almost any type running down-draft, up-draft producers being impracticable by reason of the necessity for fixing resinous oils. In the use of oak and other non-resinous woods, ordinary coke and sawdust scrubbers are sufficient for the purification of the gas, but with all woods or fuels of the resinous type some form of mechanical separator is additionally necessary, its interposition being between the producer and the scrubber.

Where wood is used it is customary to use the ordinary stove size, say $14'' + 14'' + 3''$. This gives very satisfactory results.

However, the wood is usually cut into billets approximately 2×4, or, say, 3×6 inches. Certain woods, such as fire, are especially satisfactory inasmuch as they do not " char " or charcoal (a process somewhat similar to the coking of coal) and hence, blanket or "plug" the fire.

Where shavings or sawdust chips are used some form of mechanical feeder is necessary.

The producer should be water sealed or of the Bosch type, and should preferably

have a water-cooled grate, although $\frac{3}{4}$-in. steel bars placed upon angle irons are frequently used.

The producer should be equipped with an abundance of poke holes, inasmuch as sawdust, and chips particularly, have a strong tendency to burn next the lining, creating channels and chimneys. The mechanical feeder should really have some mechanical stoking device which would tend to pack the fuel bed.

The sawdust fire bed is run to the depth of about 30 inches. The air inlets should have throttling devices to prevent excess in the producer.

The producer is best constructed with a movable hood or stack for removing the smoke while blasting and which may be lifted by counterweights or otherwise while feeding or poking.

The producer should have two air connections to which the blast may be attached. When starting, it should be blasted from the bottom until brought up to heat, after which the connection is reversed and the producer blasted from the top until the gas is driven to the engine.

The tar from resinous woods is particularly intractable and extremely detrimental to operation in the manufacture of power, a small portion of the resinous oil effecting a clogging of governors, piping, and connections and causing the pistons to seize.

In the producer illustrated, it was found necessary to put in side openings above the grate to admit air and prevent the formation of soot and to keep the fire from dying out in the bottom subtending a thick bed of finely powdered charcoal and soot, and creating a considerable obstruction to the passage of the gas.

The admission of air at this point would act both as a mechanical agitator and a chemical catalytic.

However, such admission must be most carefully arranged, as an excess tends to make the producer extremely hot (through complete combustion), and also a large formation of CO_2 (with attendant waste). If a little air is admitted the producer fills up with soot and packs as aforesaid. The mean between these two extremes should be observed.

It is possible to use almost any fuel possessing, say 20% of combustible matter, in a producer of this type. The writer in a 100-h.p. producer of similar construction has obtained a brake h.p. for about two and one-half pounds of straw and about the same amount of hay gasified.

In practice he has found it advantageous to chop the hay and straw coarsely in one of the ordinary chopping machines used for this purpose. After feeding it into the producer it may be rammed down with a square-headed tamp.

In sugar plantations bagasse is equally available and makes an excellent fuel.

Smoke.—Where bituminous fuel is used in producers under the observation of "smoke-nuisance laws" or health department regulations, smoke may be obviated during the run by: (a) properly regulated combustion (sufficient mix of secondary air); (b) light and frequent firing; (c) the maintenance of a fairly high heat in the combustion zone; (d) not too deep a distillation zone.

In starting up the producer it may be brought up to heat without smoke by the use of wood shavings and coke, or possibly a little anthracite coal. After arriving
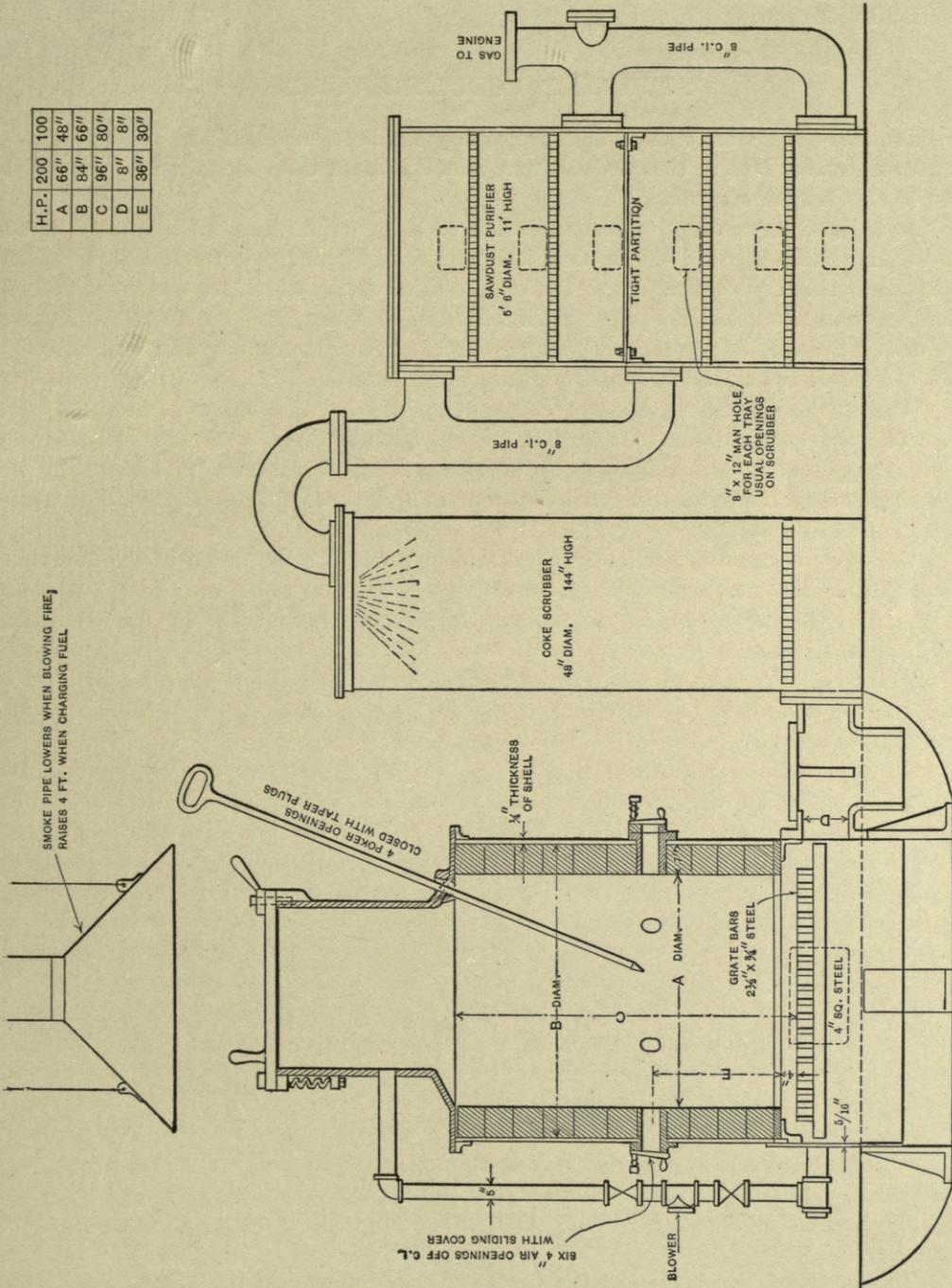
FIG. 83.—Suction Producer for Wood Fuel.

H.P.	200	100
A	66″	48″
B	84″	66″
C	96″	80″
D	8″	8″
E	36″	30″

at normal temperature it may be "switched" to bituminous fuel without smoke production by the precaution of light firing.

POWDERED FUEL PRODUCERS

Probably the most radical advance which has been made in the design of producers since the date of their initial invention, has been the adaptation of powdered fuel to this branch of work.

It is hardly necessary to call attention to the peculiar features attendant upon its use, and although it is likely that it is governed by many intricate laws of mass action and that it is the result of kinetic conditions with which we are more or less unacquainted, for practical purposes it will suffice to say that the results obtained are unquestionably due to intimate mixture of the elements and the molecular activity due to mechanical agitation, which we may term "acceleration."

Among the distinct advantages obtained by the use of powdered fuel (by which we mean a fuel powdered to approximately a 50 mesh, this size requiring no pre-drying), may be noted the rapidity of gasification, the service performed by an apparatus of a given cross-section being four or five times that of the standard shaft or cylindrical producer.

The gas produced is particularly uniform in its nature by reason of the fact that the producer does not suffer from those changes in fire bed which create the variation in gas analysis due to deep and shallow fire beds, hot and cold fuel beds, clinker, chimneys, and channeling.

The "mix" or rate of feed of the various elements being once established, the output may be said to be constant and the analysis of the gas and its calorific value exceedingly uniform.

Another distinct feature is that of the saving from stand-by losses, stand-by loss of a powdered fuel producer being almost nil, it being possible to start it up from a cold producer to a gasifying apparatus within some ten minutes of time, the only loss being the heat necessary to bring the apparatus up to a temperature of gasification. Inasmuch as the stand-by losses from the average producer are usually figured at 6 to 8% of the maximum rated consumption, this feature alone is one of considerable importance.

The third claim for an apparatus of this class, and one of considerable import, is the lessening of labor, the feeding of the producer being entirely mechanical and the stoking entirely obviated, there being neither clinkers to be barred down nor ash in any quantity to be removed, nor is there the continuous poking necessary in all of the types of producers, to maintain a uniform and compact fire bed.

The problem of ash and clinker, together with the tar and other hydrocarbon impurities, are also taken care of in this apparatus. The first and second items are reduced to a minimum, there being none of the untractable clinker which is unquestionably the most difficult feature of solution in the practical operation of the modern producer.

In the last feature, that of the tar and other impurities, the distillation of the coal is so complete that the tar is broken up by the use of hydrocarbons, and as these hydrocarbons may be fairly said to represent from 15 to 20% of the value of the

total available heat of the coal, their recovery, or rather retention in the gas, is an extremely necessary economy. The tar, as a matter of fact, in a powdered fuel producer is more thoroughly dissociated and gasified than even in producers of the down-draft type, while the conditions of the fire bed and the production of lamp-black, which are drawbacks to these types, are not met with.

The increased calorific value of the gas supplied by apparatus of this kind is probably due: First, to the intense heat developed in the plume of combustion, and a resultant complete distillation of all volatile hydrocarbons, the total efficiency of which alone represents more than 20% of the combustible. Second, the intimacy of air and carbon mixture, due to the pulverization of the latter, and the temperature aforesaid, creates a positive reaction, and there being no chimney or channels, there is no uncombined air or "air excess" escaping to the top of the fire, and there consuming the lighter hydrocarbons. The destruction of these in this manner is larger in the ordinary shaft producer than is usually realized.

As much as 97% of the available carbon in the fuel has been turned into gaseous carbon in pulverized fuel producers.

Some idea of the intimacy of union and rapidity of molecular action may be gained in case of powdered fuel, by noting the conditions obtained in cement firing for powdered fuel (100 mesh) where the following conditions will be observed.

In shaft kilns where direct firing is used, the fuel being lump, slack or run-of-mine coal, an excess of air amounting to 300 cubic feet per pound of coal, is frequently required. In the use of powdered fuel, as aforesaid, in rotary kilns only 150 cubic feet per pound of powdered fuel is required, or practically the theoretical quota necessary for chemical union or complete combustion.

The reason for the excess of air necessary for complete combustion, which is so great in direct firing and exists even in gaseous combustion, is governed by the laws of mass action.

These laws are extremely intricate in their working and their formularization a matter of great difficulty.

Briefly and simply stated, when C burns to CO_2 or CO to CO_2, the oxygen in immediate contact with the fuel is combined, and the resultant molecule forms to some extent an obstacle to the passage of fresh or additional oxygen for combination with a further amount of fuel.

Thus the rate of combination tends to fall off. Assuming pressure and temperature to remain constant, the combinations becoming less and less frequent, the reaction being slower as compared with the total mass present or the elements involved.

To overcome or offset this condition an excess of air is necessary, that is to say, this offset being to compensate the lessening frequency of the combinations due to the stagnation or interference of the newly combined molecule aforesaid.

A common analogy of this may be seen in the mixing of sugar in coffee or salt in water, these combinations requiring mechanical agitation or "stirring" with a spoon in order to accelerate the reaction. If, in the example named, the amount or volume of sugar is increased, a larger amount of combination of sugar and water solution will be produced within a given time, even without mechanical acceleration. This is because more surface is presented for action and more atoms are brought in juxtaposition or contact.

The theory of powdered fuel lies along these lines, that is to say, the mass action is relatively greater, there being a larger number of atoms or molecules of the respective elements in contact per unit of time and space.

In recapitulation, therefore, it will be seen that the theory of mass action depends upon a diminuendo of chemical propagation, the diminishing curve being due to the obstacles presented by the newly oxidized matter and the constant increase of both time and space separating more remote particles.

Naturally those atoms or molecules in closest juxtaposition will unite most readily and rapidly, while those at a distance require more time and greater travel before locating an affinity.

The circulation required by the residual particles of the elements, towards the latter part of a reaction of any given unit or volume, is therefore comparatively very great, theoretically having to pass through or around the entire mass before the uncarbonized particle of oxygen meets the unoxidized particle of carbon or *vice versa*.

This is again seen in the dissolution of salt in water, as before cited. This reaction is at first very rapid, becoming slower and slower as the virgin or uncombined particles must travel farther and farther to secure their complement of combination.

In practice, of course, for the reason herein suggested, complete reaction never takes place, the residual or uncombined elements being carried away by convection currents, gravitation, etc., before the search for combination (which if indefinitely prolonged will, according to the laws of probabilities, occur) could be completed.

By increasing the amount of one element therefore (as air) three or four hundred times, a smaller proportion of this uncombined matter escapes. This is the case in the instance of direct firing, while in the case of gaseous or powdered fuel, the mechanical intermixture or interrelation of the elements is so much more intimate, that the loss is reduced to a minimum, and the "complete" combination may be attained with but small excess.

As an offset, however, to the salvage effected by complete combustion under conditions of air excess, there is the necessity of heating a larger volume of air and bringing it up to the flame temperature, necessitating a corresponding expenditure of useful heat.

The conditions as cited above, as occurring in the matter of complete combustion. do not prevail entirely in the production of producer gas, which is that of incomplete combustion. But this discussion has been promoted in order to show the analogy between direct firing and gaseous or powdered fuel firing, and to illustrate some of the laws of mass action, which control and materially govern the production of gas under the powdered fuel system, and accounts for the low N_2 and CO_2 and the high CO and CH_4 in the gas.

THE HIRT POWDERED FUEL PRODUCER

The following is a rough memorandum of the operation of the Hirt powdered fuel producer at the Leetsdale plant of the Riter-Conley Company.

The size of the producer, inside diameter, 6 ft. 6 ins. Height, outside, 16 ft. The diameter within the producer is reduced to a narrow throat by offsetting the fire-brick linings. This throat forms a vortex through which combustion products

pass, and just above which the steam used as an endothermic agent is admitted by means of axial nozzles.

The blower and coal crusher consist of a small self-contained machine of a very compact nature, the whole being operated by a direct-connected motor. The coal passed is blown through a short tuyere which enters the producer near the base at an opening tangential to its axis.

The operation of the producer is as follows: Coal being placed in the hopper it is fed into the crusher at the outlet of which it is caught by the blast and blown into the producer. The blast pressure and the speed of the crusher are, of course, capable of separate adjustment and regulation, thereby obtaining a wide range of volume, amount of fuel, and rate of flow.

The crusher and blower being started, the producer is fired by impinging the blast upon a few handfuls of oily waste which have been previously ignited. The vortex created by the contraction of the linings in the center of the producer subtends a conical flame. Starting of the producer requires 30 minutes. The producer being run as a furnace, that is to say, with complete combustion for 15 minutes, which is succeeded by a dry run without steam for 15 minutes, after which the steam is slowly turned on.

From a rough calculation, the output of this producer was equivalent to 2500 b.h.p. at an assumed engine efficiency of 10,000 B.T.U.; there was, however, no indication that the producer would run at its maximum capacity.

The auxiliary apparatus before mentioned, consisting of a combined crusher and fan blower, reduces the coal to a 40-mesh, delivering same to the fan when it is blown to the producer at about 1 pound pressure. The power required to operate the outfit was about $\frac{5}{8}$ of 1% of the producer output. The labor consisted of one man, there being no barring down, poking, or stoking required, his work being merely the necessary regulation and adjustment of the apparatus, and the oiling of the moving parts.

Practically all fuel-bed difficulties from ash, clinker, honeycombing, channeling, and the co-related evils of necessary stoking, are overcome in this producer by the slagging of the ash, which is fused and drawn off as a slag at the bottom of the producer in the most satisfactory manner.

By reason of this, practically any fuel, no matter how inferior or low in combustible content, may be used with equal satisfaction. The producer being successfully tested upon anthracite coal, coke, bituminous, and lignite coals. The principal test was made on a bituminous coal having the following analysis:

Moisture	5.02%
Volatile matter	17.5 %
Fixed carbon	72.48%
Ash	9.5%

The residue in the form of slag when analyzed, showed the following, upon two separate samples:

	I.	II.
Silica	19.8%	40.9%
Iron	1.2%	14.20%

The following are copies of several analyses made from gas supplied by this producer:

	I.	II.	III.	IV.
CO	23.7	27.5	26.5	27.0
CO_2	3.9	2.8	2.9	5
H_2	10.0	11.5	11.0	9.5
CH_4	5.0	4.5	4.7	5

It is a well-known fact that in the shaft producer there may be said to be three general zones, the first two being that of primary and secondary distillation, and the third being that of oxidation.

In the first, particularly in certain classes of bituminous coals and lignites, the distillation commencing with the evaporation of the water vapor and moisture, commences at a relatively low temperature, and is only really complete upon reaching approximately 1300° F. in the second distillation zone, or just prior to commencing oxidation.

As may be readily seen, this volatilization or distillation of volatile matter is much more rapid than the action of oxidation, the ratio average with bituminous coals being perhaps 10 to 1, and being still more rapid in the case of certain lignites.

It will also be seen that the heavy hydrocarbons thus distilled being infinitely richer than carbonic oxide, there must necessarily be wide limits between the high and low value of the gas, the former being reached during the maximum moment of distillation, and the latter after distillation is completed, and the gas is merely the resultant product of oxidation.

Now, it is also very apparent that where powdered fuel is used, the distillation and oxidation may be said to be practically simultaneous, hence an increased uniformity in the gas due to an identity of its composition, which is almost continuous.

It would be obvious in this process that the difficulties obtained from caking or coking fuel will be obviated. The difficulty under such conditions in shaft producers being for the fuel to cohere in mats, reducing the suface contact, and hence the chemical union of the elements, and at the same time creating a porous fuel bed, subject to chimneys and fissures.

THE MARCONET POWDERED FUEL PRODUCER

A description of a gas producer recently developed in France, which utilizes all grades and kinds of fuel with equal facility, was given in *Le Génie Civil*, briefly as follows: The problem of utilizing all grades of fuel in the gas producer has been satisfactorily solved in France by the invention of M. Marconet of a producer into which the coal is introduced in a finely divided condition. M. Marconet has succeeded in developing a gas producer which utilizes with equal facility fuels entirely free from volatile constituents, such as coke dust and fuels in which the proportion of volatile matter reaches as high as 30 to 35%. Further, the percentage of ash is a matter of indifference, the producer working equally well with fuels containing 5 or 30% of incombustible matter, and good results have been obtained with even bituminous shales containing 70% of ash. Finally, not the least important advantage possessed

by this producer is the fact that it is able to utilize the fine coal and slack which ordinarily goes to waste in coal mining and washing operations. These results are obtained by charging the producer continuously with pulverized fuel, thus avoiding all the difficulties encountered in the ordinary type of producer with its intermittent charging of lump coal.

The use of pulverized fuel makes grinding necessary. This is done usually in tube mills, the cost under ordinary conditions being from $1\frac{3}{4}$ to 2 francs per ton. The fuel is introduced into the producer by means of an apparatus which resembles in principle the carbureter of a gasoline motor; that is, the air drawn into the producer carries with it the pulverized fuel with which it becomes thoroughly mixed before it enters the producer proper.

The producer proper is cylindrical in form and is lined with some sort of refractory material. The mixture of air and coal dust enters at the bottom of the cylinder and tangentially to its circumference. Combustion is set up in the first place by the introduction into the producer of a few pieces of burning wood, the admission of air and fuel being cut down to convenient proportions. The temperature rises rapidly and full working conditions are attained in a very short time. The incombustible materials are projected by centrifugal force to the walls of the producer where they collect in small liquid globules and finally run down into a slag at the bottom. This slag is tapped off every six or eight hours through a tap hole similar to that of a cupola, an arrangement which gives every satisfaction. This slag varies in appearance with different kinds of coal. It is very rare to find a coal of which the incombustible constituents will not settle in this manner, and such difficulties can generally be removed either in the grinding or in the charging of the fuel.

To obtain regular working of the apparatus, it is of prime importance that the proportions of air and coal should be capable of exact regulation and maintenance at all rates of working; in other words, that the charging device should have a simple and efficient regulating mechanism. M. Marconet has achieved this result in the following manner:

The pulverized fuel is charged into a hopper from whence it falls by gravity on to a horizontal revolving plate placed about one centimeter below the hopper. This plate is revolved by means of a friction roller, working on its under side, the distance of which from the axis of the plate can be regulated during working. During the rotation of the plate the fuel is met by a scraper placed obliquely, which causes the coal to fall in a thin stream on a second plate, which may be adjusted at any angle to the horizontal. In sliding off this latter place the pulverized fuel passes the intake of a fan which supplies air to the producer and is drawn in along with the air, the mixing process being complete.

Since the rate of working of the producer varies with the speed of the fan, and the speed of rotation of the feed plate depends entirely upon the speed at which the fan is driven, the supply of coal varies automatically with the air supply. Further regulation of the fuel supply may be obtained by changing the position of the friction roller, raising or lowering the rotating plate to increase or lessen the flow of coal from the hopper, altering the position of the scraper, or changing the angle of inclination of the adjustable plate. In the latter case, changing the angle of inclination of the plate alters the distance of the falling stream of coal from the intake of the fan. By

this means the fineness of the coal supply to the producer can be regulated, as the size of the lump that can be drawn in by the current of air depends upon the distance of the stream of fuel from the fan intake. A receptacle is provided into which the larger particles uneffected by the air current fall, whence they are returned to the tube mill for further grinding.

A 600-h.p. unit has already been constructed on this system and put in successful operation. This producer occupied a space 1.8 by 3 meters in height.

The high temperature produced at the moment of combustion and the thorough mixing of the gases by their rotary movement in the producer has the effect of completely breaking up the heavy hydrocarbons into gaseous products of simple chemical combination. After eighteen months' operation with coals containing 30 to 35% of volatile matter no trace of tarry products has been found. The absence of tar makes the cleaning of the gas an easy matter, as it is necessary only to cool it and to remove any dust which may be carried over.

CHAPTER V

MOVING GASES

Rotary Gas Blower.—A rotary blower for handling hot gas is described by Ingalls as follows: A rotary blower, or exhauster, is placed in the gas flue between the gas producer and combustion chamber for drawing the gas from the producer and forcing it into the combustion chamber. This exhauster is run at uniform speed and produces a uniform movement of gas in the flue, automatically retarding or promoting movement in the producer, accordingly as there is a tendency to produce more or less than the required amount of gas. The exhauster in the gas flue therefore coöperates with the blast beneath the fire to lessen or promote the production of gas in accordance with the quantity the exhauster takes away, and when used with the means for increasing or diminishing the draught openings beneath the fire, so as to admit more or less air, according as there comes less or more than the amount taken away by the exhauster, the required equilibrium in the upper part of the producer may readily be secured and maintained while the feeding and stoking openings are uncovered.

The exhauster comprises wings B', supported on the shafts B^2, which are extended transversely through an enlarged part of the flue adapted to the wings and supported in suitable bearings b. The wings are operated in unison by spur-wheels b' on the shafts B^2. One of the shafts is connected with suitable gearings b^2, adapted to be operated by a pulley B^3, which is driven by a belt from the power shaft. In order to secure the exhauster against accidental high heats and for keeping the shafts, spur-wheels, journals, and bearings cool the shafts are made hollow in that part which passes through the gas flue and for some distance upon each side. There is a partition c midway in the hollow shaft. At the ends outside the flue there are slots or openings c' communicating with the hollow of the shafts. The wings are also made hollow, and the openings c^2 in the shafts upon each side of the partition c are made to communicate with the hollow of the wings. Hollow boxings D are placed upon the shafts so as to cover the openings c', and a blast pipe D' is connected with the boxings, whereby a current of cold air may be forced in at one side by an ordinary blower, passing through the hollow of the shafts and out upon the opposite side.

The wings of the exhauster rub or move relatively to one another, at the point of approximate contact, and thereby cleanse each other of all accumulations of soot upon their adjacent faces, except to the extent of such small increment as will make

141

them fit more closely together; such soot as remians on them being a non-conductor, tends to protect the exhauster by preventing absorption of heat from the gas.

The soot accumulations upon the interior of that part of the flue where the exhauster is located are subject to being forced outward against the wall by the action of the wings, and thus tend to produce objectionable pressure upon or contact between the wings and flue. To obviate any difficulty on that account, a yielding section is arranged in the bottom and top of the flue where the exhauster is located, which will give way before any dangerous pressure is created in that manner, and also in case of accidental explosions. Such a safety-valve is provided by forming part of the arch E, over the wings, of cross-bars e laid sufficiently close to support a layer composed of a mixture of clay and coal dust, and of sufficient weight and strength to resist the gas pressure and yet yield to any outward pressure resulting from soot accumulations being forced outward by the action of the wings of the
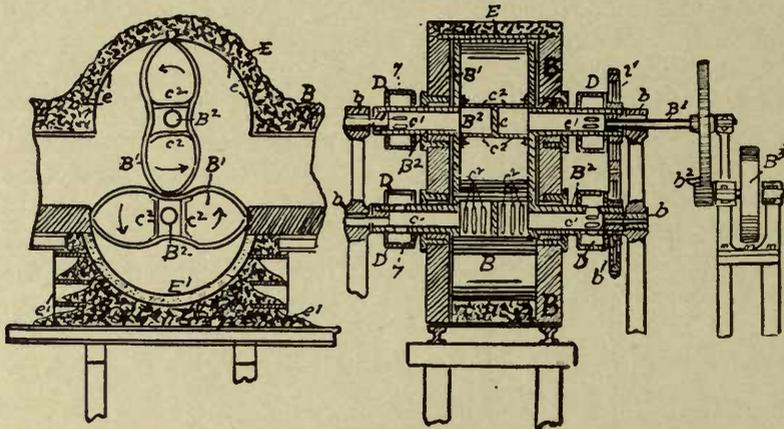
Fig. 84.—Hot Gas Exhauster.

exhauster. The bottom part E' is made of a layer of similar composition supported on a bed of dust e', piled upon the floor under the gas flue. These yielding parts of the flue not only adapt it to utilize the soot accumulations for maintaining a close fit of the wings in the flue, but also afford means of easy access to the interior of the flue for cleaning or repair. When the exhauster in the gas flue is out of repair, the gas is carried around it by means of a by-pass, while the repairing is being done. The battery of producers in such case may be worked by means of the valves controlling the communication of the several members with the gas flue and the escape chimney, whereby any single producer may be cut out during the feeding, stoking, and clinkering thereof, the other producers of the battery furnishing the supply of gas in the meanwhile, the blast beneath the fire being of sufficient strength to be turned on with increased force at the same time.

Suction Producer Exhausters.—The use of the exhauster in connection with the suction producer is multiple, inasmuch as it permits the aggregation of a number

of units, and of maintaining on the suction pipe of each a constant suction which prevents "robbing." But even more important is its ability to replace the holder and by circulating the gases withdrawing them from the producer, and by passing them so that they return, a continuous circulation is kept up, which prevents the fire from deadening at the lower loads, and retains to a great degree a more uniform condition of operation.

From the producer standpoint it will be seen that the exhauster with a seal and by-pass also has a regulating effect, and when used in exhausting the gases it creates an induced draft, which, for bringing the producer up to heats and for blasting, is much more satisfactory than its predecessor, the blower.

But the more important function of the exhauster is that of a pump whereby the suction stroke of the engine is supplied with gas under a head or pressure rather than below atmosphere.

The efficiency of the gas engine as a suction pump is very low, and in many instances the interposition of an exhauster supplying gas at from three to six inches pressure, instead of the engine receiving gas at from one to seven inches vacuum, the total capacity of the engine has been increased by from 15 to 20%, with a corresponding increase in efficiency.

Some idea of the physics involved may be given by an analogous experience of the writer, where by the interposition of an impeller exhauster which was connected in series with the inlet of an air compressor, the capacity of the compressor was increased by some 60%, while there was practically no difference in the total power used.

In this instance the compressor through the medium of the exhauster was supplied with air at about six pounds pressure instead of drawing air at a very high vacuum. It permitted the compressor cylinder to be completely filled with low compressed air at each stroke, hence a much larger volume at each stroke was handled.

It will be seen therefore that the efficiency of the impeller exhauster at low pressure is materially higher than that of a suction pump, whether in form of an air compressor or the suction stroke of a gas engine.

Through the interposition of an exhauster in supplying a gas engine with gas, instead of relying upon suction stroke of the engine to supply the producer with air and the cylinder with gas, an increased engine capacity is attained, in some instances amounting to 10%.

This is due to the increased efficiency of the exhauster over the engine when running as a suction pump, and also the increased density of the gas when supplied under pressure instead of suction to the engine and its freedom from attenuation.

Although the water-seal or "blow-back" exhauster nominally retains a constant pressure upon the engine, this pressure must, of course, vary with the suction on the producer. The pressure difference, naturally, depends upon the depth of the seal, which is necessarily affected by a minus atmosphere on the exhaust side of the exhauster, in the same way as by a plus atmosphere on the pressure side of the exhauster.

In the anthracite producer the variation of the building up of suction, due to increase of ashes, clinkering, condition of the fuel bed, etc., is comparatively slow,

and the regulation can be readily maintained by adding or subtracting water from the seal as reflected by the gauge cocks.
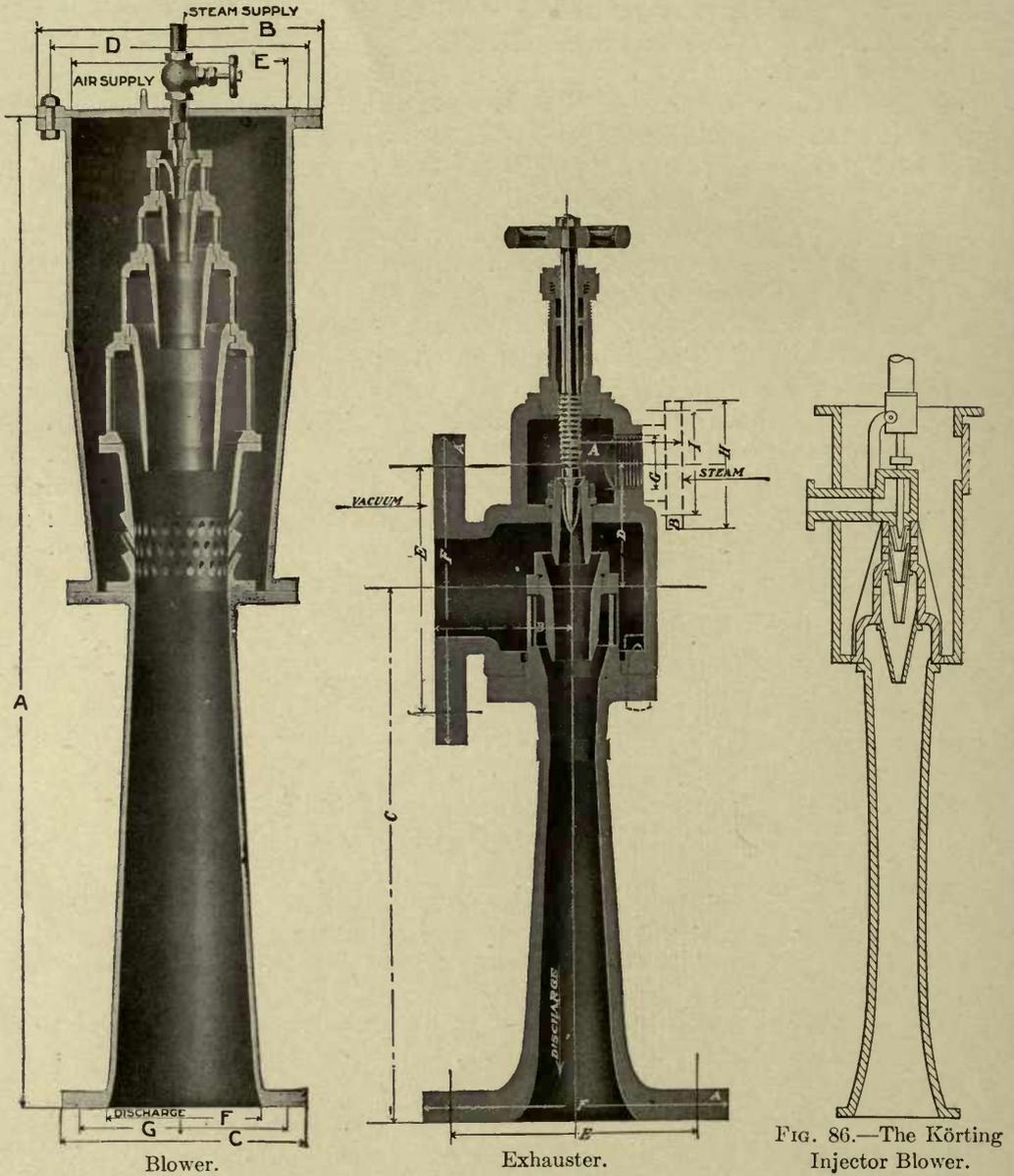
Blower.   Exhauster.

FIG. 85.—Eynon-Evans Steam Blower and Exhauster.

FIG. 86.—The Körting Injector Blower.

With bituminous, and particularly lignite fuels, this is more difficult, by reason of the extreme rapidity in the change of conditions within the producer, hence the operation of the exhauster requires more constant attention.

Steam Blowers.—Gas may be impelled or drawn along conduits or pipes by means of the injector type of steam blower, such as is used in the fireplaces of steam boilers. Two of the Eynon-Evans type and one of Körting blowers are here illustrated and need no further explanation.

Blowers and Fans Compared.—In most tables of speeds and capacities, 30,000 cubic feet of air per hour is figured to melt a ton of iron.

Figured on a basis of one pound pressure per square inch, 1000 cubic feet of air delivered will require five horsepower.

POSITIVE BLOWER	FAN BLOWER
Low Speed.	High Speed.
Belts last indefinitely and give no trouble.	Belts last a comparatively short time and are constantly giving trouble on account of their high speed.
A comparative statement of speed to do a given amount of work would be, say 200 revolutions per minute.	The fan to do a like amount of work under the same conditions would run 2000 revolutions per minute. This is a fair statement of speed ratios.
Actual tests between fan and positive blower have shown the latter to have an advantage of 50% in saving of power over the fan working under the same conditions.	The enormous speed of the fan, together with the fact that the pressure increases the efficiency decreases, accounts for the superiority of the positive blower over the fan, as regards power and efficiency.
With the positive blower the blast is forced to the center of the stock in the cupola, thus producing a hot fire, a saving of fuel, hot iron, and solid castings.	The non-positive blast produced with a fan cannot be forced as completely to center of stock in cupola, hence does not produce as hot a fire, but imperfect combustion and a waste of fuel.
POSITIVE BLAST	NON-POSITIVE BLAST

Testing Blast.—Accurate information regarding the operation of any system of blast piping can only be secured by making careful tests with special instruments.

Most important of the instruments usually employed for this purpose is the pressure gauge, which, in its most convenient form for ordinary work, is presented in the high-pressure water gauge. The large cup at the top of one arm serves as a reservoir in which, because of its size, a practically constant level is maintained, thereby reducing by one-half the length of the gauge glass that would otherwise be necessary. The atmosphere is in contact with the surface of the water in the cup, while the water in the other arm may be subjected to the pressure in any pipe or chamber by connecting the flexible rubber tube therewith. The actual pressure difference may be read in ounces per square inch, as indicated by the level of the water in the graduated glass tube. The instrument here shown is capable of measuring pressures up to 20 ounces.

Such a gauge is designed only for independent observations, so that an approach to a continuous record can only be secured by a multitude of readings taken at very

FANS REQUIRED FOR GAS PRODUCERS

Coal Burned in 24 Hrs.	Cu. Ft Air Required per Min.	2-oz. Pressure				2½-oz. Pressure				3-oz. Pressure				Fans	
		Size Fan.	Rev. per Min.	H.P.	Cu. Ft.	Size Fan.	Rev. per Min.	H.P.	Cu. Ft.	Size Fan.	Rev. per Min.	H.P.	Cu. Ft.	Size.	Cost.
3 ton	600	2	2290	1.2	688	2	2560	1.5	767	2	2840	2.0	845	0	$20
4 "	800	3	1910	1.5	967	3	2130	2.2	1080	2	2840	2.0	845	1	26
5 "	1000	4	1600	2.2	1340	3	2130	2.2	1080	3	2360	3.0	1190	2	33
6 "	1200	4	1600	2.2	1340	4	1790	3.0	1490	4	1980	4.0	1640	3	44
7 "	1400	5	1410	2.7	1690	4	1790	3.0	1490	4	1980	4.0	1640	4	55
8 "	1600	5	1410	2.7	1690	5	1570	3.8	1880	4	1980	4.0	1640	5	70
9 "	1800	6	1190	4.8	2990	5	1570	3.8	1880	5	1740	5.0	2080	6	90
10 "	2000	6	1190	4.8	2990	6	1330	6.8	3330	5	1740	5.0	2080	7	150
12 "	2400	6	1190	4.8	2990	6	1330	6.8	3330	5	1740	5.0	2080	8	200
14 "	2800	6	1190	4.8	2990	6	1330	6.8	3330	6	1475	9.0	3670	9	250
16 "	3200	7	1040	6.8	4250	6	1330	6.8	3330	6	1475	9.0	3670	10	325
18 "	3600	7	1040	6.8	4250	7	1160	9.6	4730	6	1475	9.0	3670		
20 "	4000	7	1040	6.8	4250	7	1160	9.6	4730	7	1290	13.0	5200		
22 "	4400	8	907	9.5	5810	7	1160	9.6	4730	7	1290	13.0	5200		
24 "	4800	8	907	9.5	5810	8	1010	13.0	6440	7	1290	13.0	5200		
26 "	5200	8	907	9.5	5810	8	1010	13.0	6440	7	1290	13.0	5200		
28 "	5600	8	907	9.5	5810	8	1010	13.0	6440	8	1120	17.0	7100		
30 "	6000	9	700	15.5	9530	8	1010	13.0	6440	8	1120	17.0	7100		
32 "	6400	9	700	15.5	9530	8	1010	13.0	6440	8	1120	17.0	7100		
34 "	6800	9	700	15.5	9530	9	780	21.8	10600	8	1120	17.0	7100		
36 "	7200	9	700	15.5	9530	9	780	21.8	10600	9	865	28.0	11700		
38 "	7600	9	700	15.5	9530	9	780	21.8	10600	9	865	28.0	11700		
40 "	8000	9	700	15.5	9530	9	780	21.8	10600	9	865	28.0	11700		
42 "	8400	9	700	15.5	9530	9	780	21.8	10600	9	865	28.0	11700		
44 "	8800	9	700	15.5	9530	9	780	21.8	10600	9	865	28.0	11700		
46 "	9200	9	700	15.5	9530	9	780	21.8	10600	9	865	28.0	11700		
48 "	9600	10	612	21.0	13100	9	780	21.8	10600	9	865	28.0	11700		
50 "	10000	10	612	21.0	13100	9	780	21.8	10600	9	865	28.0	11700		

Coal Burned in 24 Hrs.	Cu. Ft. Air Required per Min.	4-oz. Pressure				5-oz. Pressure				6-oz. Pressure				Fans	
		Size Fan.	Rev. per Min.	H.P.	Cu. Ft.	Size Fan.	Rev. per Min.	H.P.	Cu. Ft.	Size Fan.	Rev. per Min.	H.P.	Cu. Ft.	Size.	Cost.
3 ton	600	1	3660	2.2	676	1	4100	3.1	755	1	4500	4.1	832	0	$20
4 "	800	2	3260	3.2	977	2	3650	4.5	1095	1	4500	4.1	832	1	26
5 "	1000	3	2710	4.5	1375	2	3650	4.5	1095	2	4000	5.9	1200	2	33
6 "	1200	3	2710	4.5	1375	3	3030	6.3	1540	2	4000	5.9	1200	3	44
7 "	1400	4	2280	6.2	1900	3	3030	6.3	1540	3	3320	8.3	1690	4	55
8 "	1600	4	2280	6.2	1900	4	2560	8.7	2130	3	2800	8.3	1690	5	70
9 "	1800	4	2280	6.2	1900	4	2560	8.7	2130	4	2800	11.5	2340	6	90
10 "	2000	5	2000	7.9	2410	4	2560	8.7	2130	4	2800	11.5	2340	7	150
12 "	2400	5	2000	7.9	2410	5	2240	11.1	2700	5	2450	14.5	2970	8	200
14 "	2800	6	1700	13.9	4250	6	1900	19.5	4760	5	2450	14.5	2970	9	250
16 "	3200	6	1700	13.9	4250	6	1900	19.5	4760	6	2080	25.6	5220	10	325
18 "	3600	6	1700	13.9	4250	6	1900	19.5	4760	6	2080	25.6	5220		
20 "	4000	6	1700	13.9	4250	6	1900	19.5	4760	6	2080	25.6	5220		
22 "	4400	7	1480	19 7	6030	6	1900	19.5	4760	6	2080	25.6	5220		
24 "	4800	7	1480	19.7	6030	7	1660	27.6	6750	6	2080	25.6	5220		
26 "	5200	7	1480	19.7	6030	7	1660	27.6	6750	6	2080	25.6	5220		
28 "	5600	7	1480	19.7	6030	7	1660	27.6	6750	7	1820	36.4	7420		
30 "	6000	7	1480	19.7	6030	7	1660	27.6	6750	7	1820	36.4	7420		
32 "	6400	8	1290	26.9	8250	7	1660	27.6	6750	7	1820	36.4	7420		
34 "	6800	8	1290	26.9	8250	8	1460	37.7	9220	7	1820	36.4	7420		
36 "	7200	8	1290	26.9	8250	8	1460	37.7	9220	7	1820	36.4	7420		
38 "	7600	8	1290	26.9	8250	8	1460	37.7	9220	8	1600	51	10120		
40 "	8000	8	1290	26.9	8250	8	1460	37.7	9220	8	1600	51	10120		
42 "	8400	9	995	44.2	13500	8	1460	37.7	9220	8	1600	51	10120		
44 "	8800	9	995	44.2	13500	8	1460	37.7	9220	8	1600	51	10120		
46 "	9200	9	995	44.2	13500	8	1460	37.7	9220	8	1600	51	10120		
48 "	9600	9	995	44.2	13500	9	1110	62	15200	8	1600	51	10120		
50 "	10000	9	995	44.2	13500	9	1110	62	15200	8	1600	51	10120		

REVOLUTIONS PER MINUTE, CUBIC FEET PER MINUTE, AND HORSEPOWER OF MONOGRAM FANS

Fan.	Diameter Inlet	Diameter Wheel	Width Inlet	Width Outlet	Sq. In. Blast 3	Sq. In. Blast 2	Circum. Wheel	¼ Ounce Rev.	¼ oz Cu.Ft.	¼ oz H.P.	1 Ounce Rev.	1 oz Cu.Ft.	1 oz H.P.	1½ Ounces Rev.	1½ oz Cu.Ft.	1½ oz H.P.	2 Ounces Rev.	2 oz Cu.Ft.	2 oz H.P.	2½ Ounces Rev.	2½ oz Cu.Ft.	2½ oz H.P.
00	4⁹⁄₁₆	8¼	2⁶⁄₁₆	1¼	3.44	5.16	2′.16	1695	87.3	.0178	2400	124	.0504	2940	151	.107	3400	175	.143	3800	195	.200
0	5⁷⁄₁₆	9¼	3⅛	2	6.5	9.75	2′.55	1435	165	.0337	2030	234	.0955	2490	286	.171	2880	331	.271	3220	369	.378
1	6⅛	10⅞	3¹¹⁄₁₆	2⁵⁄₁₆	9.32	14	2′.85	1285	237	.0484	1820	336	.137	2230	410	.291	2580	475	.389	2880	528	.543
2	7	12¼	4½	3⅛	13.5	20.3	3′.2	1140	343	.070	1620	485	.199	1980	594	.422	2290	688	.554	2560	767	.787
3	8⅝	14¼	5⅜	3⅞	19	28.6	3′.85	950	483	.099	1350	683	.280	1650	835	.595	1910	967	.795	2130	1080	1.11
4	10	17½	6¼	4½	26.3	39.4	4′.57	800	667	.136	1130	943	.386	1390	1160	.82	1600	1340	1.10	1790	1490	1.53
5	11¼	20	7¾	5	33.2	50	5′.22	700	843	.173	994	1190	.49	1220	1460	1.04	1410	1690	1.39	1570	1880	1.94
6	14½	23½	8⅞	7½	58.7	88.2	6′.14	595	1490	.305	842	2110	.865	1030	2580	1.84	1190	2990	2.45	1330	3330	3.42
7	16	27	11⁵⁄₁₆	9¼	83.3	125	7′.03	520	2116	.432	736	2990	1.22	902	3670	2.6	1040	4250	3.68	1160	4730	4.85
8	18	31	14¹⁵⁄₁₆	11	113.7	170.5	8′.1	452	2890	.59	640	4080	1.67	884	5000	3.54	907	5810	4.75	1010	6440	6.60
9	21	40	16⁷⁄₁₆	14	187	280	10′.5	348	4750	.97	493	6720	2.74	604	8230	5.82	700	9530	7.78	780	10600	10.9
10	24	46	20	16¾	257	386	12′.	305	6540	1.35	432	9250	3.87	530	11300	8.03	612	13100	10.7	684	14600	15.0

Fan.	3 Ounces Rev.	3 oz Cu.Ft.	3 oz H.P.	3½ Ounces Rev.	3½ oz Cu.Ft.	3½ oz H.P.	4 Ounces Rev.	4 oz Cu.Ft.	4 oz H.P.	4½ Ounces Rev.	4½ oz Cu.Ft.	4½ oz H.P.	5 Ounces Rev.	5 oz Cu.Ft.	5 oz H.P.	6 Ounces Rev.	6 oz Cu.Ft.	6 oz H.P.	7 Ounces Rev.	7 oz Cu.Ft.	7 oz H.P.
00	4200	215	.264	4480	231	.33	4820	250	.407	5070	262	.454	5400	279	.565	5930	306	.75	6440	332	.95
0	3560	407	.498	3790	437	.625	4080	470	.77	4300	495	.861	4580	527	1.08	5030	580	1.42	5450	626	1.79
1	3180	583	.716	3390	627	.897	3660	676	1.105	3840	710	1.24	4100	755	1.55	4500	832	2.04	4880	897	2.58
2	2840	845	1.04	3020	906	1.3	3260	977	1.6	3420	1030	1.78	3650	1095	2.24	4000	1200	2.96	4350	1300	3.74
3	2360	1190	1.46	2510	1280	1.83	2710	1375	2.26	2840	1450	2.53	3030	1540	3.16	3320	1590	4.17	3620	1830	5.45
4	1980	1640	2.02	2110	1770	2.52	2280	1900	3.11	2400	2000	3.48	2560	2130	4.35	2800	2340	5.73	3040	2530	7.25
5	1740	2080	2.56	1850	2230	3.2	2000	2410	3.94	2100	5330	4.42	2240	2700	5.53	2450	2970	7.28	2660	3200	9.20
6	1475	3670	4.5	1570	3940	5.65	1700	4250	6.95	1780	4470	7.8	1900	4760	9.75	2080	5220	12.8	2660	5650	16.20
7	1290	5200	6.4	1380	5600	8.0	1480	6030	9.87	1560	5350	11.0	1660	6750	13.8	1820	7420	18.2	1980	8030	23.0
8	1120	7100	8.72	1200	7620	10.90	1290	8250	13.45	1350	8640	15.0	1460	9220	18.85	1600	10120	25.5	1740	10900	31.4
9	865	11700	14.3	920	12600	17.8	995	13500	22.10	1040	14200	24.8	1110	15200	31.00	1220	16700	20.8	1320	18000	51.5
10	756	16100	19.8	806	17300	24.7	870	18600	30.5	912	19000	34.1	975	20800	42.7	1065	22910	56.2	1160	24800	71.0

short intervals. The impracticability of such a method points to the advantages of an instrument which by its own operation records the changes in the intensity of the blast. Such is the blast pressure recorder shown herewith. The instrument, which

Fig. 88.—Blast Pressure Recorder.

Fig. 87.—Water Gauge for High Pressure.
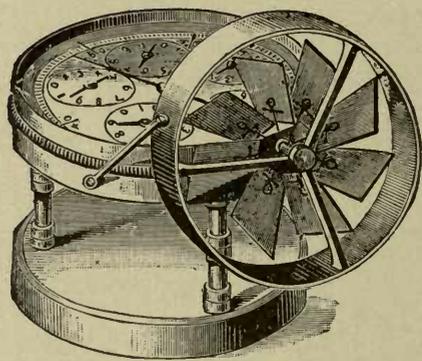
Fig. 89.—Anemometer.

is specially constructed by the Crosby Steam Gage and Valve Co., consists of two essential parts. First, the small cylinder, in which operates a practically frictionless piston under the influence of the pressure. The motion of this piston is like that of a steam-engine indicator, multiplied by the attached arm, which carries at its end

a reservoir containing ink. The second essential portion is the dial or chart, which is usually graduated so as to indicate the pressure or vacuum in inches of water. This chart, which is of paper, is held in place upon a circular plate which is caused to revolve by a system of clockwork. The point of the ink reservoir, being kept elastically in contact with the revolving dial, continuously records all variations in the draft.

The simplest instrument for determining the volume of air flowing through a given passage or orifice is the anemometer. This consists of a delicate fan wheel whose motion is transmitted to a system of gearing within the case. This movement is indicated by the hands upon the dial, from which may be read the velocity in feet per minute, which, multiplied by the area of passage, gives the volume. The instrument here shown is suitable for comparatively low velocities.

Volume by Pitot Tubes.—The volume of air discharged from an orifice or pipe is, theoretically, equal to the product of the velocity of the air flowing and the area of the orifice. Hence for the calculation of volume the velocity is an important factor. To determine the velocity the Pitot tube is commonly used, as shown in the
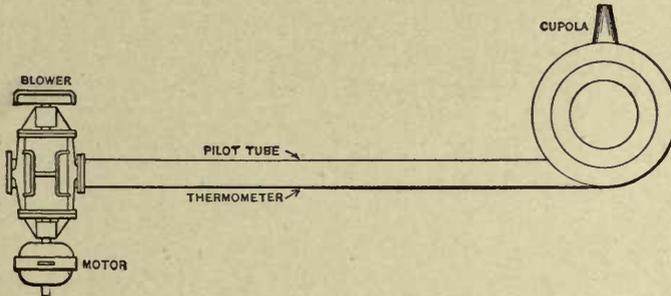
Fig. 90.—Pitot Tube Arrangement, showing Location of Test Pipe for Cupola Blast.

accompanying illustration. It should be inserted in the center of a straight run of blast pipe within about ten feet of the blower. One part of the Pitot tube transmits the total pressure, which is the sum of the static pressure and the velocity pressure. The other part in communication with the slots, as shown above, transmits
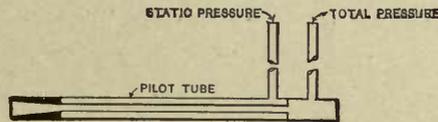
Fig. 91.—Arrangement of Tubes.

the static pressure. Evidently the difference is the velocity pressure. Each is connected to a water gauge, which should show magnified readings so that the difference may be accurately determined.

Great care should be exercised in measuring the velocity pressure, and the instruments should be carefully calibrated. In the ordinary blast pipe for conducting air from the blower to the cupola or furnace, the velocity should not exceed two or three thousand feet per minute. As this velocity corresponds to a pressure of only about

0.4 inch of water, the measurement requires care, but with good instruments the reading will be accurate enough for all practical purposes.

Volume.—The velocity pressure being known, the volume of free air passing through the pipe may be determined from the following formula:

$$V = av = \frac{60acP_1}{P}\sqrt{\frac{2gp}{d}};$$

in which V = the volume of free air in cubic feet per minute;

c = coefficient of Pitot tube, which should be determined for each tube;

a = area of pipe in square feet;

v = velocity in feet per minute;

$2g$ = 64.32;

p = velocity pressure in pounds per square foot; p is the difference between the two pressures observed on the Pitot tube.;

d = density or weight per cubic foot of air at pressure, temperature, and humidity at point of observation;

P_1 = absolute pressure of air in the pipe in pounds per square foot;

P = atmospheric pressure in pounds per square foot.

Horsepower.—Assuming that the air is compressed without cooling, the horsepower may be found from the following:

$$\text{Horsepower} = \frac{VP\left[\left(\frac{P_1}{P}\right) - 1\right]}{11,000};$$

in which V = volume of free air in cubic feet per minute, as found above;

P = pressure of the atmosphere or suction pressure (absolute) in pounds per square foot;

P_1 = pressure of compression (absolute) in pounds per square foot.

High Pressure Blowers.—There are four formulas sometimes used in computing the power required by high pressure blowers. Values obtained from these formulas have been placed in the form of curves and are shown in the accompanying diagrams.

$$\text{H.P.} = \frac{VPl_e\left(\frac{P_1}{P}\right)}{33,000} \quad \ldots \ldots \ldots \ldots \ldots \quad (1)$$

$$\text{H.P.} = \frac{VP\left[\left(\frac{P_1}{P}\right)^{\frac{1}{2}} - 1\right]}{11,000}, \quad \ldots \ldots \ldots \ldots \quad (2)$$

$$H.P. = \frac{V(P_1 - P)}{33,000} \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad (3)$$

$$H.P. = \frac{lbs.\ per\ sq.in. \times V}{200} \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad (4)$$

Formula No. (1) gives the horsepower required when the air is cooled during compression as in the ordinary air compressor.

Formula No. (2), which has been explained, is used when it may be assumed that the air is compressed so quickly that it does not have time to cool to atmospheric temperature as in nearly all blower work.
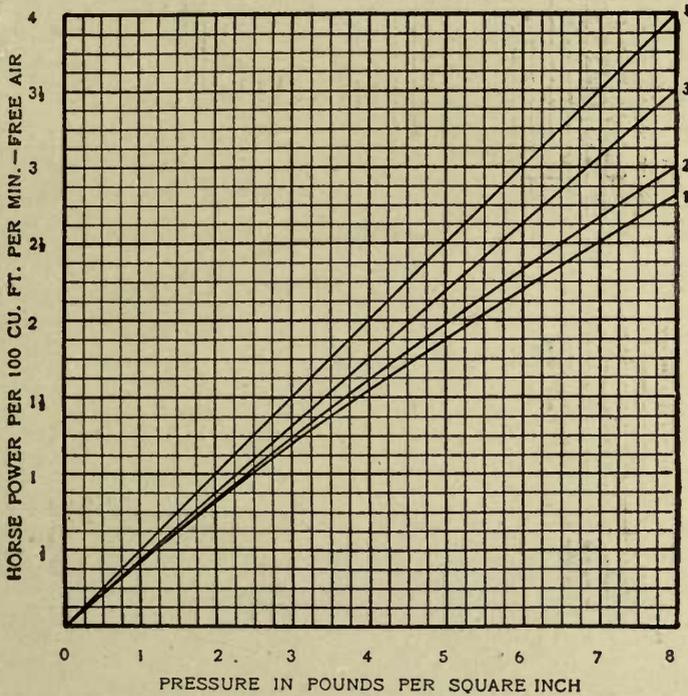
Fig. 92.—Power required by Pressure Blowers.

Formula No. (3), the ordinary "hyrdaulic" formula is ordinarily used for pressures up to 5 ounces.

Formula No. (4) is frequently used by other makers of positive or rotary blowers for determining the horsepower required for operating their machines. In this formula $V =$ the volume of air displaced by the impellers, no allowance being made for slippage.

The accompanying illustration is of a motor-driven high pressure blower made by the Brewster Engineering Co. It is rated at 110 to 440 cu.ft. per minute, and runs at 10 lbs. per sq.in. maximum pressure. Its efficiency is 85% at 2 lbs. per sq.in. pressure.
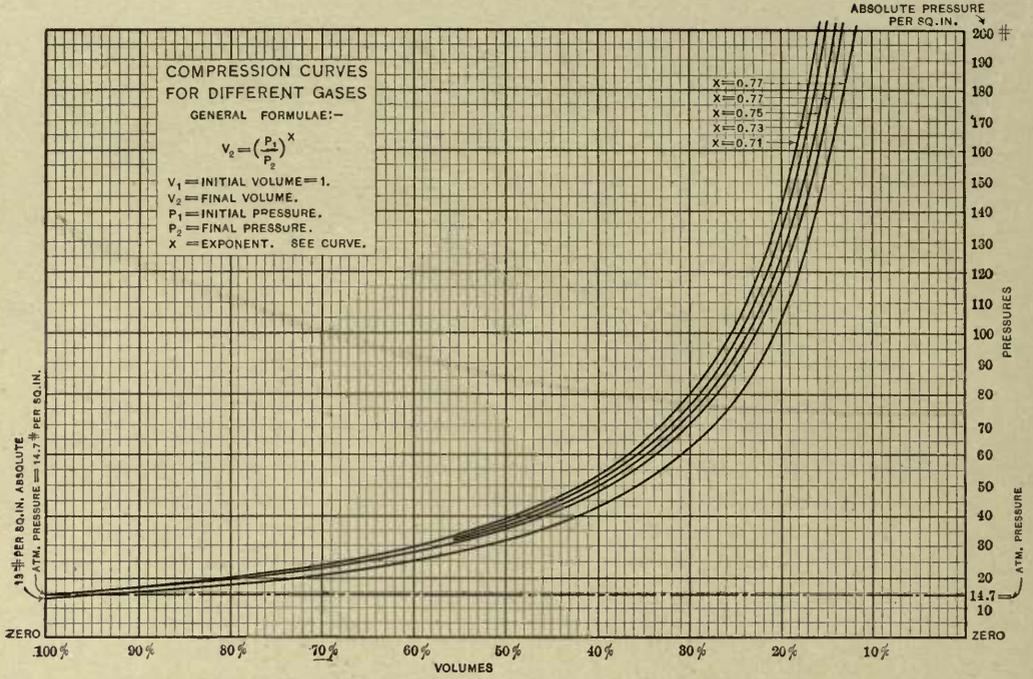
FIG. 93.—Relation of Volume to Pressure.
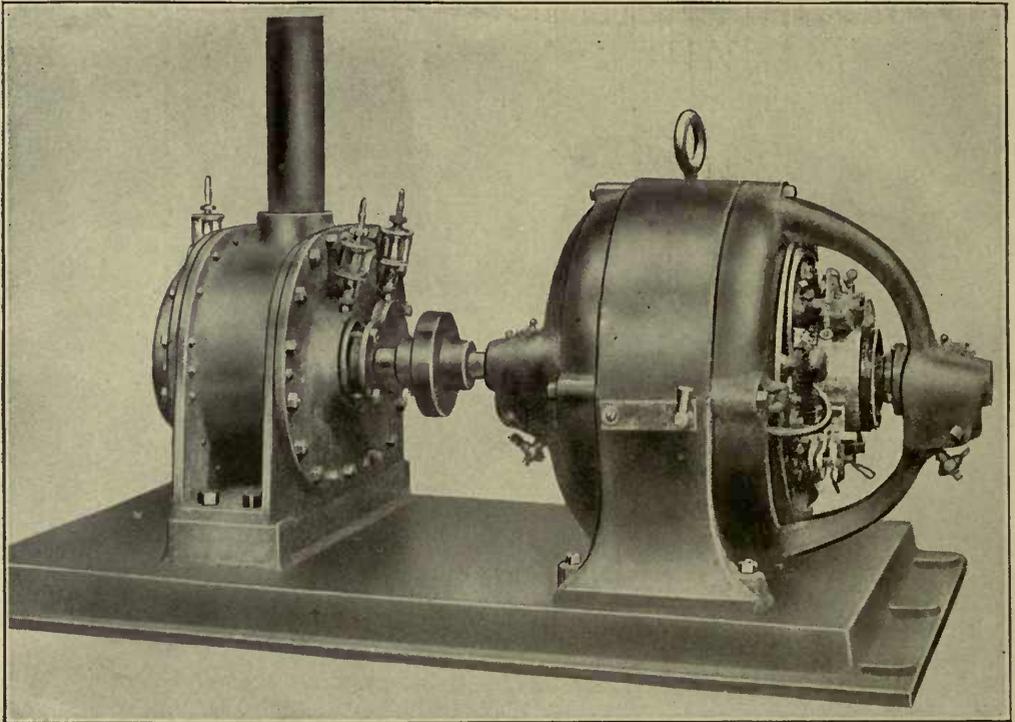
FIG. 94.—Brewster High Pressure Blower.

Venturi Meter.—The Venturi tube for measuring gas flow was described by Chas. E. Lucke in *Progressive Age* (April 1, 1907, p. 178).

In recent tests made on some large gas engines at the Lackawanna Steel Company's plant in Buffalo, and reported in the Journal of the Am. Soc. Mech. Eng. for March, 1907, a large Venturi meter was used as one of the four methods for measuring gas. This meter has an up-stream and down-stream diameter of $15\frac{7}{8}$ inches, and a throat diameter of $6\frac{1}{4}$ inches.

The formula used was:

$$V_2{}^2 = \frac{2g\frac{1}{c}p_1 v_1\left[1-\left(\frac{p_2}{p_1}\right)^c\right]}{1-\left(\frac{A_2}{A_1}\right)^2\left(\frac{p_2}{p_1}\right)^{\frac{2}{K}}},$$

where V_2 = velocity of gas at the throat in feet per second;

p_2 = absolute pressure of gas, lbs. per sq. ft. at throat;

p_1 = same at entrance;

v_2 = cu.ft. per lb. of gas at throat;

v_1 = same at entrance end of meter;

A_2 = area of pipe in sq.ft. at throat;

A_1 = same at entrance end of meter;

K = 1.4 for air. It is the ratio of the specific heat at constant pressure to that at constant volume;

$c = \dfrac{K-1}{K}$;

The corrections were found to be as follows:

Throat Velocity-head Increment in Inches of Water.	Corrections to Apply to Square Root of Velocity-head Increment Method of Computation.
1	0.0000
6	0.0032
12	0.0051

From these the corrections were plotted for each inch. It was believed from the work done that the Venturi meter was the most accurate method used, and it is freely recommended to all who have large quantities of gas to measure, even when the pressure on that gas fluctuates as violently as it may with a number of gas engines on the pipe running in parallel.

Data on Moving Air.—The pressure of the atmosphere is due to the weight of the air, and for any area is to be measured by the weight of a column of air having the given area as a base and a height equal to that of the atmosphere. Under standard conditions of barometric pressure of 29.921 inches, the atmospheric pressure is 14.69 lbs. per sq.in., or 2115.36 lbs. per sq.ft. At this pressure a cubic foot of dry air at 50° has a density of 0.077884 lbs. If air under this head were allowed to flow freely into a vacuum, the velocity would be 1321.7 ft. per second.

The velocity with which air escapes into the atmosphere from a reservoir is dependent upon the pressure therein maintained, and would vary in direct proportion to its square root were it not for certain slightly modifying influences. Most important of these is the change in density which results from a change in pressure. This has been taken into account in the calculation of an accompanying table. The volume of air at a given velocity discharged through an orifice depends upon its shape, and is always less than that measured by its full area. For a given *effective* area the volume is proportional to the velocity, as is evident in the table. The power theoretically required to move a given volume of air is measured by the product of the velocity and the total resisting pressure. This power, as given in the table of velocity, volume, and horsepower, varies as the cube of the velocity.

Evidently, with a constant velocity due to a constant head, the actual pressure must vary directly as the density of the air and inversely as its absolute temperature. Therefore if the velocity remains constant, the power required to overcome the resistance must be exactly proportional to the relative pressure.

For any size of centrifugal fan there exists a certain maximum area over which a given pressure may be maintained, dependent upon and proportional to the speed at which it is operated. If this area, known as its "capacity area," or square inches of blast, be increased, the pressure is lowered (the volume being increased), but if decreased the pressure remains constant. The pressure produced by a given fan, and its effective capacity area being known, its nominal capacity and the horsepower required, without allowance for frictional losses, may be determined from the above table. In practice the outlet of a fan greatly exceeds the capacity area; hence the volume moved and the horsepower required are in excess of the amounts determined as above.

Influence of Temperature.—The effect of increasing the temperature of the air is to decrease its density, thereby reducing the weight of a given volume, the pressure required to produce a given velocity, and the power necessary to move the same volume at the same velocity. These relations are presented in an accompanying table. The variation in pressure resulting from change in temperatures is indicated in column 3. As a consequence the values given in column 7 are identical with those in column 3. The velocity being constant, the volume discharged is also constant, but its relative weight is as shown in column 4.

If it be desired to pass through the same orifice a constant weight of air, its velocity must necessarily vary directly with its increase in absolute temperature, for its density correspondingly decreases. The velocity necessary to move the same weight is produced under each different temperature by the relative pressure shown in column 6. The pressure thus necessary to produce this velocity must at constant temperature evidently increase with the square of the velocity, and at other temperatures must coincidently decrease inversely with the absolute temperature; that is, proportionately to the density.

For illustration take the case of air at a temperature of 300°. Per the table, column 5, the velocity necessary to move the same weight as at 50° is relatively 1.49. For its production this would call for a relative pressure of $1.49^2 = 2.22$ at 50°, but at the temperature of 300° the pressure required to produce the given velocity is, per column 3, only 0.67 of that required at 50°. Hence the relative pressure required

at 300° to produce the velocity necessary to move the same weight of air is relatively $2.22 \times 0.67 = 1.49$ times that which is necessary to produce the movement of the same weight, but less volume, at 50°. Under these conditions of moving the same weight at different temperatures, the relative power required is evidently the product of the factors in column 5 and in column 6, for it is represented by the product of the pressure into the velocity. Upon this basis column 8 has been calculated. From this is evident the fact that the work performed is not proportional to the weight of the air moved, but to the distance through which the resistance is overcome.

WEIGHTS OF AIR, VAPOR OF WATER, AND SATURATED MIXTURES OF AIR AND VAPOR

At Different Temperatures under the Ordinary Atmospheric Pressure of 29.921 Inches of Mercury.

Temperature, Fahrenheit.	Volume of Dry Air. Volume at 32° being 1.000.	Weight of a Cubic Foot of Dry Air in Pounds.	Elastic Force of Vapor in Inches of Mercury (Regnault).	Mixtures of Air Saturated with Vapor.						Cubic Foot of Vapor from 1 Lb. of Water at its own Pressure in Column 4.
				Elastic Force of the Air in the Mixture of Air and Vapor in Inches of Mercury.	Weight of Cubic Foot of the Mixture of Air and Vapor.			Weight of Vapor Mixed with 1 Lb. of Air in Pounds.	Weight of Dry Air Mixed with 1 Lb. of Vapor in Pounds.	
					Weight of the Air in Pounds.	Weight of the Vapor in Pounds.	Total Weight of Mixture in Pounds.			
1	2	3	4	5	6	7	8	9	10	11
0°	.935	.0864	.044	29.877	.0863	.000079	.086379	.00092	1092.4	
12	.960	.0842	.074	29.849	.0840	.000130	.084130	.00155	646.1	
22	.980	.0824	.118	29.803	.0821	.000202	.082302	.00245	406.4	
32	1.000	.0807	.181	29.740	.0802	.000304	.080504	.00379	263.81	3289
42	1.020	.0791	.267	29.654	.0784	.000440	.078840	.00561	178.18	2252
52	1.041	.0776	.388	29.533	.0766	.000627	.077227	.00819	122.17	1595
62	1.061	.0761	.556	29.365	.0747	.000881	.075581	.01179	84.79	1135
72	1.082	.0747	.785	29.136	.0727	.001221	.073921	.01680	59.54	819
82	1.102	.0733	1.092	28.829	.0706	.001667	.072267	.02361	42.35	600
92	1.122	.0720	1.501	28.420	.0684	.002250	.070717	.03289	30.40	444
102	1.143	.0707	2.036	27.885	.0659	.002997	.068897	.04547	21.98	334
112	1.163	.0694	2.731	27.190	.0631	.003946	.067046	.06253	15.99	253
122	1.184	.0682	3.621	26.300	.0599	.005142	.065042	.08584	11.65	194
132	1.204	.0671	4.752	25.169	.0564	.006639	.063039	.11771	8.49	151
142	1.224	.0660	6.165	23.756	.0524	.008473	.060873	.16170	6.18	118
152	1.245	.0649	7.930	21.991	.0477	.010716	.058416	.22465	4.45	93.3
162	1.265	.0638	10.099	19.822	.0423	.013415	.055715	.31713	3.15	74.5
172	1.285	.0628	12.758	17.163	.0360	.016682	.052682	.46338	2.16	59.2
182	1.306	.0618	15.960	13.961	.0288	.020536	.049336	.71300	1.402	48.6
192	1.326	.0609	19.828	10.093	.0205	.025142	.045642	1.22643	.815	39.8
202	1.347	.0600	24.450	5.471	.0109	.030545	.041445	2.80230	.357	32.7
212	1.367	.0591	29.921	0.000	.0000	.036820	.036820	Infinite	.000	27.1

Other things equal, and friction neglected, the power required to drive a fan increases as the cube of its speed; for the pressure increases as its square, the velocity obviously increases as its speed, and the work done is the product of these two fac-

tors. Furthermore, the speed remaining constant, the volume also remains constant, while the weight of air moved and the power required both decrease in proportion to the density of the air; that is, inversely as its absolute temperature. The cause for the enormous waste of energy in the movement of air by a chimney is due to the fact that the energy is not directly applied, as with a fan, but that the air movement is secured by the expenditure of heat in raising the temperature, and reducing the density of the gas, so that gravity may act to produce the flow.

VELOCITY, VOLUME, AND HORSEPOWER REQUIRED WHEN AIR UNDER GIVEN PRESSURE IN OUNCES PER SQUARE INCH IS ALLOWED TO ESCAPE INTO THE ATMOSPHERE

Pressure in Ounces. Per Square Inch.	Velocity of Dry Air at 50° Temperature F. Escaping into the Atmosphere through any Shaped Orifice in any Pipe or Reservoir in which the Given Pressure is Maintained.		Volume of Air in Cubic Feet which may be Discharged in One Minute through an Orifice having an Effective Area of Discharge of One Square Inch.	Horsepower Required to Move the Given Volume of Air Under the Given Conditions.
	In Feet per Second.	In Feet per Minute.		
$\frac{1}{8}$	30.47	1,828.4	12.69	0.00043
$\frac{1}{4}$	43.08	2,585.0	17.95	0.00122
$\frac{3}{8}$	52.75	3,165.1	21.98	0.00225
$\frac{1}{2}$	60.90	3,653.8	25.37	0.00346
$\frac{5}{8}$	68.07	4,084.0	28.36	0.00483
$\frac{3}{4}$	74.54	4,472.6	31.06	0.00635
$\frac{7}{8}$	80.50	4,829.7	33.54	0.00800
1	86.03	5,161.7	35.85	0.00978
$1\frac{1}{8}$	91.22	5,473.4	38.01	0.01166
$1\frac{1}{4}$	96.13	5,768.0	40.06	0.01366
$1\frac{3}{8}$	100.80	6,047.9	42.00	0.01575
$1\frac{1}{2}$	105.25	6,315.2	43.86	0.01794
$1\frac{5}{8}$	109.52	6,571.3	45.63	0.02022
$1\frac{3}{4}$	113.64	6,817.6	47.34	0.02260
$1\frac{7}{8}$	117.58	7,055.0	49.00	0.02505
2	121.41	7,284.4	50.59	0.02759
$2\frac{1}{8}$	125.11	7,506.7	52.13	0.03021
$2\frac{1}{4}$	128.70	7,722.2	53.63	0.03291
$2\frac{3}{8}$	132.20	7,931.8	55.08	0.03568
$2\frac{1}{2}$	135.59	8,135.7	56.50	0.03852
$2\frac{5}{8}$	138.91	8,334.4	57.88	0.04144
$2\frac{3}{4}$	142.14	8,528.3	59.22	0.04442
$2\frac{7}{8}$	145.29	8,717.6	60.54	0.04747
3	148.38	8,902.8	61.83	0.05058
$3\frac{1}{8}$	151.40	9,084.0	63.08	0.05376
$3\frac{1}{4}$	154.36	9,261.5	64.32	0.05701
$3\frac{3}{8}$	157.26	9,435.4	65.52	0.06031
$3\frac{1}{2}$	160.10	9,606.1	66.71	0.063668
$3\frac{5}{8}$	162.89	9,773.3	67.87	0.06710
$3\frac{3}{4}$	165.63	9,938.0	69.01	0.07058
$3\frac{7}{8}$	168.33	10,099.6	70.14	0.07412

VELOCITY, VOLUME, HORSEPOWER, ETC.—*Continued*

Pressure.	Velocity per Second.	Velocity per Minute.	Volume.	Horsepower.
4	170.98	10,258.6	71.24	0.07771
4¼	176.15	10,568.8	73.39	0.08507
4½	181.16	10,869.5	75.48	0.09264
4¾	186.03	11,161.5	77.51	0.1004
5	190.76	11,445.5	79.48	0.1084
5¼	195.37	11,722.0	81.40	0.1166
5½	199.86	11,991.5	83.24	0.1249
5¾	204.25	12,254.8	85.10	0.1335
6	208.53	12,511.9	86.89	0.1422
6½	216.82	13,009.3	90.34	0.1602
7	224.77	13,486.4	93.66	0.1788
7½	232.42	13.945,4	96.84	0.1981
8	239.80	14,387.9	99.92	0.2180
8½	246.92	14,815.4	102.88	0.2385
9	253.83	15,229.6	105.76	0.2596
9½	260.52	15,631.0	108.55	0.2812
10	267.00	16,020.4	111.25	0.3034
10½	273.32	16,399.3	113.88	0.3261
11	279.70	16,768.1	116.45	0.3493
11½	285.46	17,127.6	118.94	0.3730
12	291.30	17,478.2	121.38	0.3972
12½	297.01	17,820.6	123.75	0.4219
13	302.59	18,155.2	126.06	0.4470
13½	308.04	18,482.4	128.35	0.4726
14	313.38	18,802.7	130.57	0.4986
14½	318.61	19,116.3	132.75	0.5250
15	323.73	19,423.6	134.89	0.5518
15½	328.75	19,725.0	136.98	0.5791
16	333.68	20,020.7	139.03	0.6067
16½	338.51	20,310.8	141.05	0.6347
17	343.26	20,595.8	143.03	0.6631
17½	347.93	20,875.8	144.97	0.6919
18	352.52	21,151.0	146.88	0.7211
18½	357.03	21,421.6	148.76	0.7506
19	361.46	21,687.8	150.61	0.7804
19½	365.83	21,949.7	152.43	0.8107
20	370.13	22,207.5	154.22	0.8412

HEIGHT OF WATER COLUMN IN INCHES

Corresponding to Various Pressures in Ounces per Square Inch

Pressure in Ozs. per Sq.in.	Decimal Parts of an Ounce.									
	.0	.1	.2	.3	.4	.5	.6	7	.8	.9
0	....	0.17	0.35	0.52	0.69	0.87	1.04	1.21	1.38	1.56
1	1.73	1.90	2.08	2.25	2.42	2.60	2.77	2.94	3.11	3.29
2	3.46	3.63	3.81	3.98	4.15	4.33	4.50	4.67	4.84	5.01
3	5.19	5.36	5.54	5.71	5.88	6.06	6.23	6.40	6.57	6.75
4	6.92	7.09	7.27	7.44	7.61	7.79	7.96	8.13	8.30	8.48
5	8.65	8.82	9.00	9.17	9.34	9.52	9.69	9.86	10.03	10.21
6	10.38	10.55	10.73	10.90	11.07	11.26	11.43	11.60	11.77	11.95
7	12.11	12.23	12.46	12.63	12.80	12.97	13.15	13.49	13.32	13.67
8	13.84	14.01	14.19	14.36	14.53	14.71	14.88	15.05	15.22	15.40
9	15.57	15.74	15.92	16.09	16.26	16.45	16.62	16.79	16.96	17.14

PRESSURE IN OUNCES PER SQUARE INCH

Corresponding to Various Heads of Water in Inches

Head in Inches	Decimal Parts of an Inch.									
	.0	1.	.2	.3	.4	.5	.6	.7	.8	9.
0	....	0.06	0.12	0.17	0.23	0 29	0.35	0.40	0.46	0.52
1	0.58	0.63	0.69	0.75	0.81	0.87	0.93	0.98	1.04	1.09
2	1.16	1.21	1.27	1.33	1.39	1.44	1.50	1.56	1.62	1.67
3	1.73	1.79	1.85	1.91	1.96	2.02	2.08	2.14	2.19	2.25
4	2.31	2.37	2.42	2.48	2.54	2.60	2.66	2.72	2.77	2.83
5	2.89	2.94	3.00	3.06	3.12	3.18	3.24	3.29	3.35	3.41
6	3.47	3.52	3.58	3.64	3.70	3.75	3.81	3.87	3.92	3.98
7	4.04	4.10	4.16	4.22	4.28	4.33	4.39	4.45	4.50	4.56
8	4.62	4.67	4.73	4.79	4.85	4.91	4.97	5.03	5.08	5.14
9	5.20	5.26	5.31	5.37	5.42	5 48	5.54	5.60	5.66	5.72

AREAS OF ORIFICES

Diameter of Circle in Inches.	Area of Circle in Square Inches.	Sides of Square of Same Area in Square Inches.	Diameter of Circle in Inches.	Area of Circle in Square Inches.	Sides of Square of Same Area in Square Inches.
1	.785	.89	21	346.36	18.61
1½	1.767	1.33	21½	363.05	19.05
2	3.142	1.77	22	380.13	19.50
2½	4.909	2.22	22½	397.61	19.94
3	7.069	2.66	23	415.48	20.38
3½	9.621	3.10	23½	433.74	20.83
4	12.566	3.54	24	452.39	21.27
4½	15.904	3.99	24½	471.44	21.71
5	19.635	4.43	25	490.88	22.16
5½	23.758	4.87	25½	510.71	22.60
6	28.274	5.32	26	530.93	23.04
6½	33.183	5.76	26½	551.55	23.49
7	38.485	6.20	27	572.56	23.93
7½	44.179	6.65	27½	593.96	24.37
8	50.266	7.09	28	615.75	24.81
8½	56.745	7.53	28½	637.94	25.26
9	63.617	7.98	29	660.52	25.70
9½	70.882	8.42	29½	683.49	26.14
10	78.540	8.86	30	706.86	26.59
10½	86.590	9.30	30½	730.62	27.03
11	95.03	9.75	31	754.77	27.47
11½	103.87	10.19	31½	779.31	27.92
12	113.10	10.63	32	804.25	28.36
12½	122.72	11.08	32½	829.58	28.80
13	132.73	11.52	33	855.30	29.25
13½	143.14	11.96	33½	881.41	29.69
14	153.94	12.41	34	907.92	30.13
14½	165.13	12.85	34½	934.82	30.57
15	176.72	13.29	35	962.11	31.02
15½	188.69	13.74	35½	989.80	31.46
16	201.06	14.18	36	1017.88	31.90
16½	213.83	14.64	36½	1046.35	32.35
17	226.98	15.07	37	1075.21	32.79
17½	240.53	15.51	37½	1104.47	33.23
18	254.47	15.95	38	1134.12	33.68
18½	268.80	16.40	38½	1164.16	34.12
19	283.53	16.84	39	1194.59	34.56
19½	298.65	17.28	39½	1225.42	35.01
20	314.16	17.72	40	1256.64	35.45
20½	330.06	18.17	40½	1288.25	35.89

REVOLUTIONS OF FAN-WHEEL OF GIVEN DIAMETER NECESSARY TO MAINTAIN A GIVEN PRESSURE OVER AN AREA WHICH IS WITHIN THE CAPACITY OF THE FAN.

Diam. of Fan-wheel in Feet.	Pressure in Ounces per Square Inch.												
	$\frac{1}{8}$	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	1	$1\frac{1}{8}$	$1\frac{1}{4}$	$1\frac{3}{8}$	$1\frac{1}{2}$	$1\frac{3}{4}$
1	582	823	1007	1163	1300	1423	1537	1643	1742	1836	1925	2010	2170
$1\frac{1}{4}$	466	658	806	930	1040	1139	1230	1314	1394	1469	1540	1608	1736
$1\frac{1}{2}$	388	549	672	775	867	949	1025	1095	1162	1224	1284	1340	1447
$1\frac{3}{4}$	333	470	576	665	743	813	878	938	996	1049	1100	1149	1240
2	291	411	504	582	650	712	769	822	871	918	963	1005	1085
$2\frac{1}{4}$	259	366	448	517	578	633	683	730	774	816	856	893	964
$2\frac{1}{2}$	233	329	403	465	520	570	615	657	697	734	770	804	868
$2\frac{3}{4}$	212	300	366	423	493	518	559	597	634	668	700	731	789
3	194	274	336	388	433	475	513	548	581	612	642	670	723
$3\frac{1}{2}$	166	235	288	332	372	407	439	469	498	525	550	574	620
4	146	206	252	291	325	356	384	411	436	459	481	502	543
$4\frac{1}{2}$	129	183	224	258	289	316	342	365	387	408	428	447	482
5	116	164	202	232	260	285	308	329	349	367	385	402	434
$5\frac{1}{2}$	106	149	183	211	236	259	280	299	317	334	350	366	395
6	97	137	168	194	217	238	256	274	290	306	321	335	362
$6\frac{1}{2}$	90	126	155	179	200	219	236	253	268	282	296	309	334
7	83	117	144	166	186	203	220	235	249	262	275	287	310
$7\frac{1}{2}$	78	110	135	155	173	190	204	219	232	245	257	268	289
8	73	103	126	146	163	178	192	205	218	230	241	251	271
$8\frac{1}{2}$	69	97	119	137	153	167	181	194	205	216	226	236	255
9	65	92	112	129	144	158	171	183	194	204	214	223	241
$9\frac{1}{2}$	61	87	106	123	137	149	162	173	183	193	203	212	228
10	58	82	101	116	130	142	154	164	174	184	193	201	217
11	53	75	92	106	118	129	140	150	158	167	175	183	197
12	49	69	84	97	108	119	128	137	145	153	160	168	181
13	45	63	78	90	100	110	116	126	130	141	148	155	167
14	42	59	72	83	93	102	110	117	124	131	138	144	155
15	39	55	67	78	87	95	102	110	116	122	128	134	145

REVOLUTIONS OF FAN-WHEEL OF GIVEN DIAMETER NECESSARY TO MAINTAIN A GIVEN PRESSURE OVER AN AREA WHICH IS WITHIN THE CAPACITY OF THE FAN—(*Continued*)

Diam. of Fan-wheel in Feet.	Pressure in Ounces per Square Inch.												
	2	2½	3	3½	4	4½	5	5½	6	6½	7	7½	8
1	2319	2590	2834	3058	3265	3460	3643	3817	3992	4141	4293	4439	4580
1¼	1855	2072	2267	2446	2612	2768	2915	3054	3186	3313	3434	3551	3664
1½	1546	1727	1889	2039	2178	2307	2429	2545	2655	2761	2862	2960	3053
1¾	1325	1480	1619	1747	1866	1977	2082	2171	2276	2366	2453	2536	2617
2	1159	1295	1417	1529	1633	1730	1822	1909	1996	2070	2146	2219	2289
2¼	1030	1151	1259	1359	1451	1538	1619	1696	1770	1840	1908	1973	2035
2½	928	1036	1134	1223	1306	1384	1457	1527	1593	1656	1717	1776	1832
2¾	843	942	1030	1112	1188	1258	1325	1388	1448	1506	1561	1614	1665
3	773	863	945	1019	1089	1153	1215	1272	1328	1380	1431	1480	1527
3½	662	740	810	874	933	989	1041	1086	1138	1183	1226	1268	1308
4	580	647	708	764	816	865	911	954	998	1035	1073	1110	1145
4½	515	575	630	679	726	769	810	848	885	920	954	986	1018
5	464	518	567	612	653	692	729	763	796	828	859	888	916
5½	422	471	515	556	594	629	662	694	724	753	781	807	833
6	386	432	472	510	545	577	607	636	664	690	716	740	763
6½	357	398	436	470	502	532	561	587	613	637	661	683	705
7	331	370	405	437	466	494	520	543	569	592	613	634	654
7½	309	345	378	408	435	461	486	509	531	552	572	592	611
8	290	324	354	382	408	432	455	477	499	518	537	555	572
8½	273	305	333	360	384	407	429	449	469	487	505	522	539
9	258	288	315	340	363	384	405	424	443	460	477	493	509
9½	244	273	298	322	344	364	384	402	419	436	452	467	482
10	232	259	283	306	327	346	364	382	398	414	429	444	458
11	211	235	258	278	247	315	331	347	362	376	390	404	416
12	193	216	236	255	272	288	304	318	332	345	358	370	382
13	178	199	218	235	251	266	280	294	306	319	330	341	352
14	165	185	202	218	233	247	260	271	284	296	307	317	327
15	155	173	189	204	218	231	243	254	266	276	286	291	305

CHAPTER VI

SOLID FUELS

Coal.—Coal is a remnant of the flora of past geological periods; consequently it is organic matter (chiefly cellulose) that has undergone chemical changes, and to which mineral impurities have been added. These chemical changes are indicated in a general way by the following table of average ultimate analyses of cellulose, wood, peat, lignite, bituminous coal, and anthracite, the sulphur and ash being disregarded.

ULTIMATE ANALYSES OF FUELS

	Carbon	Hydrogen	Oxygen	Nitrogen
Cellulose	44.4	6.2	49.4	0.
Wood	50.	6.	43.	1.
Peat	59.	6.	33.	2.
Lignite	69.	5.5	25.	0.8
Bituminous coal	82.	5.	13.	0.8
Anthracite coal	95.	2.5	2.5	trace

These figures show that the transformation of wood to anthracite is accompanied by an increase in the carbon, and a decrease in the hydrogen and oxygen, the loss in the latter element being the more pronounced. As, however, these analyses show only the elementary substances that go to compose the coal, they do not give a fair idea of the complex chemical nature of the coal itself.

The ash in bituminous coal varies from 3 to 15% and more, but for a better comparison of the coals it is taken uniformly at 8%. The sulphur varies between 0.5 and 2.5% and phosphorus between 0.007 and 0.025%. The coal gases given off during destructive distillation are inflammable in their nature, and besides water vapor contain tar, ammonia, cyanides, benzol, and naphthalene.

Classification of Coals.—Percy classified coal into three varieties: (1) Non-caking, or free-burning, rich in oxygen; (2) caking; (3) non-caking, rich in carbon. This classification was based on the chemical composition of the coals and therefore on their calorific power. Another classification, much used in Europe, divided coal not only according to the character of the residue left after dry distillation, but also according to the length of the flame produced in combustion. Thus Grüner distinguished five types of bituminous coal, as follows:

1. Non-caking coals with long flames: These coals which most closely approach lignite in character, yield 55 to 60% of pulverulent coke, the evolution of volatile

162

matter giving rise to a long smoky flame. In composition they show 75 to 80% C, 4.5 to 5.5% H, and 15 to 19.5% O and N, the ratio of the oxygen to the hydrogen being 3:1 to 4:1. In calorific power they range from 8000 to 8500 calories, 1 lb. of coal being capable of evaporating from 8 to 10 lbs. of water.

2. Caking, long-flame gas coal: The coals of this type yield 60 to 68% of caked, but very friable and porous coke, and 32 to 40% of volatile matter, of which 17 to 20% is gas. In composition they vary from 80 to 85% C, 5 to 5.8% H, and 10 to 14.2% O and N, the calorific power ranging from 8500 to 8800 and the factor of evaporation from 8 to 9.7.

3. Bituminous or furnace coal: These coals burn with a smoky flame, at the same time softening and intumescing in the fire. They yield 68 to 74% of caked and swollen coke and 15 to 16% of gas. In composition they contain from 84 to 89% C, 5 to 5.5% H, and 5.5 to 11% O and N. The ratio of the oxygen to the hydrogen being 1:1. Their calorific power varies from 8800 to 9300 and their factor of evaporation from 9.7 to 11.

4. Caking coals with short flame: These yield 74 to 82% of caked and very compact coke and 12 to 15% of gas. They contain 88 to 91% C, 4.5 to 5.5% H, and 5.5 to 6.5% O and N, the ratio of the oxygen to the hydrogen being 1:1. Their calorific power varies from 9300 to 9600 and the factor of evaporation from 11 to 12.

5. Anthracite coals: These yield 82 to 92% of pulverulent or fritted coke and 12 to 8% of gas. They burn with a short flame. They contain from 90 to 93% C, 4 to 4.5% H, and 3 to 5.5% O and N, the ratio of the oxygen to the hydrogen being 0.5:1. Their calorific power varies from 9200 to 9500, and their evaporative factor from 10.8 to 11.4. These coals are intermediate between the bituminous coals and the true anthracite of the United States.

The reason why some coals should have the caking property and others should not is not clear, non-caking coals being often of very similar chemical composition to those in which the caking property is highly developed. The caking coals undergo an incipient fusion or softening when heated, so that the fragments coalesce and yield a compact coke, while the non-caking coals (also call free-burning) preserve their form, producing a coke which is serviceable only when made from large pieces of coal, the smaller pieces being incoherent. It is found that caking coals lose their property when exposed to the air for a long period or by heating to about 300° C., and that the dust or slack of a non-caking coal may in some cases be converted into a coherent coke by exposing it suddenly to a very high temperature.

The distinction between long-flaming and short-flaming coals is not often made in the United States. A long-flaming coal is simply one having a high percentage of volatile matter, which gives off a long flame when burned in an ordinary furnace, because of the difficulty of supplying the volatile matter with sufficient quantity of hot air to insure its complete combustion. The manner in which coal is burned has a great effect upon the flame. Charcoal, for example, if burned with free access of air merely glows; but if burned with a limited supply of air in a thick bed, wherein the products of combustion from the lower part will pass through the upper part, carbon monoxide will be formed and will burn with a blue flame. The same phenomenon can be produced in the case of hard coal and bituminous coal low in volatile matter, and is taken advantage of in the method of clinker grate firing, wherein a

thick bed of coal is carried on the grate to effect an incomplete combustion in the fireplace followed by a secondary combustion of the carbon monoxide in the furnace, thus elongating the flame of a lean coal. This verges upon gas firing.

Coals are also classed sometimes as "lean" or "fat," which classification corresponds more or less to "short-flaming" and "long-flaming." All of the above classifications are more common in Europe than in America.

A convenient classification of coal is based on the relative percentages of fixed carbon and volatile matter contained in their combustible portion determined by proximate analysis. Such a classification as is commonly employed in the United States is shown in the following table:*

Class.	Fixed Carbon, Per Cent.	Volatile Matter, Per Cent.	Heating Value per Pound of Combustible, B.T.U.	Relative Value of Combustible.
Anthracite..........................	97.0 to 92.5	3.0 to 7.5	14,600 14,800	93
Semi-anthracite.....................	92.5 " 87.5	7.5 " 12.5	14,700 15,000	94
Semi-bituminous....................	87.5 " 75.0	12.5 " 25.0	15,500 16,000	100
Eastern-bituminous..................	75.0 " 60.0	25.0 " 40.0	14,800 15,200	95
Western-bituminous..................	65.0 " 50.0	35.0 " 50.0	13,500 14,800	90
Lignite.............................	Under 50	Over 50	11,000 13,500	77

The classification of coal is usually distinguished according to the following criteria: Anthracite usually contains more than ten or twelve times as much fixed carbon as volatile combustible, and burns with practically no smoke.

Bituminous coal usually contains less than three or four times as much fixed carbon as volatile combustible matter, and the amount of the former usually exceeds that of the latter.

Between true anthracite and true bituminous coal two classes are generally recognized: Semi-anthracite, which contains from six or seven to ten or twelve times as much fixed carbon as volatile combustible, and semi-bituminous, which contains from three or four to six or seven times as much fixed carbon as volatile combustible. These two classes differ also from anthracite in being softer, in this respect more like bituminous coal and in burning with a considerable amount of flame, but do not yield as much smoke as bituminous coal.

Lignite is the lower grade of coal in which some traces of the original vegetable material from which the coal is formed is generally still to be recognized. It usually contains from ten to thirty per cent of moisture, and in most cases contains less fixed carbon than volatile combustible. True lignite is usually brownish in color, although the so-called black lignites resemble bituminous coal in their color, and in other of their properties. Both the brown and the black lignites slack on exposure

* William Kent, Steam Boiler Economy, p. 42.

to the weather, and in this respect are easily differentiated from the higher grade coals. The term sub-bituminous coal has recently come into use to include the black lignite and some of the lower grades of the coals which were formerly called bituminous.

Peat consists of slightly consolidated and partly decayed vegetable material which has not been consolidated by pressure and other agencies to the extent that lignite has. The original vegetable material from which it is formed is always much in evidence, and neither the shiny surfaces nor the hardness which characterizes both lignite and coal have been developed. An equally characteristic distinction is that peat occurs as a surface deposit, while coal and lignite occur interbedded in the rocks.

Caking and Non-caking Coals.—A curious instance, as cited by Fulton, is the fact that certain coals produced in Pennsylvania and Virginia are respectively caking and non-caking, and yet possess an identical analysis. Butterfield defines caking and non-caking coals as follows:

"Caking coals are distinguished by softening or fusing on heating and yielding on the expulsion of volatile matter by heat a carbonaceous mass of cellular structure presenting no evidence of the form or shape of the original coal. The production of this mass of coke does not appear to be dependent on the ultimate composition of the coal, but rather on the forms of combination of the elements existing in it, which are in turn determined by the conditions of formation and geological position.

"Non-caking coals when heated until all volatile matter is expelled, yield a coke which retains the form of the coal, or crumbles into small fragments. No fusion or softening of the coal is apparent, and the coke has not a deeply seamed surface or open cellular structure."

Producer Fuel.—Coking or caking coal is most unsuitable for gas-producer work where producers are of the shaft type,—the possible exception being where the plant consists of many units, and the direction of the gas is periodically reversed. Where, however, such coal must of necessity be used, it should be mechanically fed (and mechanically agitated) as the labor of stoking such fuel is almost prohibitive.

In addition to this, the tendency of coking coal to agglomerate materially reduces the carbon surface presented for combustion. Also the swelling and buckling of coal creates channels, with a consequently porous fuel bed.

Tapered shaft producers, where the producer linings flare as they arise above the grates towards the top, are especially impossible with coking or caking fuels, by reason of the increased difficulty in stoking.

Where " run of mine " coal is used, it is customary to break the coal to the size of a fist.

From 10 to 12% of ash is the working limit of the average shaft producer where sulphur does not exceed 1 to $1\frac{1}{2}$%. However, the gas firing-capacity of the producer is considerably reduced thereby. With low ash a maximum of 2% sulphur may be permitted, experiments by the Geological Survey having reached a utilization of 7%. This, however, should be avoided. Ordinarily 1% is a safe working limit. The sulphur usually exists in the form of iron pyrites.

Gas Coal.—The principal gas-coal fields of the United States are located in the Appalachian coal field which stretches along the Appalachian mountain range from

New York to Alabama, but gas coal is also found in each of the other great coal fields, viz.: the Middle in Illinois, Indiana, and Western Kentucky; the Western in Missouri, Iowa, Nebraska, Kansas, Arkansas, and the Indian Territory, and the fields in the far West, the limits of which have not yet been clearly defined nor their resources fully developed.

Among the gas-coal districts of the Appalachian field the Pittsburg district which lies immediately east and south of Pittsburg on the Allegheny, Monongahela, and Youghioghenny rivers is prominent. The coal from this district is comparatively hard and dense, so that it can be transported without excessive breakage, and yields a good amount of gas of good quality and a clean hard coke. The percentage of sulphur contained in it is small, being usually well under 1%. A fair gas coal is also found in Jefferson and Beaver counties, Pennsylvania, but this coal is not quite as good as that from the main body of the Pittsburg field.

Another important field is the West Virginia field located in the northern part of West Virginia along the banks of the Monongahela river. The coal in this field is very similar to that obtained from the Pittsburg district, but is less able to stand handling without disintegrating and is apt to contain more sulphur, although some samples show very well in this respect.

The Kanawha district, also in West Virginia, extends back for about 30 miles on each side of that portion of the Kanawha river between Kanawha falls and Charleston. The coal produced here differs only slightly from the coals mentioned above, except in being apt to contain more sulphur than is found in the coal mined in the West Virginia district, the percentage running up as high as 1.5% in some samples, although as low as 0.6% in others. Cannel coal is also found in paying quantities in this district.

Kentucky possesses a little gas coal, but hardly enough to be taken into consideration, if it were not for its large deposits of cannel coals. The best known of these is the Breckenridge, which besides giving off a large amount of rich volatile matter yields also a fairly good coke which can be mixed to a proportion of 10% with the coke from ordinary gas coal without depreciating the latter.

In Tennessee good gas coal is found in Scott and Anderson counties, while in Campbell an excellent cannel coal is mined which is similar to the Breckenridge and is known as Jellico cannel. The gas coal is a clean hard coal, fully equal in all respects to that obtained from the Pittsburg district.

In Alabama there are three coal fields, the Cahaba, the Coosa, and the Warrior, in each of which some coal is found which can be used as gas coal, but the best coal for this purpose comes from the Corona seam in Walker county. This coal is clean and hard enough to bear handling well.

Although Ohio, Indiana, and Illinois produce coal that is used locally for gas making, they cannot be considered as gas-coal districts, since the coal is only used for this purpose when the gas works are practically over the mines, and Pennsylvania coal is in demand throughout these states for use in preference to the local coal.

In Kansas the Cherokee field produces a gas coal that is good in every respect, except that the amount of sulphur contained in it, and this runs from 2.5 to 5% and even as high as 8% in some samples.

The Choctaw country in Indian Territory yields a coal which is clean and hard,

stands handling, and produces a good coke. It closely resembles the Pennsylvania coals although it contains more sulphur and ash than the latter, the percentage of sulphur being a little over 1%.

The Trinidad field in Colorado also furnishes a clean bright coal that is low in sulphur and is said to give a good yield of good quality gas and from 60 to 70% of compact coke.

On the Pacific coast the South Prairie and Roslyn fields give a coal from which a fair amount of fairly good quality gas can be obtained and which is low in sulphur, but produces a soft friable and comparatively poor coke.

The principal gas-coal fields in Canada lie on Glace Bay and Cow Bay in Cape Breton. These provincial coals were formerly used quite extensively by gas works situated on the Atlantic coast of the United States. They yield a good amount of gas of a quality better than average, but they disintegrate easily, contain a large amount of sulphur and are very susceptible to spontaneous combustion. At the present time their use has been practically abandoned in the gas works of the United States.

The average analysis of some of the coals mentioned above follow:

ANALYSES OF GAS COALS

District.	Volatile Matter.	Fixed Carbon.	Ash.	Sulphur.
Pittsburg.	35 to 40	54 to 58	3 to 5	0.6
West Virginia.	35 " 40	53 " 57	4 " 7	1.0
Kanawha.	34 " 40	55 " 62	2 " 4	0.6 to 1.5
Breckenridge cannel.	47	42	10	0.6
Tennessee gas coal.	36 to 39	56 to 60	1.8 to 3	0.8
Jellico cannel.	50	35	14	1.7
Alabama Corona seam.	34 to 41	50 to 59	7 to 9	0.7
Kansas Cherokee.	37	52	9	2.5 to 8
Indian Territory.	37 to 40	51 to 55	4 to 7	0.9 to 1.3
Roslyn Washington.	28	61	9	0.1
Colorado Trinidad.	33 to 37	51 to 57	9	0.7 to 1.4
Cape Breton.	35	53	5.5	3

The anthracite coal production of the United States is confined to Pennsylvania, with small beds in Colorado, Rhode Island, and New Mexico. Bituminous coal must be stored in piles not more than 35 ft. high, owing to the danger of spontaneous combustion. Anthracite is stored much deeper in piles and can be handled with bucket conveyors and other similar implements.

Tar Yield from Gas Coal.—When an ordinary gas coal is subject to destructive distillation, the volume of gas, its heating and illuminating value, and also the quantity and quality of the tar undergo great changes, according to the temperature at which the distillation is carried out, and the following table shows the average results that are obtained with a good sample of gas coal. The term "average results" is used, as variations in the coal employed introduced alterations in the results, although they will all follow similar lines:

YIELD OF GAS AND TAR PER LONG TON OF COAL CARBONIZED

Temperature of Distillation.		Volume of Gas, Cubic Feet.	Tar, Gallons.	Specific Gravity of Tar.
Degrees C.	Degrees F.			
900	1652	11,000	9	1.200
800	1472	10,000	12	1.170
700	1292	9,000	15	1.140
600	1112	7,750	18	1.115
500	932	6,400	21	1.087
400	752	5,000	23	1.020

Coal Analysis.—The method of determining the coking qualities of a coal is by actual experiment. The usual form of laboratory test is known as the crucible test.
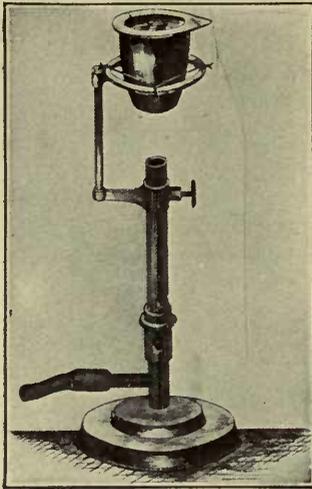
FIG. 95.—Crucible Proximate Coal Test.

It consists in placing a known weight of dried coal in a covered platinum crucible and heating it till all the volatile matter is driven off, combustion of the residue being prevented by the close-fitting lid which keeps out the air. The nature of the residue indicates approximately the coking properties of the coal, and its weight the approximate yield of coke to be expected, while the loss of weight corresponds to the "volatile" matter. This process corresponds on a small scale with the treatment of coal in the coke oven. The re-heating of the coke in the crucible without the lid until all the carbon is consumed, leaves the ash as the sole residue, the loss of weight in this case indicating the "fixed carbon." This crucible test, together with separate determinations of sulphur and phosphorus, are the usual tests made to ascertain the character of a coal under investigation. Such tests of the coking coals of this country, ranging from those of low to those of higher volatile matter, would be as follows:

CRUCIBLE TESTS OF BITUMINOUS COALS AND COKE

Kind of coal.	Low volatile coal	Coking coals	High volatile or gas coal		
Behavior when heated . .	Expanding	Neutral	Moderately shrinking	Strongly shrinking	
Character of coke.	Very dense and firm	Dense and firm	Larger cells but firm	Spongy and brittle	Typical blast furnace coke
Crucible Test:					
Volatile matter.	18.0	25.0	32.0	38.0	1.5
Fixed carbon.	74.0	67.0	60.0	54.0	87.5
Ash.	8.0	8.0	8.0	8.0	11.0

Sulphur.—Coal possessing more than 0.5% of sulphur content is not advocated for use in producers, especially for power work, there being a tendency to form sulphurous oxide and sulphuric acid, both of which attack the packing of the pistons and the stuffing boxes of engines.

It has also been shown, where gas produced from coal of a highly sulphur quality and used unpurified for cooking, that the results have been detrimental to both the food and products of combustion.

Coal containing a high content of sulphur may frequently be crushed and washed with a considerable degree of purification. This is particularly so when the pyrite occurs free in the seams of the coal.

ANALYSES OF ASH
From Carpenter's Engineering

	Specific Gravity.	Silica.	Alumina.	Oxide of Iron.	Lime.	Magnesia.	Loss.	Acids, S. & P.
Pennsylvania anthracite.	1.559	45.6	42.75	9.43	1.41	0.33	0.48	....
Pennsylvania bituminous	1.372	76.0	21.00	2.60	....	....	0.40	....
Welsh anthracite.......	1.32	40.0	44.8	....	12.0	trace	....	2.97
Scotch bituminous.....	1.26	37.6	52.0	....	3.7	1.1	....	5.02
Lignite...............	1.27	19.3	11.6	5.8	23.7	2.6	....	33.8

Calculating Heat Value.—A rapid and convenient method for the determination of the calorific power of coal to within 1% (2% for lignites) is given by Goutal in *Stahl und Eisen.*

Moisture is first removed from a small sample of the coal by drying in a crucible at about 240° F. The volatile matter and ash are determined by coking in a white-hot crucible. If C be the resulting percentage of carbon, and V the percentage of volatile matter, the proportion X of volatile to total combustible is given by the equation

$$X = 100 \frac{V}{C + V}.$$

The calorific power Q of the coal is then found by the equation

$$Q = 147.5C + aX,$$

wherein a is found from the following table of values in terms of X:

X, Per Cent.	a, B.T.U.	X, Per Cent.	a, B.T.U.	X, Per Cent.	a, B.T.U.	X, Per Cent.	a, B.T.U.
5	161	14	216	23	189	32	174
6	256	15	211	24	187	33	173
7	250	16	207	25	185	34	171
8	245	17	204	26	184	35	169
9	239	18	202	27	182	36	164
10	234	19	198	28	180	37	158.5
11	229	20	196	29	178	38	153
12	223	21	194	30	176	39	148
13	220	22	193	31	175	40	144

Moisture in Boiler Coal.—In the Sturtevant trade handbook entitled "Mechanical Draft," is treated the subject of the influence of moisture in coal. Moisture in coal is an exceedingly variable quantity, depending upon the character of the coal, its temperature, and its previous exposure to the atmosphere. Under ordinary conditions its percentage varies from 1 to 5%. Whatever its amount, it must all be raised to 212°, evaporated into steam, and the steam raised to the temperature of the escaping gases. It therefore has an important influence upon the theoretical heat value of a given coal. Thus, if one coal was composed of 80% carbon, 15% ash, and 5% water, and another consisted of the same proportion of carbon, with 5% ash and 15% water, the theoretical calorific value, viz., 11,720 B.T.U., would be the same, being directly dependent upon the amount of carbon. But in the first case the available heat (neglecting losses not due to water) would be 10,600 B.T.U., while in the second it would be 10,488 B.T.U. if the waste gases were assumed to escape at 500°.

COAL ANALYSIS

COALS SUCCESSFULLY GASIFIED IN LOOMIS-PETTIBONE GAS PRODUCERS

Name of Mine.		Carbon, Fixed.	Volatile.	Sulphur.	Water.	Ash.	B.T.U.
Big Muddy..	Ill.	53.9	28.3	1.0	7.4	10.5	13,757
" "	"	52.7	30.1	1.2	6.1	9.2	13,613
Brazil.	Ind.	50.3	34.5	1.39	8.68	6.3	14,542
Cumberland.	Md.	80.7	13.0	. . . .	1.25	5.0	16,321
George's Creek. . . .	"	. . . .	. . . .	. . . .	. . . .	6.1	15,140
Cambridge.	Ohio	50.3	37.8	3.01	2.43	9.4	14,474
Youghioghenny. . .	Pa.	54.7	32.6	. . . .	. . . .	5.9	13,752
New River.	W. Va.	. . . .	. . . .	. . . .	. . . .	0.6	14,359
" "	"	. . . .	. . . .	. . . .	. . . .	5.7	14,601
Pocahontas.	"	73.6	18.3	0.57	0.80	7.2	15,682
"	"	75.1	18.6	0.57	0.63	5.6	15,718
"	"	73.6	17.1	0.60	0.75	8.6	15,730
Webster.	Pa.	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .
Shawmut.	"	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .
Cerrilos.	N. M.	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .
Barotoran.	Mex.	66.8	11.5	. . . .	. . . .	21.7	. . . .
"	"	63.2	10.8	. . . .	. . . .	26.0	. . . .
"	"	59.8	11.7	. . . .	. . . .	28.5	. . . .
"	"	63.0	12.1	. . . .	. . . .	24.9	. . . .

The makers of this producer are willing to handle any coal of a non-coking character that contains volatile 42% and less, the ash effects only the capacity. When ash above 12% is gotten, its use is questioned.

The same guarantee of fuel consumption is made for the Loomis-Pettibone system or the suction producer system.

Clinkering Properties of Coal.—It is generally agreed that clinkering is due to the high fuel bed temperaturres on such of the mineral constituents in the ash as will form a fusible mixture. It must be remembered that the fineness of subdivision and the distribution of the minerals through the coal are probably as important as the temperature and chemical composition. Thus it is that "sulphur" (pyrites) in the

form of little balls is nearly harmless; in the form of veins or layers it is liable to cause trouble; but in the form of "black sulphur," so finely distributed as to be invisible, it is most troublesome.

Sulphur is an undesirable element in coal. It generally occurs in combination with iron, as iron pyrites, and in combination with calcium, as calcium sulphate or gypsum. The calcium sulphate occurs in smooth, thin, white flakes, more or less transparent. Of the two sulphur compounds the pyrites is generally contained in larger amount in the coal and is harmful, as it increases the tendency of the coal to clinker.

The impression is general that iron causes clinkering. The results of tests made at the fuel-testing plant of the U. S. Geological Survey at Pittsburg confirm this impression, as the percentage of iron in dry coal increases in general with the clinker. Nevertheless, iron is only one of the causes of clinkering, and its presence in considerable quantity does not necessarily mean that a coal will clinker badly.

The exact and scientific reasons why certain coals clinker has not thoroughly been determined.

Coals which give a very heavy clinker which cannot readily be broken up by the use of steam may be burned satisfactorily by spreading over the grate bars a thin layer of limestone before the furnace is put in commission for its daily run. The limestone combines with the clinker with the result that the latter does not adhere to the grate bars.

Purchasing of Coal.—As it has elsewhere been stated, the difficulty in making a complete analysis of coal is so great and such skill and constant practice is required, that in case of smaller plants and plants accessible to large laboratories, it is as a rule more economical to send samples for analysis to laboratories which are properly equipped, than attempt to make any absolute determinations.

However, calorimetric tests may and should be made as a continuous practice, and, by way of analogous comparison of coal purchased and used, may be checked to a fair degree of accuracy.

The question of transportation to some extent effects the economic consideration of the coal to be bought; that is to say, where most of the total cost consists in freight, handling, or transportation, it might prove an economy to pay considerable more for the initial fuel, inasmuch as it costs as much to transport ash, moisture, or neutral content as combustible matter, and under these circumstances it is better to buy combustible matter in a more condensed and compact form.

It should ever be kept in mind that the purchase is that of thermal units and the question is that of delivery of thermal units to the furnace, the greatest number at the least cost.

The following interesting matter is abstracted from Bulletin No. 339 of the U. S. Geological Survey:

"The aim in the purchase of coal for any power plant should be to obtain a fuel which will produce a horsepower for the least cost, all things being considered, such as the equipment, the price of coal, and the cost of labor and repairs. Experiments have been made which seem to indicate that almost any fuel may be burned with reasonble efficiency in a properly designed apparatus. The recognized requirements are as follows:

"A supply of fuel fed to the furnace as uniformly and continuously as possible. An air supply slightly in excess of the theoretical amount required for complete combustion.

"A sufficiently high temperature to ignite the gases which are driven off from the fuel. A complete mixture of these gases with the air supplied before they reach the cooling surface, such as the shell or tubes of a boiler."

Some of the factors which may influence the commercial results obtained in a boiler are the cost of the coal, as determined by price and heating value; care in firing; design of the furnace and boiler setting; size of grate, etc.; formation of excessive amounts of clinker and ash; draft available; size of coal (uniformity of size is desirable).

The value of a coal is indicated by the number of heat units it contains. This heating value is expressed in terms of British thermal units per pound of coal, and is determined by means of a special apparatus called a calorimeter.

When coal is mined it contains moisture to a greater or less extent. It is exposed to the air in shipment and is either dried out or drenched by rain. The moisture in the coal delivered is worthless to the purchaser and really costs him a considerable amount in freight and cartage, and in the loss of the heat absorbed during its evaporation in the furnace. If all coal had the same proportion of moisture, or if the moisture in coal delivered by a given dealer was constant in amount, the purchasers' problem, so far as this factor is concerned, would be simplified. Under present conditions the moisture is an important element in the valuation of a ton of coal. It is evidently necessary to consider the coal just as it is received in order to determine its value to the consumer, but chemical reports should be made on the basis of both the "dry coal" and the "coal as received." The dry coal basis is convenient for comparing several coals in regard to the relation of each element to the others; this is important, because the moisture in the same coal varies from day to day. The dry coal basis is also convenient for comparing the performance of boilers when burning the same or similar coals. Of several coals having a similar composition, the one which has the least moisture and the least ash will generate the most steam when burned under a boiler.

Ash is made up of earthy matter and other impurities which will not burn. In commercial coals its proportion may range from 4 to 25%. Coals containing small percentages of ash are most valuable, not only because of their correspondingly higher heating capacity, but because there is less resistance to the free and uniform distribution of air through the bed of coal. The labor and cost of managing the fires and of handling the ashes are also correspondingly less and are items to be considered in the choice of a coal. With the ordinary furnace equipment there may be a considerable loss of efficiency and capacity through a large percentage of ash. It has been found that with some kinds of equipment, as the ash increases, there is a decided drop in both efficiency and capacity. In some experiments, made to determine the influence of excessive amounts of ash, coal containing as high as 40% would generate no steam when fired on a chain grate, and therefore the efficiency and capacity of the plant would be zero. Such coal would not only be worthless, but involve a direct expense due to the cost of handling it. Whether the result would be similar with equipment other than a chain grate has not yet been determined. However, coals

so high in ash that they are unsuited to boiler furnaces can be utilized in gas producers.

The volatile part of coal, as shown by the analysis, may in some coals be all combustible, but it generally contains some inert matter. This varies in different coal deposits and makes it impossible to determine the heating value of the coal from the approximate analysis alone.

Moreover not all coals having the same proportion of volatile matter behave alike in the furnace. It is important to know both the chemical composition and the British thermal units in order to determine the value of one coal as compared with another for the same purpose.

Of two coals of different character, the one which contains the higher proportion of fixed carbon is most easily burned so as to give the maximum efficiency. However, if the coal containing the higher volatile matter is properly burned in a suitably designed furnace, it may be made equally efficient.

A. Berthold shows that, in the ordinary method of determining the volatile matter in coal by heating in a platinum crucible, both the dimensions and weight of the crucible employed affect the results to a very considerable extent. For instance, using three different crucibles ranging in diameter at the mouth from 33 to 40 mm., in height from 38 to 46 mm., and in weight from 20.1 to 27.6 gms. he found that the same coal, heated in a flame varying in height from 9 to 29 cm., gave from 80 to 86.82% yield of coke. He concludes that, for estimating coal for gas-works use, a comparatively small crucible is the best, and suggests that it shall be 19 mm. wide at the base, 33 mm. wide at the top, 38 mm. high, and weigh approximately 20 gms. It should be supported 3 cm. above the top of the Bunsen burner of which the flame, when burning freely, should be at least 18 cm. in height. Such conditions give results as nearly as may be in agreement with those afforded in carbonization in gas works. For coke oven valuations he prefers to use a larger and heavier crucible.

Sulphur may be present in the free state, or as is more commonly the case, in combination with iron and other elements. Other impurities with sulphur often form a clinker which shuts out the air and increases the labor of handling the furnaces. It is possible, however, to burn coals containing up to 5% of sulphur without particular difficulty from clinkers. Clinker may be due to other causes than sulphur, as any constituents of the ash which are easily fusible may produce it. There is need of further investigation to determine the influence of sulphur and the elements which comprise the ash on furnace fires and combustion.

The results of tests tend to show that, other conditions being equal, coals of similar composition are of value in proportion to the British thermal units in the coal as received—a basis on which, indeed, all coals may be valued approximately. It should be remembered, however, that the value of a coal for any particular plant is influenced by the fact that all furnaces are not equally suitable for burning the many grades of coal. Aside from this factor, coals may be compared in terms of the British thermal units obtained for one cent or on the cost per million heat units.

Mine samples when properly taken indicate the general character of the coal and enable one to judge of its probable value for any definite purpose. Samples taken from the cars should not be limited to a few shovelsful of coal from the top of the car, because the heavier pieces gradually work down toward the bottom. Some samples

taken at the bottom of a car have shown as much as 8% more ash than the coal at the top. The moisture also may vary from top to bottom, depending on the weather. The only way to get a fair sample is to take a number of shovelsful of coal from various points in the car, so as to procure a representative portion of the coal from top to bottom and from end to end.

Bituminous coal when exposed to the air gradually depreciates in heating value owing to losses of volatile matter, but aside from this loss there should be the same total number of heat units in a car of coal when it reaches its destination as when it started. If rain falls on the coal it will become heavier and a greater number of pounds will be delivered, but each pound will have a correspondingly lower heat value. On the one hand if the weather is fair and the coal dries out on the way, it will weigh less and the heating value of each pound will be correspondingly higher. In other words, under a specification, such as is used by the government, neither the dealer nor the purchaser will gain or lose by change in the moisture content of the coal between the time it is weighed at the mine and the time it is weighed on delivery. The price per ton will be correspondingly lower if the coal is wet and higher if it is dry.

In order to determine the maximum variation in moisture in several sizes of anthracite coal, the following experiments were made: The coal was soaked in water to allow it to absorb as much moisture as possible, the result representing the extreme conditions due to rains or other causes. Each sample was then weighed and allowed to dry in a room exposed to the air. When this sample ceased to lose moisture it was assumed to be air dried, which represents the condition of least moisture to be expected in a delivery of coal. The results are summarized in the following table:

EXPERIMENTS TO DETERMINE POSSIBLE VARIATION OF MOISTURE IN ANTHRA-
CITE COAL DURING SHIPMENT

	Furnace.	Pea.	Buckwheat.
Number of samples used in experiment............	13	10	12
Number of hours dried in air at ordinary room temperature.................................	0.5 to 24	24	24
Total moisture in thoroughly wet coal............	5.12	5.75	8.44
Moisture in air-dried samples....................	3.58	1.84	2.24
Loss of moisture................................	.73 to 1.54	3.1 to 3.9	4.5 to 6.2
Percentage of maximum variation in moisture from wet to air-dried coal........................	30	68	74

The air-dried anthracite still contains from 1.8% to 3.6% of moisture. Moisture in air-dried coal varies with the weather, just as it does in wood.

The moisture in air-dried bituminous coal depends upon the character of the coal. It is about 1% in West Virginia coal and about 7% in Illinois coal. The moisture in the same Illinois coal delivered may range from 7% to 17%.

Owing to these variations some method should be used to correct for the difference in moisture in coals of different character.

Sampling Coal.—The following suggestions are presented for the guidance of those who wish to send samples to a laboratory for analysis:

If samples are taken at the building as the coal is delivered, it will usually be satisfactory to take one shovelful of coal from each third of fifth wagon load, the load

being selected without the knowledge of the driver. It must be kept in mind that the main object is to obtain a portion of coal which represents as nearly as possible the entire delivery. The sample should contain about the same proportion of lump and fine coal as exists in the shipment as a whole. The practice of taking a shovelful near the bottom of the pile should be avoided, as the larger lumps of coal roll down and collect near the bottom and such a sample will not truly represent the coal.

These samples should be immediately deposited in a metal receptacle having a tight-fitting cover and provided with a first-class lock.

Except when samples are being deposited or when the contents are being quartered down, this receptacle should be securely locked and the key held by a responsible employee. The receptacle should be placed in a comparatively cool location to avoid loss of moisture in the coal. When it becomes filled, or at the end of a sampling period, the contents should be emptied on a clean dry floor, in a cone-shaped pile. The larger lumps should be broken down by a coal maul or sledge, and the pile reformed and quartered into four equal parts, a shovel or board being used to separate the four sections. Two opposite sections should then be rejected and the remaining two again mixed, broken down, and reformed into a pile to be quartered as before. This process should be continued until the lumps are no larger than the size of a pea, and a quart sample is finally procured. The samples should then immediately be placed in suitable receptacles for shipping and sealed air tight. The Geological Survey inspectors use a metal can, 3 inches in diameter and 9 inches high, with a screw cap 2 inches in diameter for making the shipments to the chemical laboratory. These cans are sealed air-tight by winding adhesive electrical tape around the joint of the screw cap. Each can holds a quart of about 2 lbs. of coal.

The process of quartering down and preparing samples for shipment to the chemical laboratory for analysis should be carried on as rapidly as possible to avoid loss of moisture.

The samples should be forwarded promptly and notice of shipment sent under separate cover. Receptacles should be marked plainly on the outside, and a corresponding number or description should be placed inside. A complete record of all deliveries should be kept, showing dates, names of contractor, kind of coal, total weight delivered, condition of coal (wet or dry), and other particulars of importance.

The procedure at the Chemical Laboratory of the Geological Survey testing plant is described in Survey Bulletin No. 261. The samples are crushed and ground to a fine powder, and then analyzed and tested. Persons not experienced in taking samples have a tendency to select a sample better than the average. In many cases a lump of coal is broken and shipped in a cloth sack to the laboratory. This allows the moisture to dry out; moreover, the lump selected is usually free from layers of slate and impurities, and of course then represents the best coal in the lot, and shows a higher value than can be expected to hold throughout the coal delivered.

The preceding statements show that the purchaser should usually have the quality determined on the basis of coal "as received" in order to correct any excess or deficiency in the moisture content.

In the purchase of coal for producer work, the minimum size of mesh to be specified should not be less than $\frac{1}{4}$ inch. This is to prevent excessive packing, inasmuch as

there will, in any event, be sufficient amount of powdered coal to fill all voids by reason of the fining of the coal at an early temperature.

Storage of Coal.—The spontaneous combustion of coal is due primarily to the pid absorption of oxygen by the finely divided coal and to the oxidation of iron pyrites occurring in the coal. The conditions favorable to this process are: first, a supply of air sufficient to furnish oxygen, but of insufficient volume to carry off the heat generated; second, finely divided coal, presenting a large surface for the absorption of oxygen; third, a considerable percentage of volatile matter in the coal; and fourth, a high external temperature.

A good way to extinguish a fire in a coal pile not provided with ventilators consists in removing and spreading out the coal and flooding the burning part with water. Another method consists in driving a number of iron or steel pipes provided with "driven well points" at the place where combustion is taking place, and through these forcing water or steam on the fire.

Another method being adopted by one of the gas companies storing a particularly
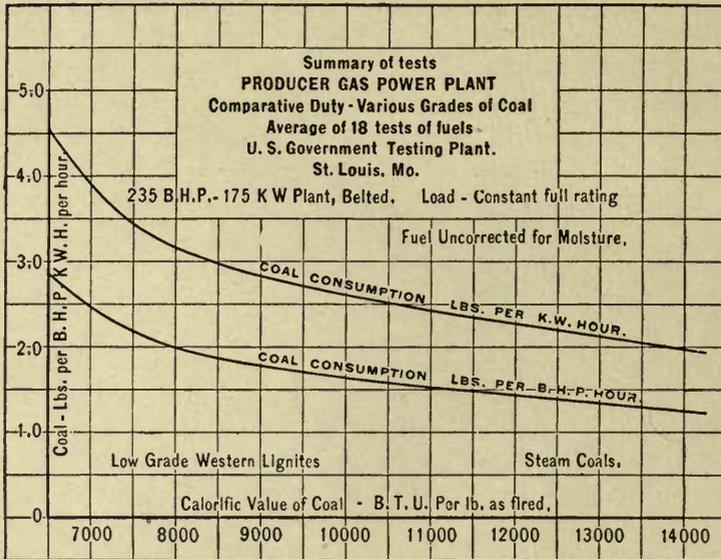
Fig. 96.—Pounds of various Coals per Horse-power.

inflammable coal, is to store the coal in large concrete tanks which are flooded with water, the water being drawn when the coal is desired for use.

The coal department of the A. D. Little laboratory, Boston, has found instances where a small coal pile cooled down after being as hot as 165° F. This was probably a rare occurrence as the temperature generally increases rapidly as the coal heats up above 150°; and there is no doubt that when 212° F. is reached the coal must be moved, or soon steps will have to be taken to cool it in order to prevent fire. Temperatures as high as 485° F. have been observed, and at that temperature the coal ignited when exposed to the air.

Transportation.—The best engineering practice dictates the shipping of coal rather than of coke, by reason of the considerable bulk of the latter per unit of weight. The standard coke car holds 20 tons of coke, maximum car 30 tons; standard coal car holds 50 tons. Even if it be taken into consideration that 1.25 to 1.35 tons of average coking coal is necessary for the production of one ton of coke, it would still be preferable to ship the coal. Railroad rates upon shipping coal are materially cheaper than for shipping coke, for the above reasons.

Coal and Lignite Compared.—The following is a summary of results from fuels tested by the gas producer division U. S. Geological Survey fuel testing plant, at St. Louis, Mo., during the year 1905.

	B.T.U. per Pound.
Coal as fired...	12,500
Lignite...	7,526
Dry coal..	13,420
Dry lignite...	10,870
Average B.T.U. per cubic foot of gas from coal..............	151.
Average B.T.U. per cubic foot of gas from lignite...........	161.
Average cubic feet of gas per pound of coal as fired........	59.8
Average cubic feet of gas per pound of lignite as fired.....	29.1
Average cubic feet of gas per pound of dry coal.............	64.4
Average cubic feet of gas per pound of dry lignite..........	40.9
Average pounds of coal as fired per square foot of fuel bed area...........	8.0
Average pounds of lignite as fired per square foot of fuel bed area..........	14.5
Average pounds of dry coal per square foot of fuel bed area...............	7.4
Average pounds of dry lignite per square foot of fuel bed area.............	10.1
Average* equivalent pounds coal as fired per e.h.p. developed.............	1.74
Average equivalent pounds lignite as fired per e.h.p. developed............	2.94
Average* equivalent pounds dry coal per e.h.p. developed................	1.56
Average equivalent pounds dry lignite per e.h.p. developed................	2.04
Ratio of total coal per e.h.p. (under boiler) to total coal per e.h.p. (in producer) equals...	2.7
Ratio of total lignite per e.h.p. (under boiler) to lignite per e.h.p. (in producer) equals...	2.6
Pounds of mixture of tar, water, soot, etc., delivered by tar extractor per ton of coal..	385.
Pounds of mixture of tar, water, soot, etc., delivered by tar extractor per ton of lignite..	175.
Average sulphur in coals tested, per cent................................	2.55
Average sulphur in lignites tested, per cent.............................	2.00

AVERAGE OF GAS ANALYSES

	Coal.	Lignite.
Carbon dioxide, CO_2...	9.5	9.1
Oxygen, O_2...	0.0	0.0
Ethylene†, C_2H_4...	0.0	0.0
Carbon monoxide, CO..	19.2	22.6
Hydrogen, H_2...	12.4	14.6
Methane, CH_4...	3.1	3.0
Nitrogen, N_2...	55.8	50.7

* This includes all coal charged to producer and coal for auxiliary boiler.
† Not separated from Methane (CH_4) in this series of tests.

Producer Fuel Tests.—At the U. S. Geological Survey fuel testing plant at St. Louis, Mo., a long series of tests were made of fuels used in gas producers and the results are now published.

The equipment used was a 250 h.p. pressure producer with a centrifugal tar extractor and gas holder. A 235 h.p. 3-cylinder vertical gas engine belted to a generator produced power which was measured by electric instruments connected with the switchboard. As will be seen the results obtained are much better than those from steam plants of corresponding size. The following table, in which the word equivalent means total fuel used in producer and steam boiler, gives in abstract the results obtained.

Fuel.	Florida Peat.	Four Lignites, Average.	Four Illinois Coals, Average.	Four Pennsylvania Coals, Average.	Four West Virginia Coals, Average.
PROXIMATE ANALYSIS:					
Moisture............................	21.00	35.05	11.51	3.47	2.47
Volatile matter......................	51.72	28.96	31.81	19.68	32.12
Fixed carbon........................	22.11	27.72	43.46	67.31	60.24
Ash.................................	5.17	8.27	13.22	9.54	5.17
B.T.U. per fuel pound:					
As fired...........................	8,127	7,164	10,651	13,651	14,248
Dry...............................	10,299	11,038	12,030	14,136	14,610
Gas made cu.ft. per lb. equivalent fuel:					
As fired...........................	28.5	26.3	49.6	71.4	77.5
Dry...............................	36.1	40.3	56.1	74.0	79.5
B.T.U. gas, per cu.ft.................	175.2	169.9	153.2	141.6	149.6
Fuel, equivalent per b.h.p. hour:					
As fired...........................	2.57	2.43	1.66	1.16	1.03
Dry...............................	2.03	1.73	1.47	1.12	1.00

Of the four Pennsylvania coals tested, two came from the lower Kittanning bed, one from the lower Freeport, and the fourth from the Pittsburg bed. Of the West Virginia coals, one came from the Ansted bed, another from the Eagle, both of these being mined in the New River district; a third from the Pittsburg, and the fourth from the Keystone bed.

Clinkering Test.—The most satisfactory preliminary test of a coal is by a diminutive gas apparatus capable of treating a few pounds of coal and so disposed as to permit measurement of the gas and by-products. Chemical examination alone affords insufficient data. While a "proximate analysis" showing specific gravity, moisture, volatile matter, fixed carbon, ash, and sulphur affords some criterion of its value, about the only advantage of an ultimate or elementary analysis is the knowledge of the percentage of free hydrogen present; poor gas coals have less than 4%, and those very rich over 5%.

Some varieties yield their gas more readily than others, but it serves economy to use it as soon as possible after mining. Long storing or weathering diminishes yield of gas and impairs its quality. Much moisture lowers the heat of retorts, promotes the formation of condensable constituents, produces less gas of poorer quality, and liberates a portion of the sulphur which otherwise would be retained by the coke. Protection during necessary storage is therefore very desirable and should be secured with efficient ventilation to guard against spontaneous ignition.

The yield of Pennsylvania gas coals in present practice is something over 10,500

cubic feet of 18 candle-power gas per gross ton, depending very much, however, upon the general conditions surrounding the plant.

A fair idea of the fuel for producer work may be obtained by using a short piece of pipe, 6 or 8 ins. diameter and 2 or 3 feet long, in connection with an ordinary blacksmith's forge. The pipe should set on end over the air inlet of the forge and the fire started within it, after which fuel is gradually fed in in varying quantities and to various depths.

The pressure and amount of the air blast can be altered and the fuel consumed at different rates of combustion.

The gas escaping from the top of the pipe may be lighted, and from the nature of this flame the rate of combustion and the nature of the resultant clinker and ash, the quality of the fuel may be approximately determined.

Gas Yields of Coals.—In presenting the accompanying charts, too much emphasis cannot
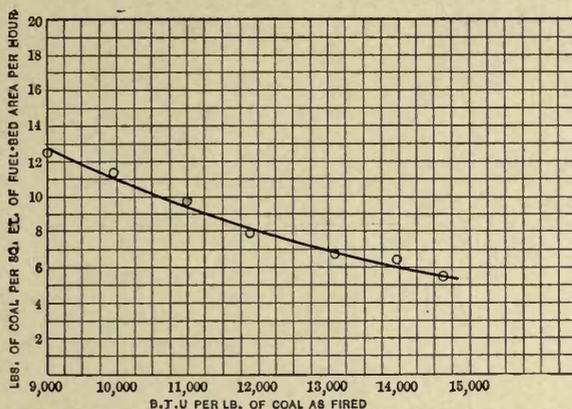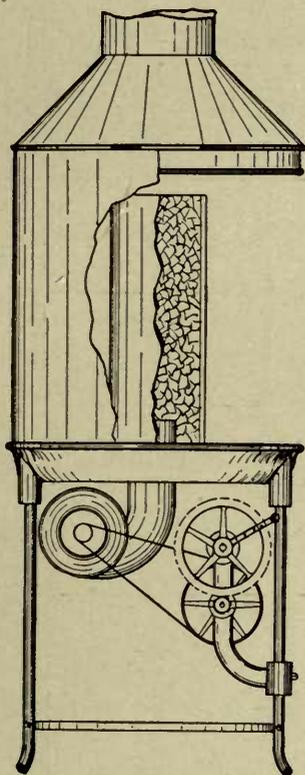
Fig. 97.—Combustion Test for Coal.　Fig. 98.—Relation of Richness of Coal to Rate of Combustion.

be given to the fact that the tests from which these curves were deduced have been subjected to absolutely no refinements. With the possible exception of two or three coals, one test only has been made on each fuel, and the result of each test has, to a great extent, depended upon the ability of the producer operator to "catch on" to the methods of handling a given coal within the eight or ten hours allowed preliminary to the official test.

It should also be borne in mind that all the tests have been made on one type and in one size of producer—a type designed primarily for anthracite coal—and that it has been imperative that the test be made and the required power generated without regard to the proper relations between the gas-producing qualities of the coal and the fuel-bed area.

The restrictions have been such that the tests have been conducted on the basis of steady load on the engine (325 brake horsepower) and not on the basis of maximum power-producing quality of the coal.
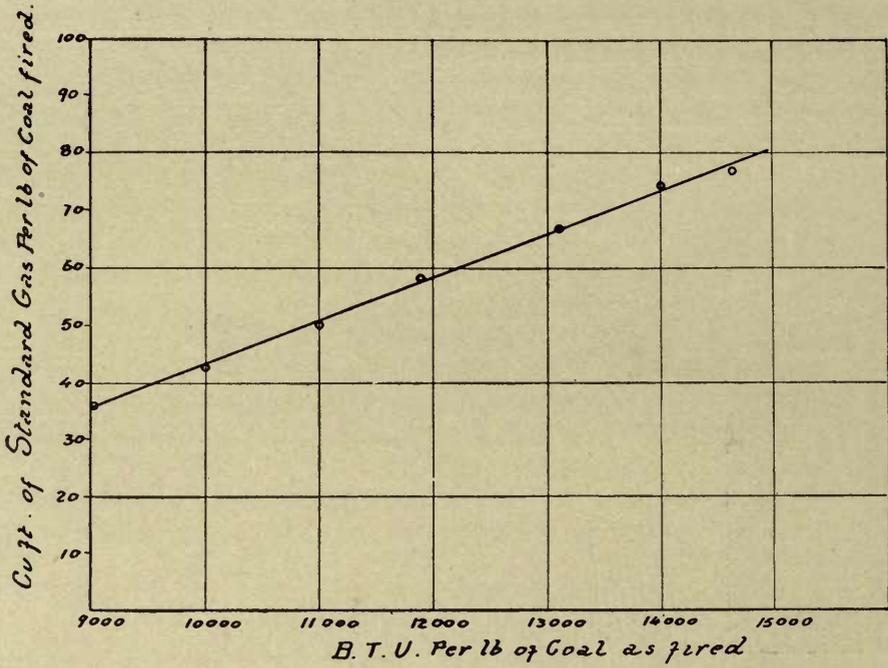
FIG. 99.—Relation of B.T.U. of Coal to cu.ft. per lb.
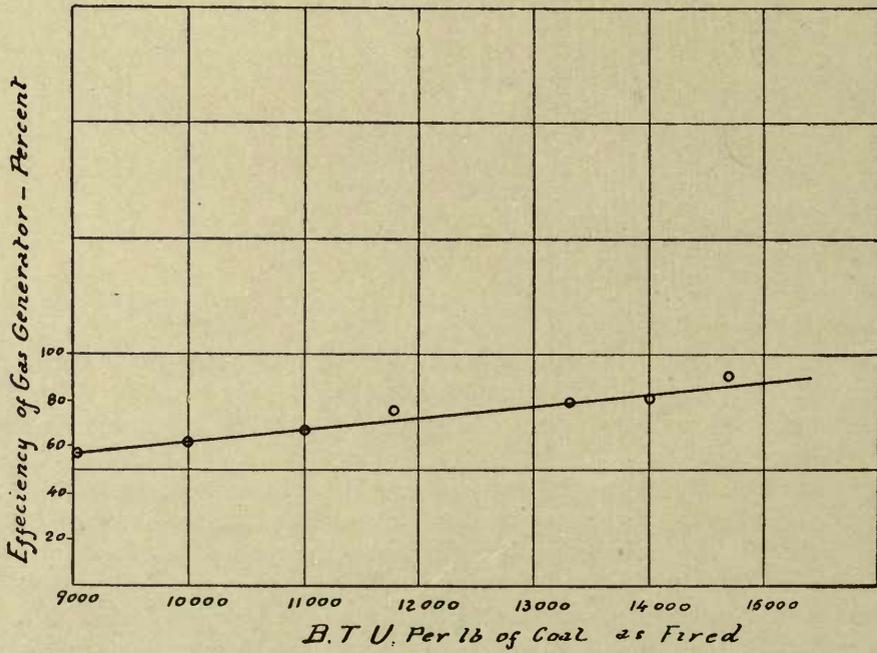
FIG. 100.—Relation of B.T.U. per Pound to Producer Efficiency.

In spite of those restricted conditions, the general conclusions derived from tests upon fifty odd coals made during 1905 are regarded as sufficiently significant for pre-
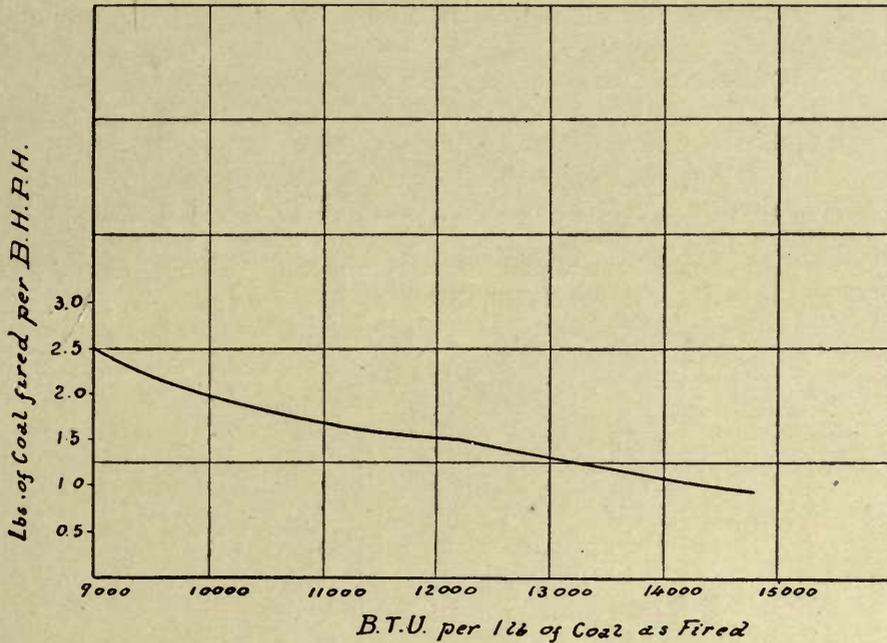
FIG. 101.—Richness of Coal and Power Yield.
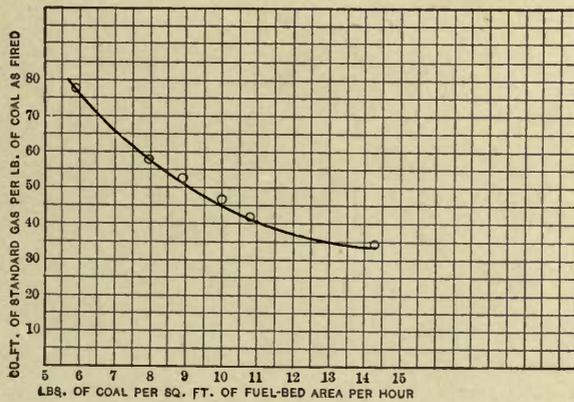
FIG. 102.—Relation of Combustion Rate to Gas Yield per Pound.

sentation at this time, although subject to modification in the light of later investigations. They are accordingly indicated in the following diagrams:

According to another authority the quantity of gas produced from a ton of coal varies with the composition and general character of the coal and the method of oper-

ation, of which we may note especially the proportion of steam used in blowing the producer. But on the average it may be assumed that one ton of anthracite buckwheat coal produces about 170,000 cu.ft. of gas, containing 138 heat units per 1000 cu.ft. Its composition will average as follows:

Producer Gas.	Per Cent.
CO, carbon monoxide............................	22.0 to 30.0
H, hydrogen....................................	15.0 " 7.0
CH$_4$, methane, marsh gas......................	3.0 " 1.5
CO$_2$, carbon dioxide, "carbonic acid"..........	6.0 " 1.5
N, nitrogen....................................	54.0 " 60.0

The analysis of gas from bituminous coal is nearly the same, except that CH$_4$ is a trifle higher and the H frequently above the maximum noted in table. But, as a matter of fact, an analysis of bituminous gas does not properly represent its energy, as some of the volatile combustible of the coal passes off as a non-fixed vapor and does not appear in the analysis (being condensed in the tubes of the analytical apparatus), yet it is utilized in the furnace.
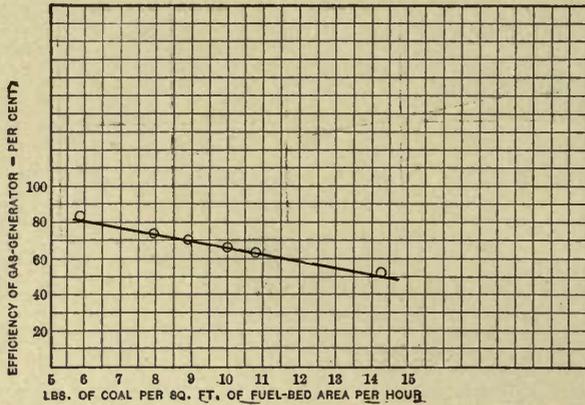
FIG. 103.—Relation of Combustion Velocity to Efficiency of Producer.

The yield of gas from different fuels varies within wide limits, depending upon the composition and general character of the fuel and method of operation. More as an index to differences of yield than as accepted data the following figures are given for the fuel free from ash, the dry gas and an air blast:

Producer Fuel.	Yield per Pound, Cubic Feet.	Producer Fuel.	Yield per Pound, Cubic Feet.
Coke or charcoal.............	104	Turf......................	45
Bituminous coal..............	75	Wood....................	35
Brown coal..................	55		

ANALYSIS OF PENNSYLVANIA GAS COAL AND GAS GENERATED FROM SAME BY A SMITH PRODUCER

Analysis of Coal.	Per Cent.	Analysis of Coal.	Per Cent.
Moisture...................	1.19	Ash......................	6.26
Volatile carbon.............	36.05	Sulphur..................	0.74
Fixed carbon...............	55.76		

Analysis of Gas.	Per Cent.	Analysis of Gas.	Per Cent.
Hydrogen, H...............	11.41	Carbon monoxide, CO......	22.98
Oxygen, O.................	0.08	Carbon dioxide, CO$_2$.......	4.04
Carbohydrates..............	3.61	Nitrogen, N...............	57.88

ANALYSIS OF ANTHRACITE GAS, SMITH SUCTION PRODUCER

Load less than 25% of rated capacity

CO₂.	O.	CO.	H.	N.	Heating Capacity.
8	0.7	20.3	17.0	54.0	131
4	0.2	27.0	13.9	54.9	140
5	2.0	23.5	12.0	57.5	121

Load 25 to 125% of rated capacity

CO₂.	O.	CO.	H.	N.	Heating Capacity.
5.0	1.0	22.0	21.3	50.7	157
4.0	1.0	23.0	22.6	49.4	158
9.0	1.0	21.0	21.5	47.5	146
7.0	2.0	23.0	23.5	44.5	160
4.8	0.2	25.6	22.9	46.5	167

LIGNITE GAS

CO₂.	O.	CO.	H.	N.	Heating Value.
8.4	1.8	18.3	25.6	45.9	152
8.0	3.5	15.5	27.0	46.0	147
6.6	2.2	20.2	25.0	46.0	165

The analyses given are selected at random, and from producers of from 25 to 200 h.p. rated capacity, and under all possible conditions of load and service.

ANALYSIS OF SEMI-ANTHRACITE BEING RUN IN FAIRBANKS-MORSE SUCTION PRODUCERS

	Per Cent.
Fixed carbon.....................................	75.30
Volatile combustibles.............................	7.40
Ash...	15.10
Moisture...	2.20
Sulphur..	2.99
Heat value per pound, B.T.U......................	12,020

This coal comes from the neighborhood of Bernice, Pa.

Lignites.—The Power and Mining Machinery Co. have tried lignite in their Loomis-Pettibone gas producers installed at their works and the results have been highly satisfactory. The lignites used were mined in North Dakota and gave following analyses:

U. S. GEOLOGICAL SURVEY	WASHBURN LIGNITE COAL CO.
Moisture......... 39.56	Moisture......... 22.06
Volatile matter..... 27.78	Volatile matter..... 42.72
Fixed carbon 26.30	Fixed carbon 30.50
Ash.............. 6.36	Ash.............. 4.72
Sulphur.......... 0.93	

The following figures are the results obtained in a test made with this coal:

Hours run.	93
Total lignite consumed in generators, lbs.	1862
Total coke consumed in generators, lbs.	795
Total b.h.p. hours (corrected).	8289
Lignite per b.h.p. hour, lbs.	2.24
Coke per b.h.p. hour, lbs.	0.09
Lignite consumed per hour in generator, lbs.	200
Lignite consumed per square foot of grate surface in generator, lbs.	20

The approximate yield of gas was arrived at by the occasional observation of the holder. The cubic feet of gas per pound of fuel averaged 44.

The gas furnished in every respect proved itself extremely desirable for use in the gas engines then being run at the shop. The gas producer ran from 2 to 3 hours without reversing, consequently, the percentage of variation of hydrogen is extremely low. The gas averaged 105 to 110 B.T.U.'s per cubic foot.

Experiments made in the application of Texas lignite in revolving bottom gas producers, under the inspection of the State geologist of Texas, resulted in demonstrating its great worth as a basis of gas production. The lignite tested resembles in composition much of this class of fuel abounding in the Western states.

TEXAS LIGNITE COMPOSITION

	Per Cent.
Moisture.	21.86
Volatile matter.	31.81
Fixed carbon.	36.85
Ash.	9.48

The gas is high in hydrocarbons, and, as a consequence, its flame produces an intense heat.

The following analysis of the coal and gas show the result of gasifying similar Peruvian coals:

PERUVIAN COAL		PRODUCER GAS	
Water.	18	CO_2.	6.4
Volatile matter.	40	C_2H_4.	0.7
Fixed carbon	31	O.	0.8
Ash.	9	CO.	22.0
Sulphur.	3.5	H.	9.6
		CH_4.	1.6
		N.	58.9 (diff.)

Gas from the earthy and brown coals is very largely employed in Europe in many metallurgical works and manufactories requiring high-temperature furnaces, as in iron and steel, potteries, glass works, etc. There is no apparent reason why the lignitic coals of the West should not be as satisfactorily used.

ANALYSIS OF NEW MEXICO LIGNITE

AMERICAN FUEL CO.

Car sample as received:

	Per Cent.		Per Cent.
Moisture	12.29	Ash	6.99
Volatile matter	34.58	Calorific value, B.T.U.	11,252
Fixed carbon	46.14		

Analysis of air-dried sample:

	Per Cent.		Per Cent.
Moisture	10.86	Ash	7.10
Volatile matter	35.14	Calorific value, B.T.U.	11,290
Fixed carbon	46.90		

CALEDONIA COAL COMPANY, OTERO MINE, NEAR GALLUP

Analysis of sample as received:

	Per Cent.		Per Cent.
Moisture	10.79	Ash	18.66
Volatile matter	33.82	Calorific value, B.T.U.	9,907
Fixed carbon	36.73		

Analysis of air-dried sample:

	Per Cent.		Per Cent.
Moisture	8.13	Ash	19.22
Volatile matter	34.82	Calorific value, B.T.U.	10,136
Fixed carbon	37.83		

ANALYSIS OF WASHINGTON LIGNITES

	Per Cent.		Per Cent.
Ash	4.01	Sulphur	0.10
Volatile matter	38.42	Moisture	18.07
Carbon	39.40		

GAS FROM LIGNITES

Constituents.		Simpson Mine, Colorado.	Hoyt Lignite, Texas.
Lignite:	Moisture	20.24	33.71
	Volatile matter	32.26	29.25
	Fixed carbon	41.65	29.76
	Ash	5.85	7.28
	Sulphur	.60	.53
Gas:	CO_2	10.11	9.60
	O	.55	.20
	CO	17.38	18.22
	H	11.05	9.63
	CH_4	5.00	4.81
	N	55.90	57.53
B.T.U. per lb. as fired		9767	7348
Gas per lb.		42.1 cu.ft.	34.2 cu.ft.
B.T.U. per cu.ft.		149.	156.2

Gas-house Coke.—Where gas-house coke is used as a producer fuel, great care should be taken that the coke thoroughly carbonized and a uniform quality throughout, for should the coke be green, it would be found, especially in up-draft producers, that the volatile matter and heavier hydrocarbons, which have not been evaporated during the dissociation process, will be distilled and carried off together with fine dust in the form of paste, which is exceedingly difficult of separation from the gas.

This "tar-fog" or mist, entrains mechanically dust and dirt from both the fuel itself and the blast and, going over in the form of paste which is almost inseparable from the gas, creates a stoppage wherever bends or turns occur in the pipe, and also in the mixing chamber and governor valve of the engine, besides creating a "muck" inside of the cylinders.

The coke used as producer fuel should be crushed to not exceed a 1.5-inch mesh in order to prevent an inefficient percentage of voids. The bed should be carried some 50% deeper than in the case of anthracite, in order that additional weight be given to the fuel bed and that it may pack more closely, otherwise the coke on account of its lack of weight and density is apt to blow more readily into fissures and chimneys, permitting the undissociated passage of the air.

A compactness of fire bed is particularly necessary in the operation of coke, as its high flame temperature subtends the formation of a particularly refractory class of clinker when the blast is concentrated upon any section of the bed through follow a line of least resistance, in cases of honeycombing, chimneys, or blow holes.

The rapidity with which coke burns, due to its lack of density, creates another reason for close supervision of the fire bed, as the nature of this bed, by reason of the rapid combustion, alters continually and with astonishing rapidity.

The efficiency usually obtained with gas-house coke is about 1.25 lbs. of coal per b.h.p. hour on small installations.

PRODUCER GAS FROM COKE, LOOMIS-PETTIBONE PRODUCERS

	Galitzen, 24 Hours.	Chest Creek.	Frick, 1½ Minute Run.	Chest Creek, 48 Hours.
CO_2, H_2S	3.9	5.2	4.80	3.50
O	0.6	0.1	0.80	.50
CO	44.66	40.9	39.01	40.47
H	47.81	48.33	50.67	50.70
N	3.03	5.47	4.72	4.83

The above table is a summary of a number of analyses in each case on the different fuels mentioned, and running under commercial conditions upon Loomis-Pettibone apparatus in 1891. The samples were taken during 3-minute runs, unless otherwise specified. The generators were 9×14 ft., producing 30,000 cu.ft. per hour per pair of generators.

Tan Bark.—Gasification of spent tan bark has also been successfully accomplished.

The spent tan bark contained: moisture, 38.67%; and ash 3.24%. The gas obtained from the producer plant of special character, after its cooling and washing, analyzed as follows:

Per Cent by Volume.	I.	II.	III.
CO_2	10.8	18.8	15.0
O	0.6	0.4	0.4
CO	17.6	10.2	14.2
CH_4	2.4	4.8	5.6
H	16.4	14.0	8.7
N	52.2	51.8	56.0

Calorific powers determined repeatedly by a Junker's calorimeter gave 125, 132, and 141 B.T.U. per cubic foot. Mixed with 25% of coke fines an average of 145 B.T.U. was obtained.

By-Product Coke Oven Results.—The following figures are taken from the actual records of operation of an existing United-Otto plant for a period of six months, and are representative of the returns that may be expected under the prevailing conditions. A coal mixture averaging 30 to 32% of volatile matter, gave the following results:

Average daily coal carbonization .... 503 net tons
Average yield of coke (per cent of coal) 74%
Average yield of ammonia (NH_3) per net ton coal................. 5.20 lbs.
Average yield tar per net ton of coal .... 10.17 gals.
Average quantity illuminating gas sold per net ton coal corrected to
  60° F. and 29.92 ins. barometrical pressure................... 4,630 cu.ft.
Average illuminating value of gas .... 18.07 candles

Gas Analyses.	Illuminating Gas.	Fuel-Gas (For Oven Heating.)
Illuminants	5.8	2.8
Methane	40.8	29.6
Hydrogen	37.6	41.6
Carbon monoxide	5.6	6.3
Carbon dioxide	3.7	3.2
Oxygen	.4	.4
Nitrogen	6.1	16.1
British thermal units (gross) per cu.ft.	730.3	551.3

YIELD OF COKE AND BY-PRODUCTS
(From Dry Coal)

	Per cent by weight.		
Coke	70	to	82
Heating gas	12	"	11
Surplus	7.5	"	2
Tar	5	"	2
Crude ammonia liquor	5.5	"	3

The results from coking 100 net tons of coal are as follows:

Bee-hive Ovens: 65 net tons coke.

By-product Ovens: 75 net tons coke, 1,000 gallons tar, 2,300 lbs. sulphate of ammonia and 450,000 cu.ft. illuminating gas.

Fuel Data.—The following data may be of service to the user or student of fuels:

WEIGHT PER CUBIC FOOT OF COAL AND COKE

	Pounds per Cubic Foot.	Storage for Long Ton, Cubic Feet.
Anthracite coal, market sizes, loose..............	52–56	40–43
Anthracite coal, market sizes, moderately shaken.	56–60	
Anthracite coal, market size, heaped bushel, loose.	77–83	
Bituminous coal, broken, loose.................	47–52	43–48
Bituminous coal, moderately shaken............	50–56	
Bituminous coal, heaped bushel................	70–78	
Dry coke.....................................	23–32	80–97
Dry coke, heaped bushel (average 38)..........	35–42	

HEATING VALUE OF SOME FUELS

	B.T.U.
Peat, Irish, perfectly dried, ash 4%.....................	10,200
Peat, air-dried, 25% moisture, ash 4%...................	7,400
Wood, perfectly dry, ash 2%...........................	7,800
Wood, 25% moisture...................................	5,800
Tanbark, perfectly dry, 15% ash.......................	6,100
Tanbark, 30% moisture................................	4,300
Straw, 10% moisture, ash 4%..........................	5,450
Straw, dry, ash 4%...................................	6,300
Lignites...	11,200

The above are approximate figures, for on such materials qualities are very variable.

Coal and coke are often measured by the bushel. The standard bushel of the American Gas Light Association is $18\frac{1}{2}$ ins. diameter and 8 ins. deep = 2150.42 cu.ins. A heaped bushel is the same plus a cone $19\frac{1}{2}$ ins. diameter and 6 ins. high, or a total of 2747.7 cu.ins. An *ordinary* heaped bushel = $1\frac{1}{4}$ struck bushel = 2688 cu.ins. = 10 gallons dry measure.

Crude petroleum = 7.3 lbs. per gallon.

ANTHRACITE-COAL SIZES

Size and Name.	Through a Round Hole.	Over a Round Hole.
Chestnut........................	$1\frac{1}{2}$ ins. diam.	$\frac{7}{8}$ ins. diam.
Pea..............................	$\frac{7}{8}$ " "	$\frac{9}{16}$ " "
No. 1 buckwheat..................	$\frac{9}{16}$ " "	$\frac{3}{8}$ " "
No. 2 buckwheat or rice..........	$\frac{3}{8}$ " "	$\frac{7}{16}$ " "
No. 3 buckwheat or barley........	$\frac{3}{16}$ " "	$\frac{3}{32}$ " "
Dust............................	$\frac{3}{32}$ " "	
Broken..........................	..	$2\frac{3}{4}$ " "
Egg.............................	$2\frac{3}{4}$ " "	2 " "
Stove...........................	2 " "	$1\frac{3}{8}$ " "
Chestnut........................	$1\frac{3}{8}$ " "	$\frac{3}{4}$ " "
Pea..............................	$\frac{3}{4}$ " "	$\frac{1}{2}$ " "
No. 1 Buckwheat.................	$\frac{1}{2}$ " "	$\frac{1}{4}$ " "
Rice............................	$\frac{1}{4}$ " "	$\frac{1}{8}$ " "

WOOD FUEL

	Weight per Cord, Pounds.	Coal Equivalent, Pounds.
Hickory or hard maple	4500	2000
White oak.................................	3850	1711
Beech, red oak, black oak...................	3250	1445
Poplar, chestnut, elm.......................	2350	1044
Pine......................................	2000	890

Sharpless assumes a coal equivalent of about 10% less than that given above.

Coal and other solid fuels vary considerably in composition, as shown by these average examples:

ANALYSES OF FUELS

	Water.	Volatile Matter.	Fixed Carbon.	Ash.	Sulphur.
Anthracite (mixed)............	3.40	3.80	83.80	8.40	0.60
Semi-bituminous.............	1.00	20.00	73.00	5.00	1.00
Bituminous..................	1.20	32.50	60.00	5.30	1.00
Lignite.....................	22.00	32.00	37.00	9.00	....
Coke.......................	....	....	89.00	10.00	0.80

	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Ash.
Wood, dry..................	50.0	6.0	41.0	1.0	2.0
Charcoal...................	75.5	2.5	12.0	...	1.0
Peat, dry and ash-free........	58.0	5.7	35.0	1.2	

COMPARATIVE COST OF FUEL GASES

Bituminous producer gas:											
Cost per ton coal.............	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00	3.25	....	....
Cost per 1000 ft. gas..........	.007	.0084	.0097	.01	.012	.013	.015	.016	.018	....	....
Cubic feet for one cent ,.......	1400	1200	1040	900	800	720	660	625	550	....	....
B.T.U. for one cent	168000	144000	124800	108000	96000	86400	79200	75000	66000	....	....
Anthracite producer gas:											
Cost per ton coal.............	2.75	3.00	3.25	3.75	4.00	....	....	....	....	....	....
Cost per 1000 ft. gas..........	.015	.016	.018	.019	.022	....	....	....	....	....	....
Cubic feet for one cent	660	625	550	500	460	....	....	....	....	....	....
B.T.U. for one cent	79200	75000	66000	60000	55200	....	....	....	....	....	....
Fuel oil:											
Cents per gallon 6.7 lbs........	2¼	2½	2¾	3	3¼	3½	3¾	4	4¼	4½	4¾
B.T.U. for one cent	60450	54400	49400	45600	41800	38800	36200	34000	31000	30000	38600
Coal gas or water gas:											
Cost per 1000 ft. gas..........	.80	.90	1.00	1.10	1.15	1.20	1.25	....	....	....	....
Cubic feet for one cent	12.5	11.1	10	9	8.7	8.3	8	....	....	....	....
B.T.U. for one cent	6570	5838	5260	4734	4576	4365	4203	....	....	....	....
Natural gas:											
Cost per 1000 ft. gas, cents....	.10	.15	.20	.25	.30	....	....	....	....	....	....
Cubic feet for one cent	100	66	50	40	33	....	....	....	....	....	....
B.T.U. for one cent	96700	63800	48300	38700	31900	....	....	....	....	....	....
Coke-oven gas:											
Cost per 1000 ft. gas, cents	4	4½	5	5½	6	6½	7	7½	8	9	10
Cubic feet for one cent	250	220	200	180	166	153	143	133	125	111	100
B.T.U. for one cent	136200	119100	109000	98100	90500	83400	77900	72400	68100	60500	54500

ANALYSES OF ABOVE GASES

	B.T.U. per Cu.ft.	Hydrogen.	Methane, CH_4.	Carbon Monoxide, CO.	Ethylene, C_2H_2.	Carbon Dioxide, CO_2.	Nitrogen, N.	Oxygen, O.	PerCent Total Combustible	PerCent Total Incombustible
Bituminous producer gas........	131.2	13	5	15	0.2	7.3	59	0.5	33.2	66.8
Anthracite producer gas	127.5	15	2.5	20	0.0	8.0	54	0.5	37.5	62.5
Fuel oil, per pound	20000	....	....	....	....	....	....	....	....	....
Coal gas or water gas...........	526.5	40	25	19	8.5	3.0	4.0	0.5	92.5	7.5
Natural gas	967.2	3	92	0	3	0	2	0	98	2
Coke-oven gas	545.2	50	6	6	4	1.5	2	0.5	96	4

CHAPTER VII

PHYSICAL PROPERTIES OF GASES

Siebel defines a gaseous body as follows: "Speaking more specifically, a gas is a body in which the distance between the constituent atoms or molecules is so great that the dimensions of the molecules themselves may be neglected in comparison therewith. The atoms or molecules in a gas are constantly vibrating to and fro, and the average momentum or energy of this motion represents the temperature of the gas. The vehemence or force with which the atoms or molecules impinge on the walls of a surrounding vessel in consequence of this motion represents the pressure of the gas."

Regardless of quantity of a gas, it will always fully occupy the vessel or space which contains it. The force which this gas exerts when confined in a limited space is known as "tension."

General Properties of Gases.—*Unit of Pressure.*—The general unit of pressure is the pressure of the atmosphere per square inch, which is equal to that of a column of water of about 30 feet, or that of a column of mercury of about 30 inches, and also equivalent to a pressure of 14.7 pounds—in round numbers 15 pounds per square inch.

Manometer Gauges.—Glass tubes filled with mercury are frequently used to measure higher pressures than that of the atmosphere and are called manometers. For this purpose, however, aneroid gauges are used chiefly for the measurement of atmospheric boiler and vacuum pressures.

Action of Vacuum.—The pressure of the atmosphere is the cause of the raising of water by suction pumps, the air in the pumps being removed by the movement of the piston, and its space occupied by water forced up by the pressure of the outside atmosphere. For the same reason such a pump cannot lift water higher than 32 feet, a column of water of this height exerting nearly the same pressure as the atmosphere at the earth's surface. For the same reason the mercury in a barometer (or glass tube from which the air is withdrawn) stands about 29 inches high, varying with the pressure of the atmosphere between 27 and 30 inches at the earth's surface, but decreases with the height above the earth at the rate of 0.1 inch for 84 feet.

Absolute and Gauge Pressure.—The pressure gauges in general use indicate pressure in pounds per square inch above the atmospheric pressure. To convert gauge pressure into absolute pressure 14.7 has to be added to the former. Lighter pressures are designed by the number of inches of mercury which they will sustain, or in the metric system by millimeters of mercury.

Weight of Gases.—The weight of a gas is determined by weighing a glass balloon filled with the same, and by subtracting from this weight that of the balloon after it has been exhausted by means of an air pump. One hundred cubic inches of air weighs 31 grains at a pressure of the atmosphere of 30 inches, and at a temperature of 60° F.; therefore the density of the air is 0.001293, or one one hundred and seventy-third that of water. One hundred cubic inches of hydrogen, the lightest of the common gases, weighs 2.14 grains.

Mixture of Gases.—Two or more gases present in vessels communicating with each other, mix readily, and each portion of the mixture contains the different gases in the same proportion. Mixtures of gases follow the same laws as simple gases.

Critical Temperature.—There appears to exist for each gas a temperature above which it cannot be liquefied, no matter what amount of pressure is used. It is called the critical temperature. Below this temperature all gases or vapors may be liquefied if sufficient pressure is used.

Critical Volume.—The critical volume of a gas is its volume at the critical point, measured with its volume at the freezing point, under the pressure of an atmosphere as unit. The critical temperature, pressure, and volume are frequently referred to as critical data.

Dalton's Law.—The pressure exerted on the interior walls of a vessel containing a mixture of gases is equal to the sum of the pressures which would be exerted if each of the gases occupied the vessel itself alone.

Critical Pressure.—The pressure which causes liquefaction of a gas at or as near below the critical temperature as possible, is called the critical pressure. Between these two temperatures—that is, in the neighborhood of the critical point—the transition from one state to another is not discernable.

Buoyancy of Gases.—The Archimedian principle applies to the buoyancy of gases; hence a body lighter than air will ascend (air balloons, smoke, etc.).

Specific Heat of Gases.—A gas may be heated while its volume is kept constant and also while its pressure remains constant. In the former case the pressure increases and in the latter the volume increases; therefore we make a distinction between specific heat of gases at a constant volume and at a constant pressure. In the former case the heat added is only used to increase the momentum of the molecules, while in the latter case an additional amount of heat is required to do the work of expanding the gas against the pressure of the atmosphere. The specific heat of all permanent gases for equal volumes at constant pressure is nearly the same, and equal to about 0.2374, water taken as unit.

Heat of Compression.—When gases or vapors are being compressed, the energy or work spent to accomplish the compression appears in the form of heat.

Adiabatic Changes.—As gas is said to be expanded or compressed adiabatically when no heat is added or abstracted from the same during expansion or compression, an adiabatic line or curve represents graphically the relations of pressure and volume under such conditions.

Liquefaction of Gases.—If sufficient pressure be applied to a gas, and the temperature is sufficiently lowered, all gases can be compressed so as to assume the liquid state.

Latent Heat of Expansion.—When a gas expands while doing work, such as propelling a piston, an amount of heat equivalent to the work done becomes latent or disappears. It is called the latent heat of expansion.

Perfect Gas.—The above rules and formulæ apply, strictly speaking, only to a perfect or ideal gas, that is, a gas in which the dimensions of the molecules may be neglected as regards the distance between them. Therefore when a gas approaches the state of a vapor these rules do not apply.

Free Expansion.—When gas expands against an external pressure much less than its own, the expansion is said to be free. The refrigeration due to the work done by such expansion may be used to liquefy air. (Linde's Method.)

Volume and Pressure.—The relation of volume, pressure, and temperature of gases are embodied in the following formulæ in which V stands for the initial volume of a gas at the initial temperature t and the initial pressure p. V', t', and p' stand for the corresponding final volume, temperature, and pressure.

For different temperatures,

$$V' = V\,\frac{t'+461}{t+461}.$$

For different pressures,

$$V' = V\,\frac{p}{p'}.$$

For different temperatures and pressures,

$$V' = V\,\frac{p(t'+461)}{p'(t+461)}.$$

If the initial temperature is 60° F. and the initial pressure that of the atmosphere, the final pressure may be found after the formula,

$$p' = \frac{V(t'+461)}{35.58\,V'}.$$

If the volume is constant,

$$p' = \frac{t'+461}{35.58}.$$

If the temperatures in above formula are expressed in degrees Fahrenheit above absolute zero, the 461 is to be omitted.

Isothermal Changes.—A gas is said to be expanded or compressed isothermally when its temperature remains constant during expansion or compression, and an isothermal curve or line represents graphically the relations of pressure and volume under such conditions.

Absolute Zero.—The expansion of a perfect gas under constant pressure being one four hundred and ninety-third of its volume per degree at 32° F., it follows that if a perfect gas be cooled down to a temperature of 493° below freezing or

461° below zero its volume will become zero. Hence this point is adopted as the absolute zero of temperature.

Absorption of Gases.—Gases are absorbed by liquids; the quantities of gases so absorbed depend upon the nature of the gas and liquid, and generally increase with the pressure and decrease with the temperature. During the absorption of gas by a liquid a definite amount of heat is generated, which heat is again absorbed when the gas is driven from the liquid by increase of temperature or decrease of pressure. Solids, especially porous substances, also absorb gases. Thus charcoal absorbs ninety times its own volume of ammonia gas.

Velocity of Sound.—The velocity V of sound in gases is expressed by the formula

$$V = \sqrt{\frac{ghD}{d}(1+at) - \frac{c}{c'}}.$$

In which formula g is the force of gravity, h is the barometric height, D the density of mercury, d the density of the gas, t its temperature, c its specific heat at constant pressure, c' its specific heat at constant volume. Hence the quotient $\frac{c}{c'}$ for a certain gas can be determined by the velocity of sound in the same.

Friction of Gas in Pipes.—The loss of pressure in pounds P sustained by gas in traveling through a pipe having the diameter d in inches. for a distance of l feet, and having a velocity of n feet is

$$P = 0.00936 \frac{n^2 l}{d}.$$

Properties.—One authority compiles the following characteristics of gases usually met in metallurgical calculations.

CARBONIC ACID OR CARBON DIOXIDE

Formula . . . . CO_2
Composition by weight . . . . 73.7% O, 27.3% C
Density or specific gravity, air = 1 . . . . 1.529
Pounds per cubic foot 116
Cubic feet per pound 8.62
Cubic feet air necessary to consume 1 cu.ft . . . . Non-combustible
B.T.U. per cubic foot . . . . Non-combustible
Solubility: Volumes absorbed in 1 volume water . . . 1.23

ILLUMINANTS OR HEAVY HYDROCARBONS

Formula . . . . 90% C_2H_4
Composition by weight . . . . 85.7% C, 14.3% H
Density or specific gravity, air = 1 985
Pounds per cubic foot 074
Cubic feet per pound 13.38
Cubic feet air necessary to consume 1 cu.ft 14.34
B.T.U. per cubic foot 1675
Solubility: Volumes absorbed in 1 volume water 15

OXYGEN

Formula . . . .   O
Composition by weight . . . . .100% O
Density or specific gravity, air = 1 . . . .   1.105
Pounds per cubic foot 084
Cubic feet per pound 11.94
Cubic feet air necessary to consume 1 cu.ft . . . . Non-combustible
B.T.U. per cubic foot . . . . Non-combustible
Solubility: Volumes absorbed in volume water 028

CARBONIC OXIDE OR CARBON MONOXIDE

Formula . . . .   CO
Composition by weight . . . . 42.9% C, 57.1% O
Density or specific gravity, air = 1 967
Pounds per cubic foot 073
Cubic feet per pound 13.57
Cubic feet air necessary to consume 1 cu.ft 2.39
B.T.U. per cubic foot 341
Solubility: Volumes absorbed in 1 volume water 023

HYDROGEN

Formula . . . .   H
Composition by weight . . . . .100% H
Density or specific gravity, air = 1 069
Pounds per cubic foot 006
Cubic feet, pounds 189.23
Cubic feet air necessary to consume 1 cu.ft 2.39
B.T.U. per cubic foot 345
Solubility: Volumes absorbed in 1 volume water 019

METHANE OR MARSH GAS

Formula . . . . CH_4
Composition by weight . . . . 75% C, 25% H
Density or specific gravity, air = 1 556
Pounds per cubic foot 0422
Cubic feet per pound 23.72
Cubic feet air necessary to consume 1 cu.ft 9.56
B.T.U. per cubic foot 1065
Solubility: Volumes absorbed in 1 volume water 035

NITROGEN

Formula . . . .   N
Composition by weight . . . . .100% N
Density or specific gravity, air = 1 971
Pounds per cubic foot 073
Cubic feet per pound 13.57
Cubic feet of air necessary to consume 1 cu.ft . . . . . . Non-combustible
B.T.U. per cubic foot . . . . Non-combustible
Solubility: Volumes absorbed in 1 volume water 015

ACETYLENE

Formula	CH_2
Composition by weight	93.3% C, 7.7% H
Density or specific gravity, air = 1	.918
Pounds per cubic foot	.069
Cubic feet per pound	14.32
Cubic feet air necessary to consume 1 cu.ft	11.91
B.T.U. per cubic foot	.1600
Solubility: Volumes absorbed in 1 volume water . . .	1.11

AIR

Formula	Mixture O and N
Composition by weight	77% N, 23% O
Density or specific gravity, air = 1	1.000
Pounds per cubic foot	.076
Cubic feet per pound	13.15
Cubic feet air necessary to consume 1 cu.ft	Non-combustible
B.T.U. per cubic foot	Non-combustible
Solubility: Volumes absorbed in 1 volume water . . .	.017

Properties of Vapors.—As long as a volatile substance is above its critical temperature it is called a gas, and if below, it is called a vapor. This definition, although the most definite, is not the most popular one. Frequently a vapor is defined as representing that gaseous condition at which a substance has the maximum density for that temperature or pressure. Generally gaseous bodies are called vapors when they are near the point of their maximum density, and a distinction is made between saturated vapor, superheated vapor, and wet vapor.

Dalton's Law for Vapors.—The tension and consequently the amount of vapor of a certain substance which saturates a given space is the same for the same temperature, whether this space contains a gas or is a vacuum. The tension of the mixture of a gas and a vapor is equal to the sum of the tensions which each would possess if it occupied the same space alone.

Dissociation.—The term dissociation is used to denote the separation of a chemical compound into its constituent parts, especially if the separation is brought about by subjecting the compound to a high temperature.

Vaporization.—A liquid exposed to the atmosphere or to a vacuum forms vapors until the space above the liquid contains vapor of the maximum density for the temperature.

Tension of Vapors.—Like gases vapors have a certain elastic force, by virtue of which they exert a certain pressure on surrounding surfaces. This elastic force varies with the nature of the liquid and the temperature, and is also called the tension of the vapor.

Elevation of Boiling-point.—Substances held in solution by liquids raise their boiling-point. Thus a saturated solution of common salt boils at 214° F. and one of chloride of calcium at 370° F. Water may be caused to boil at a much higher temperature than the one indicated by the normal boiling-point, so water free from

gases may be heated to over 260° F. without showing signs of boiling. This retardation of boiling sometimes takes place in boilers, and may cause explosions if not guarded against by a timely agitation produced in the water.

Sublimation.—The change of a solid to the vaporous state without first passing through the liquid state is called sublimation. Camphor, ice, or snow will sublimate in this manner.

Different Boiling-points.—The boiling-point varies with the nature of the liquid, and always increases with the pressure. It is not affected by the temperature of the source of heat, the temperature of the liquid remaining constant as long as ebullition takes place. The heat which is imparted to a boiling liquid, but which does not show itself by an increase of temperature, is called the latent heat of vaporization.

Vapors from Mixed Liquids.—The tension of vapor from mixed liquids (which have no chemical or solvent action on each other) is nearly equal to the sum of tension of the vapor of the two separate liquids.

Dry or Superheated Vapor.—Vapors which are not saturated are also called dry or superheated vapors, and behave like permanent gases.

Liquefaction of Vapors.—When vapors pass from the aeriform to the liquid state, that is when they are liquefied, the heat which becomes latent during evaporation, appears again, and must be removed by cooling. Vapors of liquids, the boiling-point of which is above the ordinary temperature, can be liquefied at the ordinary temperature without additional pressure (distilling, condensation). Permanent gases require additional pressure and in some cases considerable refrigeration, to become liquefied (compression of gases).

Boiling-point.—The temperature at which ebullition of a liquid takes place is called its boiling-point for the pressure then obtaining. When no special pressure is mentioned we understand by boiling-point that temperature at which liquids boil under the pressure of the atmosphere.

Refrigerating Effects.—If liquids possess a boiling-point below the temperature of the atmosphere the latent heat of vaporization is drawn from its immediate surroundings causing a reduction of temperature, i.e., refrigeration.

Latent Heat of Vaporization.—The heat which becomes latent during the process of volatilization is composed of two distinct parts. The one part is absorbed while doing the work of disintegrating the molecular structure while doing internal work, as it is termed. The other part of heat, which becomes latent, is absorbed by doing the work of expansion against the pressure of the atmosphere, and is called the external work. In a liquid vaporized in vacuum, in which case no pressure is to be overcome, the external work becomes zero, and only heat is absorbed to do the internal work of vaporization (free expansion).

Ebullition.—If the temperature is high enough the vaporization takes place throughout the liquid by the rapid production of bubbles of vapor. This is called ebullition, and the temperature at which it takes place is a constant one for one and the same liquid under a given pressure.

Saturated Vapor.—A vapor is saturated when it is still in contact with some of its liquid; vapors in the saturated state are at their maximum density for that temperature. Compression of a saturated vapor, without change of temperature,

produces a proportionate amount of liquefaction. But if the temperature rises correspondingly to the work done by the compression, or partially so, it becomes superheated.

General Laws.—*Temperature.*—The weight of dry air at 32° F. and atmospheric pressure (14.7 lbs. per square inch) is 0.0807 lbs. per cubic foot; from which the volume of one pound = 12.4 cu.ft. At other temperatures and pressures its weight in pounds per cubic feet is $W = \dfrac{1.325 \times B}{459.2 + t}$, in which B = reading of barometer in inches and t = temperature F.

The absolute zero of temperature on the Fahrenheit scale is 492° below 32°, or −460° F. The absolute temperature then is obtained by adding 460° to the temperature as read from the Fahrenheit scale. Thus 60° F. = 60° + 460° = 520° absolute; and −20° F. = −20° + 460° = 440° absolute.

Mechanical Equivalent of Heat.—Heat energy and mechanical energy are mutually convertible, that is, a unit of heat requires for its production, and produces by its disappearance, a definite amount of mechanical energy, namely, 778 ft.-lbs. of work for each British thermal unit.

Pressure.—Boyle's law states that the product of the pressure and volume of a portion of gas is constant so long as the temperature is constant, that is, $pv = c$ in which p = pressure in pounds per square foot and v = volume in cubic feet. For air at 32° F., this constant quantity is 26,200 ft.-lbs., or $pv = 26{,}200$ ft.-lbs.

Charles' and Gay-Lussac's law states that when the pressure is constant all gases expand alike for the same increase of temperature. The amount of this expansion between 32° and 212° F. is 0.365 of the original volume; and for each degree it equals $0.365 \div 180 = 0.00203$. Similarly, when the volume remains constant the pressure varies in the above ratio.

Combining Boyle's and Charles' laws we see that the product of the pressure and volume of a portion of gas is proportional to the absolute temperature. Thus, $\dfrac{pv}{p_1 v_1} = \dfrac{T}{T_1}$, in which p and p_1 = absolute pressures (that is, pressures above a vacuum) in pounds per square foot; v and v_1 = volumes in cubic feet; T and T_1 = absolute temperatures.

Transforming the above equation and substituting 32 for T_1 and 26,200 for $p_1 v_1$, we get

$$pv = \frac{p_1 v_1}{T_1} T = 53.2\, T.$$

The specific heat of a gas is the quantity of heat in heat units necessary to raise the temperature of one pound of the gas through one degree of temperature.

The specific heat of air is at constant pressure, $c_p = 0.238$, and at constant volume, $c_v = 0.169$ B.T.U.

Adiabatic expansion or compression of a gas means that the gas is expanded or compressed without transmission of heat to or from the gas. This would be the case were the expansion or compression to take place in an absolutely non-conducting

cylinder, in which case the temperature, pressure, and volume would vary as indicated by the following formulæ:

$$\frac{v_2}{v_1} = \left(\frac{p_2}{p_1}\right)^{0.71}, \qquad \frac{p_2}{p_1} = \left(\frac{v_1}{v_2}\right)^{1.41}, \qquad \frac{T_2}{T_1} = \left(\frac{v_1}{v_2}\right)^{0.41};$$

$$\frac{v_2}{v_1} = \left(\frac{T_1}{T_2}\right)^{2.46}, \qquad \frac{p_2}{p_1} = \left(\frac{T_2}{T_1}\right)^{3.46}, \qquad \frac{T_2}{T_1} = \left(\frac{p_2}{p_1}\right)^{0.29}.$$

in which p_1, v_1, and T_1 = initial absolute pressure, volume, and absolute temperature, and p_2, v_2, and T_2 final absolute pressure, volume, and absolute temperature of the gas.

Isothermal expansion or compression of a gas means that the gas is expanded or compressed with the addition or rejection of sufficient heat to maintain the temperature constant. In this case, the temperature being constant, the pressure and volume will vary according to Boyle's law, namely,

$$pv = C,$$

in which p = absolute pressure in pounds per square foot, v = volume in cubic feet, and C = a constant depending upon the temperature. For a temperature of 32° F. this constant is 26,200 ft.-lbs., and for isothermals corresponding to other temperatures it may be found from the formula $C = 53.2\,T$, in which T = the absolute temperature of the isothermal.

Combined compression of air is compression under conditions that permit of some withdrawal of heat during compression, but not sufficient to keep the temperature of the air constant. In this case the compression curve lies between the isothermal and adiabatic curves, and the relation of pressure to volume may be expressed by the formula,

$$pv^n = C,$$

in which p = absolute pressure in pounds per square foot; v = volume in cubic feet; C = a constant; and n = an exponent whose value may vary from 1, that for isothermal, to 1.41, that for adiabatic compression or expansion.

Constant Pressure and Constant Volume.—The terms " constant pressure " and " constant volume " mean, as their nomenclature would indicate, that if a gas is heated and not allowed to expand, the pressure will rise very rapidly. The volume is constant, that is, unchanged, and the heat produces more energy in the gas, which is reflected in pressure. In this manner steam may by its pressure burst a boiler if confined without relief and heat increased.

If, again, a gas is heated and kept at the same pressure the heat will cause an increase in volume. The pressure is constant and does not change, but in this

instance the volume changes since the heat forces the molecules further apart. The energy of the heat expends itself partly in increasing the volume of the gas.

Less heat is required to raise the temperature of a gas while under pressure than is required if allowed to expand, that is, the specific heat of a gas is less at constant volume than at constant pressure.

Ordinarily considered, a gas is usually taken at constant volume for purposes of calculation, although in furnace work or reactions involving heat the calculation is usually made at constant pressure.

Density.—The density of elementary gases are directly proportional to their atomic weights. The density of a compound gas referring to hydrogen as one, is one-half its molecular weight. Thus the relative density of CO_2 is $\frac{1}{2}(12+32)=22$.

To find the weight of a gas in pounds per cubic foot at 32° F. multiply one-half the molecular weight of the gas by 0.00559. Thus one cubic foot of marsh gas $CH_4 = \frac{1}{2}(12+4) \times 0.00559 = 0.0447$ pounds.

Volume Conversion.—Gases increase directly in volume with their temperature (starting at 0° C.), one two hundred and seventy-third for each degree C. or one four hundred and ninetieth above 32° F. (about 1% for each 5° F.), that is to say, at 273° C. the volume is just double that at 0° C. and at 522° F. double that at 32° F.

The volume of a gas is directly proportional to its absolute temperature, its density inversely proportional to its absolute temperature. To calculate we have $T_2 \div T_1 = V$. T_1 equals absolute temperature at normal or standard conditions; T_2 equals the absolute temperature to which the sensible temperature is increased.

As the volume increases with temperature, the larger of the two factors must necessarily constitute the enumerator and the lower the denomination or the fraction or vice versa; for example, 100 cubic feet of a gas at 10° C., raised to 60° C., to find the volume:

$$\frac{60+273}{10+273} = \frac{333}{283} \times 100 = V \text{ cu.ft. at } 60° \text{ C.}$$

Again, take 100 cubic feet at 40° F., raised to 60° C., to find the volume:

$$\frac{60-32+490}{60-32+490} \times 100 = V \text{ cu.ft. at } 60° \text{ F.}$$

To reduce observed volumes to those at absolute standard pressure and temperature Dawson and Larter present the following discussion:

(a) At a given temperature, the volume of a given mass of gas is inversely proportional to its pressure.—(Boyle's Law.)

(b) At a given pressure, the volume of a given mass of gas is directly proportional to its absolute temperature.—(Charles' Law.)

Hence if V_1 be the volume of a given mass of gas at pressure P_1 and absolute

temperature T_1, and if V_0 be the volume which the gas would occupy at some other pressure P_0 and absolute temperature T_0, then

$$\frac{P_1 V_1}{T_1} = \frac{P_0 V_0}{T_0},$$

and therefore

$$V_0 = V_1 \times \frac{P_1}{P_0} \times \frac{T_0}{T_1}.$$

The reduction of the volume of a gas to the standard temperature and pressure is done as follows:

Unless otherwise stated, the volume of a gas means the volume it would occupy under the standard conditions of temperature and pressure, viz., 0° C. (32° F.) and 760 mm. (29.92 inches) of mercury.

If V_1 be the observed volume of the gas, measured at a temperature t_1° C. and under a pressure P_1 mm. of mercury, the reduced volume (i.e., the volume which the gas would occupy at the standard temperature and pressure) is

$$V_0 = V_1 \times \frac{P_1}{760} \times \frac{273}{t_1 + 273}.$$

If V_1 be the observed volume of the gas, measured at a temperature of t_1° F. and under a pressure P_1 inches of mercury, the reduced volume is

$$V_0 = V_1 \times \frac{P_1}{29.92} \times \frac{491.4}{t_1 + 459.4}.$$

When a gas is measured over water (e.g., in a gasholder or by a wet meter) it is saturated with aqueous vapor. The actual pressure P_1 of the gas is the observed pressure minus the maximum pressure of aqueous vapor at the temperature of the gas.

Required the weight of a cubic meter of hydrogen at 1000° C. and 250 mm. pressure, its weight (volume×specific gravity) at standard conditions being 0.09 kg. Example:

$$W_1 = 0.09 \times \frac{273}{1000 + 273} \times \frac{250}{760} = 0.00637 \text{ kg.}$$

Tension of Aqueous Vapor.—According to Wyer as the vaporization of the moisture in fuel, and the destructive distillation of the fuel, always produce steam or water vapor, it is nearly always found in producer gas. Above the boiling-point corresponding to the pressure of the gas, all the water will be in the vapor state; below this point, part of the steam will condense, but a certain amount of water will always remain in the gas. Water vapor, on account of its high specific heat, may cause a large heat loss in the products of combustion.

Air consists of a mixture of oxygen and nitrogen with very small quantities of other substances, such as argon, ammonia, carbon dioxide, and water vapor, the amount of the latter depending upon the temperature and relative humidity of the atmosphere. The amounts of argon, ammonia, and carbon dioxide are so small that

they need never be considered. Pure dry air is composed of 20.91 parts O and 79.09 parts N by volume, or 23.15 parts O and 76.85 parts N by weight.

$$N \div O \ldots\ldots\ldots \text{By volume } \frac{79.09}{20.91} = 3.77. \qquad \text{By weight } \frac{76.85}{23.15} = 3.32.$$

$$\text{Air} \div O \ldots\ldots\ldots \text{By volume } \frac{100}{20.91} = 4.78. \qquad \text{By weight } \frac{100}{23.15} = 4.315.$$

$$\text{Air} \div N \ldots\ldots\ldots \text{By volume } \frac{100}{79.09} = 1.265. \qquad \text{By weight } \frac{100}{76.85} = 1.302.$$

AMOUNT OF MOISTURE TO 100 LBS. OF DRY AIR WHEN SATURATED AT DIFFERENT TEMPERATURES.—(Siebel.)

Temperature, Degrees F.	Aqueous Vapor, Pounds.	Temperature, Degrees F.	Aqueous Vapor, Pounds.	Temperature, Degrees F.	Aqueous Vapor, Pounds.
−20	0.0350	62	1.179	142	16.170
−10	0.0574	72	1.680	152	22.465
0	0.0918	89	2.361	162	31.713
+10	0.1418	92	3.289	172	46.338
20	0.2265	102	4.547	182	71.300
32	0.379	112	6.253	192	122.643
42	0.561	122	8.584	202	280.230
52	0.918	132	11.771	212	Infinite

Water Vapor.—In calculations of gases the tension of water vapor for the temperature observed must be found from tables containing these tensions for the different temperatures, such as the following:

TENSION OF AQUEOUS VAPOR IN INCHES OF MERCURY

Temperature, Degrees F.	Inches of Mercury.	Temperature, Degrees F.	Inches of Mercury.	Temperature, Degrees F.	Inches of Mercury.
40	0.247	57	0.465	74	0.840
41	0.257	58	0.482	75	0.868
42	0.267	59	0.500	76	0.897
43	0.277	60	0.518	77	0.927
44	0.288	61	0.537	78	0.958
45	0.299	62	0.556	79	0.990
46	0.311	63	0.576	80	1.023
47	0.323	64	0.596	81	1.057
48	0.335	65	0.617	82	1.092
49	0.348	66	0.639	83	1.128
50	0.361	67	0.661	84	1.165
51	0.374	68	0.685	85	1.203
52	0.388	69	0.708	86	1.242
53	0.403	70	0.733	87	1.282
54	0.418	71	0.759	88	1.323
55	0.433	72	0.785	89	1.356
56	0.449	73	0.812	90	1.401

TEMPERATURE CORRECTION FOR BAROMETRIC READINGS TO 60° F. AND 30 INCHES

(Divide observed volume by the factor found under column of observed temperature and opposite observed barometer.)

Therm.	32°	34°	36°	38°	40°	42°	44°	46°	48°	50°	52°	54°	56°	58°
Bar., In.														
28.0	0.998	0.993	0.988	0.984	0.979	0.974	0.970	0.965	0.960	0.956	0.951	0.946	0.942	0.937
28.1	1.002	0.997	0.993	0.988	0.983	0.978	0.973	0.969	0.964	0.959	0.955	0.951	0.945	0.941
28.2	1.006	1.001	0.996	0.991	0.986	0.981	0.977	0.972	0.967	0.963	0.958	0.953	0.949	0.944
28.3	1.009	1.004	1.000	0.995	0.990	0.985	0.980	0.976	0.971	0.966	0.961	0.957	0.952	0.947
28.4	1.012	1.007	1.002	0.998	0.993	0.988	0.984	0.979	0.974	0.970	0.965	0.960	0.955	0.951
28.5	1.016	1.011	1.006	1.001	0.997	0.992	0.987	0.983	0.978	0.973	0.968	0.964	0.959	0.954
28.6	1.020	1.015	1.010	1.005	1.001	0.995	0.991	0.986	0.981	0.977	0.972	0.967	0.962	0.958
28.7	1.023	1.018	1.013	1.009	1.004	0.999	0.994	0.990	0.985	0.980	0.975	0.970	0.966	0.961
28.8	1.027	1.022	1.017	1.012	1.007	1.003	0.998	0.993	0.988	0.984	0.979	0.974	0.969	0.964
28.9	1.031	1.026	1.021	1.016	1.011	1.006	1.001	0.997	0.992	0.987	0.982	0.977	0.973	0.968
29.0	1.034	1.029	1.024	1.019	1.014	1.010	1.005	1.000	0.995	0.990	0.986	0.981	0.976	0.971
29.1	1.038	1.033	1.028	1.023	1.018	1.013	1.008	1.004	0.999	0.994	0.989	0.984	0.979	0.975
29.2	1.041	1.036	1.031	1.026	1.021	1.017	1.012	1.007	1.002	0.997	0.992	0.988	0.982	0.978
29.3	1.045	1.040	1.035	1.030	1.025	1.020	1.015	1.011	1.006	1.001	0.996	0.991	0.986	0.981
29.4	1.048	1.043	1.038	1.033	1.028	1.024	1.019	1.014	1.009	1.004	0.999	0.995	0.990	0.985
29.5	1.052	1.046	1.041	1.036	1.032	1.027	1.022	1.018	1.013	1.008	1.003	0.998	0.993	0.988
29.6	1.055	1.050	1.045	1.040	1.036	1.031	1.026	1.021	1.016	1.011	1.006	1.001	0.996	0.992
29.7	1.059	1.054	1.049	1.044	1.039	1.034	1.029	1.025	1.019	1.015	1.010	1.005	1.000	0.995
29.8	1.063	1.058	1.053	1.048	1.043	1.038	1.033	1.028	1.023	1.018	1.013	1.008	1.003	0.998
29.9	1.066	1.061	1.056	1.051	1.046	1.041	1.036	1.031	1.026	1.022	1.017	1.012	1.007	1.002
30.0	1.070	1.065	1.060	1.055	1.050	1.045	1.040	1.035	1.030	1.025	1.020	1.015	1.010	1.005
30.1	1.073	1.068	1.063	1.058	1.053	1.048	1.043	1.038	1.033	1.029	1.024	1.019	1.014	1.009
30.2	1.076	1.071	1.066	1.062	1.057	1.052	1.047	1.042	1.037	1.032	1.027	1.022	1.017	1.012
30.3	1.080	1.075	1.070	1.065	1.060	1.055	1.050	1.045	1.040	1.036	1.030	1.025	1.020	1.015
30.4	1.084	1.079	1.074	1.069	1.064	1.059	1.054	1.049	1.044	1.039	1.034	1.029	1.024	1.019
30.5	1.087	1.082	1.077	1.072	1.067	1.062	1.057	1.052	1.047	1.042	1.037	1.032	1.027	1.022
30.6	1.090	1.085	1.080	1.075	1.071	1.066	1.061	1.056	1.051	1.046	1.041	1.036	1.031	1.026
30.7	1.094	1.089	1.084	1.079	1.074	1.069	1.064	1.059	1.054	1.049	1.044	1.039	1.034	1.029
30.8	1.098	1.093	1.088	1.083	1.078	1.073	1.068	1.063	1.058	1.053	1.048	1.043	1.037	1.032
30.9	1.101	1.096	1.091	1.086	1.081	1.076	1.071	1.066	1.061	1.056	1.051	1.046	1.041	1.036
31.0	1.105	1.100	1.095	1.090	1.085	1.080	1.075	1.070	1.065	1.060	10.55	1.049	1.045	0.039

TEMPERATURE CORRECTION FOR BAROMETRIC READINGS TO 60° F. AND 30 INCHES—*(Continued)*

(Divide observed volume by the factor found under column of observed temperature and opposite observed barometer.)

Therm. Bar., In.	60°	62°	64°	66°	68°	70°	72°	74°	76°	78°	80°	82°	84°
28.0	0.932	0.927	0.922	0.917	0.912	0.907	0.902	0.897	0.892	0.887	0.881	0.875	0.870
28.1	0.936	0.930	0.926	0.921	0.916	0.911	0.905	0.900	0.895	0.890	0.884	0.879	0.873
28.2	0.939	0.934	0.929	0.924	0.919	0.914	0.909	0.904	0.898	0.893	0.887	0.882	0.876
28.3	0.942	0.937	0.932	0.928	0.922	0.917	0.912	0.907	0.902	0.896	0.891	0.885	0.880
28.4	0.946	0.941	0.936	0.931	0.926	0.921	0.915	0.910	0.905	0.900	0.894	0.888	0.883
28.5	0.949	0.944	0.939	0.934	0.929	0.924	0.919	0.914	0.908	0.903	0.897	0.892	0.886
28.6	0.953	0.947	0.943	0.938	0.932	0.927	0.922	0.917	0.912	0.906	0.901	0.895	0.889
28.7	0.956	0.951	0.946	0.941	0.936	0.931	0.925	0.920	0.915	0.909	0.904	0.898	0.893
28.8	0.959	0.954	0.949	0.944	0.939	0.934	0.929	0.924	0.918	0.913	0.907	0.901	0.896
28.9	0.963	0.958	0.953	0.948	0.942	0.937	0.932	0.927	0.921	0.916	0.910	0.905	0.899
29.0	0.966	0.961	0.956	0.951	0.946	0.941	0.935	0.930	0.925	0.919	0.914	0.908	0.903
29.1	0.969	0.964	0.959	0.954	0.949	0.944	0.939	0.933	0.928	0.923	0.917	0.911	0.906
29.2	0.973	0.968	0.963	0.958	0.952	0.947	0.942	0.937	0.931	0.926	0.920	0.914	0.909
29.3	0.976	0.971	0.966	0.961	0.956	0.950	0.945	0.940	0.935	0.929	0.923	0.918	0.912
29.4	0.980	0.975	0.969	0.964	0.959	0.954	0.949	0.943	0.938	0.932	0.927	0.921	0.915
29.5	0.983	0.978	0.973	0.968	0.962	0.957	0.952	0.947	0.941	0.936	0.930	0.924	0.919
29.6	0.986	0.981	0.976	0.971	0.966	0.960	0.955	0.950	0.944	0.939	0.933	0.927	0.922
29.7	0.990	0.985	0.980	0.974	0.969	0.964	0.959	0.953	0.948	0.942	0.937	0.931	0.925
29.8	0.993	0.988	0.983	0.978	0.972	0.967	0.962	0.957	0.951	0.946	0.940	0.934	0.928
29.9	0.997	0.991	0.986	0.981	0.976	0.970	0.965	0.960	0.954	0.949	0.943	0.937	0.932
30.0	1.000	0.995	0.990	0.985	0.979	0.974	0.968	0.963	0.958	0.952	0.946	0.941	0.935
30.1	1.003	0.998	0.993	0.988	0.983	0.977	0.972	0.966	0.961	0.955	0.950	0.944	0.938
30.2	1.007	1.002	0.996	0.991	0.986	0.980	0.975	0.970	0.964	0.959	0.953	0.947	0.941
30.3	1.010	1.005	1.000	0.995	0.989	0.984	0.978	0.973	0.968	0.962	0.956	0.950	0.945
30.4	1.014	1.008	1.003	0.998	0.993	0.987	0.982	0.976	0.971	0.965	0.959	0.954	0.948
30.5	1.017	1.012	1.006	1.001	0.996	0.990	0.985	0.980	0.974	0.969	0.963	0.957	0.951
30.6	1.020	1.015	1.010	1.005	0.999	0.994	0.988	0.983	0.977	0.972	0.966	0.960	0.954
30.7	1.024	1.018	1.013	1.008	1.003	0.997	0.992	0.986	0.981	0.975	0.969	0.963	0.957
30.8	1.027	1.022	1.017	1.011	1.006	1.000	0.995	0.990	0.984	0.978	0.972	0.967	0.961
30.9	1.031	1.025	1.020	1.015	1.009	1.004	0.998	0.993	0.987	0.982	0.976	0.970	0.964
31.0	1.034	1.029	1.023	1.018	1.013	1.007	1.002	0.996	0.991	0.985	0.979	0.973	0.967

TENSION OF AQUEOUS VAPOR (Metric)

Degrees Centigrade.	Tension in Millimeters of Mercury.	Degrees Centigrade.	Tension in Millimeters of Mercury.	Degrees Centigrade.	Tension in Millimeters of Mercury.
− 20	0.927	6.6	7.292	15.6	13.197
− 10	2.093	6.8	7.392	15.8	13.366
−− 2	3.955	7.	7.492	16.	13.536
− 1.8	4.016	7.2	7.595	16.2	13.710
− 1.6	4.078	7.4	7.699	16.4	13.885
− 1.4	4.140	7.6	7.840	16.6	14.062
− 1.2	4.203	7.8	7.910	16.8	14.241
− 1.	4.267	8.	8.017	17.	14.421
− 0.8	4.331	8.2	8.126	17.2	14.605
− 0.6	4.397	8.4	8.236	17.4	14.790
− 0.4	4.463	8.6	8.347	17.6	14.977
− 0.2	4.531	8.8	8.461	17.8	15.167
− 0.	4.600	9.	8.574	18.	15.357
+ 0.2	4.667	9.2	8.690	18.2	15.552
+ 0.4	4.733	9.4	8.807	18.4	15.747
+ 0.6	4.801	9.6	8.925	18.6	15.945
+ 0.8	4.871	9.8	9.045	18.8	16.145
+ 1.	4.940	10.	9.165	19.	16.346
+ 1.2	5.011	10.2	9.288	19.2	16.552
+ 1.4	5.082	10.4	9.412	19.4	16.758
+ 1.6	5.155	10.6	9.537	19.6	16.967
+ 1.8	5.228	10.8	9.665	19.8	17.179
+ 2.	5.302	11.	9.792	20.	17.391
+ 2.2	5.378	11.2	9.923	20.2	17.608
+ 2.4	5.454	11.4	10.054	20.4	17.826
+ 2.6	5.530	11.6	10.187	20.6	18.047
+ 2.8	5.608	11.8	10.322	20.8	18.271
+ 3.	5.687	12.	10.457	21.	18.495
+ 3.2	5.767	12.2	10.596	21.2	18.724
+ 3.4	5.848	12.4	10.734	21.4	18.954
+ 3.6	5.930	12.6	10.875	21.6	19.187
3.8	6.014	12.8	10.919	21.8	19.423
4.	6.097	13.	11.162	22.	19.659
4.2	6.183	13.2	11.309	22.2	19.901
4.4	6.270	13.4	11.456	22.4	20.143
4.6	6.350	13.6	11.605	22.6	20.389
4.8	6.445	13.8	11.757	22.8	20.639
5.	6.534	14.	11.908	23.	20.888
5.2	6.625	14.2	12.064	23.2	21.144
5.4	6.717	14.4	12.220	23.4	21.400
5.6	6.810	14.6	12.378	23.6	21.659
5.8	6.904	14.8	12.538	23.8	21.921
6.	6.998	15.	12.699	24.	22.184
6.2	7.095	15.2	12.864	24.2	22.453
6.4	7.193	15.4	13.029	24.4	22.723

TENSION OF AQUEOUS VAPOR—(Continued)

Degrees Centigrade.	Tension in Millimeters of Mercury.	Degrees Centigrade.	Tension in Millimeters of Mercury.	Degrees Centigrade.	Tension in Millimeters of Mercury.
24.6	22.996	29.8	31.190	99.8	754.57
24.8	23.273	30.	31.548	99.9	757.28
25.	23.550	31.	33.405	100.	760.
25.2	23.834	32.	35.359	100.1	762.73
25.4	24.119	33.	37.410	100.2	765.46
25.6	24.406	34.	39.565	100.3	768.20
25.8	24.607	35.	41.827	100.4	771.95
26.	24.988	40.	54.906	100.5	773.71
26.2	25.288	45.	71.391	100.6	776.48
26.4	25.88	50.	91.982	100.7	779.26
26.6	25.891	55.	117.478	100.8	782.04
26.8	26.198	60.	148.791	100.9	784.83
27.	26.505	65.	186.945	101.	787.63
27.2	26.820	70.	233.093	105.	960.41
27.4	27.136	75.	288.517	110.	1075.37
27.6	27.455	80.	354.643	120.	1491.28
27.8	27.778	85.	433.041	130.	2030.28
28.	28.101	90.	525.450	140.	2717.63
28.2	28.433	95.	633.778	150.	3581.23
28.4	28.765	99.	733.21	160.	4651.62
28.6	29.101	99.1	738.5	170.	5961.66
28.8	29.441	99.3	741.16	180.	7546.39
29.	29.782	99.4	743.83	190.	9442.70
29.2	30.131	99.5	746.5	200.	11688.96
29.4	30.479	99.6	749.18	220.	17390.
29.6	30.833	99.7	751.87	224.7	25 atmos.

Ignition Temperature of Gaseous Mixtures.—As a matter of fact, for reasons unknown to the writer, pre-ignition in gas engines will be found to occur from any variation in the calorific value of the gas or in its analysis. This may be due either to conditions of stagnation, conditions of heat propagation, or to unknown chemical reactions of the explosive mixture. Suffice it that such is an observed phenomena.

Professor K. G. Falk has made some exceedingly valuable researches in the matter of ignition temperature of gaseous mixtures, presenting them from time to time before the American Chemical Society. His most successful method has been the adiabatic, wherein he experimented through the compressing of gas by means of a piston and airtight cylinder.

Extracts of some of his results are herewith noted:

IGNITION TEMPERATURES

HYDROGEN AND OXYGEN

Reaction.	T_2.
$4H_2 + O_2$	878
$2H_2 + O_2$	813
$H_2 + O_2$	787
$H_2 + 2O_2$	803
$H_2 + 4O_2$	844

CARBON MONOXIDE AND OXYGEN

Reaction.	T_2.
$6CO + O_2$	994
$4CO + O_2$	901
$2CO + O_2$	874
$CO + O_2$	904

HYDROGEN, OXYGEN, AND NITROGEN

Reaction.	T_2 (obs.)	T (calc.).
$H_2 + O_2 + N_2$	820	817
$H_2 + O_2 + 2N_2$	851	847
$H_2 + O_2 + 4N_2$	910	907
$2H_2 + O_2 + N_2$	846	843
$2H_2 + O_2 + 4N_2$	922	933
$H_2 + 2O_2 + N_2$	837	833
$H_2 + 2O_2 + 4N_2$	914	923

CARBON MONOXIDE, OXYGEN, AND NITROGEN

Reaction.	T_2 (obs.).	T (calc.).
$2CO + O_2 + N_2$	917	914
$2CO + O_2 + 2N_2$	958	954
$CO + O_2 + N_2$	979	984
$CO + O_2 + 2N_2$	1085	1064
$4CO + O_2 + N_2$	925	921
$4CO + O_2 + 2N_2$	940	941

HYDROGEN, CARBON MONOXIDE, AND OXYGEN

Reaction.	T (obs.).	Ta (calc.).	Tb (calc.).
$H_2 + O_2 + CO$	812	817	984
$H_2 + O_2 + 2CO$	851	847	914
$H_2 + O_2 + 4CO$	898	907	921
$2H_2 + O_2 + 2CO$	877	873	954
$2H_2 + O_2 + 4CO$	938	933	941
$H_2 + 2O_2 + 2CO$	869	863	944
$H_2 + 2CO_2 + 4CO$	888	923	894
$2H_2 + 3O_2 + 2CO$	825	822	1030

Although there has been a considerable amount of work done on the determination of the ignition temperatures of mixtures of hydrogen and oxygen, there has been comparatively little with mixtures of other gases. V. Meyer and Krause found the ignition temperature of the mixture $2CO + O_2$ to lie between 791° and 879° absolute, using the method of enclosing the mixture in sealed bulbs, which were plunged into baths heated to definite temperatures. They found the same ignition temperature for the mixture $2H_2 + O_2$. Mallard and Le Chatelier, by passing the gas into a tube heated to a definite temperature, found the ignition temperature of the mixture containing 70% carbon monoxide and 30% oxygen to be about 923°. They also found that diluting this mixture, as well as the detonating gas mixture, with one of the active constituents or with an inert gas, modified the ignition temperature only slightly.

Calorific Power.—The heat value of a gas depends upon whether the water formed by combustion is or is not condensed, the latter giving the net value, as shown in the following tables:

CALORIFIC POWER OF GASES (Burnt at Constant Pressure)

Gas.	Calorific Power.							
	Calories per Kilo.		B.T U. per Pound.		Calories per Cubic Meter.		B.T.U. per Cubic Foot.	
	Higher Value.	Lower Value.	Higher Value.	Lower Value.	Higher Value.	Lower Value.	Higher Value.	Lower Value.
Carbon monoxide.......	2,436[2]	....	4,385	....	3,046	....	342.4	....
Ethylene...............	12,182[2]	11,404	21,928	20,527	15,239	14,266	1713.0	1603.0
Hydrogen..............	34,500[2]	29,050	62,100	52,290	3,088	2,601	347.1	292.3
Methane...............	13,344[2]	11,981	24,019	21,566	9,541	8,567	1072.0	963.0
Carbon...............	81,375	....	146,475					

1 calorie per kilo = 1.8 B.T.U. per pound.
1 B.T.U. per pound = 0.555 calorie per kilo.
1 calorie per cubic meter = 0.1124 B.T.U per cubic foot.
1 B.T.U. per cubic foot = 8.900 calories per cubic meter.

If the combustion is accompanied by a change in volume the calorific powers at constant pressure and at constant volume will be different.

Let n_1 be the number of molecular volumes (22.32 cm.) of the gas together with the oxygen required for its combustion, and let n_2 be the number of molecular volumes of the products of combustion.

The $n_1 - n_2$ is the change in volume, and the work done by or against the pressure of the atmosphere is equivalent to $541 \times (n_1 - n_2)$ calories.

The nitrogen in the air used for combustion is also present in the products, and is therefore not taken into account. If the volume of the products (at 0° C) is less than the volume of the mixture of gas and oxygen, work is done by the pressure of the atmosphere when the gas is burnt at constant pressure, and the heat of combustion at constant pressure is greater than the heat of combustion at constant volume by $541 \times (n_1 - n_2)$ calories.

CALORIFIC POWER OF GASES (Burnt at Constant Volume)

Gas.	Calorific Power.							
	Calories per Kilo.		B.T.U. per Pound.		Calories per Cubic Meter.		B.T.U. per Cubic Foot.	
	Higher Value.	Lower Value.	Higher Value.	Lower Value.	Higher Value.	Lower Value.	Higher Value.	Lower Value.
Carbon monoxide.......	2,426	....	4,367	....	3,033	....	340.9	
Ethylene.............	12,143	11,365	21,858	20,457	15,191	14,218	1707.0	1597.0
Hydrogen.............	34,095	28,645	61,371	51,561	3,052	2,565	343.0	288.2
Methane.............	13,276	11,913	23,897	21,444	9,492	8,518	1067.0	958.0
Carbon...............	81,375	....	146,475					

In calculating the lower value of the calorific power, the change of volume during combustion is the same as for higher value; the products of combustion are cooled to 0° C., so that at constant volume the steam is actually condensed, but the lower value of the calorific power is found by deducting the latent heat of the steam from the higher value, whether the gas is burnt at constant volume or at constant pressure.

Or it may be calculated from the gross calorific power at constant pressure, found as above, and the change in volume during combustion as follows:

Constituent.	Molecular Volumes in 22.32 c.m. of the Gas.	Molecular Volumes of Oxygen Required for Combustion.	Volume, after Combustion (Molecular Volume).
Hydrogen........................	0.162	0.081	
Carbon monoxide.................	0.210	0.105	0.210
Methane.........................	0.013	0.026	0.013
Carbon dioxide..................	0.085	......	0.085
Oxygen..........................	0.002	......	0.002
Nitrogen........................	0.528	......	0.528
Total.....................	1.000	0.212	0.838

MEAN MOLECULAR HEATS OF GASES AT CONSTANT PRESSURE BETWEEN THE ABSOLUTE ZERO AND THE TEMPERATURE $t°$ C.

Gas.   Mean Molecular Heat * (Centigrade Units).

Carbon monoxide ⎫
Hydrogen   ⎪
Methane   ⎬ .... $6.5 + 0.0006 \times (t + 273)$
Nitrogen   ⎪
Oxygen   ⎭

Carbon dioxide .... $6.5 + 0.0037 \times (t + 273)$

Water vapor .... $6.5 + 0.0029 \times (t + 273)$

* Le Chatelier, "Cours de Chimie Industrielle."

DATA ON COMBUSTION

Combustibles, One Pound of	Cu. Ft. at 62° F.	Burning to	Oxygen Required.		Cu. Ft. O. per Cu. Ft. Comb.	Air Required.		Cu. Ft. Air per Cu. Ft. Comb.	Heat Developed (B.T.U.)	
			Pounds.	Cu. Ft. at 62° F.		Pounds.	Cu. Ft. at 62° F.		Per Pound Comb.	Per Cu. Ft. Comb. at 62° F.
Carbon................	......	CO$_2$	2.66	31.6	......	11.6	152	......	14,500	
Carbon............	......	CO	1.33	15.8	......	5.8	76	......	4,450	
Carbon monoxide....	13.55	CO$_2$	0.57	6.8	0.5	2.5	32.5	2.4	4,385	324
Hydrogen..........	190.00	Water vapor H$_2$O	8.00	95.0	0.5	34.8	456	2.4	62,000	326
Marsh gas, CH$_4$......	23.75	CO$_2$ and water vapor	4.00	47.5	2.0	17.4	228	9.6	23,976	1010
Olefiant gas, C$_2$H$_4$ ...	13.55	"	3.43	40.7	3.0	14.9	195	14.4	21,476	1590

WEIGHT AND VOLUME OF GASES AND AIR REQUIRED IN COMBUSTION

Name.	Weight per Cubic Foot in Pounds at 32° F. and 14.7 Pounds per Square Inch.	Volume in Cubic Feet of 1 Pound of Gas at 14.7 Pounds per Square Inch.		Cubic Feet Required to Burn 1 Cubic Foot of Gas.		Pounds Required to Burn 1 Pound of the Gas.		Cubic Feet Formed of	
		32° F.	62° F.	Oxygen	Air.	Oxygen	Air.	Steam.	CO$_2$.
Air...................	0.08073	12.39	13.12						
Carbon dioxide........	0.12300	8.12	8.60						
Carbon monoxide.......	0.07830	12.77	13.55	0.5	2.39	0.57	2.4	0	1
Hydrogen.............	0.00599	178.80	189.80	0.5	2.39	8.00	34.8	1	0
Marsh gas............	0.04470	22.37	23.73	2.0	9.60	4.00	17.4	2	1
Nitrogen.............	0.07830	12.77	13.55						
Olefiant gas...........	0.07830	12.77	13.55	3.0	14.4	3.43	14.9	2	2
Oxygen..............	0.08940	11.20	11.88						

HEATING VALUE OF GASES

Gas.	B.T.U.'s per Cu.Ft.	Gas.	B.T.U.'s per Cu.Ft.
Acetylene	1556	Coke-oven gas	600
Alcohol, amyl	1684	Ethane	1860
Alcohol, ethyl	1684	Ether....................	3264
Alcohol, methyl	1135	Ethylene	1670
Aldehyde	1612	Hydrogen	344
Benzene	3818	Methane	1049
Blast-furnace gas	90	Natural gas, average	1000
Butane	3415	Oil gas..................	845
Butylene	3300	Producer gas, coke	125
Carbon vapor to CO	282	Producer gas, hard coal	145
Carbon vapor to CO$_2$	1342	Producer gas, soft coal	145
Carbon monoxide	337	Propane	2627
Carbureted water gas	575	Propylene	2500
Coal gas	680	Water gas	300

Specific Heat.—This term denotes the amount of heat, expressed in heat units, which is required to raise by 1° the temperature of unit weight of a substance. Since a heat unit is the amount of heat required to raise by 1° the temperature of unit weight of water, the specific heat of a substance is the ratio between the amount of heat needed to raise by 1° the temperature of unit weight of the substance and the amount of heat required to raise by 1° the temperature of unit weight of water. If the unit of weight is the pound avoirdupois, and the temperature is measured in Fahrenheit degrees, the specific heat is expressed in British thermal units, while if the unit of weight is the kilogram, and the temperature is measured in Centigrade degrees, the specific heat is expressed in calories. It is expressed by the same number in each case.

The amount of heat required to raise by 1° the temperature of a body which is free to expand, or, as it is said, is kept under constant pressure, is not the same as the amount required to produce the same change in temperature in the body if it is kept at a constant volume. For every substance there are, therefore, two values for the specific heat, one for constant pressure and one for constant volume. There is also what is termed specific heat by volume, which is the amount of heat, expressed in heat units, required to raise by 1° the temperature of unit volume of a substance. But when the term "specific heat" is used without any qualification, as in the statement "the specific heat of nitrogen is 0.244," it refers to specific heat by weight and at constant pressure.

CALCULATING MEAN SPECIFIC HEAT IN A GAS

Constituent.	Per Cent by Volume.	Weight of 1 Cubit Foot. in Pounds.	Weight of Constituent in Pounds.	Specific Heats.	Sp. H × Wt. × Vol.	Authority for Value of Sp. H.
Benzol.	1.00	0.20640	0.20640	1.187	0.2450	Wullner
C_2H_4.	3.75	0.07410	0.27787	1.245	0.3460	"
CO.	8.04	0.7407	0.59552	1.403	0.8355	"
H.	47.04	0.00530	0.24931	1.396	0.3580	Regnault
CH_4.	36.02	0.04234	1.52508	1.319	2.0115	Masson
CO_2.	1.60	0.11637	0.18619	1.300	0.2420	"
O.	0.39	0.08463	0.03300	1.405	0.0464	Regnault
N.	2.15	0.07429	0.16046	1.405	0.2255	"
	100.00	....	3.22383	.....	4.3099	

$\dfrac{4.3099}{3.22383} = 1.337$, the value of the mean specific heat for the above gas.

TABLE OF MEAN SPECIFIC HEATS AT CONSTANT PRESSURE
(In B.T.U. per Pound)

Degrees, F.	Carbon Dioxide.	Water Vapor.	Nitrogen.	Oxygen.
212	0.201	0.446	0.244	0.214
392	0.210	0.462	0.249	0.218
572	0.219	0.478	0.253	0.222
752	0.227	0.494	0.257	0.225
932	0.236	0.510	0.262	0.229
1112	0.245	0.526	0.266	0.233
1292	0.254	0.541	0.270	0.237
1472	0.263	0.557	0.275	0.241
1652	0.271	0.573	0.279	0.244
1832	0.280	0.589	0.284	0.248
2012	0.289	0.605	0.288	0.252
2192	0.298	0.621	0.292	0.256
2372	0.307	0.637	0.297	0.260
2552	0.315	0.652	0.301	0.264
2732	0.324	0.668	0.305	0.267
2912	0.333	0.684	0.310	0.271
3092	0.342	0.700	0.314	0.275
3272	0.351	0.716	0.318	0.279
3452	0.360	0.732	0.323	0.282
3632	0.368	0.748	0.327	0.286
3812	0.377	0.764	0.331	0.290
3992	0.385	0.780	0.336	0.294
4172	0.394	0.796	0.340	0.298
4352	0.403	0.812	0.344	0.301
4532	0.412	0.828	0.349	0.305

Inaccuracies in the experimental data on which this table is based render it useless to attempt to interpolate more closely than to 90°.

Inasmuch as the specific heat of a gas is dependent upon its density and temperature, it is better called its "coefficient of heat absorption."

TABLE OF SPECIFIC HEAT OF GASES (SIEBEL)

For equal weights, water = 1.	At Constant Pressure.	At Constant Volume.
Air	0.02377	0.1688
Carbonic acid (CO_2)	0.2164	0.1714
Carbonic oxide (CO)	0.2479	0.1768
Hydrogen	3.4046	2.4096
Light carbureted hydrogen	0.5929	0.4683
Nitrogen	0.2440	0.1740
Oxygen	0.2182	0.1559
Steam, saturated	......	0.3050
Steam, gas	0.4750	0.3700
Sulphurous acid	0.1553	0.1246

Other authorities give the following values:

SPECIFIC HEATS AT CONSTANT PRESSURE

Air 0.2375
Oxygen 0.2175
Hydrogen 3.4090
Nitrogen 0.2438
Carbon dioxide, CO_2 . . . . 0.2170
Carbon monoxide, CO 0.2479
Olefiant gas (ethylene), C_2H_4 . . . . 0.4040
Marsh gas (methane), CH_4 . . . . 0.5929
Blast-furnace gas 0.2280
Chimney gases from boilers 0.2400
Steam, superheated 0.4805

VOLUMETRIC SPECIFIC HEATS

Air, oxygen, carbon monoxide, hydrogen, and nitrogen = 0.019.
Carbon dioxide and marsh gas = 0.027.
Producer gas = 0.019.
Volumetric specific heat is the quantity of heat required to raise the temperature of 1 cu.ft. 1° from 32° to 33° F.

SPECIFIC HEAT OF GASES AND VAPORS

		Specific Heat of Equal Weights.	Specific Heat of Equal Volumes.	Specific Heat of Constant Volumes.
Simple Gases	Air.	0.2374	0.2374	0.1687
	Oxygen.	0.2175	0.2405	0.1559
	Nitrogen.	0.2438	0.2370	0.1740
	Hydrogen.	3.4090	0.2359	2.4096
	Chlorine.	0.1210	0.2962	
	Bromine.	0.0555	0.3040	
Compound Gases	Binoxide of nitrogen.	0.2315	0.2406	
	Carbonic oxide.	0.2450	0.2370	0.1768
	Carbonic acid.	0.2163	0.3307	0.1714
	Sulphureted hydrogen.	0.2432	0.2857	
	Sulphurous anhydride.	0.1553	0.3414	0.1246
	Hydrochloric acid.	0.1845	0.2333	
	Nitrous oxide.	0.2262	0.3447	
	Nitric oxide.	0.2317	0.2406	
	Ammonia.	0.5083	0.2966	
	Marsh gas.	0.5929	0.3277	0.4683
	Olefiant gas (ethylene).	0.4040	0.4106	
Vapors	Water (steam).	0.4805	0.2984	0.3337
	Ether.	0.4810	1.2296	0.3411
	Chloroform.	0.1567	0.6461	
	Alcohol.	0.4534	0.7171	0.3200
	Turpentine.	0.5061	2.3776	
	Bisulphide of carbon.	0.1570	0.4140	
	Benzole.	0.3754	1.0114	
	Acetone.	0.4125	0.8244	

SPECIFIC HEAT OF WATER AT VARIOUS TEMPERATURES—(Siebel)

Temp. Deg. F.	Specific Heat.	Heat to Raise One Pound of Water from 32° to Given Temperature.	Temp. Deg. F.	Specific Heat.	Heat to Raise One Pound of Water from 32° to Given Temperature.
32	1.0000	0.000	248	1.0177	217.449
50	1.0005	18.004	244	1.0202	235.791
68	1.0012	36.018	284	1.0232	254.187
86	1.0020	54.047	302	1.0262	272.628
104	1.0030	72.090	320	1.0294	291.132
122	1.0042	90.157	338	1.0328	309.690
140	1.0056	108.247	356	1.0364	328.320
158	1.0072	126.378	374	1.0401	347.004
176	1.0089	144.508	392	1.0440	365.760
194	1.0109	162.686	410	1.0481	384.588
212	1.0130	180.900	428	1.0524	403.488
230	1.0153	199.152	446	1.0568	422.478

SPECIFIC HEATS

Solids

Alumina	0.1970	Magnesia	0.2220
Aluminum	.2185	Limestone, magnesian	.2170
Antimony	.0508	Marble	.2100
Bismuth, melted	.0308	Mercury	.0333
Brass	.939	Nickel	.1086
Cadmium	.0567	Oak	.5700
Chalk	.2150	Pear woods	.5000
Charcoal	.2410	Phosphorus	.1887
Clay, burnt	.1850	Pine (turpentine)	.4670
Coal	0.20--.2400	Platinum	.0324
Coke	.2030	Quartz	.1880
Copper	.0951	Quicklime	.2170
Corundum	.1980	Sand (river)	.1950
Fir	.6500	Silica	.1910
Gold	.0324	Soda	.2310
Glass	.1937	Silver	.0570
Graphite	.2020	Steel, hard	.1175
Gypsum	.1970	Steel, soft	.1165
Ice	.5040	Sulphur	.2026
Iron, cast	.1298	Sulphur, melted	.2340
Iron, wrought	.1138	Tin	.0562
Lead	.0314	Tin, melted	.0637
Lead, melted	.0402	Zinc	.0956

Weights and Volumes.—The molecular weights, when substituted for the symbols in a chemical equation, also form an equation and the quantities represent relative weights of the members of the equation. Thus,

$$C + H_2O = CO + H_2,$$
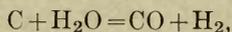
$$12 + 18 = 28 + 2.$$

Here the carbon may be any unit of weight, pounds, kilograms, etc. Then 12 lbs. of carbon would release 2 lbs. of hydrogen by this reaction. Also the molecules of all true gases occupy equal volumes. The conversion from weight to volume may be obtained in the calculation of gases as follows: The weight of 1 cu.m. of hydrogen is 0.09 kg.; its molecular weight is 2; then $2 \div 0.09 = 22.22$ is its molecular volume, which is the same for all true gases. Assuming the molecular weight of the gas to be represented by kilograms, then each molecule of the gas may be assumed to be 22.22 cu.m. The weight of one molecule (O_2) of oxygen thus occupies 22.22 cu.m.; its molecular weight is 32 and its weight would therefore be

$$32 \div 22.22 = 1.44 \text{ kg. per cu.m.}$$

Professor Richards points out that the molecular weight may also be taken as avoirdupois ounces when the result will be obtained in cubic feet. Let $O^2 = 22.22$ cu.ft. and the molecular weight of oxygen be again 32, or 32 oz. Then $32 \div 22.22 = 1.44$ oz. per cu.ft.

As Professor Richards mentions, the ratio of the ounce to the kilogram, 1:35.26, is nearly identical with that of the cubic foot to the cubic meter, 1:35.31, the difference being but $0.0-\frac{1}{7}$th%.

Again, dividing the molecular weight of any gas by the factor 22.22 gives as a result its actual weight in kilograms. Where the molecular weight is expressed in pounds the gas occupies 357.5 cu.ft.

As an axiom it must be remembered that equal volumes of gases contain equal numbers of molecules (pressure and temperature being equal); this is known as Avogradro's law.

MOLECULAR WEIGHT

Name.	Symbol.	Molecular Weight.	Name.	Symbol.	Molecular Weight.
Hydrogen	H_2	2.00	Allylene	C_3H_4	39.91
Oxygen	O_2	31.92	Benzene	C_6H_6	77.83
Nitrogen	N_2	28.02	Toluene	C_7H_8	91.80
Carbon monoxide	CO	27.93	Naphthalene	$C_{10}H_8$	127.72
Carbonic acid	CO_2	43.89	Diphenyl	$C_{12}H_{10}$	153.65
Methane (marsh gas)	CH_4	15.97	Anthracene	$C_{14}H_{10}$	177.59
Ethane	C_2H_6	29.94	Pyrene	$C_{16}H_{10}$	201.54
Propane	C_3H_8	43.91	Chrysene	$C_{18}H_{12}$	227.48
Butane	C_4H_{10}	57.89	Ammonia	NH_3	17.01
Pentane	C_5H_{12}	71.86	Sulphureted hydrogen	H_2S	33.98
Hexane	C_6H_{14}	85.83	Carbon disulphide	CS_2	75.95
Ethylene (olefiant gas)	C_2H_4	27.94	Nitrous oxide	N_2O	43.98
Propylene	C_3H_6	41.91	Nitric oxide	NO	29.97
Butylene	C_4H_8	55.89	Cyanogen	C_2N_2	51.96
Pentylene	C_5H_{10}	69.86	Water vapor	H_2O	17.96
Acetylene (ethine)	C_2H_2	25.94	Chlorine	Cl_2	70.74

ATOMIC WEIGHT OF SOME ELEMENTS

Name.	Symbol.	Atomic Weight.	Name.	Symbol.	Atomic Weight.
Aluminum	Al	27.02	Lithium	Li	7.01
Antimony	Sb	120.0	Magnesium	Mg	24.0
Arsenic	As	74.9	Manganese	Mn	55.0
Barium	Ba	136.8	Mercury	Hg	199.8
Bismuth	Bi	208.0	Nickel	Ni	58.6
Broon	B	11.0	Nitrogen	N	14.01
Bromine	Br	79.75	Oxygen	O	15.96
Cadmium	Cd	111 7	Palladium	Pd	106.3
Calcium	Ca	39.91	Phosphorus	P	30.96
Carbon	C	11.97	Platinum	Pt	194.3
Cerium	Ce	139.9	Potassium	K	39.04
Chlorine	Cl	35.37	Rhodium	Rh	102.7
Chromium	Cr	52.45	Silicon	Si	28.3
Cobalt	Co	58.8	Silver	Ag	107.66
Copper	Cu	63.2	Sodium	Na	22.995
Fluorine	F	19.0	Strontium	Sr	87.3
Gold	Au	196.7	Sulphur	S	31.98
Hydrogen	H	1.0	Thorium	Th	232.0
Iodine	I	126.53	Tin	Sn	118.8
Iridium	Ir	192.5	Titanium	Ti	47.9
Iron	Fe	55.9	Uranium	U	239.0
Lead	Pb	206.4	Zinc	Zn	65.3

CUBIC FEET OF GASES TO THE POUND

Acetylene	13.750	Ethane	11.950
Air	12.333	Ether, vapor	4.860
Alcohol, grain, vapor	7.775	Ethylene,	12.580
Alcohol, wood, vapor	11.203	Ethylene chloride, vapor	3.631
Aldehyde, vapor	8.085	Fusel oil, vapor	3.936
Ammonia	21.000	Hydrogen	178.230
Benzene, vapor	4.808	Hydrogen sulphide	10.370
Blast-furnace gas	12.650	Methane	22.301
Butane	6.245	Natural, gas, average	22.500
Butylene	6.414	Nitrogen	12.752
Carbon, vapor	14.930	Oxygen	11.209
Carbon dioxide	8.147	Producer gas	13.333
Carbon disulphide, vapor	4.706	Propane	8.148
Carbon monoxide	12.804	Propylene	8.540
Coal gas	31.600	Water gas	22.000
Cyanogen	6.880	Water, vapor	19.912

SPECIFIC GRAVITY, WEIGHT, AND SOLUBILITY IN WATER OF VARIOUS GASES AT 60° F. AND 80 INCHES BAROMETER

Name.	Specific Gravity, Air Equal 1.000.	Weight of a Cubic Foot in Pounds, Avoirdupois.	Weight of a Cubic Foot in Grains.	Number of Cubic Feet Equal to 1 Pound.	Solubility 100 Vols. of Water Absorbed.
Hydrogen...................	0.0691	0.00529997	37.09	188.68	1.93 vols.
Light carburetted hydrogen.....	0.5559	0.0428753	300.12	23.32	3.91 "
Ammonia....................	0.590	0.045253	316.77	22.09	72,720 "
Carbonic oxide...............	0.967	0.0741689	519.18	13.48	2.43 "
Olefiant gas.................	0.968	0.0742456	519.71	13.46	16.15 "
Nitrogen...................	0.9713	0.07449871	521.49	13.42	1.48 "
Air........................	1.000	0.0767	536.90	13.03	1.70 "
Nitric oxide..................	1.039	0.0796913	557.83	12.54	Not soluble
Oxygen.....................	1.1056	0.08479952	593.59	11.79	2.99 vols.
Sulphuretted hydrogen........	1.1747	0.09009949	630.69	11.09	323.26 "
Nitrous oxide................	1.527	0.1171209	819.84	8.53	77.78 "
Carbonic acid................	1.529	0.1172743	820.92	8.52	100.20 "
Sulphurous acid..............	2.247	0.1723449	1206.41	5.80	4276.60 "
Chlorine....................	2.470	0.189449	1326.14	5.27	236.80 "
Bisulphide of carbon..........	2.640	0.202488	1417.41	4.93	Not soluble

WEIGHTS OF GASES

Gas.	Formula.	Molecular Weight.	Density Referred to Hydrogen.	Weight of Cubic Meter.
Hydrogen....................	H_2	2	1	0.09 kilos
Water vapor...................	H_2O	18	9	0.81 "
Nitrogen.....................	N_2	28	14	1.26 "
Oxygen......................	O_2	32	16	1.44 "
Carbon monoxide................	CO	28	14	1.26 "
Carbon dioxide..................	CO_2	44	22	1.98 "
Marsh gas....................	CH_4	16	8	0.72 "
Etc.				

CHAPTER VIII

CHEMICAL PROPERTIES OF GASES

THE gases present in producer gas may be classed as follows, according to Sexton:

  1. COMBUSTIBLE GASES.

    Hydrogen . . . . H

    Carbon monoxide . . . . CO

    Marsh gas, methane . . . . CH_4

    Ethylene . . . . C_2H_4

    Acetylene . . . . C_2H_2

  2. DILUENTS.

    Nitrogen . . . . N

    Carbon dioxide . . . . CO_2

    Oxygen . . . . O

In addition there may be present combustible and non-combustible vapors, such as tarry matters and some other substances which may have considerable influence on the quality of the gas, but which are not given in the ordinary analysis of the gas, because they are condensed, and thus removed in the preparation of the sample for analysis.

COMBUSTIBLE GASES

Hydrogen (H).—Atomic weight 1; molecular weight, 2. This gas is always present in larger or smaller quantity. It is found in considerable quantity in the products of the destructive distillation of coal, and is therefore present in coal gas. It is also liberated whenever steam comes in contact with very hot carbon, carbon monoxide, or carbon dioxide being formed at the same time, according to the temperature and the quantity of carbon present, thus

$$C + H_2O = CO + 2H, \qquad \qquad \text{(1)}$$

$$C + 2H_2O = CO_2 + 4H. \qquad \qquad \text{(2)}$$

Hydrogen is colorless and odorless and very light; indeed, it is the lightest known substance. It is less than $\frac{1}{14}$ as heavy as air; its specific gravity (air = 1) being 0.06926 and 1 cu.ft. weighs at 0° C. and 760 mm. barometer, 0.0056 lbs., or 1 lb. occupies 178.57 cu.ft. Its specific heat is 2.414. It is very readily com-

bustible, and burns with a pale blue, almost non-luminous, flame. One pound evolves on combustion 34,180 calories or 61,524 B.T.U. of heat. It is therefore one of the most valuable constituents of fuel gas, but owing to its extreme lightness, if present in large proportion, it makes the gas light and bulky. One cubic foot evolves only one 191.4 calories or 344.5 B.T.U. on combustion. When it burns water is formed,

$$2H + O = H_2O. \qquad \ldots \ldots \ldots \ldots \quad (3)$$

It requires eight times its own weight or half its own volume of oxygen for combustion, and yields nine times its own weight of water, which, if the temperature be above 100° C., will occupy the same volume as the hydrogen would do under the same conditions of temperature and pressure. It requires about 2.4 times its own volume or 34.78 times its own weight of air for complete combustion. The influence of hydrogen in a gas is to make it light and bulky, to add largely to its heating power, and, at the same time, to increase very much the amount of air required for combustion, and, since the specific heat of steam is very high, also to increase the amount of heat carried away in the products of combustion.

Carbon Monoxide (CO).—Molecular weight, 27.93, or practically 28. This is one of the most important constituents of fuel gas. It is colorless and odorless, and burns with a characteristic pale blue, feebly luminous flame, forming carbon dioxide thus:

$$CO + O = CO_2. \qquad \ldots \ldots \ldots \ldots \quad (4)$$
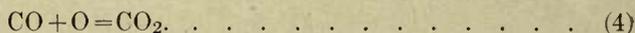
One pound evolves on combustion 2430 calories or 4374 B.T.U. It requires for complete combustion 0.57 times its own weight and half its own volume of oxygen, and yields 1.57 times its own weight of carbon dioxide. The amount of air required is about 2.4 times its own volume or 2.48 times its own weight.

It is among the products of the destructive distillation of coal, and is produced by the action of hot carbon on carbon dioxide, thus

$$CO_2 + C = 2CO, \qquad \ldots \ldots \ldots \ldots \quad (5)$$

and of steam on hot carbon (equation (1)).

As the specific heat of carbon dioxide is only 0.2479, the amount of heat carried away by the products of combustion is not large. Its specific gravity (H = 1) is 14; and (air = 1) is 0.9671 and one cubic foot weighs 0.0781 lb.

Marsh Gas, Methane (CH$_4$).—Molecular weight, 15.97 (practically 16).—This is a colorless and odorless gas which occurs in large quantity in natural gas. It is produced by the decompositions by which vegetable matter passes into coal, and is therefore often present in coal mines, where it is known as fire-damp. It is among the products of the destructive distillation of coal, and is therefore always present in coal gas, through rarely in large quantity. Its specific gravity (air = 1) is 0.5530, whence it is often called light carbureted hydrogen. One cubic foot weighs 0.0447 lb. It burns readily with a slightly luminous flame, forming carbon dioxide and water thus:

$$CH_4 + 4O = CO_2 + 2H_2O. \qquad \ldots \ldots \ldots \quad (6)$$

If the quanity of oxygen be insufficient for complete combustion it yields carbon monoxide, hydrogen, and lower hydrocarbons with but little free carbon, so that little or no smoke is produced. It requires for complete combustion four times its own weight and twice its own volume of oxygen, or 17.3 times its weight and 9.52 times its own volume of air. It yields 2.25 times its own weight of water and 2.75 times its own weight of carbon dioxide. Its calorific power is 13,062 calories or 23,512 B.T.U.

Ethylene (C_2H_4).—Molecular weight, 27.94 (28). This gas is present in considerable quantity in gases, such as coal gas produced by destructive distillation. It is colorless and odorless, burns very easily, with a very luminous flame, which becomes readily smoky. It is the chief illuminating constituent of coal, and similar gases. On complete combustion it yields water and carbon dioxide,

$$C_2H_4 + 6O = 2CO_2 + 2H_2O. \quad \ldots \ldots \ldots \quad (7)$$

It requires for complete combustion 3.42 times its own weight and three times its own volume of oxygen, or 14.87 times its own weight, and 14.28 times its own volume of air. It yields twice its own volume of carbon dioxide and twice its own volume of steam. With an insufficient supply of air it burns with a very smoky flame. Its specific gravity (air = 1)· is 0.9784, and a cubic foot weighs 0.0784 lbs. Its specific heat is 0.4040. It yields on complete combustion 11,143 C.U. or 20,057 B.T.U. of heat.

Acetylene (C_2H_2).—This is a colorless gas, having a most unpleasant odor. It burns readily with a very brilliant flame, and shows a great tendency to produce smoke by the separation of carbon:

$$C_2H_2 + 5O = 2CO_2 + H_2O. \quad \ldots \ldots \ldots \ldots \quad (8)$$

It requires three times its own weight and 2.5 times its own volume of oxygen for complete combustion. Its specific gravity (air = 1) is 0.91, and a cubic foot weighs 0.0734 lbs. It is an unstable body, decomposing very readily with evolution of heat, and is of little importance as a fuel gas.

Natural Gas.—Sexton says that natural gas is composed almost entirely of combustible gases, there being only 4.4% of diluents, as compared with 95.6% of combustible gases and its calorific power will therefore be very high. Owing to the large quantity of methane, it burns with a non-luminous flame. The percentage composition is about:

	Volume, Per Cent.		Weight, Cu.Ft.		Weight of Gas, Lbs.	Weight, Per Cent.
Carbon dioxide..	0.6	×	0.1227	=	0.0736	1.82
Carbon monoxide	0.6	×	0.0781	=	0.0469	1.16
Oxygen.........	0.8	×	0.0893	=	0.0714	1.77
Ethylene.......	1.0	×	0.0784	=	0.0784	1.94
Ethane.........	5.0	×	0.0837	=	0.4185	10.35
Methane........	67.0	×	0.0447	=	2.9949	74.09
Hydrogen.......	22.0	×	0.0056	=	0.1232	3.05
Nitrogen........	3.0	×	0.0784	=	0.2352	5.82
					4.0421	100.00

DILUENT GASES.

Nitrogen (N).—Atomic weight 14; molecular weight 28. This is a colorless and odorless gas, always present in fuel and lighting gases. It is produced in small quantity by the destructive distillation of nitrogenous organic matter, and is therefore present in small quantities in coal and similar gases. It forms a large percentage of the air, and is therefore always present in large quantity in gases produced by incomplete combustion. Its specific gravity (air = 1) is 0.9701, and one cubic foot weighs 0.0784 lbs. It is not combustible, and has no influence on fuel gas, except to act as a diluent. Its specific heat is 0.2438.

Carbon Dioxide (CO_2). Molecular weight 43.89 (practically 44). This is a colorless, odorless, non-combustible gas. It is produced in small quantity by destructive distillation, and is therefore present in small quantity in coal gas. It is often present in producer gas in considerable quantity, being produced by the combustion of carbon. Its specific gravity (air = 1) is 1.5196; one cubic foot weighs 0.1227 lbs., and its specific heat is 0.2163. In presence of excess of carbon at high temperatures it is reduced to carbon monoxide, thus:

$$CO_2 + C = 2CO. \qquad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

Oxygen (O).—This gas is never present in fuel gas except by leakage after the gas has cooled, since at high temperatures it would at once combine with the combustible constituents of the gas.

Steam (H_2O).—Molecular weight, 17.97 (practically 18). Water vapor is always present in fuel gas, being produced by the vaporization of the moisture in the fuel, and it is always among the products of destructive distillation, and it may be produced by the combustion of hydrogen or hydrocarbons owing to the leakage of air into the gas. At temperatures above 100° C. the whole of the water will be in the condition of vapor, and will behave exactly like any other gas. At temperatures below 100° C. part of the steam will condense, but a certain amount of water vapor will always remain in the gas, the amount depending on the temperature, as at every temperature water can exist in the condition of gas or vapor till it exerts a definite pressure.

The specific gravity of steam or water vapor at 0° and 760 mm. is 0.622 (air = 1), and one cubic foot weighs 0.0502 lbs. As its specific heat is 0.4805, the presence of water vapor causes a large amount of heat to be carried away in the products of combustion. There may also be present a considerable amount of condensed water in the form of fine globules or mist.

Tarry Matter.—These are mostly dense hydrocarbons of very uncertain composition, which condense at moderate temperatures to tarry and oily liquids. They burn with a luminous, often smoky flame. On being passed over red hot coke or red hot brickwork they are broken up into carbon, which is deposited, and permanent gases such as largely marsh gas and hydrogen. The influence of tarry matters on the quality of gas is discussed elsewhere.

The Air.—In practice, fuels are always burnt in air. The air consists of a mixture of oxygen and nitrogen with small quantities of other substances, some inert gases resembling nitrogen—which have been recently discovered, but which, since they have no influence on combustion, can be neglected—carbon dioxide, very minute

quantities of ammonia, acid gases, etc., and a considerable quantity of water vapor. For all practical purposes, dry air may be taken as containing:

	By Weight.	By Volume.
Oxygen	23	21
Nitrogen	77	79

The average analysis of atmospheric air as made by Professor Lewes, is as follows:

Oxygen	20.61
Nitrogen	77.95
Carbon dioxide	0.04
Water vapor	1.40
Nitric acid	trace
Ammonia	trace
	100.00

Composition of Industrial Gases.—The following are the general characteristics of some of the most used gases:

PROPERTIES OF COMMERCIAL GASES (WYER)

Names.	H.	CH₄.	C₂H₄.	N.	CO.	O.	CO₂.	B.T.U. in 1 Cu. Ft. Explosive Mixture	B.T.U. per Cu. Ft.	O. Required for Combustion.	Air for Combustion.
Natural gas (Pittsburg)	3.0	92.0	3.0	2.0	.....	.....	.....	91.0	978	1.94	9.73
Oil gas	32.0	48.0	16.5	3.0	.....	0.5	.....	93.0	846	1.61	8.07
Coal or bench gas	46.0	40.0	5.0	2.0	6.0	0.5	0.5	91.7	646	1.21	6.05
Coke-oven gas	50.0	36.0	4.0	2.0	6.0	0.5	1.5	91.0	603	1.12	5.60
Carbureted water gas	40.0	25.0	8.5	4.0	19.0	0.5	3.0	92.0	575	1.05	5.25
Water gas	48.0	2.0	.....	5.5	38.0	0.5	6.0	88.0	295	0.47	2.35
Producer gas from hard coal	20.0	.....	.....	49.5	25.0	0.5	5.0	68.0	144	0.22	1.12
Producer gas from soft coal	10.0	3.0	0.5	58.0	23.0	0.5	5.0	65.5	144	0.24	1.20
Producer gas from coke	10.0	.....	.....	56.0	29.0	0.5	4.5	63.0	125	0.19	0.98

The following table is credited to J. M. Morehead.

APPROXIMATE COMPOSITION OF ORDINARY GASES

Gas.	Carbon Dioxide.	Illuminants.	Oxygen.	Carbon Monoxide.	Hydrogen.	Methane.	Nitrogen.	B.T.U. per Cu. Ft.	Specific Gravity.
Water-gas, 24 c.p.	4.5	13.0	0.5	29.0	32.0	16.0	5.0	720	0.63
Coal-gas, 16 c.p.	2.0	5.5	0.5	11.5	43.5	35.0	2.0	610	0.45
Acetylene (commercial)	.....	96.0	1.0	.....	.....	.....	4.0	1600	0.92
Flue gas	16.0	.....	4.5	0.5	.....	.....	79.0	.....	1.06
Pintsh gas	0.5	23.5	0.5	1.0	18.5	52.5	3.5	1100	0.73
Engine exhaust	8.0	.....	17.0	.....	.....	.....	75.0	.....	1.04
Producer-gas	6.0	.....	.....	22.0	11.0	3.0	58.0	150	0.89
Natural gas	2.0	2.7	0.1	1.0	.....	88.1	5.2	900	0.56
Blue water-gas	3.0	.....	.....	43.25	50.0	0.5	3.25	350	0.42
Air	.....	.....	20.7	.....	.....	.....	79.3	.....	1.00

The above figures are given as an average of those which ordinarily obtain in the best practice. Local conditions and requirements probably will, of course, vary these figures in individual instances.

For convenient reference the following tables from another source is here inserted, showing what may be considered average volumetric analyses and the weight and energy of 1000 cubic feet, of the four types of gases used for heating and illuminating purposes:

APPROXIMATE COMPOSITION OF ORDINARY GASES

Composition by Volume.	Natural Gas.	Coal Gas.	Water Gas.	Producer Gas.	
				Anthracite.	Bituminous.
CO....................	0.50	6.0	45.0	27.0	27.0
H.....................	2.18	46.0	45.0	12.0	12.0
CH_4.................	92.6	40.0	2.0	1.2	2.5
C_2H_4...............	0.31	4.0	....	....	0.4
CO_2.................	0.26	0.5	4.0	2.5	2.5
N.....................	3.61	1.5	2.0	57.0	55.3
O.....................	0.34	0.5	0.5	0.3	0.3
Vapor, H_2O..........	....	1.5	1.5		
Pounds in 1000 cu.ft.........	45.6	32.0	45.6	65.6	65.9
B.T.U. in 1000 cu.ft.........	1,100,000	735,000	322,000	137,455	156,917

Industrial Gases.—Their composition is variable. In artificial gases it varies with the nature of the fuel and the method of operating. The following tabulation indicates their general character:

COMPOSITION OF INDUSTRIAL GASES
VOLUMETRIC

Kind.	CO_2	O	Illuminants or C_2H_4	CO	CH_4	H	N	B.T.U. per Cu.Ft.
Natural gas..................	0.29	0.30	0.15	0.60	93.57	1.40	2.80	989
"	0 60	0.80	6.00	0.60	67.00	22.00	3.00	892
Oil gas......................	0.90	....	17.40	....	58.30	24.30	....	967
"	....	0.50	16.50	....	48.00	32.00	3.00	846
Illuminating gas	0.60	0.10	3.80	7.50	39.50	46.00	2.50	650
Coke oven gas	2.00	....	2.00	6.00	35.00	53.00	2.00	620
Water gas { Carbureted	1.50	0.50	18.50	19.00	25.00	40.00	4.00	575
{ "Blue" or uncarb'r'd.	4.25	....	....	39.53	1.05	49.50	8.75	295
PRODUCER GASES.								
Anthracite: Fuel	3.9	...	....	27.3	1.0	12.3	55.5	147
Power	6.2	....	....	26.0	1.3	14.4	52.1	153
"	12.1	0.2	...	18.3	1.0	20.5	47.9	144
Suction	5.6	0.6	...	24.4	1.0	18.0	50.4	157
"	6.1	0.7	....	20.2	1.2	15.6	56.2	136
Bituminous: Fuel....	5.7	0.4	0.6	22.0	2.6	10.5	58.2	150
Power.............	7.9	....	....	23.4	2.1	17.1	49.1	162
"	10.8	....	0.5	16.6	2.4	14.9	54.8	144
Mond gas	13.9	....	....	13.8	2.0	24.3	46.0	153
Lignite: Fuel gas	6.4	0.8	0.7	22.0	1.6	9.6	58.9	138
Power gas	9.6	0.2	....	18.22	4.81	9.63	57.53	148
Coke: Power gas	4.8	....	....	27.6	2.0	7.0	58.6	140
Suction gas	5.4	0.6	....	25.3	0.35	13.2	55.15	136
Charcoal: Fuel gas............	0.8	....	....	34.1	....	0.2	64.9	119
Wood: Fuel gas	11.5	....	0.6	28.4	2.9	0.5	56.1	145
" "	6.9	....	....	28.6	2.2	8.5	53.8	131
Peat, power gas	12.4	....	0.4	21.0	2.2	18.5	45.5	175
Siemens	4.2	....	....	24.2	2.2	8.2	61.2	135
Blast furnace	9.37	....	....	25.84	0.54	2.96	56.0	105

Producer Gas Analyses.—The gases made in gas producers are characterized by high percentage of nitrogen, as shown by the following analyses:

EXAMPLES OF PRODUCER GAS (Sexton)

	I	II	III	IV	V
Hydrogen..................	8.60	12.13	10.90	19.43	12.60
Hydrocarbons..............	2.40	2.00	1.28	2.66	3.50
Carbon monoxide...........	24.40	26.40	27.00	16.15	20.40
Carbon dioxide............	5.20	9.16	4.50	11.53	5.50
Nitrogen..................	59.40	50.31	56.32	50.23	58.00
Combustibles, per cent......	35.40	40.53	39.18	38.24	36.50

The analysis of the gas made in a producer by the Washburn & Moen Manufacturing Co. is as follows:

$$CO_2 \dotfill 4.9$$
$$O \dotfill None$$
$$CO \dotfill 26.8$$
$$C_2H_4 \dotfill 0.4$$
$$CH_4 \dotfill 3.5$$
$$H \dotfill 18.1$$
$$N \dotfill 46.3$$

ANALYSIS OF PRODUCER WATER GAS—Loomis-Pettibone Producer

	Sept. 12, '03	Oct. 9, '03
Carbon dioxide.....................	6.25	8.76
Oxygen...........................	0.23	0.95
Ethylene..........................	0.37	....
Carbon monoxide..................	27.63	26.20
Hydrogen.........................	48.37	36.21
Methane..........................	3.65	4.61
Nitrogen.........................	13.50	22.32
Illuminants.......................	.....	0.95
B.T.U. per cubic foot..............	304	286

The lower carbon dioxide, and higher hydrogen and carbon monoxide indicates they are working generators hotter and producing a higher grade of gas from poor coal.

ANALYSIS OF MIXED GAS (E. C. Atkins)

	Morning	Afternoon
Nitrogen.........................	57.78	54.00
Oxygen...........................	0.33	.....
Carbon dioxide....................	9.20	10.00
Carbon monoxide..................	16.00	16.15
Hydrogen.........................	15.12	16.33
Illuminants.......................	0.05	0.30
Methane..........................	1.52	2.80
Heat units per cubic foot..........	125.64	133.6

AVERAGE ANTHRACITE PRODUCER GAS

I. MADE WITH STEAM

77 cu.ft. of this analysis were produced from 1 lb. of No. 1 buckwheat coal.

Component Gases.		Heat Value.		
Kind.	Volume, Per Cent.	B.T.U.	Per Cent of Gas.	Per Cent of Value of Coal.
CO...............	27.	87.48	67.3	57.2
CH_4.............	1.	9.19	7.	6.
H_2.............	12.	33.36	25.7	21.8
CO_2.............	3.	.....	.....	....
N_2.............	57.	.....	.....	....
Total............	100.	130.	100.	85.

NOTE.—The producer gas of the above analysis made with steam is based on the use of buckwheat No. 1 coal, shown in table on page 8, and is based on the use of 0.3 lbs. of steam per pound of coal. To generate this amount of steam from water at 60° F., there are required 335 B.T.U. or only 2.85% of the total heat value of this coal.

II. MADE WITH CARBON DIOXIDE

109 cu.ft. of this analysis were produced from 1 lb. of No. 1 buckwheat coal.

Component Gases.		Heat Value.		
Kind.	Volume, Per Cent.	B.T.U.	Per Cent of Gas.	Per Cent of Value of Coal.
CO...............	30.	97.2	90.7	77.3
CH_4.............	1.	9.19	8.1	6.9
H_2.............	0.4	1.11	1.2	0.8
CO_2.............	1.	.....	.....	.....
N_2.............	67.6	.....	.....	.....
Total............	100.	107.5	100.0	85.0

NOTE.—The value of the B.T.U. as given above is based on the temperature of the gas being 62° F. pressure, 14.7 lbs., and a deduction has been made of 966 B.T.U. per pound of steam in the products of combustion on the basis that the latent heat of steam has no influence on the heat value of the gas for all lines of work for which producer gas is used industrially

ANALYSIS OF A GAS FROM A SUCTION PRODUCER

Carbon dioxide, CO_2................................. 8.0
Carbon monoxide, CO............................... 26.0
Hydrogen, H....................................... 18.5
Marsh gas, CH_4.................................. 0.5
Nitrogen, N....................................... 47.0

varying of course with the method of operation in its proportion of H and CO.

TYPICAL ENGINE EXHAUST GAS, SUCTION PRODUCER

Components......	CO_2	O_2	CO	H_2	CH_4	N
Percentage.....	17.0	1.5	0.6	0.0	0.0	80.9

Comparison of Producer and Illuminating Gas.—First-class carbureted water gas, made with $4\frac{1}{2}$ gallons of Lima oil per 1000 feet of gas, c.p. $26\frac{1}{2}$, contains 730 B.T.U. per cubic foot.

In a producer one pound of anthracite coal (C 85%, hydrocarbons 5%, Ash 10%) will make about 90 cubic feet of gas of following composition:

CO 27%, H 12%, CH_4 1.2%, CO_2 2.5%, N 57%. This gas contains about 137 B.T.U. per cubic foot.

Therefore 17 cubic feet of carbureted water gas are equal in heat units to gas from one pound of anthracite, and 1000 cu.ft. of carbureted water gas equals gas from 59 lbs. of anthracite.

Bituminous Producer Gas.—This gas differs from that made from anthracite, in containing a much larger percentage of hydrocarbons. It consequently has greater calorific energy and also much more luminosity. This latter quality gives it special value in high-temperature work, according to the latest theories of combustion. To utilize these hydrocarbons the gas must be kept at a temperature that will prevent their condensation. At the same time it must be borne in mind that a very high temperature will break down the hydrocarbons, and cause the deposition of soot.

In collecting a sample of gas for analysis, it is cooled to the temperature of the atmosphere, and the hydrocarbons are almost all condensed. This accounts for the fact that while the gas from bituminous coal may be doing 50% more work than the gas from the same amount of anthracite, yet their analysis will not differ materially, as shown in the following:

AVERAGE BITUMINOUS PRODUCER GAS ANALYSIS—BY VOLUME

Constituents.	European.	American.	
	Siemens Gas.	Anthracite Gas.	Soft Coal Gas.
CO................	23.7	27.0	27.0
H.................	8.0	12.0	12.0
CH_4..............	2.2	1.2	2.5
CO_2..............	4.1	2.5	2.0
N.................	62.0	57.3	56.5

When soft coal gas is passed through the cooling tube of the old Siemens producer, or through long unlined flues, the hydrocarbons are condensed, and the gas really has the composition as shown in the preceding analysis. A comparison of these analyses with the hypothetical one given below, in which none of the hydrocarbons are lost, shows the importance of preventing their condensation as far as possible.

To examine more closely into the conversion of bituminous coal, a theoretical gasification of 100 lbs. of coal, containing 55% of carbon and 32% of volatile com-

bustible (which is about the average of Pittsburg coal), is made in the following table. It is assumed that 50 lbs. of carbon are burned to carbon monoxide and 5 lbs. to carbon dioxide; one-fourth of the oxygen is derived from steam and three-fourths from air; volatile combustible is taken at 20,000 heat units to the pound, probably a safe assumption, notwithstanding that a high authority puts it at 18,000. In computing volumetric proportions, all the volatile hydrocarbons, fixed as well as condensing, are classed as marsh gas, since it is only by some such tentative assumption that even an approximate idea of the volumetric composition can be formed. The energy, however, is calculated from weight, and is strictly correct:

GASIFICATION OF BITUMINOUS COAL

Producer Reaction.	Products.		
	Pounds.	Cubic Feet.	Per Cent by Vol.
50 lbs. C burned to............................CO	116.66	1580.7	27.8
5 lbs. C burned to............................CO_2	18.33	157.6	2.7
32 lbs. vol. HC (distilled)........................	32.00	746.2	13.2
80 lbs. O are required, of which 20 lbs. derived from H_2O, liberate H	2.5	475.0	8.3
60 lbs. O, derived from air, are associated with...............N	200.70	2709.4	47.8
Total...	370.19	5668.9	99.8

Energy in 116.56 lbs. CO............................	504,554	heat-units
Energy in 2.00 lbs. vol. HC..........................	640,000	"
Energy in 32.50 lbs. H............................	155,000	"
Total....	1,299,554	"
Energy in coal...	1,437,500	
Per cent of energy delivered in gas............................	90.0	
Heat-units in one pound of gas.................................	3484.0	
Heat-units in one cubic foot of gas.............................	229.2	

When these figures are compared with the theoretical gasification of anthracite, the vastly greater energy, both by weight and volume, in the bituminous gas, is seen at once. It is worth even more in practice than appearance indicates, since the high percentage of hydrocarbons is associated with lower nitrogen. All of the 32% of volatile combustible, except the tarry matter, must be volatilized and utilized in its full strength, whether it be fixed gas or simply distilled hydrocarbon. For this purpose it should not be suffered to cool below 300° before it enters the combustion-chambers or regenerators—the higher its temperature at the furnace the better.

The comparative value of the two gases in high-temperature work is illustrated by the fact that when anthracite gas is used in regenerative furnaces for heating iron, it is frequently necessary to gasify in the producers from two to three times more coal per ton of iron heated than when bituminous gas is used. It is also well known that the rate and effectiveness of heating rises with the percentage of volatile combustible. The results may prove that it can be used advantageously, especially when supplemented with a little oil, which could be introduced into the furnace about where the air and gas unite, and thus secure a luminous hydrocarbon flame. Such use of oil is said to be practiced to a limited extent in Europe, as a supplement to water gas.

Broadly speaking, and for a wide field of work, the quality of the heating that has been done with anthracite gas is good. The comparison with bituminous gas is not always as unfavorable as the one we have considered. The energy of the bituminous gas described was 3484 heat units per pound, as against 2246 heat units for the anthracite; but most bituminous coals are lower in volatile combustible and higher in carbon than our specimen coal. Possibly a fair average would be 70% of fixed carbon and 20% of hydrocarbon with 10% of ash. A theoretical gasification of 100 lbs. of such coal, burning 5 lbs. of carbon to carbon dioxide, and deriving one-fourth of the oxygen from water and three-fourths from air would show this result:

AVERAGE BITUMINOUS COAL YIELD

Producer Reaction.	Products.		
	Pounds.	Cubic Feet.	Per Cent by Vol.
65 lbs. C burned to.....................................CO	151.6	2054	30.8
5 lbs. C burned to......................................CO$_2$	18.3	157	2.3
20 lbs. vol. HC (distilled)...................................	20.0	466	7.0
25 lbs. O, from water liberate..........................H	3.1	588	9.0
75 lbs. atmosphere O mixed with.........................N	251.2	3391	50.9
Total...	444.2	6656	100.0

Calorific energy of the gas............................ 1,247,870 heat-units
Calorific energy of the gas per pound.................. 2,809 "
Calorific energy of the gas per cubic foot............... 187.4 "
Calorific energy of the coal........................... 1,415,000 "
Efficiency of the conversion................................... 88 per cent

Anthracite Producer Gas.—In considering the gasification of anthracite coal we find in it a volatile combustible, varying in quantity from 1.5 to over 7%, and while its flame resembles that of hydrogen, the amount of marsh gas found in anthracite producer gas corresponds practically with the total volatile hydrocarbons in the coal. If this is correct, all the hydrogen in the gas is derived from the dissociation of water-vapor; but this, as previously shown, is in practice higher than the theoretical quantity. We generally find 1.5% or more of marsh gas in anthracite gas made from coal containing about 5% of volatile combustible, and this proportion is about what should be expected if all the volatile combustible in the coal is marsh gas. But if it is not, it is difficult to explain the presence of the marsh gas and the excess of hydrogen in the producer gas. If the percentage of carbon dioxide were high and the resulting excess of heat were expended in an increased dissociation of steam, that would account for the hydrogen; but with low carbon dioxide, and all the volatile combustible represented by marsh gas in the producer product, it is difficult to account for all the hydrogen in the face of our assumption that we cannot gasify with steam more than one-quarter of the carbon.

If we felt confident that solid carbon and marsh gas were the only combustibles to be considered in anthracite, it would be easy to calculate from an analysis of producer gas the amount of energy derived from the coal, as is shown in the following theoretical gasification made of coal with assumed composition: Carbon, 85%; volatile hydro-

carbons, 5%; ash, 10%; 80 lbs. carbon assumed to be burned to carbon monoxide; 5 lbs. carbon burned to carbon dioxide; three-fourths of the necessary oxygen derived from air, and one-fourth from water.

TYPICAL ANTHRACITE PRODUCER REACTION

Producer Reaction.	Products.		
	Pounds.	Cubic Feet.	Anal. by Vol.
80 lbs. C burned to.....................................CO	186.66	2529.24	33.4
5 lbs. C burned to.....................................CO_2	18.33	157.64	2.0
5 lbs. vol. HC (distilled).............................	5.00	116.60	1.6
120 lbs. oxygen are required, of which 30 lbs. from H_2O liberate H	3.75	712.50	9.4
90 lbs. from air are associated with.......................N	301.05	4064.17	53.6
Total...	514.79	7580.15	100.0

Energy in the above gas obtained from 100 lbs. anthracite:

186.66 lbs. CO.....................................	807,304	heat-units
5.00 lbs. CH_4....................................	117,500	"
3.75 lbs. H.......................................	232,500	"
	1,157,304	"
Total energy in gas per pound.........................	2,248	"
Total energy in gas per cubic foot.....................	152.7	"
Total energy in 100 lbs. of coal.......................	1,349,500	"
Efficiency of the conversion..........................	86 per cent	

It will be noticed that 1.6% of marsh gas represents all the volatile combustible in the coal, and that 86% of the total energy is delivered in the gas; but the sum of carbon monoxide and hydrogen exceeds the results obtained in practice. The sensible heat of the gas will probably account for this discrepancy, and it is quite safe to assume the possibility of delivering at least 82% of the energy of anthracite.

To illustrate the loss caused by forming carbon dioxide in the producer, when none of the heat of primary combustion is used for dissociating water, the following theoretical gasifications of carbon are adduced, showing the resulting gases, in which 0, 5, 10, 15, 25 and 50% of carbon are successively burned to carbon dioxide, and giving the percentage of energy delivered in each case, without considering the increasing proportion of nitrogen as a factor in reducing the energy-ratio of the poorer gases.

EFFECT OF BURNING TO CARBON DIOXIDE

C burned to CO_2.................	0%	5%	10%	15%	25%	50%
Products:						
CO per cent...................	34.4	31.5	29.5	26.6	22.7	12.9
CO_2 per cent....................	....	1.6	3.2	4.6	7.6	12.9
N per cent...................	65.6	66.9	67.3	68.8	69.7	74.2
Pounds of gas....................	679	708	737	766	824	969
Cubic feet of gas.................	9183	9468	9759	10,065	10,387	12,189
Per cent of carbon energy in gas.....	70	66	63	59	52	35
Heat-units per cubic foot of gas.	109.7	100.5	94.1	85.8	72.04	41.1

But the formation of carbon dioxide in the producer is objectionable, not only when the heat of its combustion is lost, but even when a large portion of this heat is recovered by dissociating water. A theoretical gasification, in which 100 lbs. of carbon are completely burned to carbon dioxide, and 70% of the resulting heat of combustion (1,450,000 heat units) is assumed to be recovered by dissociating water, is illustrated in the following table:

COMBUSTION FOR DISSOCIATION

Producer Reaction.	Products.		
	Pounds.	Cubic Feet.	Per Cent by Vol. (Approx.)
100 lbs. C burned to................................CO$_2$	366.66	3,153	25
70 per cent of 1,450,000 heat-units is 1,015,000 units, which liberate from water................................H	16.34	3,110	25
130.96 lbs. O, liberated from this water, combines with 49.2 lbs. C to form CO$_2$. This leaves 50.8 lbs. C to combine with 135.13 lbs. atmospheric O, which is associated with.......N	453	6,115	50
Total..	836.00	12,378	100

Here we have only 25% of combustible hydrogen, representing 70% of the carbon energy, in 836 lbs., or 12,378 cu.ft. of gas; the latter is, therefore, of poor quality, and compares very unfavorably with the 70% conversion of the all-monoxide gas in the preceding table, where 34.4% of combustible (carbon monoxide) are found in 679 lbs., or 9138 cu.ft. of gas. It follows that whenever carbon dioxide is formed and its heat used for dissociating water, there is at best but a poor utilization of the energy. Probably all that can be recovered in this way does not exceed one-half of what may be obtained from carbon burned to carbon monoxide. But in special cases where practically all the sensible heat of the gas is utilized in a non-regenerative furnace or kiln, where mechanical difficulties effectually prevent good combustion, a very hot gas, containing 7 to 9% of carbon dioxide is found to be preferable to a cold gas low in carbon dioxide.

Power Gas.—There are some properties of producer gas which are of special importance when used in gas engines, as shown in the following tables:

AVERAGE GAS ANALYSIS TAKEN AT NATIONAL METER CO. GAS ENGINE TEST OF GAS FROM A REGULAR R. D. WOOD GAS-PRODUCER SYSTEM

B.H.P.	B.T.U. by Calorimeter.	Time.	CO$_2$.	O$_2$.	CO.	H$_2$.	CH$_4$.	B.T.U. Calculated by Analysis.	N.	Remarks.
		A.M.								
100	147	10.45	3.5	1.9	23	13	2.1	139	56.5	
100	138	11.45	4.6	1.5	23.8	15.5	1.1	139.2	53.5	
100	134	12.45	6.8	1.1	17.8	15.0	2.0	129	57.3	
100	132	1.45	6.5	1.2	18.6	15.5	0.7	118.4	57.5	
75	125	2.45	8.1	1.3	15.9	12.5	1.1	103.7	61.1	Engine back-firing
100	141	3.45	4.5	1.1	22.7	15.5	1.7	141.8	54.5	
100	135	4.45	6.5	1.2	16.6	18.5	.7	121.7	56.5	Engine pre-igniting
		4.45	17.0	1.5	0.6	0.0	0.0	....	80.9	Exhaust

GENERAL PROPERTIES OF COMMERCIAL POWER GASES

	Gas.	Origin.	General Characteristics for Power Work.	Approximate Order of Value for Power Gas.
1	Natural gas.	Geological.—Results from decomposed vegetation.	Ideal power gas. Rich, pure, rather slow burning. Requires no cleaning.	1
2	Oil gas.	Vaporizing crude oil. Used to enrich water gas.	Very rich in heavy hydrocarbons. Liable to carbon deposits. Seldom used for power except in small oil (petrol) engines.	9
3	Coal gas.	Destructive distillation of coal in closed retorts.	Excellent gas, resembling natural gas. Not hard to clean. Manufacturing costs usually too high for general power purposes.	8
4	Coke-oven gas. (By-product).	Liberation of volatiles of coal in closed chambers without combustion.	Gas should be drawn off during early part of coking run. Good gas, rather high in H and S, requiring much purification.	5
5	Water gas.	Decomposition of steam on incandescent coke. Hydrogen freed, carbon burned to CO.	Pure gas, too snappy (high in H) for gas engines. More suitable if enriched with oil gas. Rather expensive gas for general power purposes.	10
6	Oil-water gas.	Decomposition of steam and oil in retort heated by crude oil.	Rich gas, high in H, and rather snappy. Free from impurities, except S. Manufacturing cost low.	6
7	Producer gas.	Obtained from coal, coke, peat, lignite, or wood. Largely incomplete oxidation of carbon to CO by a steam air blast. H_2O decomposes into free H. Some CO_2 formed.	Cheapest and best of artificial fuel gases, lean and comparatively slow burning. Made from any grade fuel.	2
8	Producer bituminous	Bituminous coal. Breaking up of volatile hydrocarbons and conversion of fixed carbon into CO.	Richest of producer gases. Tar distillate difficult to remove. Most grades of coal suitable, including slack, lignite, and wood.	2
9	Producer anthracite.	Anthracite coal. Practically no volatiles. Conversion of fixed carbon.	Gas free from tar, requiring little cleaning. Excellent power gas. Buckwheat size coal may be used.	3
10	Producer coke.	Coke or charcoal. No volatiles. Conversion of fixed carbon.	Gas practically clean, except dust. Most suitable for small producers. Fuel rather expensive.	7
11	Blast gas.	By-product of blast furnaces. Conversion of fixed C in coke into CO by air blast. Some CO_2 formed.	Gas very lean, dusty, and sluggish. Difficult to clean except mechanically. Excellent gas for engines taking high compression.	4

CONSTITUENTS OF POWER GASES WITH GENERAL PROPERTIES

Gas.		Heating Value.		Characteristics, Where Found.
Name.	Chemical Symbol.	B.T.U., Cubic Feet, Net.	Relative.	
Hydrogen..............	H	278	1	Element, formed from decomposition of steam (H_2O) or hydrocarbon compounds. Burns very rapidly with high flame temperature.
Oxygen..............	O	0	....	Element, not considered a combustible, as it displaces an equal amount of O in air for combustion.
Nitrogen.............	N	0	....	Element, inert gas entering with air (N 79%; O 21%). Retards speed of combustion.
Carbon monoxide or carbonic oxide.......	CO	326	1.17	Valuable constituent. Product of incomplete combustion (oxidation) of C in presence of excess carbon.
Carbon dioxide.........	CO_2	0	....	Inert gas. Product of complete combustion of C. Occurs in all producer and blast gases. Retards speed of combustion.
Methane or marsh gas...	CH_4	913	3.29	Most valuable constituent evolved by natural or artificial decomposition of vegetable matter, coal, or crude oils.
Acetylene.............	C_2H_2	1427	51.4	Higher hydrocarbons, usually as "illuminants," occur in small quantities in the richer gases liberated during destructive distillation of coal or oil. Acetylene used alone for lighting.
Ethylene or Olefiant gas.	C_2H_4	1490	53.6	
Ethane................	C_2H_6	1615	58.1	
Benzene or benzol......	C_6H_6	3655	131.5	
Carbon................	C	....	....	C oxidizes to CO (incomplete) and CO_2 (complete). CO oxidizes to CO_2.
Sulphur...............	S	....	....	S oxidizes to SO_2 forming H_2SO_4 (sulphuric acid) with water.

Blending Producer Gas with Coal Gas.—Harold G. Coleman (*Journal of Gas Lighting*, September 18, 1906, p. 754) says that the blending of producer gas with the coal gas made in the ordinary way of gas manufacture, thus increasing the total volume of gas made into "a consistent bulk or whole," produces a coal gas of about 110 to 125 B.T.U. per cubic foot. Assuming that a ton of coal gives 11,000 cu.ft. of gas of 570 B.T.U., and that 1000 cu.ft. of producer gas of 120 B.T.U. be added, the resultant mixture would be 12,000 cu.ft. of 532 B.T.U. gas.

To offset this, however, allowance must be made for the calorific value of the hydrocarbon vapors retained, and which would otherwise be carried away by the tar. This cannot be given exactly, but from tests made with tars such as are produced from coal affording the aforesaid yield, it would appear as if the vapor retained (mainly benzene) will not exceed 1% of the producer gas added. This would amount to 10 ft. of vapor, increasing the above yield to 12,010 cu.ft. of gas of 535 B.T.U. gross.

Assuming the costs of the illuminating and producer gases to be 24.3 cents and 1.5 cent per 1000 cu.ft. respectively, the resultant price of the mixed gas will be 22 cents. With a selling price of 60 cents per 1000, this would mean a reduction in price of 3%, and a reduction in calorific value of 6%. The reduction in flame temperature will also be considerable, although this can only be determined by direct experiment.

Water Gas.—There is much more literature at our command on water gas than on producer gas. It is made, as is well known, in an intermittent process, by blowing up the fuel bed of the producer with air to a high state of incandescence (and in some cases utilizing the resulting gas, which is a lean producer gas), then shutting off the air and forcing steam through the fire, which dissociates the steam into its elements of oxygen and hydrogen, the former combining with the carbon of the coal, and the latter being liberated.

This gas can never play a very important part in the industrial field, owing to the large loss of energy entailed in its production; yet there are places and special purposes where it is desirable, even at a great excess in cost per unit of heat over producer gas; for instance, in small, high-temperature furnaces, where much regeneration is impracticable, or where the " blow-up " gas can be used for other purposes instead of being wasted. Some steel melting has been done in Europe with this gas, under the claim that much more work can be gotten out of a furnace in a given time owing to the greater energy of the gas, so that the extra cost is more than balanced. The lack of luminosity (hydrocarbon flame) in water gas makes this doubtful, unless some oil is introduced into the furnace, as before described.

We will now consider the reactions and the energy required in the production of 1000 ft. of water gas, which is composed, theoretically, of equal volumes of carbon monoxide and hydrogen.

	Pounds.
500 cu.ft. of H weigh.........................	2.635
500 cu.ft. of CO weigh........................	36.89
Total weight of 100 cu.ft.....................	39.525

Now, as carbon monoxide is composed of 12 parts carbon to 16 of oxygen, the weight of carbon in 36.89 lbs. of the gas is 15.81 lbs. and of oxygen 21.08 lbs. When this oxygen is derived from water (steam) it liberates, as above, 2.635 lbs. of hydrogen. The heat developed and absorbed in these reactions (disregarding the energy required to elevate the coal from the temperature of the atmosphere to say 1800°) is as follows:

	Heat-units.
2.635 lbs. H absorb in dissociation from water $2.635 \times 62,000$..	$=163,370$
15.81 lbs. C burned to CO develop 15.81×4400........	$= 69,564$
Excess of heat-absorption over heat-development........	$= 93,806$

The loss due to this absorption must be made up in some way or other, while 6.47 lbs. of carbon burnt to carbon dioxide would supply this heat, theoretically, but in practice, owing to the imperfect and indirect combustion and radiation, more than double this amount is required. Besides this, it is not often that the sum of the carbon monoxide and hydrogen exceed 90%, the remainder being carbon dioxide and nitrogen.

Blast-furnace Gas.—The gases from an iron blast furnace contain on an average,

	Per cent.
Carbon dioxide.	12
Carbon monoxide.	23
Hydrogen.	2
Methane.	2
Water vapor.	3
Nitrogen.	58

The efficiency of the utilization of this gas in gas engines could be greatly improved even by the simple removal of the high content of carbon dioxide, as in any operative apparatus in which a combustible gas containing a reactive proportion of carbon dioxide may be passed through a bed of ignited fuel in such a manner that the combustible gas first comes into contact with the latest charged layer of the fuel, fully answers the requirements.

Blast Furnace Gas Power.—In a discussion of gas power for rolling mills, Dr. Franz Erich Junge-Hermsdorf says:

"If a blast furnace is shut down, either on account of a depression on the money market or for showing signs of distress, the gas producer may be drawn upon to deliver the required energy to stoves, engines, boilers, etc. Also when there is need of higher blast pressures, as sometimes happens. With steam-blowing engines, it is easier to get sufficient pressure on when gas is used under the boilers than when direct coal firing. Also, with gas firing, the efficiency of coal conversion, or the calorific effect attained is from 5 to 25% greater and the labor is less. Producer gas, moreover, permits at all times of perfect control, allowing less variation in the amount of air blown through the furnace, thus giving greater regularity of product. By regenerating blast furnace gas with the aid of producer gas of higher heat value, the plant fuel consumption can be reduced to about 40% of the ordinary. (When steel furnaces are fired with ordinary gas, rolling mills being driven by steam power and heating stoves being fired with coal, then the total consumption runs up to about 100% of the finished product.) The scheme of installing reserve gas producers is now being generally recommended, allowing of concentration and control of fuel conversion at one central place with all resulting advantages and growing the more efficient the larger the plant. Regenerating the blast furnace gas with producer gas renders it at once useful for firing steel furnaces, and at the same time eliminating the irregularity of its composition, which varies between 85 and 106 B.T.U., thus making it better fit for gas power work, for the engines grow smaller in size or higher in capacity the greater the calorific value of the gas used."

However, a comparison of total heat used by either gas-engine power or steam gas generated turbine power, will show a heat consumption upon the part of the latter of about 50% higher than where the gas is used in the engine directly, the figures showing about 7580 calories per kilowatt hour, with steam power, and about 5050 calories with the gas engine.

"The consumption per indicated horse-power in gas engines is here figured as 3 cubic meters, the blast furnace gas having an average calorific value of 900 calories

per cubic meter, the engine efficiency being assumed as 0.8 and the mean efficiency of the generator as 0.915, giving a consumption of 5020 calories per kilowatt-hour for gas power, under the above outlined conditions."

It must be understood that the above figures are based upon a mean and highly fluctuating load, the efficiency in favor of direct gas-power generation being 75 to 100% at full load. It is necessary to provide for both variations in value of blast gas and also to take care of temporary over-loads, by installing engines of plus normal capacity. According to H. Wild, for steel plants service, the gas engine should have a capacity of 1.8 that of the steam engine rating. As a protection against irregularities in gas and to take care of over loads.

Carbon Dioxide in Gas.—As is well known the presence of any large amount of carbon dioxide in a combustible gas—particularly in a gas intended for use in an internal-combustion engine—has a very injurious effect upon the calorific power of the gas. This is due to two causes, first, the high specific heat of the carbon dioxide causes the absorption of a large amount of the heat developed in the combustion of the gas. Secondly, the already formed carbon dioxide has a tendency to diminish the completeness of the combustion of the gas. This is due to the fact that the avidity of carbon monoxide for oxygen diminishes with the increase in the vapor tension of the carbon dioxide formed. When we start our combustion, therefore, in the presence of a large amount of carbon dioxide, and hence in an atmosphere in which the vapor tension of that component of the gas is high to start with, the energy and velocity of the oxidizing reaction is much lessened. The combustion is, so to speak, dampened and rendered sluggish. Therefore, unless the conditions under which the combustion is made to take place are highly favorable, it is liable to be incomplete. If the temperature of the reaction is low—as when the gas is burned in contact with the comparatively cool tubes of a boiler—or, if the time of exposure of the gases to the reacting temperature is short—as is the case again in boiler practice—the combustion is sure to be very incomplete.

In internal combustion engines, the disadvantages mentioned are particularly marked. The specific retarding effect exerted by carbon dioxide on the velocity of propagation of the flame through an explosive mixture in the cylinder of a gas engine, necessitates the advancing of the spark to the furthest practical limit. If now, the content of carbon dioxide in the gas should suddenly drop, we are liable to get pre-ignition of the charge with the consequent loss of economy, racking of the engine, and, in some cases, running backward of the engine with the liability to accident which that entails. Even where the gas maintains a uniform proportion of carbon dioxide, the slowness of the combustion, of necessity, entails a great waste of energy, particularly with any high speed engine. The efficiency of a gas engine depends upon the difference between the maximum temperature developed by the explosion and the temperature of the exhaust gases.

When the gas is high in carbon dioxide, the combustion is so slow that the piston has covered part of its forward stroke before the combustion is complete. The result is that the initial temperature is low, the expansion is shortened, and the efficiency of the engine consequently lowered.

For all these reasons it is highly desirable in gas engine work, to have as little carbon dioxide in the gas as possible.
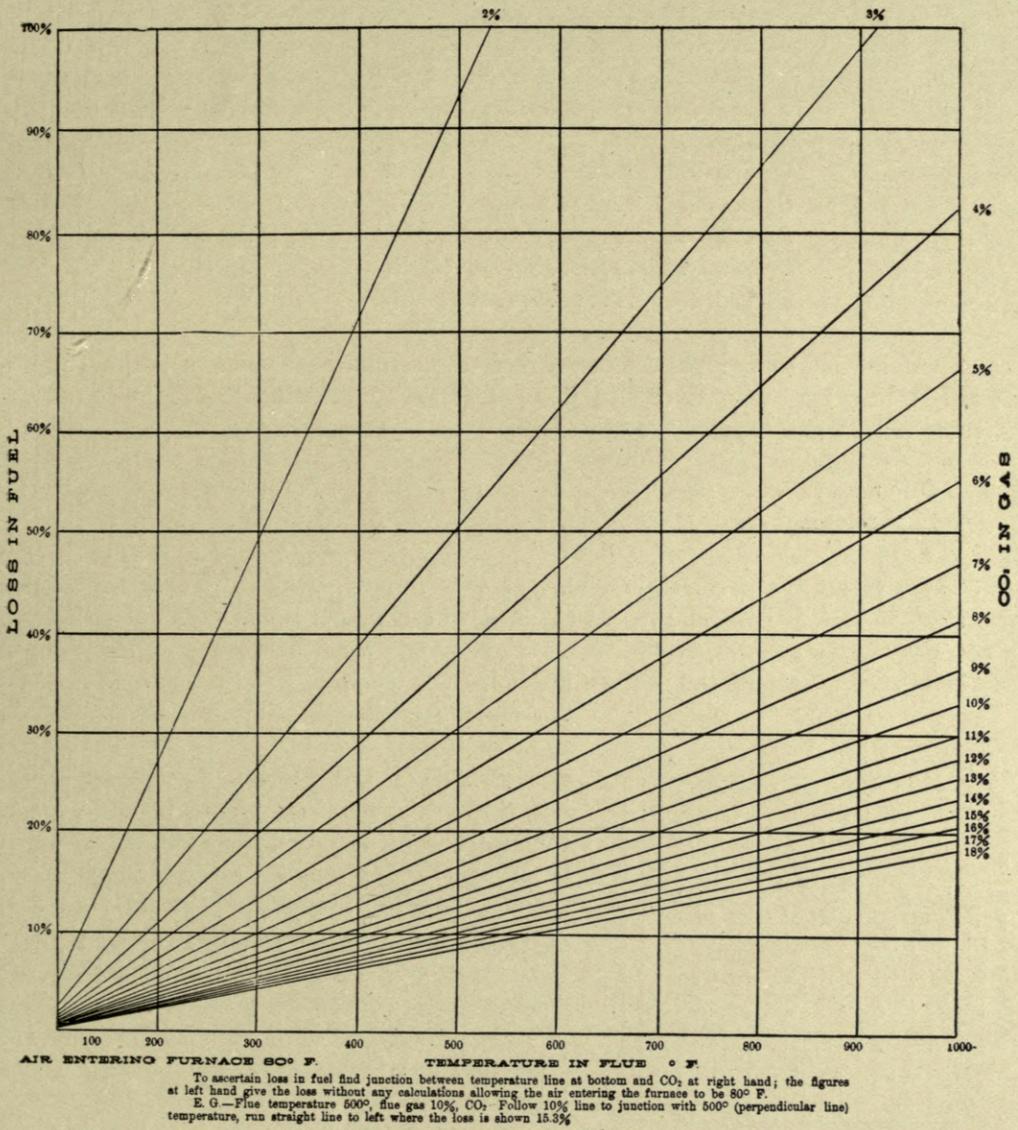
FIG. 104.—Diagram showing the loss of Fuel in Fuel Gas under different conditions.

EXCESS OF AIR CORRESPONDING TO GIVEN PERCENTAGE OF CO_2 IN FLUE GASES
FROM DIRECT COMBUSTION

CO_2.	Soft Coal.	Hard Coal.
18%............................	none	$1\frac{1}{9}$
16	$1\frac{1}{8}$	$1\frac{1}{4}$
14	$1\frac{2}{7}$	$1\frac{3}{7}$
12	$1\frac{1}{2}$	$1\frac{2}{3}$
11	$1\frac{7}{11}$	$1\frac{9}{11}$
10	$1\frac{4}{5}$	2
9	2	$2\frac{2}{9}$
8	$2\frac{1}{4}$	$2\frac{1}{2}$
7	$2\frac{4}{7}$	$2\frac{6}{7}$
6	3	$3\frac{1}{3}$
5	$3\frac{3}{5}$	4

The following table gives the percentage of the total heat value of the coal represented by varying amounts of CO_2 in producer gas, according to Campbell (manufacturer of iron and steel):

CO_2 per cent...	2	3	4	5	6	7	8	9	10
Loss per cent...	5.3	8.0	10.8	13.7	16.6	19.6	23.0	26.5	30

There is always a certain amount of CO_2 formed, even in the best producer practice; in fact, it is inevitable, and if kept within proper limits does not constitute a net loss of efficiency, especially with very short gas flues, because the energy of the fuel so burned is represented in the sensible heat or temperature of the gas, and results in delivering a hot gas to the furnace. However, the loss increases rapidly above 4% of CO_2 even when the gas is carried hot in short flues. If *too* hot, the hydrocarbons are broken up and deposit their carbon as soot, and the loss from radiation is very great. If attempt is made to run too cool, by increasing the proportion of steam, the result is equally bad, as a low gas temperature permits the deposition of tar in the flues, and both the heating value and capacity are largely reduced.

The best result is at about 4% CO_2, a gas temperature between 1100° and 1200° F., and flues less than 100 ft. long.

The accompanying diagram shows how fuel loss increases as percentage of CO_2 decreases in stack or exhaust gases.

FIG. 105.—Relation of CO_2 to Heat Loss.

Vapor Saturation.—In an elaborate set of tests made for the U. S. Government by Professor C. E. Lucke and S. M. Woodward on the use of alcohol in gas engines, the following vapor tensions of saturation for various liquids in millimeters of mercury are given:

VAPOR TENSION AT GIVEN TEMPERATURES

| Temperature, | | Pure Ethyl Alcohol. | Pure Methyl Alcohol. | Water. | Gasoline. |
Degree C.	Degree F.				
0	32	12	30	5	99
5	41	17	40	7	115
10	50	24	54	9	133
15	59	32	71	15	154
20	68	44	94	17	179
25	77	59	123	24	210
30	86	78	159	32	251
35	95	103	204	42	301
40	104	134	259	55	360
45	113	172	327	71	422
50	122	220	409	92	493
55	131	279	508	117	561
60	140	350	624	149	648
65	149	437	761	187	739

SOLUBILITY OF GASES IN WATER AT ATMOSPHERIC PRESSURE AND VARIOUS TEMPERATURES—(Siebel)

1 Volume Water Dissolves Volume Gases.	32° F.	39.2 ° F.	50.° F.	60° F.	70° F.
Air.	0.0247	0.0224	0.0195	0.0179	0.0171
Ammonia.	1049.6	941.9	812.8	727.2	654.0
Carbon dioxide.	1.7987	1.5126	1.1847	1.0020	0.9014
Sulphur dioxide.	79.789	69.828	56.647	47.276	39.374
Marsh gas.	0.0545	0.0499	0.0437	0.0391	0.0350
Nitrogen.	0.0204	0.0184	0.0161	0.0148	0.0140
Hydrogen.	0.0193	0.0193	0.0191	0.0193	0.0193
Oxygen.	0.0411	0.0372	0.0325	0.0299	0.0284

EXPLOSIVE MIXTURES (Wyer)

Combustible Gas.	Air.	Gas.
Hydrogen.	1	2.4
Carbon monoxide.	1	2.4
Marsh gas.	1	9.6
Olefiant gas.	1	14.4
Acetylene.	1	12.
Coal gas.	1	5.7

CHAPTER IX

GAS ANALYSIS

The Orsat Apparatus.—This is very generally used for the analysis of flue, exhaust and chimney gases, and also for producer gas, and may be considered accurate within limits of 2%, 1% being a practical attainment with fairly fresh reagents.

It consists of three double pipettes seen in the accompanying illustration of Orsat's apparatus, B, C and D, which are arranged in a case and connected by means of a

Orsat's Apparatus.   Petrizilka's Apparatus.
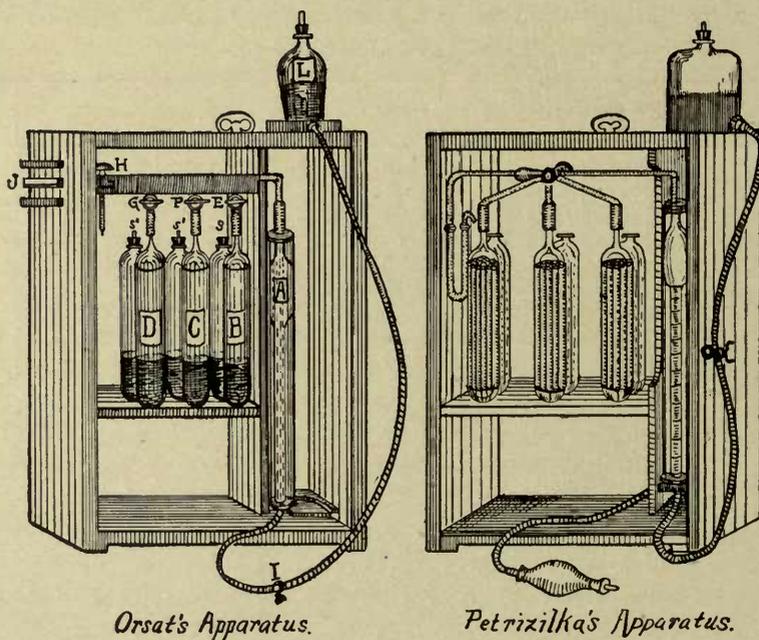
Fig. 106.—Forms of Orsat Apparatus.

capillary tubing to a measuring burette A, which is enclosed by a water jacket. Each pipette is closed by glass stop-cocks, represented by E, P and G, and by the glass stop-cock H, which furnishes an inlet for air from J.

A leveling bottle L provides a means for transferring the gas; connected below by glass tubing to the pipettes B C and D are three others of similar nature, whose ends S, S' and S'' are connected to a flexible rubber bag with small rubber tubing.

238

This bag acts as a seal and prevents the reagents in the pipette from absorbing any oxygen from the air.

Usually the water jacket may be filled with ordinary water, the function of which is to prevent changes in the volume of gas due to temperature. This is especially the case where the apparatus is so situated as to be subject to sudden changes in temperature or to drafts, both of which conditions should be as much as possible avoided, but where such are extreme, such water connection should be made with the jacket as to insure a water circulation and secure uniform temperature.

The Fisher modification of the Orsat apparatus is of particular convenience for use in traveling.

The manipulation of these various apparatuses are identical. The level bottle marked L is filled with pure and preferably distilled water. The stop-cocks E, F and G are closed, and the cock H is open. The measuring burette is then partly filled by raising the level bottle L and forcing air through the exit J. The stop-cock H is then closed and the level bottle L is again lowered, the air remaining in the burette and capillary tube is exhausted to such an extent that upon opening the stop-cock E the reagent in pipette B will be drawn up to a point just below the connecting rubber M. The stop-cock E is then closed and the reagents in pipettes C and D are raised to corresponding positions in a similar manner.

When this has been accomplished the stop-cock H must be opened and the level bottle L raised, the result being to force any air through both the burette A and all the capillary tubing, displacing same by the water which should overflow for an instant from the end of the capillary at the point J, and while same is overflowing stop-cock H must be closed.

Orsat Analysis.—This being done, the apparatus is ready for making an analysis. Connection is made with the gas sample tube or other source of supply at the end J of the capillary tubing. The precautions to be taken being the same as before, that is, the gas should be blowing from the source of the sample to some extent at the moment of making connection, in order that there be no residual air in the connecting tubing.

Draw in about 50 cc. of gas (there is a content of 100 cc. from the stop-cock H on the capillary tube to a point marked 100 cc. near the bottom of the jacketed and graduated burette, the graduations being in tenths of cc.) This is done by lowering the level bottle L.

Immediately after admitting the gas the stop-cock H is closed. The level bottle L is raised and lowered to cause the gas to come in complete contact and effusion with the water which is thus saturated with the absorbable factors of the gas.

The stop-cock H is then again opened and the gas expelled, so as to completely fill the burette and capillary with the saturated water and upon its overflowing at J, the stop-cock H is again closed.

The sample for analysis is now taken, being drawn in through the tube J, as before, to the amount of a little more than 100 cc., say 1 or 2%. Stop-cock H is immediately closed upon securing this amount, and a minute or so should elapse to permit the walls of the burette to drain, after which the pinch-cock I is closed on the rubber tubing, which connects the level bottle L and the burette which is close to it.

By raising the level bottle L a pressure is created, which is of course due to the

height of the water column formed, so that, when gradually opening the pinch-cock I the gas is slowly forced into the burette.

This should be continued until the lowest point of the meniscus reaches the 100 cu.cm. mark on the burette A, when the pinch-cock I must be closed. You will then have 100 cc. of gas at slightly above atmospheric pressure. By opening the stop-cock H for an instant, this excess will escape to the air, leaving exactly 100 cc. of gas at atmospheric pressure.

The pinch-cock I is then opened and the level bottle L brought to a position where the level of the liquid contained equals the level of the liquid in the burette. It will be found that this level in the burette will be at the 100 cc. mark, indicating the amount of gas contained to be correct, or 100 cc. at atmospheric pressure.

CO_2.—To determine carbon dioxide, we use the first absorbent, usually potassium hydroxide (KOH), which is contained in pipette B; opening the stop-cock E, the level bottle L is raised and the reagent forced down the front pipette B and up into the rear pipette, laying bare the contained glass tubes which are wet with the reagent and thereby exposing a great absorbing surface. The reagent quickly absorbs the CO_2 which is present in the gas. One passage of the gas through the pipette is usually sufficient. Assuming the reagent to be reasonably fresh, the exposure in this instance should be about two minutes.

By raising and lowering the level bottle L several times all the gas is brought into complete contact with the absorbent. It may then be drawn back into the burette for measurement by lowering the level bottle L, the stop-cock E then being closed; when the reagent has ascended to its former position the rubber connection must also be closed.

The period of a minute or more should then elapse for the walls of the burette to drain; the level of the liquid in the level bottle L and the level in the burette must then be brought to the same height and the level read on the graduated scale, taking the lowest point of the meniscus on the scale, the difference between this and 100 giving the quantity of CO_2 absorbed. The operation can then be again repeated (the stop-cock E being closed as before), after waiting one minute for the burette to drain the measurement is again taken and a comparison made to see if the latter reading corresponds with the former. This is to assure yourself that the absorption has been complete. The reading subtracted from 100, the total volume of the gas sample, gives the percentage of CO_2.

O.—With regard to the determination of oxygen, the residue or gas remaining after the previous absorption is passed into the second pipette marked C which should contain an alkaline aqueous solution of potassium pyrogallate. This absorbs the oxygen. Previous to taking the final measurement, the operation should be repeated, as before stated, to make sure that all oxygen is absorbed. The period of contact between the gas and the reagent should be from 2 to 3 minutes in each absorption, the absorption being repeated until there is no difference in the reading. One minute must of course be allowed previous to making the final reading for the draining of the walls of the burette, this being done whenever a reading is made.

The reading here obtained, when subtracted from the previous reading, gives the percentage of oxygen contained in the sample.

CO.—The most difficult determination is that of the carbon monoxide, which is obtained by passing the residual of the sample into the third pipette marked *D*. A longer time should be allowed for absorbing this gas, the period running from 5 to 20 minutes, and the operation is repeated, as before explained, until no further absorption is manifest. The final reading obtained, subtracted from the previous one (the potassium pyrogallate test) gives the percentage of carbon monoxide.

N.—To find the nitrogen content, the percentages of CO, O, and CO_2, may be added together and subtracted from the total 100, which gives the percentage of nitrogen by difference. This of course is a broad and inaccurate assumption, inasmuch as nearly all gases contain small quantities of hydrogen and hydrocarbons.

Precautions.—Care should be taken in making analyses with the Orsat apparatus, that the operations are performed in the order above named. Between absorptions, either in the same or different burettes, allow an interval of time to elapse for burettes and capillaries to drain.

The glass stop-cocks may be kept from binding by the use of a little glycerine or a mixture of 1 part tallow and 3 parts vaseline. Considerable care should be taken in noting the activity of the reagents. This may be done by keeping a record of the length of time of exposure and the result of absorption.

Improved Form.—A pipette has been designed by The United Gas Improvement Co. to take the place of the old form of double-absorption pipettes in general use among gas analysts. Although two pipettes are combined in one, the whole is lighter than one of the old form, besides taking up no more room. In this form only one connecting up is necessary, the gas being passed from one pipette to the other by a simple manipulation of the stop-cock. Any one who has ever tried to fill one of the old style pipettes will appreciate the ease of filling. By disconnecting the pipettes they may be filled without difficulty with the aid of a funnel. Also the cost of the single pipette is much less than the cost of two of the old style.

FIG. 107.—The U. G. I. Form of Orsat Apparatus.

Apparatus for making quantitive determinations of the Orsat type, are necessarily more or less inaccurate, the degree of which being dependant upon (*a*) activity of the reagents, (*b*) skill of the operator, (*c*) condition (including freedom from leakage) of the apparatus.

It must be borne in mind that the reagents used in the absorption of O, CO and CO_2 have a strong affinity for atmospheric oxygen, and must be protected from the air by careful corking when not in use.

In using absorption burettes of this type even where the reagents are fresh, to insure thorough absorption, the CO should be exposed to the action of the reagents 25 minutes, the CO_2 for 2 minutes, and the O for 4 minutes.

The Morehead Apparatus.—The seven constituents which compose most industrial gases, and which are ordinarily analyzed for, are:

$$\begin{aligned}
&\text{Carbonic dioxide.} \dots\dots\dots\dots\dots\dots\dots\dots\dots CO_2 \\
&\text{Ethylene.} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots C_2H_4 \\
&\text{Oxygen.} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots O \\
&\text{Carbon monoxide.} \dots\dots\dots\dots\dots\dots\dots CO \\
&\text{Hydrogen.} \dots\dots\dots\dots\dots\dots\dots\dots\dots H \\
&\text{Methane.} \dots\dots\dots\dots\dots\dots\dots\dots\dots CH_4 \\
&\text{Nitrogen.} \dots\dots\dots\dots\dots\dots\dots\dots\dots N
\end{aligned}$$

Of these, the first four are determined by absorption, the next two by explosion and the last by difference.

The gas analyzing apparatus, as designated by Mr. Morehead, consists of a graduated burette fitted with platinum electrodes and a storage bulb. Three aspirator bottles with rubber tubing and an electric sparking outfit are also required. Both glass pieces are fitted with three-way cocks. The measuring, explosion, washing, and the entire analysis is made in the graduated burette; the bulb is used only for storage of the reserve supply of gas after the copper absorption in case the explosion is unsatisfactory. All measurements of the gas in the burette must be made with the surface of the water in the bottle A and that of the water in the burette at the same level, and the cock 3 set to connect the two. This insures atmospheric pressure on the gas in the burette.

In preparing the apparatus for an analysis, first fill the aspirator bottles A, B, and C with water, then open No. 3 so that the water from A can run into the burette and funnel, and be careful to see that all bubbles of air are out of the rubber tubing, then open No. 1 and No. 2, so that bulb will fill with water from B. When these are full, close No. 1 and No. 2. The three-way cock No. 3 at the base of the burette is fitted with a long stem intended to dip into a beaker of water so that a water seal can be maintained during the analysis. When the apparatus is quite full of water, open the cock leading to the hose from which the sample is to be taken, allow the gas to blow through the hose for a few seconds to insure the expulsion of all air, and then remove the funnel and attach the hose to the outlet at No. 1 and open No. 3 so that the water will run through the stem of the cock into the breaker. As the surface of the water lowers, the gas will follow. After the water is all expelled allow the gas to pass through the stem of the cock and bubble through the seal. When the gas has passed through for say ten seconds, close No. 1 and turn No. 3 so that the bottle A is connected with burette. Place funnel on No. 1 and fill with water. Then open No. 1 slowly and let some of the gas bubble through the water in the funnel. Then close No. 1 and take the bottle A in the hand and raise and lower it until the surface of the water in the bottle is on a level with the surface of the water in the burette and both at the 100 cc. mark. When there is just 100 cc. in the burette the analysis may be started.

Place the bottle A on the shelf, turn the cock No. 3 so as to connect the burette with the beaker, drain the funnel, leaving about $\frac{1}{4}$-inch of water in the bottom, and put in the funnel about 20 cc. of potassium hydrate solution. Be sure that No. 3

is set so that the burette is connected with the beaker. Now open No. 1 and let the potassium hydrate drain slowly into the burette. When it has nearly all gone through close No. 1 and open No. 2 and let water from bottle B or C through into the burette for about ten seconds. Rinse the funnel, and fill it with water. Then close No. 1 and No. 2, turn No. 3 so that the burette is connected with bottle A, and read the contraction of the gas by holding the bottle A with the surface of the water in the
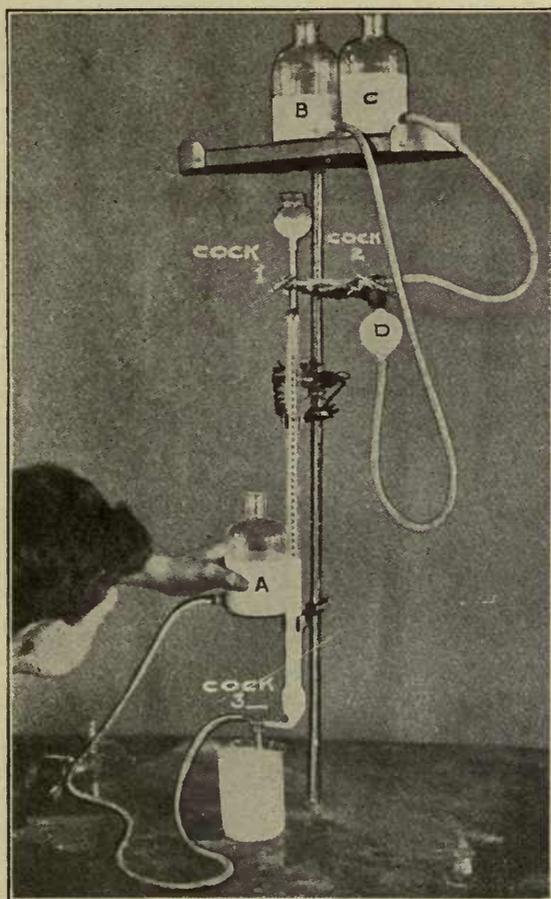
Fig. 108.—The Morehead Gas Burette in use.

bottle level with the surface of the water in the burette. The amount absorbed as indicated by the contraction equals the carbon dioxide.

Replace the bottle A on shelf, turn No. 3 to connect the burette with the beaker, and with the pipette put about two drops of bromine in the funnel under the surface of the water. Drain this slowly into the burette as in the previous operation until the burette is filled with brown bromine fumes, then admit the rest of the bromine and most of the water in the funnel. Then pour into the funnel about 30 cc. of potassium hydrate solution and drain part of this solution in slowly until the burette

and the surface of the water are quite free from bromine fumes and until the surface of the water ceases to rise. Only the most superficial, if any, washing at all with water from B is necessary after this absorption. Measure as explained above. The amount absorbed equals the illuminants.

Next add about one-half of a small spoonful of pyrogallic acid to the 20 or more cc. of hydrate solution left in the funnel, and stir with a glass rod. Drain this through, wash the burette and funnel and measure in the way previously explained. The resulting contraction equals the oxygen.

Next place about 20 cc. of a saturated solution of copper monochloride in strong hydrochloric acid in the funnel, drain through wash, and measure. The amount absorbed equals the carbon monoxide. This reagent should be added rather slowly and several minutes allowed for its action on the CO. The carbon monoxide is the last constituent to be determined by absorption. Of the remaining three, two must be determined by an explosion and the third by difference.

Turn cock No. 3 so as to give connection between bottle and burette. Turn No. 1 and No. 2 so as to connect A through burette and bulb with B. Place B on the table and A on the shelf, thus causing the gas to enter the storage bulb. When all but exactly 10 cc. has passed into the bulb close No. 1 and No. 2. Then measure gas as usual, first passing a little water from C direct into the burette so as to get all of the gas out of the passages between the bulb and the burette. By manipulating A have the amount of gas in the burette just 10 cc. A small excess may be gotten rid of through No. 1 and the funnel. Turn No. 3 so as to connect burette and beaker, drain funnel and open No. 1 and let about 10 cc. of air enter. Then close No. 1, remove funnel, and connect oxygen hose to inlet No. 1. Then open No. 1 and let about 20 cc. of oxygen enter. Close No. 1 and measure contents of burette accurately. The quantity of the mixture in burette should be about 40 cc. Attach wires to the electrodes on the sides of the burette, turn No. 3 so that burette is connected to the beaker and cause a spark to pass between the electrodes. Run in a little water from C to cool the gas, or better, if provided with a lead covered table, run some water over the outside of the burette by raising the funnel a little way. Measure the contraction. This contraction is known as the "first contraction." Make a note of this, then place about 15 cc. of potassium hydrate solution in the funnel and drain into burette, wash and measure. This contraction is known as the "second contraction." The amount of gas left after the absorption for CO is called the "Constant."

The amount of hydrogen in the original mixture is equal to the first contraction multiplied by two, minus four times the second contraction, the result divided by three and multiplied by the constant.

$$\text{Volume of H} = \frac{(\text{First contraction}) \times 2 - 4 \text{ (second contraction)}}{3} \times \text{" constant."}$$

$$\text{Vol. of CH}_4 = \text{Second contraction} \times \text{" constant."}$$

The difference between the sum of all the percentages found and 100 is the percentage of nitrogen.

Precautions.—Make all of the solutions full strength.

Do not mix the pyrogallic acid with the hydrate solution until ready for use, as the potassium pyrogallate thus formed will absorb oxygen from the air and lose its strength. A couple of minutes should be given the oxygen absorption with pyrogallate when flue gases or engine exhaust is being analyzed.

Always mix the copper chloride a few days before using, and keep several pieces of clean bare copper wire in the bottle with the solution. It grows stronger with standing. When it turns milky in the burette it has good strength.

The apparatus may be cleaned from time to time by running in a solution of potassium bichromate in sulphuric acid. This is useful when the platinum points become coated with carbon.

Always keep clean water in the aspirator bottles, and in the apparatus, even when standing from day to day, as this allows the water to attain the temperature of the room, and it also prevents the cocks from getting tight.

The surface of the water in the burette will be curved and all readings are taken by observation of the bottom of the meniscus.
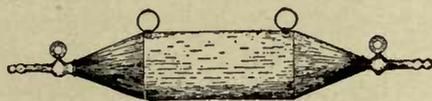
Fig. 109.—Gas Sample Can.

For getting samples it is best to get four sample cans. In getting the sample the can is placed in an upright position and filled quite full of water in order to expel all of the air. A tube connected with the upper stop-cock is then introduced into the space from which the gas sample is to be drawn, and the lower stop-cock is opened allowing the water to run out, and thus the sample is aspirated into the can. In drawing samples from places which have a suction instead of a pressure, such as the inlet of an exhauster, or at the base of a stack, or in the breeching of a boiler, the water should be allowed to flow out through a U-shaped glass tube attached by a piece of rubber hose to the lower stop cock. If this is not done, after the water is all out, air will enter and spoil the sample. It is essential to draw out all of the water, even if only a small sample is required, as a number of the constituents, illuminants and CO_2 for example, are soluble in water. To get the sample out of the can the lower stop-cock is connected by a hose with a source of water under pressure such as a hydrant, and as the water runs into the can the gas will be displaced and may be led by means of a hose to the burette.

The entire apparatus can be supported by clamps from one standard fastened to or placed upon the table.

By keeping the apparatus and the bottles filled with water and the reagent bottles in immediate proximity, they acquire about the temperature of the room and of the gas, and the error arising from the source of temperature changes in the gas is negligible.

The explosions take place in the measuring burette. A coil which will give a $\frac{1}{4}$-inch spark is ample. Too strong a spark is apt to crack the glass as is a continuous play of sparks between the points, or a play of sparks when the burette is dry. If the explosion does not occur simultaneously with the first spark, the spark need not be continued as something else is wrong.

No special care need be taken in measuring the amount of air, or of oxygen added for the hydrogen determination. Variations of these, through fairly wide limits, are immaterial. Care must be taken, however, to measure accurately the amount of gas taken for the explosion, and the total amount of the gas, air and oxygen just before the explosion.

The bulb D, which is not graduated, is used to hold the excess of gas when the explosion is being made. The analyst occasionally loses an explosion, and if it were not for the gas held in this bulb, the entire analysis would have to be made over. By putting into the bulb all of the gas which is left after the copper absorption except the 10 cc. which is used for the explosion, several explosions may be made as checks on each other, or in case the first one is lost.

The principal precaution necessary is to see that the temperature of the apparatus and of the water used, and of any additional water which may be added, as well as the temperature of the sample undergoing examination, does not change during the analysis. A change of 4.93° F. will cause a change of 1% in the volume of any gas. The temperature at which the analysis is made is immaterial if it only remains constant.

If the apparatus is to be installed for constant use, it is well to fasten the standard to a laboratory table over a lead covered drain to a sink; then the excess of any reagent in the funnel which is not used may be disposed of, or the funnel itself may be washed by raising it a little way, and pouring in water, and allowing the water or the excess of the reagent to run down the outside of the burette on to the lead cover of the table. This, however, does *not* apply to any excess of bromine which must run through the burette into the beaker and not be liberated in the air of the laboratory. It is well to wash the glass tube or pipette used in handling the bromine before laying it down.

Care should be taken in handling bromine. Keep it always under water, and do not allow it to come in contact with the skin. Bromine is an exceedingly energetic reagent and will cause painful chemical burns. If bromine fumes are breathed, relief can be obtained from the irritation caused to the throat by inhaling steam. The slick feeling caused by getting potassium hydrate on the hands may be removed by a little dilute hydrochloric acid.

Just before the readings are taken it is well to admit to the burette a little water from B in order to expel what gas may be held in the glass tubing.

The absorption of illuminants by bromine is a heat-producing reaction, and the increased temperature is apt to cause the sample to expand unduly and may cause the loss of a part of the same, and thus vitiate the analysis. If it is seen that the expansion is becoming excessive a little water may be added from B. The bulb at the bottom of the burette is provided for this contingency, however. In the analysis of acetylene, which contains over 90% of illuminants, this is especially apt to occur. If the percentage of illuminants is high, it may be well to admit a little water from B to restore the normal temperature to the gas after the absorption with bromine.

Air is added to the mixture to be exploded merely to lessen the jar. If the gas is very poor, or contains large quantities of nitrogen, no air need be added. Oxygen is added to insure combustion.

The same hydrate solution is used for the absorption of CO_2, of bromine fumes, of CO_2 after methane and with the pyrogallic acid for oxygen. This should be about

one part by weight of KOH to two parts of water. 1 c.c. of this will absorb about 44 cc. of CO_2 though it is well to use a large excess. Use only commercially pure chemicals.

In acetylene, flue gas, engine exhaust, air and gasoline gas there is no hydrogen or methane, and hence the analysis need not be carried beyond the absorption with copper for CO, and the oxygen tank or apparatus, the electric coil, batteries, etc., need not be purchased. In these analyses the sum of the first four contractions subtracted from 100 gives the percentage of nitrogen.

Never allow the funnel to become quite empty, always keep about $\frac{1}{4}$-inch of water or other liquid in the bottom to prevent the suction of air into the burette.

If the cocks stick, they can usually be loosened by a little hot water on the outside. They should be kept well lubricated with a mixture of one part of vaseline to $1\frac{1}{2}$ parts paraffine.

Where many analyses are to be made, or where dispatch is an important element, it will be more satisfactory to obtain a cylinder of compressed oxygen for use in the hydrogen and methane determinations, but where the apparatus is to be moved from place to place, or is to be used only occasionally, or where the analyses are confined for the most part to gases which do not contain hydrogen or methane, such as flue gases, acetylene, air, engine exhaust, etc., a cheaper and quite satisfactory substitute can be had in a small retort by means of which the oxygen can be generated on the spot as needed.

To generate oxygen this retort is filled not more than one-half full with a pulverized thoroughly mixed charge of potassium chlorate and manganese dioxide in the proportions of 20 of the first to 1 of the latter by weight. This is heated gently over a Bunsen lamp. The evolution of oxygen begins at once and it may be led to the burette by means of a rubber tube. As 100 gms. of potassium chlorate will produce 27,000 cc. of oxygen, and only about 20 cc. of oxygen are used for one analysis, a very small spoonful of the mixture will suffice for a great many explosions.

The portable form of Morehead's apparatus for the analysis of gases not containing hydrogen or methane is intended chiefly for the use of engineers for determining the quality of flue gases as an indicator of the efficiency of the fuel used and the manner in which it is applied to the fires for the economical production of heat for steam boilers or other purposes, or it may be used for the determination of all other gases whose combined volume does not exceed 50% of the original sample, except hydrogen and methane. It consists of a modified form of Morehead's gas burette, enclosed in a wooden carrying case of convenient form, measuring 2 ft. long, $8\frac{1}{2}$ ins. wide by 4 ins. deep with a handle on the side, and is fitted with a metal eyelet at the top by which to suspend it when in use. No table or support other than a nail in the wall is needed for the convenient operation of this outfit. When properly suspended the top of the box containing the outfit is used as the upper shelf for the leveling bottle, the bottom end of the box being the lower shelf or table for the support of the beaker which forms the seal at the lower end of the burette. In the same case with the burette are bottles containing the necessary reagents and also the beaker and leveling bottle, each in a compartment of its own. The entire outfit, including chemicals, etc., weighs $11\frac{1}{2}$ lbs.

The syphon jet here illustrated shows a method of using the Orsat or similar apparatus in conjunction with a suction pump. The analytical apparatus may be

connected to or in series with the pipe line between the gas main and the jet. The latter method is preferable for the introduction of filters for the determination of solid impurity or moisture. With this arrangement the gas meter must also be interposed.

Checking Results.—Dr. J. M. Morehead, Chief Chemist to the People's Gas Light Plant of Chicago, in discussing the possibility of checking the analysis of the gas determination of an Orsat or similar apparatus, stated as follows:

There is a sort of a check which in a rough sort of a way may be used to check the accuracy of a flue gas analysis, but I do not know of any formula which would be accurate. I have had a search made of the literature on this subject and have been unable to locate such a formula. I do not see how any formula could be accurate.
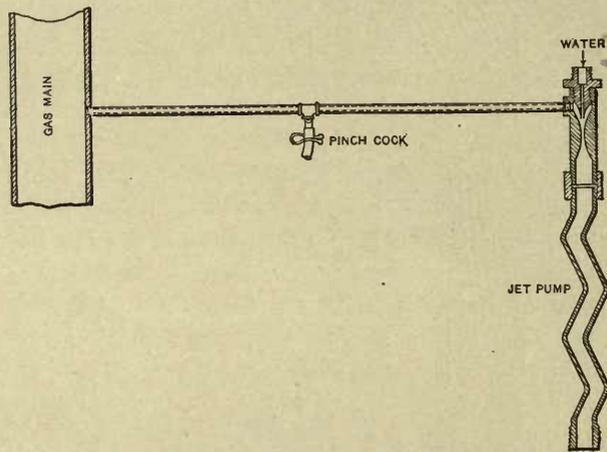

Fig. 110.—Suction Pump for Gas Sampling.

In regard to a check formula for flue gas, the air contains practically 21% by volume of oxygen and when this oxygen combines with carbon to form CO_2, it produces its own volume of carbon dioxide. Hence if carbon is burned to CO_2 with the oxygen from the air, the oxygen which combines with the carbon produces an equal volume of CO_2 to replace the oxygen combined and removed, and hence the sum of the oxygen and the CO_2 must equal 21% of the volume of the products of combustion, provided the combustion is complete, i.e., if no CO is produced.

When oxygen combines with carbon to form CO it makes twice its volume of gas, hence if pure carbon was partially burned in air and produced both CO_2 and CO, then the formula $CO_2 + \frac{1}{2}CO + O = 21$, would be correct and might be used as a check on the accuracy of the analysis, where coke or hard coal is used as a fuel.

The use of such a formula, however, as a check on a flue gas or engine exhaust analysis where the fuel contained any proportion of either free or combined hydrogen would not answer, as the hydrogen in the fuel combines with the oxygen in the air of the draft to form water, and as this moisture would not appear in the analysis some of the oxygen will not be accounted for, and the percentage of nitrogen which would go to make up the 100% would seem unduly high and might indicate poor boiler economy when such might really not be the case. You can see that, theoretically,

just the proper amount of hydrogen burned in air would form water with all of the oxygen and give a flue gas or engine exhaust analysis showing 100% free nitrogen.

When soft coal, oil, gas, or in fact any fuel excepting pure carbon, is burned with air the hydrogen, either free or combined, combines with a portion of the oxygen and this oxygen does not appear in the analysis at all, and its place is taken by nitrogen. The excess of nitrogen over the 79% which air contains is roughly in proportion to the amount of hydrogen, either free or combined, which the fuel contains. This applies to all the hydrocarbons, and, though in a much less degree to the carbohydrates such as wood, which, while they do contain hydrogen, also contain oxygen in the form of water.

Incidentally this fact destroys the accuracy of the tables made by people trying to sell continuous flue gas analysis apparatus, in which they say that the deficit of CO_2 below 21% shows poor combustion in the boiler.

Tests for Impurities in Gas.—Ammonia.—If red litmus paper is moistened and held over a gas jet of unlighted gas and the color of the litmus changes from red to blue the gas contains ammonia.

If yellow turmeric paper, slightly moistened with water and held over a jet of unlighted gas, turns to a brown color, ammonia is in the gas.

Carbonic Acid.—Impregnate water with the gas and add a few drops of sulphuric acid; if minute bubbles of carbonic acid gas are readily disengaged, there is CO_2 in the gas. Or, pass it through a solution of barium chloride; if the gas contains carbonic acid, carbonate of barytes will be precipitated; or, pass the gas through clear lime-water, and carbonate of lime will be precipitated.

Sulphureted hydrogen.—Saturate a piece of writing paper with a solution in distilled water of acetate of lead or nitrate of silver and hold over a jet of unlighted gas. Pure gas will produce no discoloration; if a brown stain is given, the lime in the purifiers should be renewed as the gas contains H_2S.

Bisulphide of carbon.—The presence of this impurity can only be detected by means of special apparatus, of which there are several types.

Atmospheric air test.—Collect a portion of the gas over mercury and pass up a few drops of caustic potash, and afterwards a drop or two of a solution of pyrogallic acid. If the liquor assumes a blood red hue, oxygen, indicating the presence of atmospheric air, is mixed with the gas.

CARBON DIOXIDE DETERMINATION

To the experienced gas producer operator the gas content in CO_2 tells the story of the entire producer operation, indicating low heats, thickness of fire bed, irregularity of draft, porosity of fire, air leaks, or other irregularity. A compact and remarkably convenient burette has been designed by G. M. S. Tait for the determination of CO_2 and its operation is extremely simple.

Tait CO_2 Burette.—The illustration herewith shows a new type of simplified Orsat apparatus especially designed for the analysis of gas containing carbon dioxide, and, as shown in the illustration herewith, is equipped with only one pipette for the testing of that element. The operation of this apparatus is extremely simple and is as follows:

The water bottle (11) is filled with water in the usual manner and by raising same the water flows over into measuring burette (8) until same is filled.

In the meanwhile inlet (1) has been connected with a rubber tubing to the source of the gas supply, while outlet (2), also a rubber tubing, is closed by means of some form of pinch-cock.

Now by lowering bottle (11) the water in burette (8) will flow out producing a suction in pipe (1) which will draw gas into measuring burette (8), which should be done until gas reaches the zero mark on the scale of the burette.

The pinch-cock on inlet (1) should then be closed and the three-way glass cock (3) should then be turned in position shown in illustration.

Then by raising water bottle (11) so as to cause water to flow back into burette (8) the gas contained therein will then be forced down through capillary tubing (6) and be caused to bubble up through the absorbent contained in chamber (7) until all the gas has been drawn off in this way and is contained in pipette (6). By again lowering the water bottle (11) and reversing the position of glass cock (3), the gas, *minus the carbon dioxide which has been absorbed*, will then pass off through outlet (4) and back into burette (8), giving a direct reading of the percentage of carbon dioxide which has been absorbed.

In use this apparatus is found to be very quick acting, the average time necessary for analyzing the flue gas or producer gas being two minutes.

The extreme simplicity of this apparatus and the fact that its use can be learned by any one in a few minutes, makes it a particularly useful piece of apparatus for all those interested in combustion, whether in the form of gas producers or fires under steam boilers.

The percentage of CO_2 in producer gas is a valuable indicator of the working and

Fig. 111.—Tait CO_2 Burette.

condition of the fuel bed. It has therefore seemed advisable to give at some

length descriptions of some of the apparatus used for the purpose of giving continuous indications during operation.

Uehling Gas-Composimeter.—The action of the gas-composimeter is based on the law governing the flow of gas through two small apertures. This law may be illustrated by a simple diagram representing two chambers C and C' which are in communication with each other through the aperture B, and with the source of gas through the aperture A. C' is connected with an aspirator D as shown. The monometers p and q indicate the gas tension within the respective chambers.

The aspirator set in action, a vacuum is created in chamber C', the gas will flow from the chamber C through aperture B to chamber C', creating a vacuum in C which will cause gas to enter through aperture A, thus establishing a continuous flow of gas through both apertures.

If a constant vacuum of say 48 ins. be maintained in chamber C' and the two apertures A and B are of the same size and are maintained at the same temperature,
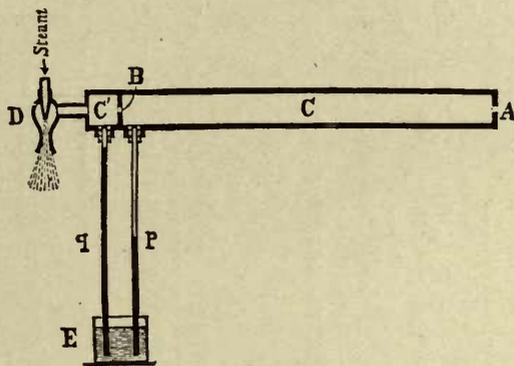

FIG. 112.—Principle of the Gas-Composimeter.

the monometer p will show about one-half the vacuum maintained in C', due to the fact that the apertures oppose equal resistance to the passage of the gas. This relation will be maintained so long as the same volume of gas flows through B that enters at A.

If, however, a constituent of gas be continuously taken away or absorbed from the gas in passing through chamber C the vacuum therein will be correspondingly increased. This increase of vacuum in C, shown by the manometer p therefore correctly indicates the volume of gas absorbed and in the gas-composimeter is utilized to indicate the percentage of the constituent of the gas to be determined.

To embody the principle described into a practical apparatus, the following conditions must be fulfilled:

I. The gas must be brought to the instrument under a constant tension and must be drawn through the apertures with a continuous and uniform suction.

II. Both apertures must be located in a medium of constant temperature.

III. Provision must be made that the apertures remain perfectly clean.

IV. The chamber C must be made perfectly tight so that no gas can enter, except through the aperture A.

V. The constituent to be measured must be completely absorbed after the gas passes through A and before it passes through B.

Condition I.—The regulator consists of a cylinder H, 8 ins. in diameter and 5 ft. high, filled with water, as shown, into which project the tubes aa', bb' and cc'. The tube aa' is open to the atmosphere at a and extends to within a few inches of the bottom of H. The end of the tube bb' is exactly 48 ins. above the lower end of aa'
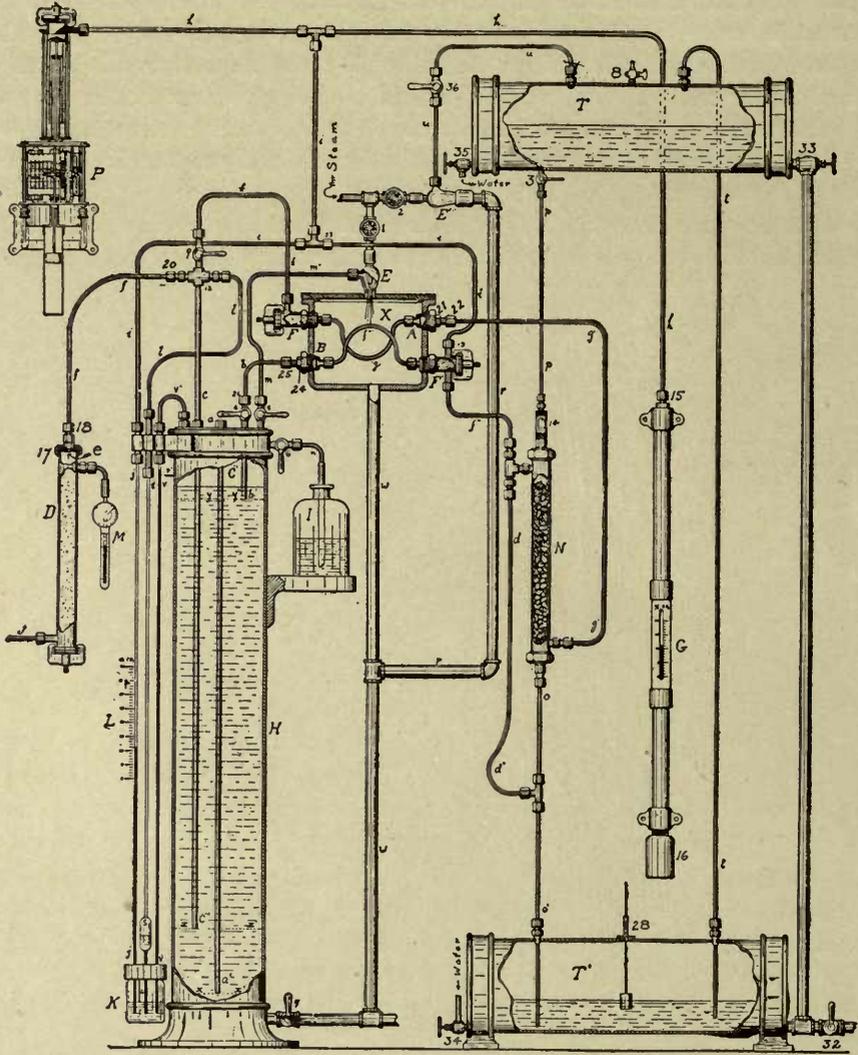
Fig. 113.—Diagram of the Uehling Gas-Composimeter.

and the lower end of cc' is just 6 ins. above the lower end of aa'. The cylinder is filled with water so that the tube bb' is submerged several inches. The gas inlet J which connects with the source of gas communicates with aperture A through D, f, k, F, g, and also communicates with the regulator H by means of a pipe cc' which joins pipe f and k at 12.

If valve 1 is opened, the aspirator E is started, suction is created through the pipe mm' in the chamber C'' above the water, which suction increases until the pressure of the atmosphere overcomes the pressure of the water column in the tube aa' when air bubbles through the water into C''. The air thus entering satisfies the aspirator and prevents any further increase in suction, and neutralizes irregularities due to change in steam pressure, etc.

It is evident, that so long as the suction is sufficient to draw air through aa', the horizontal plane of water xx' in which the plane aa' terminates is under atmospheric pressure. The plane yy' lying 48 ins. above xx' is under a suction of 48 ins. and the plane zz' being 6 ins. above xx' is under a suction of 6 ins. of water. Therefore the contents of tube bb' corresponding to chamber C in the first figure must be under a constant suction of 48 ins. of water, similarly the contents of tube fcc'. from which the gas flows to aperture A, is under a constant suction of 6 ins. of water.

Aperture e at upper end of filter D is so gauged that more gas will pass through it than can pass through aperture A and still not be sufficient in quanitty to destroy the 48-in. suction in tube bb'. The excess escapes at c' and bubbles up through the water into C'' from where it is drawn off together with the air entering at aa' and the gas from which the CO_2 has been absorbed entering at b'.

This arrangement fulfils condition I so long as the water level in H is not allowed to fall below the plane yy'. When this occurs the water must be replenished from jar I by opening cock 6.

Condition II is fulfilled by placing both apertures A and B in a chamber X which is kept at a uniform temperature of 212° by the exhaust steam of the aspirator E, which is permitted to escape at atmospheric pressure through the pipe ww.

Condition III is fulfilled by placing a large filter, not shown, at the source of the gas supply, together with cotton filters D and the small filters F and F' before each aperture by which the gas is perfectly cleaned and the apertures protected from being fouled.

Condition IV.—Chamber C is composed of all the tube connections and chambers, between apertures A and B. All these connections consist of drawn copper tubing, all the joints of which are accurately made and carefully tested so that no leak can occur, which fulfills this condition.

Condition V.—To remove the element to be determined from the gas drawn through the apertures, with certainty, a continuous supply of an efficient absorbent flowing in the opposite direction and exposing an abundant surface must be supplied. For this purpose, the absorption tube N is provided.

Chamber C of the first diagram is in the second composed of the pipe g', absorbtion chamber N, the pipe f'', filter F', pipe f''' and pipe i branching off at 13. To the latter is connected the manometer tube jj, the recording gauge P through the pipe h' and the observation gauge G through pipe h. The manometer tube jj and gauge G are so calibrated that the suction between aperture A and B can be read off in per cent. of CO_2 contained in the gas.

The tube h connecting gauge G may be extended so that the gauge can be placed at a point most convenient for the fireman or attendant for whose guidance it is to serve.

The water in manometer tube vv shows the height of water in the regulator H above the line xx' *and must be kept above the index r'.*

The water level in glass s shows the 6-in. suction, and the water levels in the U tube M show the resistance in the line plus the chimney draft.

Operation.—Opening valve 1 starts the aspirator E, a vacuum is created in chamber C'', which causes the flow of gas through the system. An excess of gas enters through $J\ D$ and aperture e into f, and the quantity not required for analysis escapes through cc' into C'' direct. A continuous sample flows from f through k to F from F into g where, surrounded by the exhaust steam from the aspirator E, it is heated to 212°, thence passes through aperture A and through $g'g'$ into the absorption tube N, where the constituent to be determined is absorbed by a suitable reagent. From the absorption tube the remaining gas flows through f'' and F' into f''' where it is again heated to 212°, thence passes through aperture B and by way of bb' into chamber C'' from where it is continuously removed by the aspirator together with all other gases entering the chamber. The absorption tube N is filled with quartz pebbles. For the continuous analysis of gas for CO_2 the surfaces of these pebbles are kept moist by continuously dropping a dilute solution of caustic soda or potash upon them, which flows from the tank T through the pipe p. The flow is regulated by the cock 3 and can be observed through the sight feed at 14.

The absorbing solution flows from N through oo' into the receiving tank T'. Pipe d is simply to guard against the possibility of any absorbent reaching filter F'. When T is nearly empty the solution is lifted back by closing the cocks 3 and 8 and opening valve 2, thus creating a vacuum in T by means of the aspirator E'. This operation is repeated each time T is empty, until the solution has become saturated, after which a fresh solution must be supplied. When solution in tank T' has been lifted to T cock 8 should again be opened.

The gas-composimeter is continuous in its operation, the water column in jj and that in observation gauge G varies in height in front of a scale graduated to show the percentage of CO_2 contained in the gas passing through the instrument and the recording gauge makes a continuous autographic record of same.

Sarco Recorder.—The recorder is suspended on a wall, preferably in the immediate vicinity of the boiler or furnace, to which it is attached, so that the furnaceman may have it in continuous view, and be enabled to turn to account immediately the information which the machine provides. It may, however, also be placed any distance away from the producers, in an office or other convenient situation, as may be desirable, without any detriment to the results obtained.

A $\frac{3}{4}$-in. pipe, which taps the gas chamber of producer or furnace, is connected to the inlet pipe D of the instrument, and the gas is drawn through the machine by a special aspirator Q, fixed to the top of the instrument by means of standard T. Thus a continuous, rapid passage of the gas is secured, which, in average cases, renders it possible to read on the chart the effect of an alteration in the firing within a few minutes of its occurrence.

The power required to procure and deal with the gas samples is derived from a fine stream of water at a head of about 2 to 3 ft. Any ordinary clean water may be used; only 6 to 8 gallons are required per hour (according to the speed at which the machine is operated), and the water may be used again after passing through the recorder.

After actuating ejector Q, a portion of the water flows to the small tank L, which serves as a pressure regulator, and is provided with an overflow tube R. From this tank the water enters tube H in a fine stream, the strength of which is adjusted by the cock S (according to the number of records that may be desired per hour), and gradually fills the vessel K, which consists of an upper and a lower compartment, the two being in communication with one another through a tube erected in the upper chamber and reaching nearly to the top of same.

The water, which enters this vessel K through the tube H, gradually fills the upper chamber and thus compresses the air contained in it. This pressure is transmitted to the lower compartment through the communication tube above mentioned, and here acts upon the mixture of glycerine and water (1 part of the former to 3 of the latter) with which this is filled, driving it out into the calibrated tube C.

While this has been taking place, the aspirator Q has been drawing a continuous stream of gas through D, C, and E, in the direction indicated by the arrows. When the rising liquid in C has reached the inlet and outlet to this vessel, no further gas can enter the calibrated tubes for the moment, and the aspirator will now draw the gas through the seal F, and out in the direction of the arrow for the time being.

Before the liquid can close the center tube in C, the gas has to overcome the slight resistance offered by the elastic bag P, and is thereby forced to assume atmospheric pressure. The moment the liquid has sealed the lower open end of this center tube, exactly 100 cc. of flue gas are trapped off in the outer vessel C and its companion tube, under atmospheric pressure.

Fig. 114.—The Sarco Automatic CO_2 Recorder.

As the liquid rises further, the gas is forced through the thin tube Z and into vessel A, which is filled with a solution of caustic potash (KOH) of 1.27 specific gravity. Upon coming into contact with the surface of the potash and the moistened sides of the vessel, the gas is freed from any carbon dioxide that may be contained in the sample, this being rapidly and completely absorbed by the potash.

The remaining gas gradually displaces the potash solution in A, sending it up into vessel B. This has an outer jacket, filled with glycerine and supporting a float N. Through the center of this float reaches a thin tube, through which the air in B

is kept at atmospheric pressure. The float is suspended from the pen gear M by a silk cord and counterbalanced by the weights X.

The rising liquid in B first forces a portion of the air therein out through the center tube in the float, and then raises the latter. This causes the pen lever to swing upwards, carrying pen Y with it.

The mechanism is so calibrated and adjusted that the pen will travel right to the top, or zero line, on the chart when only atmospheric air is passing through the machine, and nothing is absorbed by the potash in A.

Thus, should any carbon dioxide be contained in the gas sample, it would be absorbed by the potash in A, not so much of this liquid would be forced up into vessel B and the float would not cause the pen to travel up so high on the chart, in exact accordance to the amount of CO_2 absorbed.

The tops of the vertical lines recorded on the chart, therefore, provide a continuous curve showing the percentage of CO_2 contained in the exit gases from the flues, on a permanent diagram arranged for 24 hours.

When the liquid in C has reached the mark on the narrow neck of that tube, the whole of the 100 cc. have been forced on to the surface of the potash, one analysis being thus complete. At this moment the power water, which, simultaneously with rising in tube H, has also traveled upwards in syphon G, will have reached the top of this syphon, which then commences to flow.

Through syphon G a much larger quantity of water is disposed of than flows in through cock S, so that the
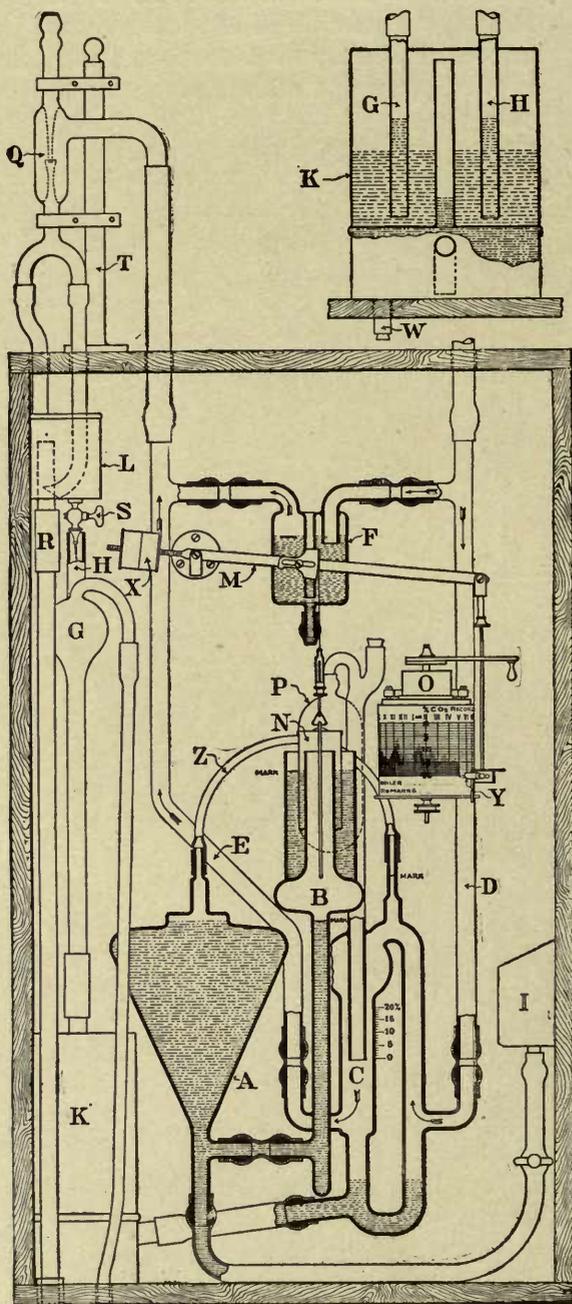
Fig. 115.—Section of the Sarco CO_2 Recorder.

power vessel K is rapidly emptied again. The moment the pressure on this vessel is released, the liquid from C returns into the lower compartment, and float N to its original position.

As soon as the liquid in C has fallen below the gas inlets and outlets to this vessel, the whole of the remaining gas is rapidly sucked out through E by the powerful ejector Q.

It will be seen that the gas, when analyzed, leaves the recorder by a set of tubes entirely separate from those through which the samples are obtained, so that there is no possibility of mixing the old with the new.

The important problem of purification of the gas has been met by the introduction of a specially large filter of greatly improved design. One of these is supplied with each recorder. The vessel F is provided with a small center tube, open to atmosphere, and this serves as an indication that the pipe line is clear, the ejector drawing air through the seal in the case of stoppage.

This recorder is provided with a permanent and automatic check as to its correct adjustment and working. The instrument, once erected, works entirely automatically and requires no attention beyond changing of the chart and winding of the clock every 24 hours, and renewal of the potash solution every fortnight.

The Wise CO_2 Indicator.—The following description of an invention by W. L. Wise, was the subject of a communication from the Jones-Julia Manufacturing Company of New York:

This device relates to apparatus for analyzing continuous stream of gas for the purpose of ascertaining the percentage of a constituent thereof. It has been proposed heretofore, the patentees point out, to ascertain the percentage of constituent by feeding the gas continuously in limited amount through an absorbent, and determining the value of such constituent by the change of tension produced by the removal of such constituent by the absorbent as indicated upon a suitable manometer. But this method is said to be open to the objection that a change in the pressure or tension at which the gas is fed to the instrument will cause a fluctuation in the tension of the gas in the space with which the manometer is connected, and will therefore affect the reading of the instrument; and hence with this method the results will be only accurate for a given pressure for which the apparatus has been adjusted, and which has been kept stationary. The accuracy of the reading will likewise, for a similar reason, be affected by changes at the vacuum or suction end of the system.

The object of the apparatus is to overcome this objection by feeding the gas in two streams, absorbing an absorbable constituent thereof from one of the streams passing in limited amount through the absorbent and then through a chamber in which the tension may be observed, and utilizing the difference between the changed tension or pressure thus produced and the tension or pressure of the other stream as an indication of the percentage of such constituent. The limited flow of gas in the chamber or chambers whose difference of pressure is measured, is preferably secured by connecting them with the pressure and exhaust pipes through minute inlets and outlets. A manometer is connected to the two streams, so as to give readings which measure the distance of tension or pressure between them due to the removal of a constituent of the gas in one of the streams by the action of the absorbent. To balance the resistance of the passage of the gas through the absorbent for one of the

streams, it is preferable to employ a non-absorbing solution in the path of the other streams; and to secure a reading due to the difference of tension in the streams of gas, the two sides of the manometer may be connected respectively to the chambers or spaces through which the streams of gas flow in limited amounts. Under this condition, the manometer will respond properly to differences of tension between the two streams; but it will be affected alike on its two sides by any changes in the difference of tension between the inlet or supply and the exhaust or suction ends of the streams respectively. The readings will thus not be disturbed.

In the illustration, B is the supply end of the system through which the gas (say, flue gas) is fed after passing any necessary filter or condenser. A is the suction or exhaust end of the system; the flow of gas being due to the difference in tension or pressure between B and A. At I the gas divides into two streams, one of which passes through a minute inlet 2 (comprising, preferably, a tube of very small bore),
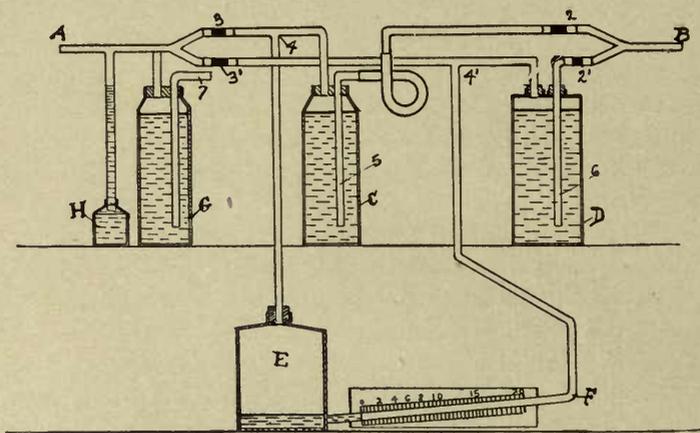

FIG. 116.—Wise Continuous CO_2 Indicator.

and escapes through a similar outlet 3 to the suction end A of the system. The other stream passes in a similar manner through a minute inlet or outlet 2' and 3'. In this way a limited amount of gas only can pass, and a certain amount of vacuum will be produced in the chambers or passages located between 2 and 3 and between 2' and 3'. Between 2' and 3' is the absorption chamber, comprising, for instance, a tank D containing a solution of caustic potash or other absorbent.

At 4' (or at any other suitable point where the tension of the gas feeding from B is changed from the normal, owing to the absorption of the constituent carbon dioxide or other gas), a pipe is led to one side of a manometer F. At 4, in the pipe or passage between 2 and 3, connection is made to the other side E of the manometer.

Preferably, there is interposed in the connection from 2 to 3 another tank C containing a non-absorbing solution through which the gas is caused to pass, so that, by regulating the depth of an immersion of the tubes 5 and 6, the resistance to the passage of the gas in the two chambers may be adjusted to produce a tension which would be the same if the gas were of such a nature as not to be absorbed or modified in respect to its constituents by passing through either tank D or C. Owing to the

system of connections, it is obvious that the changes of tension at 4 and 4' will be the same if caused by any changes or difference of tension between B and A.

If, now, gas containing carbon dioxide be passed through the apparatus, it will be absorbed in the potash solution in D, the equilibrium in the manometer will be disturbed, and the liquid in the measuring tube of the manometer connected to F will rise in direct proportion to the amount of gas removed by the solution in D. This reading enables the operator to ascertain the percentage of carbon dioxide as usual. The manometer shown has a sloping or inclined graduated tube on the side F of very small internal diameter, which, in practice, may be 3 mm. At the other end E, a large tube or bottle is employed; so that practically all the movement due to changes of pressure will be in the small tube. If the capillary attraction in the small tube causes its surface to stand at right angles to the bore of the tube, instead of occupying a horizontal plane, the apparatus may be arranged to indicate 1% for each one-fiftieth of an inch of vertical rise, by inclining the small tube at such an angle that this movement is multiplied by 10. Thus, if the tube rises 1 in 10, the liquid, in rising one-fiftieth, will move one-fifth inch in the bore of the tube for each 1%.

To bring the apparatus to scale or to register correctly, means are provided for regulating the suction applied at A. A device suitable for this purpose comprises a liquid containing tank G, connected to the suction pipe A, and having a regulable gas inlet tube 7, which immersion may be altered to vary the rate of inflow of air or gas into the pipe A at or near where it is attached to the outlets 3 and 3'. By depressing the tube 7, the suction or vacuum in A can be made stronger; while by raising it the vacuum will be decreased, owing to the admission of air or gas through G. A manometer H filled with glycerine may be used to indicate the degree of suction or vacuum.

CHAPTER X

GAS POWER

Development.—In discussing the evolution of gas power, F. E. Junge (*Power*, January, 1906, p. 37), in a paper red before the Am. Soc. Mech. Eng.. said that for ideal continuous combustion it is necessary that air and fuel should be introduced into gas engines in correct proportions under similar cyclic conditions during the entire range of load. Further, the two constituents must be perfectly mixed when entering the cylinder; and, since combustion causes a rise of internal pressure while the initial piston stroke tends toward its reduction, the rapidity of heat influx must bear a certain fixed relation to the piston speed in order that the two counteracting influences may be equalized, and continuous combustion at constant pressure secured.

In the Diesel engine none of the foregoing conditions are realized. We have a constant body of air to support combustion, a pressure of injected oil vapor which does not bear a fixed relation to the varying internal pressure, and therefore a speed of fuel influx which is irregular and in no way corresponds to the piston speed of that period. Nor does each fuel molecule on entering the cylinder find at once its corresponding quantity of oxygen.

The Weidmann engine is similar to the Diesel in that gasified fuel is injected into a highly compressed body of air in the working cylinder, with the remarkable difference, however, that a corresponding amount of air is introduced with the fuel by a receiver piston corresponding to the speed of the working piston. The fuel and air are so intimately mixed that combustion must occur regularly.

Although engines of the Otto type have been developed to a remarkable state of perfection, they have one fundamental weakness, namely, the impossibility of controlling the combustion. The irregularity and imperfect mixing of the charge, the possibility of premature ignition and after-burnings, are drawbacks of the present working cycle of gas engines.

Various attempts to improve the efficiency of gas engines, such as prolonged expansion, compounding and water injection, have proved to be entries on the wrong side of the balance sheet. The drawbacks common to all these so-called improvements are increased bulk, weight, first cost, and negative work expended. The combustion process pure and simple, as used in the standard types of engines, gives the highest economic efficiency attainable in the Otto cycle.

Regarding the latest thermal performances of internal combustion engines, attention is called to a 14-h.p. Marienfelder alcohol motor and a 70-h.p. Diesel oil engine, each showing an indicated thermal efficiency of 41.7%; a 20-h.p. Güldner engine

running on city gas with 42.7% efficiency; and a 500-h.p. Borsig-Oechelhaueser coke oven gas engine with 38.6% efficiency, all running under full load conditions. The operating efficiency is, therefore, between 32% and 33%.

Quality of Gas.—It is hardly necessary to recite the economic conditions in the industrial world which are urging forward the development of a more efficient and less wasteful system for the development of heat and its correlate power. Generally speaking, however, these may be divided under two heads, viz:

    I. The conversion into useful work of a greater proportion of heat latent in the fuel consumed.

    II. The utilization of diversified and inferior fuels for the production of the said heat.

In the first consideration we find a possible saving of, not only a fuel *per se* and its first cost, but the attendant conditions involved of transportation, labor of handling, amount of reserve stock, and the capital investment required to maintain such stock. It will be evident that an increased fuel efficiency of one-third would decrease by one-third the labor and transportation involved (frequently a large portion of the total expense), and decrease the necessary storage, together with the captial tied up in same, by an equal ratio, showing a saving in both actual cash, inexpediency (which may be of equal import under conditions of inadequate transportation facilities), labor stringency, or limited space.

Taking the second consideration, modern practice shows that any fuel is applicable to producer work which contains above 20% of combustible matter. The yearly inroads that we are making into the world's limited supply of high class coal makes it all the more necessary to utilize the enormous supply of inferior coal, lignite and peat. Lignite will average perhaps 9400 B.T.U. (2400 calories) per pound, or about 3.3 lbs. per b.h.p. hour, although results have been known in test as high as 1.19 lbs. per h.p. hour (Meissen).

Briefly, the author will outline what, in his estimation, should constitute an ideal gas power system.

    1. The plant should be susceptible of complete and immediate control.

    2. The plant should embrace a wide range of capacity.

    3. The plant should possess the maximum of durability.

    4. The cost of the plant and its installation should not be prohibitive.

Covering the first point, from the producer standpoint *the quality of the gas should be as nearly as possible constant and the constituents of the gas as nearly as possible of uniform quantity or proportion.* This matter of uniform heat value cannot be too strongly emphasized.

Upon the initial and constant quality of the gas generated, all subsequent calculations and regulations must depend and a constant quality of gas must be assumed as a primary condition or premise.

Of course, under working conditions, this is not attainable, the output being modified by such conditions as—

    1. The state of the fire.

    2. The time after coaling.

    3. Nature of fuel, amount of output or demand, etc.

Its quality should, however, be kept as near a fixed standard as lies in human power, and to overcome these minor irregularities where possible a small storage tank is to be recommended. The connections of the holder are the reverse of those in ordinary practice.

No general laws can be laid down for the manufacture of a specific gas, it being necessary in each individual instance to obtain a routine of practice experimentally, as the result of operation with a particular fuel under exact conditions in each apparatus and load factor. When it is found that a certain gas gives the highest efficiency and the most satisfactory results the conditions of operations are noted and a system of manipulation may be evolved for daily practice.

Pre-ignition Due to Hydrogen.—It may be found that, as a result of certain proportions of steam, blast and fuel, the resultant gas causes pre-ignition. This (so say the best authorities) has been erroniously attributed heretofore to too much free hydrogen in the gas.

In reality this is not the case, nor has it been found possible to definitely determine exactly what this is to be attributed to; but it is most probably caused by the ratio of free hydrogen to some other component, such as marsh gas or other carbon compound, rather than to the actual quantity of free hydrogen itself.

Certain it is that whatever may be the origin of this difficulty, a series of observations upon cause and effect can be established, and, by process of elimination, a more or less fixed system or method of operation may be determined.

It is at least certain that the action of hydrogen in the cylinder very nearly approximates hydrogen in its properties of flame propagation. Its initial pressure is sudden, flamboyant, and intense, dropping off after a severe peak. It is the belief of the author (in which he may be wrong) that the action of hydrogen is somewhat governed or tempered by the flame temperature resulting from the other constituents of the gas.

The flame propagation of hydrogen is so rapid, and the heat generated so intense, as to make it practically valueless as a dynamic or engine gas. The result of its combustion is static rather than potential, the energy generated going off in the form of radiant heat rather than of power due, as for example with the slower expansion and combustion of carbon monoxide. A direct example of this we find in the calorific efficiency of various producer gases, where we find that while the efficiency curve is almost vertical up to a thermal value of 104 B.T.U.; after this point the curve debouches at an angle closely approximating 90°. This is due to the fact that this critical point represents the maximum content (in commercial practice) of CO in producer, and that with other so-called producer gas of nominally higher calorific value the increment is represented by hydrogen.

The matter of the hydrogen content in gas is considered much less vital a matter now than formerly, due perhaps to such experiments as those of Dr. Charles Lucke, which go to show that the point of ignition of hydrogen in gas, due to heat of compression, is approximately the same as that of CO.

There can be no doubt, however, of the easy ignition of the hydrogen in gas and the high velocity of the flame propagation, whether this ignition comes from burning refuse in the cylinder or any other igniting source. A decrease in the annoyance due to the presence of hydrogen and a tendency toward " prematures " appears to come

with improved engine designs involving the proper calculation of cylinder thickness, the better distribution of water jacketing, the cooling of valves, etc., until a point has been reached, as for instance, in the case of the Riverside engine, where a gas of from 30 to 40% of hydrogen is used without showing any tendency to premature ignition.

It will be found that gas with considerable hydrogen content is especially difficult, if not impossible, to use in engines which do not thoroughly and rapidly purge or which have any tendency to " pocket " or trap products of combustion. This is also true where, through faulty designs, engine cylinders are inclined to show " hot spots " or to possess other inequalities of temperature.

The author has known of gas containing 17 to 18% of hydrogen operating with perfect satisfaction, while the production of hydrogen being reduced to 14 or 15%, pre-ignition occurred. This in spite of the popular belief that pre-ignition varies directly with the amount of the hydrogen content.

In the present condition of the science, the author is predisposed to a low thermal value, slow burning gas, as furnishing fewer of these exigencies to cope with, and a more even mean effective pressure. It is very possible that there are other conditions in this connection with which we are unacquainted and which are thus far unobserved.

At the present stage of our knowledge on this subject, we must content ourselves with avoiding conditions known to produce trouble, in which connection the writer would discourage the use in gas engines of a producer gas under 135 B.T.U. value, with a content of over 12% hydrogen, where the compression exceeds 100 to 125 lbs. Even this amount of hydrogen has been known to give trouble through premature ignitions.

Aqueous Vapor.—Another reason which may be inserted here for retaining the content of hydrogen at a minimum in industrial processes, is the fact that in all metallurgical operations where there is a combustion reaction of H to H_2O, this aqueous vapor in contact with any metal in a state of reduction has a powerful oxidizing effect, which, though less than that of oil, entails considerable loss through oxidation. Again, in any operation of a calcining nature, this same vapor has a strong catalytic effect, extremely detrimental to the product.

Another property of aqueous vapor is the fact that its specific heat, better termed its coefficient of heat absorption, since it varies at different temperatures, has never been exactly determined at high temperatures. In addition to the 966 B.T.U. which it contains as latent heat, it carries a larger portion of sensible heat than is usually realized among the products of combustion.

It may be observed in this connection that where hydrogen in large proportion occurs in producer gas of very low calorific value, that the resultant products of the hydrogen combustion, namely H_2O, appears in the form of aqueous vapor of low tension, almost approximating that of saturated steam. On the other hand, where the combustion of hydrogen takes place in the presence of other hydro-carbon compounds of high heat value, such as CH_4 and C_2H_4 and C_4H_6, the resultant temperature or heat liberated has a tendency to superheat and attenuate this vapor to a very high degree.

It is undoubtedly a fact that the saturated, or heavier aqueous vapor, acts as a

retardent of combustion, forming a damper or veil over the ignition point, and frequently creating back-firing through a " hang-fire " on the part of a portion of the gas on the ignition stroke.

Gas Power Development.—It will be found that, in spite of the most careful manipulation, theoretical or test conditions can not be obtained in daily or commercial practice by perhaps 50%. It is fortunate, therefore, that the large margin offered by gas engines over other prime movers still permits a chance for considerable saving where not counterbalanced by the original installation or first cost of the plant. It is unfortunate that under present conditions in America this frequently exceeds that of a steam plant by as high as 50%, but it is probable that this state of affairs is but temporary, the cost at which gas power plants are being installed abroad going to show that a large portion of cost is due to promoting expense rather than to the intrinsic cost of the material and manufacture. Already the price line of gas plants is reaching a more rational basis, and obtaining a close parity to its steam competitor.

In this connection it must be remembered in all comparisons involving gas power, that its development scarcely covers a period of ten years, placing it practically in its infancy. Only recently, in fact, has gas power been successful in the production of alternating currents, and driving in parallel. In this case it may be said that where such work is proposed, there should be invariably a collaboration between the gas engineer and the electrician, and their specifications should be made to coincide by a third engineer familiar with both branches of the work. As an extra precaution, " anti-hunting " devices should be specified, and it will be found that induction apparatus will work more satisfactorily than synchronous.

The spread of gas power for this class of service is becoming daily more rapid, there being units as large as 6000 kilowatts in operation. Altogether, there is in the United States to-day some 260,000 gas-driven horsepower, largely used for the generation of electricity, but when it is considered that this only constitutes 3.3% of the two million available horsepower, the enormous field for the spread of this industry may be comprehended.

A great advance has been made along the line of engine regulation by the abolition of the " hit-or-miss " type and the substitution of the throttling or admission regulation system of governing the combustible constituents.

Operation Conditions.—It is evident that each atom of gas must meet and properly combine with its proper valence of oxygen. Upon the thoroughness of this union depends efficiency; upon the volume depends power. It will be observed, therefore, as a fundamental principle of combustion, that

1. The value of the gas (quantitative analysis) must be constant;
2. The ratio of air to any given quantity of gas of fixed value must be constantly maintained;
3. The volume of combined ingredients must vary with the load.

Although this is the goal to which all effort must be directed, it is impossible, at present, of absolute attainment, due to, for instance, the variations caused in the operation of the producer, such as the condition of fuel bed, coaling and cleaning periods, nature of fuel, condition of heats, etc. In this connection much stress should be laid on the care and character of the management, as upon this factor almost entirely depends the economical and satisfactory operation of the plant.

The conditions aforesaid are especially difficult of attainment in the case of the direct-connected suction producer (without holder), the analysis of the gases of which are particularly varying, due to such influences as the variation of the blast by reason of changing load factors, and the resultant changes in both temperatures and the products of combustion.

In order to obtain greater equalization in the quality of the gas produced, the writer urges where praticable the use of a storage holder and exhauster, even if of a small size, as it tends in a marked degree to regulate and distribute those inequalities in production caused by coaling, cleaning, irregular heats, etc. Its use as a possible agent of over-load capacity is problematical, producers themselves as a rule being so much more elastic than the engines which they supply, when properly designed, as to obviate most difficulties in this connection. It should be seen, however (except in the case of suction producers), that the connecting mains should be of such size in section and length as to equalize the minor variations in both pressure and production.

Suction Pipe.—Suction vacuum or vacuum on the suction pipe varies in general practice from 2 to 14 ins.; both of these extremes, particularly the latter, are excessive. The former usually reflects a porous fire, while the last named involves heavy duty upon, and an inadequate supply of gas, to the engine. Where the suction exceeds 6 ins. the engine should be relieved of this duty by the interposition of an exhauster. The exhauster should also be interposed in all producer plants above 200 h.p.

The exhauster should be used where there is a plurality of engines connected to any unit, and is also preferable where there are more than one producer connected to the engine. It is, of course, necessary where gas is to be abstracted for heating or furnace work. The exhauster tends to prevent robbing, and when water sealed or by-passed, very effectively regulates the demand of supply. It must be remembered, however, that when the gas is delivered to an engine under pressure, where the engine has been designed for suction, it is necessary to throttle the pressure to prevent " flooding " or choking the air supply in the mixing chamber. This control is most readily affected by means of a small gasometer, or pressure-reducing valve, the former being the most flexible and sympathetic.

Coke Oven Gas.—A ton of coal in coking generally approximates 9000 cu.ft. of purified gas averaging 375 to 400 B.T.U. per cubic foot. Of this about 5000 to 5500 is used in the heating of the ovens, leaving a margin of net by-product for general power purposes. Of this margin about 10% is required for the various mechanical processes of gas scrubbing, cleaning, blowers, exhausters, etc.—that is to say, the gross by-product being about 3600 cu.ft., about 2600 ft. are left as a net product for the production of power for sale or outside work. This product ranges from 100 to 175 h.p. per ton of coal coked per twenty-four hours.

As approximate figures it may be taken that 60% of the heat units of a coal are required for heating the retorts, about 10% for various power purposes, and 30% available as a net by-product for outside use. This of course varies with various classes of coal and the efficiency of different types of apparatus.

It may also be taken as a tentative estimate that one ton of coke is required for the production of one ton of iron. Again, depending upon the particular coal analysis, the transfer of coal to coke may be approximated at 75%.

The German Otto ovens yield about 4800 cu.ft. of gas per ton of German coal, the gas possessing an average value of 450 B.T.U.

Blast-furnace Gas.—Of the total quantity of gas generated in the blast furnace plant, about 50% is required for the operation of the plant itself, including driving
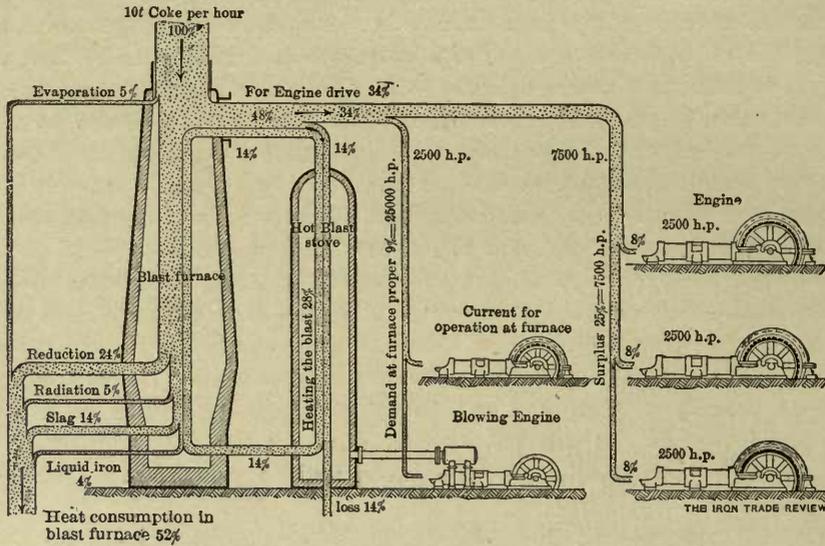

Fig. 117.—Heat Balance of Blast Furnace of 250 Tons Daily Capacity.

blowing engines, washers, scrubbers, electricity, and the heating of the blast furnace. About 50% of roughly speaking 25 h.p. per ton of pig iron manufactured per twenty-four hours is available for outside work.
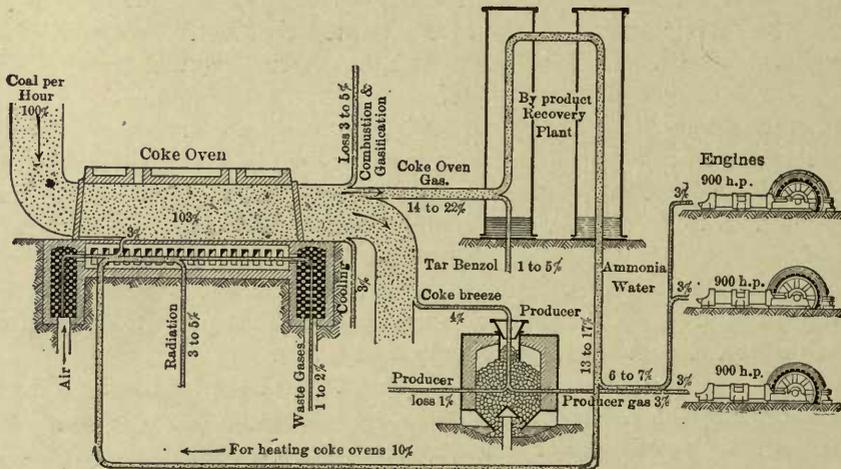
Fig. 118.—Heat Balance of a By-product Coke Oven of 200 Tons Daily Capacity.

In the production of one ton of pig iron there is produced available for power purposes as a net by-product approximately 90,000 cu.ft. of blast furnace gas having

a heat value ranging from 80 to 100 B.T.U. per foot, a fair approximation of the average being 90 B.T.U., which usually supplies the most satisfactory power gas, inasmuch as the higher values show high content of hydrogen due as a rule to jacket leakage of water and also large factor of CO_2. Used under boilers this gas per ton usually produces an output of 250 h.p. hours. To use in the gas engine its efficiency is doubled and frequently trebled.

Comparison of Steam and Gas Power.—It remained for the United States Geological Survey in its testing plant at Saint Louis to attempt the use of any and
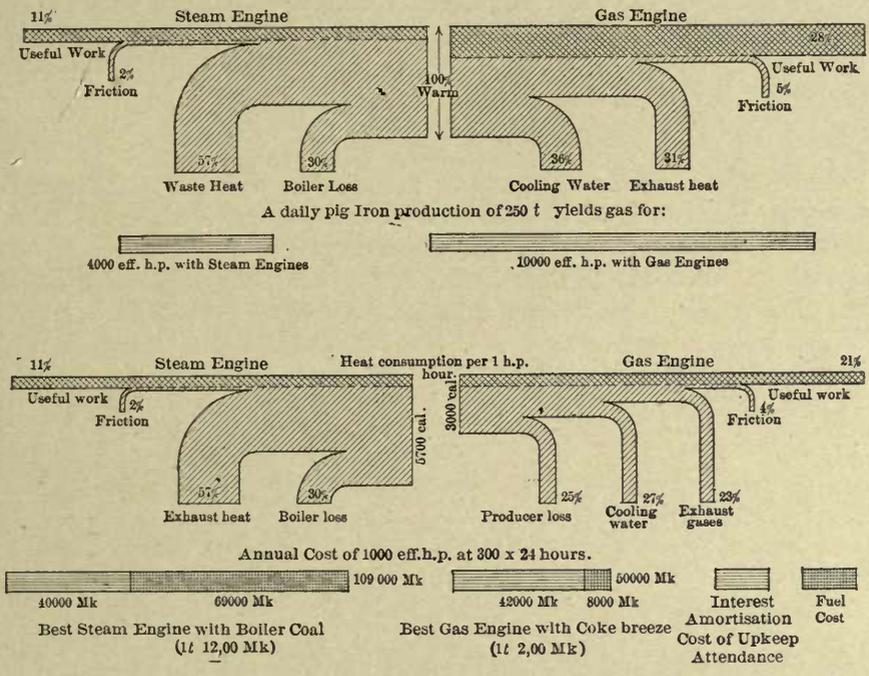
FIG. 118½.—Comparative Heat Utilization of Steam and Gas Engines and Relation of Heat Consumption and Annual Cost.

all bituminous coals, lignites and peats, without reference to the amount of sulphur or tarry matter to be found in the fuel. It is gratifying to note that every bituminous and semi-bituminous coal received has been run through the producer and that the results have been more than satisfactory.

Relative Results of Steam and Producer Gas Tests.—In considering the relation between the economic results of the two types of plants under discussion, viz., steam and producer gas, attention is called to the fact that to-day in the ordinary manufacturing plant operated by steam power less than 5% of the total energy in the fuel consumed is available for useful work at the machine.

AVERAGE LOSS IN THE CONVERSION OF ONE POUND OF COAL CONTAINING 12,500 B.T.U. INTO ELECTRICITY

	B.T.U.	Per Cent.
Loss in gas producer and auxiliaries.....	2,500	20
Loss in cooling water in jackets.........	2,375	19
Loss in exhaust gases.................	3,750	30
Loss in engine friction...............	813	6.5
Loss in electric generator..............	62	0.5
Total losses........................	9,500	76.0
Converted into electric energy........	3,000	24
Total........................	12,500	100.00

Especial attention should be called to the fact that several low grade fuels, coals and lignites which have proved of little value or even worthless under the steam boiler, have given excellent returns in the gas producer.

The ratios of the total fuel per brake horsepower hour required by the steam plant and producer gas plant under full load conditions, not counting stand-by losses, are presented below as derived from 76% coals, 6 lignites and 1 peat.

RATIOS OF FUELS REQUIRED PER B.H.P. HOUR.

Under Boiler ÷ in Producer.	Average.	Maximum.	Minimum.
Coal.........................	2.7	3.7	1.8
Lignite......................	2.7	2.9	2.2
Peat.........................	2.3	...	...

In the case of the results for the producer gas tests the figures include not only the coal consumed in gas generator, but also the coal used in the auxiliary boiler for generating the steam necessary.

Stand-by Losses.—It is probable that the most reliable figures obtainable to-day relating to this point are those presented by Messrs. Dowson and Larter in their recent book entitled "Producer Gas." The results secured by these gentlemen from a number of engineers and experimenters, including such well known names as that of Bryan Donkin, indicate that for plants of about 250 h.p. the stand-by losses amount to about 67 lbs. of coal per standing hour for the steam plant and to about 4 lbs. per standing hour for the producer gas plant.

It should again be noted that many fuels are not fit for use under boilers. Many of these poor fuels have been used with the greatest ease in the gas producer, thus opening the way for the utilization of many fuels that have heretofore been regarded as practically of no value. Several of the poorest grades of bituminous coal have shown remarkable efficiency in the gas producer, and the lignites and peat have also responded with great readiness to the demands of the gas producer, thus opening the

way to the introduction of cheap power into large districts that have thus far been commercially unimportant owing to the lack of industrial opportunities.

Official records have been made as low as 0.95 lb. of dry coal per hour burned in the producer per electrical horsepower developed at the switch-board; or 0.80 lbs. of dry coal per hour burned in the producer per brake horsepower per hour, on the basis of an efficiency of 85% for generator and belt.

CHAPTER XI

GAS ENGINES

General Details.—Internal combustion engines, where gas is burned explosively in the cylinder itself, have reached a state of development hardly anticipated, and therefore the gas engine problems have become as complex as the devices themselves. This development has been sufficiently well treated by competent authorities, and our attention will be here confined to some practical details of operation. The general
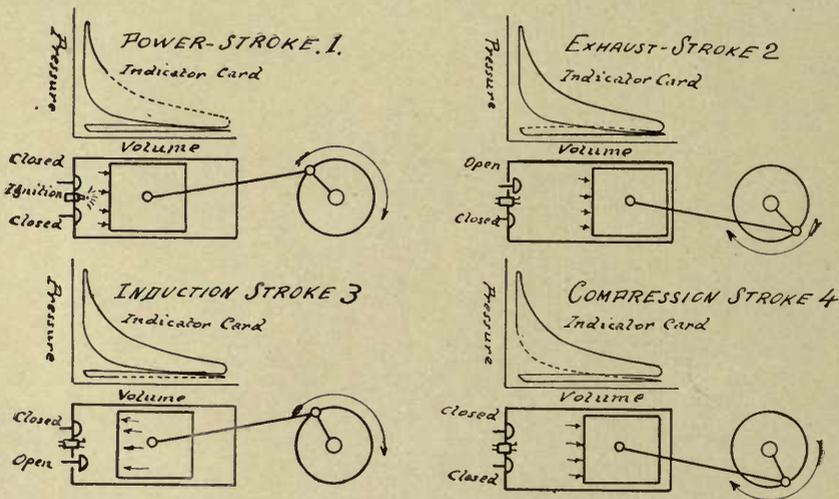

FIG. 119.—Gas Engine Cycles.

theory of the 4-stroke cycle is illustrated, the dotted line on each diagram indicating the stroke represented in the diagram below it and the upper valve the exhaust. The pressure exerted by the explosion of gas and air mixture in the cylinder depends upon the richness of the mixture as shown. The gas engine charge of coal gas is 1 part gas to 8–12 parts of air.

The expansion and compression curves depend upon the gas largely as shown in the curves. The pressure at the time of explosion rises to 300 to 450 lbs. per square inch, which drops rapidly until the exhaust port opens. The compression is from 100 to 110 lbs. per square inch. O'Conner says that to raise the compression from 10 to 100 atmospheres requires only 2.5 times the power required for 10 atmospheres. The consumption of 18 c.-p. 600 B.T.U. gas per effective horsepower is 16.5 cu.ft. The indicated horsepower developed is equal to the mean effective pressure in pounds
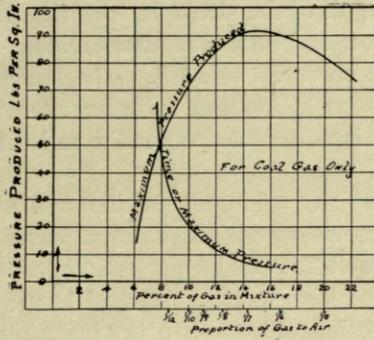
FIG. 120.—Combustion Pressures.
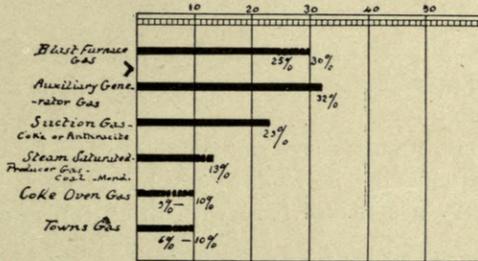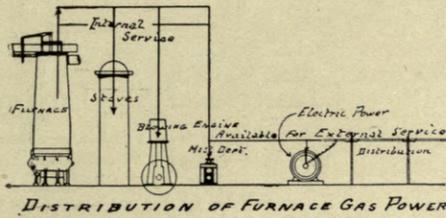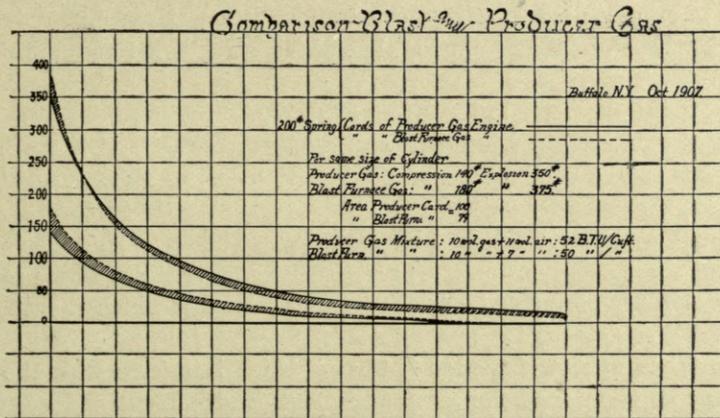
FIG. 121.—Comparison of Blast-furnace Gas and Producer Gas.

per square inch times the length of the stroke in feet, times the area of piston in square inches, times the number of explosions per minute divided by 33,000. The mechanical efficiency of a gas engine is about 80 to 85%. The heat efficiency, however, is only about 28%. The temperature inside the cylinder rises to 2500 or 3000° F. The temperature of the exhaust is sufficient frequently to heat the pipe red hot, a temperature of about 1000° F.

Foundations.—As an arbitrary figure, it is assumed by many gas engineers that the cost of erecting gas engines upon foundations supplied, engines being F. O. B. cars at a convenient side track, for $12.00 per ton complete.

The cost of erecting producers usually rated in the same manner, $6.00 to $8.00 per ton complete. The erection of complete producer plants are roughly estimated at $12.00 per ton.
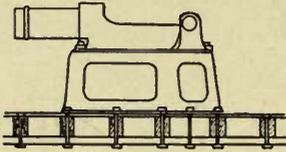

FIG. 122.—Floor Foundation.   FIG. 123.—Masonry Gas Engine Foundation.
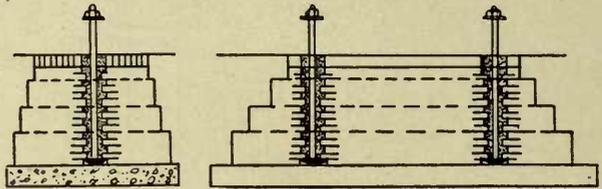
In calculating concrete foundations for gas engines where the natural conditions are reasonably good and pinning unnecessary, concrete foundations are usually figured as arbitrary at 30 cents per cubic foot.

The foundation of an engine requires consideration. In small plants it need not be as elaborate as for steam engines. The engine may be set upon boards as shown, or for more elaborate machinery a concrete base with brick top and anchor bolts is required.

To find size of dry meter for gas engines, multiply the brake horsepower $\times 3.4$ $+5 =$ number of lights.

The size of supply pipe to engine can be found by reference to a table of meter dimensions. The size of exhaust pipe is thus obtained: From 1 to 5 b.h.p., 1 in. to $1\frac{3}{4}$ ins. diameter.

Above that size, diameter in inches $= 0.528 \times$ h.p.$^{0.57}$.

The heat of exhaust pipes is great, and likely to burn wood if too near. Bends of 6 ins. or more radius only should be used; no elbows or tees. Turn the outlet of the pipe to look downwards.

To Prevent Excessive Noise in Exhaust Pipe.—The pipe can be carried into a drained pit and surrounded with stones, over which a covering of straw can be placed. There are many ways of multiplying the exhaust, among which are those herewith illustrated.

As an instance of one of the many things which interferes with the valves of a gas engine, may be mentioned the case of the Fort Dodge Light and Power Company, who had an analysis made in 1907 of a substance deposited on the seat of the mixing valve of a gas engine at Fort Dodge, Iowa, which gave the following:

	Per Cent.
Mineral matter..........................	24.58
Phenoloid bodies......................	17.32
Basic hydrocarbons....................	1.47
Indifferent hydrocarbons...............	56.63
Sulphur..............................	1.42

The mineral matter was chiefly silica and contained some iron and alumina. The deposit was supposed to be due to tar from gas-house coke.
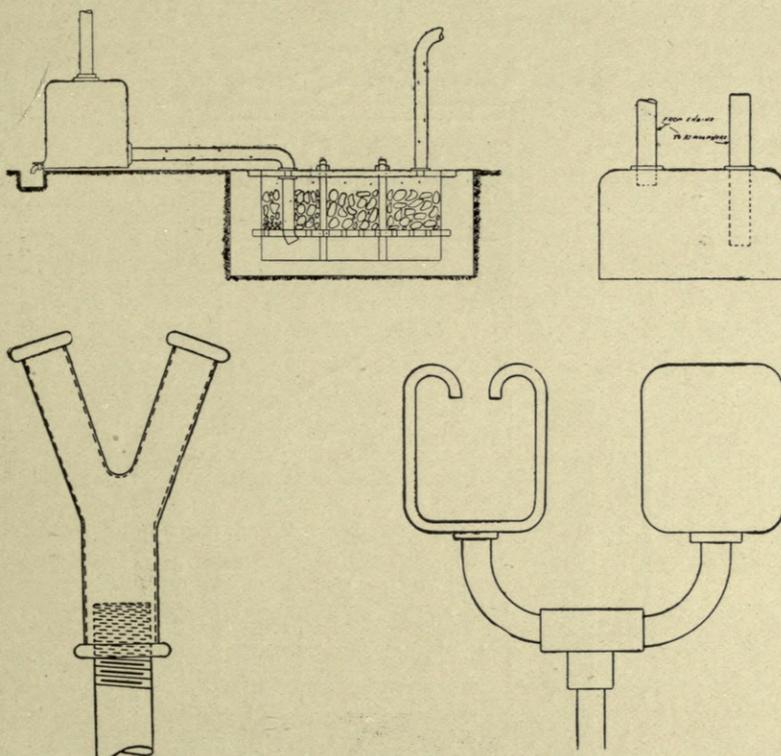

FIG. 124.—Gas Engine Exhaust Mufflers.

The cause of a thumping noise in the interior of the cylinder is thus explained: Single-acting engines thump with light loads because the cylinder is not full of mixture and the compressoin is reduced. In the vis-a-vis engine the piston connecting rod running under is more liable to thump than on the other side, for the reason that the tendency is to lift the piston against the top of the cylinder when the explosion takes place. When there is no explosion, of course, the piston rests on the bottom of the cylinder. This up-and-down motion at different intervals causes the thumping. It doesn't occur at the position of the connecting rod running over, with as much violence.

Oil engines, as far as we have any record of them, have not been built in powers above 200 horse with any degree of success. Therefore, this question only effects

engines of small powers.   Where oil is cheap, in engines of small powers, the oil engines should be the preferable engine to use, providing the customer is willing to take the risk of getting cheap oils throughout the entire life of the engine. Past history, however, in the oil business, does not justify this condition and any one purchasing an oil engine, places themselves in a position to use fuel that is apt to be doubled in price any time.

Ignition.—Jump sparks are usually impracticable under any high limit of engine compression, sparking under such conditions requiring extremely high potential.
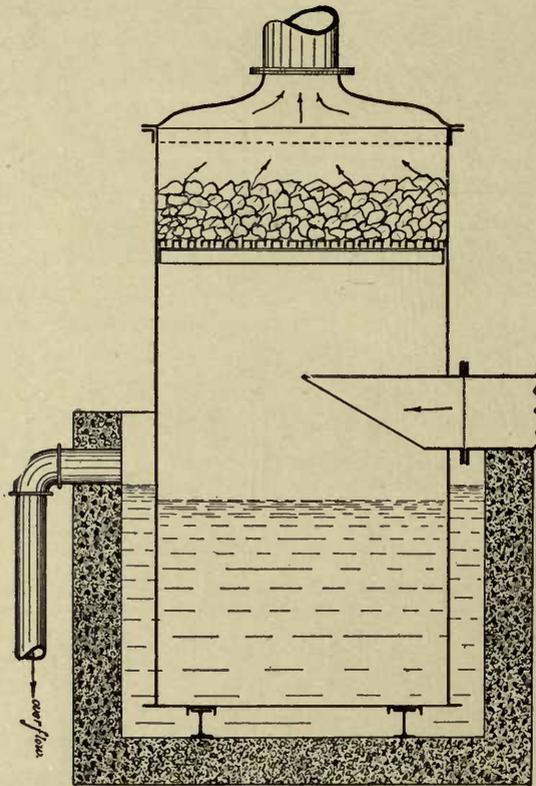
FIG. 125.—Nürnberg Type of Water Cushion Exhaust.

Under condition of high compression, the density of the charge materially increases the electric resistance and there is a tendency on the part of the spark to hesitate and refuse the gap. Under these conditions the make-and-break is much more positive and furnishes a hotter and better timed ignition.

There are many causes for early firing, chief among which are: Accumulation of dirt in the interior of the cylinder in pockets that are in the head. This dirt becoming incandescent and remaining so until the fresh mixture comes in, sets fire to it and causes it to pre-ignite. A bolt sticking into the cylinder, the end of which becomes red hot, or any other projection that becomes red hot, will cause pre-ignition. Any

kind of fibrous packing may become incandescent or in fact any incandescent particles will cause this condition. Premature ignition frequently occurs in engines from an ignition or spark occurring or being carried in the piston packing. This frequently causes premature troubles, which may otherwise be accounted for, and can only be discovered by examination of the packing and in the scraping or shearing of same.

Severe premature explosion on the part of a gas engine is frequently effectively cured by the admission of a small amount of water vapor into the air pipe probably causing a reduction of flame propagation within the explosive mixture. This arrangement is usually made by a small water overflow connection tapped into the air pipe aforesaid. In cases of emergency, an ordinary large oil-can filled with water and horizontally tapped into the intake has been successfully used, the container of the can having one or more pin holes in the top, the air drawn through picking up a certain amount of water spray in its passage, and humidifying the air before coming to the engine.

Starting.—One of the easiest methods of starting a gas engine is to open the air valve about one-half to one-third, as soon as the engine has started to move under compressed air, to open the gas valve gradually until the explosion occurs.

Under conditions where the gas arises to the engine under pressure either through the intermediary of an exhauster blower or pressure producer, the pressure of the gas must under all circumstances be reduced to atmospheric. This to prevent the choking of the engine with gas. It is often much easier to start the engine in the way indicated than to open the air valve entirely right from the beginning. By having a small opening, not only the gas but also the air is under control.

In obstinate cases sometimes results are obtained when starting the engine, by having the engine make two or three revolutions with the gas valve entirely closed, and then to open the gas valve suddenly and immediately prior to the suction stroke. These instructions of course vary more or less, as the individual experience of both different engines and engineers differ in the matter.

In the case of a multi-cylinder engine satisfactory results have often been obtained by starting up with air on one cylinder alone, and after purging the other cylinders with air, to gradually admit gas upon the other cylinders until an explosion is formed, meanwhile running the first cylinder entirely with air pressure.

Compression.—H. W. Jones, a gas engine expert, said, in a recent article: "We need higher compression in gas engines. Some gas engine manufacturers are sure to take this suggestion in all seriousness, and act upon it and furnish engines that have the proper compression. We ask that they first design the compression chamber or clearance space to conform to the gas with which it is to be used; then, build around this compression an engine that will stand the terrific pressure generated by the rapid burning of the gases; that they design the exhaust port to quickly get rid of the products of combustion; that their intake valve be so constructed as to allow the engine to take full charge of gas without drawing it around any elbows of piping between the valve and the gas bag, and that the gas comes into the engine cold; that the air supply is extra large to allow the engine all the air needed to properly secure enough oxygen to give the highest and best efficiency in the combustion chamber, and that they equip their engine with a graduated scale cock on the air supply, so

that the air supply can be regulated when conditions change. What is the proper compression for an illuminating-gas engine? One authority says:

"The higher the compression, the greater the efficiency and less gas required to produce satisfactory results.

"The higher the compression, the cleaner the mixture, for there is less space for the burned gases to remain in the cylinder.

"The higher the compression the less water needed, as the combustion chamber is, as a matter of course, smaller.

"The higher the compression the more power to each charge; consequently less charges.

"The higher the compression, the less gas; smaller bills; pleased customers; more of them; greater sales of gas; less trouble with the engine. (This is a fact.)

"Figured in pounds by calibrated scale, what should the compression be to give best results as to economy of fuel per b.h.p. in illuminating gas engines using 650 effective B.T.U. gas, and at same time not overtax the engine? To set minds at rest on the question of pre-ignition, I know of an engine running with 104 lbs.; it is a 15-h.p. engine, 2 cylinder, vertical; it generates 15 h.p. for one hour or so, occasionally 2 or 3 times per day, but runs on 9 h.p. as an average.

"Let us confine ourselves to engines of 5 to 40 h.p. From my experience, and it has been varied and comparatively thorough, 95 lbs. is a conservative compression; this is when the engine is running and well warmed up; 105 lbs. if engine will stand it, and it will take something more than argument to convince gas companies or users of gas in engines that this is wrong."

Cylinder Dimensions.—The influence of cooling surface on clearance volume in gas engines is the subject of the following from the pen of R. Wintzer: It was the intention to determine approximately in which manner the gas consumption and the maximum output of a gas engine is influenced by the cooling surfaces in the compression volume. The discussion refers to the conditions on a 30×42 in. 2-cylinder double-acting tandem gas engine, run with 107 r.p.m., equal to 749 ft. piston speed per minute, but the conditions will be similar for engines of other sizes. From the sizes of two different surfaces they can compare the heat carried away in cooling water. From the difference of the two losses we can figure the difference in temperature of the working medium, and from the difference in temperature in the gas we can figure the difference in the pressure represented in the indicator card. The difference in pressure represents then the gain or loss for less or more cooling surface. The calculation is made with three different cooling surfaces in the compression volume of 2200, 3300 and 4400 sq.in. In these limits are comprised practically all modern engines, the surface of 2200 sq.in. representing a clearance volume which is formed of a simple cylinder of a height corresponding with the necessary compression volume. Between 3500 and 4400 sq.in. include most of the double-acting gas engines with valves on top and underneath the cylinder. Assuming that the piston displacement per minute is 3.7 cu.ft. per brake horsepower and that the suction and compression line will cut the atmosphere line in the indicator card at 90%, the volume of mixture at atmospheric pressure will be $3.7 \times 0.9 = 3.33$ cu.ft. per minute. The weight of the same is about 0.0807 lbs. per cubic foot, therefore the weight of the working medium per b.h.p. hour is $33.33 \times 60 \times 0.0807 = 16.1$ lbs. One illustration (No. 1) shows an
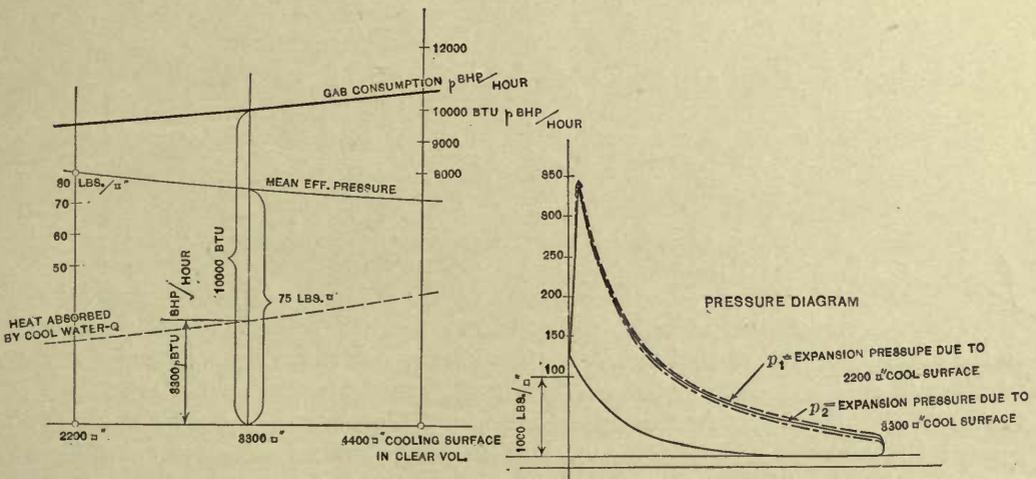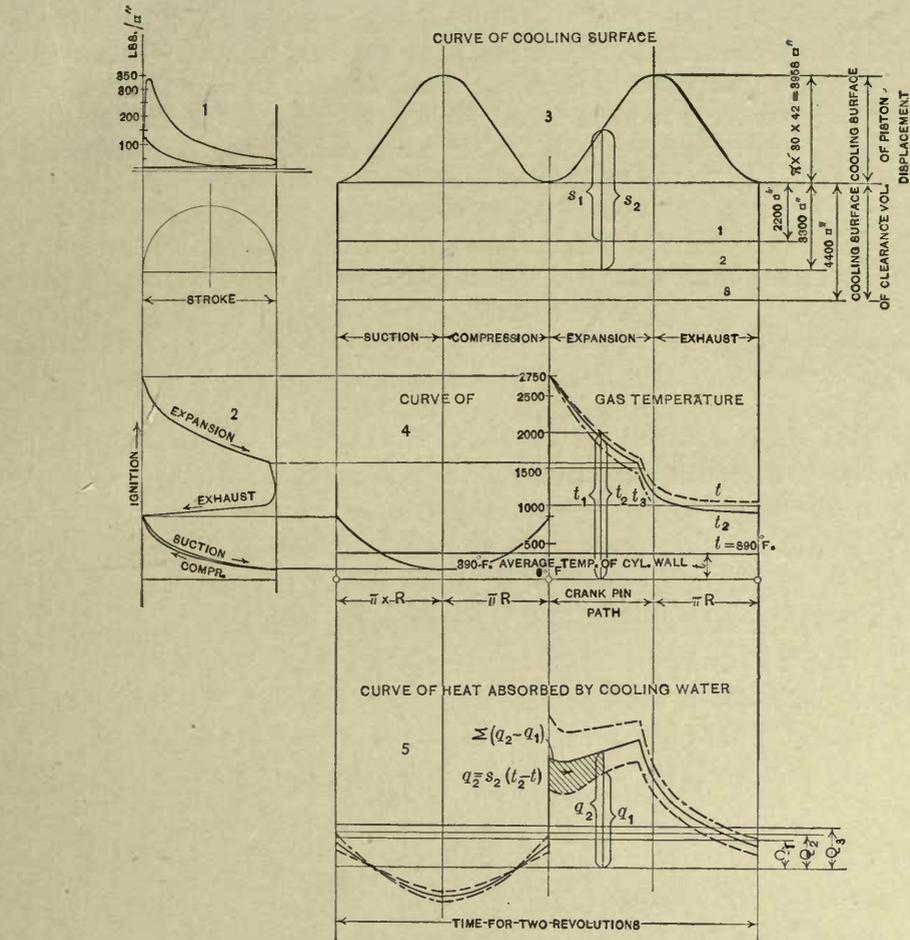
FIG. 126.—Relation of Cooling Surface to Clearance Volume.

indicator card, and the other (No. 2) the corresponding temperature diagram of an engine under average conditions. From the latter diagram is developed the curve of temperature with time as basis given in No. 4. The temperature of the cylinder wall will certainly fluctuate to some extent during one cycle, but these fluctuations will be very small in comparison with the temperature difference between cylinder wall and gas. To simplify the investigation, the temperature of the wall is assumed to be constant at 390° F. Right over the temperature diagram is shown, in No. 3, the corresponding size of the cooling surface which consists of a constant one equal to the surface in the clear volume and the variable one corresponding to piston displacement.

Piston displacement per b.h.p. min. $= 3.7$ cu.ft. $3.7 \times 0.9 = 3.33$ cu.ft. of mixture at atmospheric pressure.

$W = 161$ lbs. of mixture used per b.h.p. hour (0.0807 lbs. per cu.ft.).

$S_1 =$ Surface exposed to gas, 2200 sq.in. cooling surface.

$S_2 =$ Surface exposed to gas, 3300 sq.in. cooling surface.

$t = 390°$ F. $=$ average temperature of cooling surface, constant.

$t_1 =$ Gas temperature, degrees F., for 2200 sq.in. cooling surface.

$t_2 =$ Gas temperature, degrees F., for 3300 sq.in. cooling surface.

$J =$ Joule's equivalent $= 778$ ft.lbs.

$C_v =$ Specific heat at constant voulme.

$q_1 =$ Heat absorbed by cooling water, 2200 sq.in. cooling surface.

$q_2 =$ Heat absorbed by cooling water, 3300 sq.in. cooling surface.

$$q_2 = S_2(t_2 - t_1)$$

$p_1 =$ Pressure from indicator card, 2200 sq.in. cooling surface.

$p_2 =$ Pressure from indicator card, 3300 sq.in. cooling surface.

$$q_2 - q_1 = WC_v(t_1 - t_2) + \frac{1}{J}\int p_1 dv - \frac{1}{J}\int p_2 dv.$$

The last two terms are so small as to be neglected.

$$\frac{p_1}{p_2} = \frac{t_1 + 461}{t_2 + 461} \quad \text{or} \quad p_1 = p_2\frac{(t_1 + 461)}{(t_2 + 461)}.$$

Therefore the work gained by the smaller cooling surface is represented by $\int p_2 dv - \int p_1 dv.$

The heat transmitted in each time unit to the cooling surface will be proportional to the surface exposed at that time, and the difference between the wall and gas temperature in said moment and the constant coefficient depending on the conditions of the wall. We do not know this latter coefficient, therefore we cannot determine at present the absolute amount of heat carried away, but we can compare different engines with different cooling surfaces. The three curves given in the diagram No. 5

represent this heat absorbed in the cooling water by the walls. In diagram is shown the total area of each curve Q_1, Q_2 and Q_3, with height and the surface in the clearance volume as basis. Taking a cylinder with 3300 sq.in. cooling surface as an average good engine, with a gas consumption of 10,000 B.T.U. per b.h.p. hour, we know from tests that about 33% of the total heat admitted to the engine is carried away in the cooling water. This will give us a scale for Q curve, and we could determine the heat carried away in the cooling water by the other engines, supposing that all would run with the same average of temperature of the cylinder walls.

At the first glance it would look as if the maximum output and also the gas consumption of the engine would improve proportioning this Q curve with the decrease in cooling surface, but that is far off. The effect will be only that by less deduction of the heat in the cooling water the gas temperature of the gas in the cylinder, and therewith the pressure, will rise. Assuming a heat consumption of 3300 B.T.U. per b.h.p. hour in the cooling water for the medium engine, we will be able to determine the rise or fall in temperature for the other engines. If t_2 in diagram No. 4 represents the temperature for 3300 sq.in. cooling surface, this temperature will rise for 2200 sq.in. cooling surface corresponding to the area represented by the curves q_1 and q_2 in diagram No. 5. If C_v, equal to 0.189 B.T.U. per pound, is the specific heat of the gas at constant volume, we have the relation:

$$S(q_2 - q_1) = WC_v(t_1 - t_2) + \frac{1}{J}\int (p_1 - p_2)dv.$$

The second part of this formula represents a heat equivalent of the difference of expansion work for the two gases, and is so small compared with the first member that it can be neglected. The heat absorbed for 2200 sq.in. surface is calculated by using the temperature of the gas expanding with 3300 sq.in. clearance surface, instead of re-calculating the gas temperature for 2200 sq.in. and then using the latter for determining the final temperature for t_1; also this error is so small that it can be neglected. By neglecting these two errors we get a curve for t_1 and p_1 which is higher than it should really be.

If p_2 in No. 7 represents the indicator card for 3300 sq.in. cooling surface, you can calculate the pressure for 2200 sq.in. surface according to absolute temperature in each moment.

$$p_1 = p_2\left(\frac{t_1 + 461}{t_2 + 461}\right).$$

The work really gained is an increase of the mean effective pressure represented by the area between the curves for p_1 and p_2 in diagram No. 7. For the larger, the cooling surface for 4400 sq.in. the loss is found in a similar way. The mean effective pressure and the corresponding gas consumption are drawn again in diagram No. 6, and show clearly that the gas consumption is changing in quite a different ratio than the heat absorbed in the cooling water.

This investigation does not represent absolute results, but only a fair comparison between otherwise equal engines with different cooling surfaces. They can be used

for example in the following way: A certain kind of exhaust valve on a 30 × 42 in. engine may increase the cooling surface in the compression volume for 300 sq.in. over first engine. If both engines are run with the same temperature of the walls and if the heat absorbed in the cooling water of the first engine is 3300 B.T.U. per b.h.p hour, the same in the second one will be 3518 or 6.6% more, but the gas consumption will rise from 10,000 B.T.U.'s per b.h.p. hour to 10,159, or 1.59% more. This percentage may come down to 1.3 or 1.4% when the two factors are taken into consideration which are neglected in the above deduction. Most of the heat which is saved in the first case in the cooling water is spent again in heating the exhaust gases.

The results of this investigation agree very nicely with the well-known fact that the gas consumption of an engine does not at all decrease in the same ratio as a saving is made in the heat carried away in the cooling water. It agrees also with the result which M. L. Letombe of Lille, France, got recently from many different tests and experiments, that " the total heat carried away in the cooling water and in the exhaust is very nearly a constant."

Cooling Water.—In regard to the question of the total amount of water used per b.h.p. in engines with and without cooled pistons, the temperature of the water has to be taken into consideration. Assuming 60°, we are quite safe in stating while the water runs to waste, that the engine will consume not to exceed 5 gallons per b.h.p. rating per hour. However, such statements should not be used with a customer unless the customer is given to understand that he should supply an excess capacity. It is much better to state that 7 to 8 gallons are required as the tendency on their part is to put in pumping arrangements to suit your statements, rather than to have a surplus. When cooling towers are used three-fourths to one gallon will take care of evaporation losses.

No record of the amount of water for the pistons alone has ever been made that we have any record of. It is fair, however, to assume that one-third of the total consumed by the engine would be the amount required for the pistons, two-thirds for exhaust valve and jackets and heads.

If the plant is so situated that there is plenty of ground around it, it is best to put in a concrete basin in which the depth of the water would be not to exceed 18 in. This basin should be rectangular in shape and as a sample dimension for a 1000 h.p. plant, should be about 8 ft. wide by 40 ft. long. Erect at the side of this basin an ordinary construction like a stairway in which the tread would not exceed 6 in. and the step a like amount. This structure is to be built of wood. The height of it would depend somewhat upon the cooling effect required. Discharge the water into a long trough at the top, permitting it to overflow and flow down the steps. This is about the cheapest and most effective cooling system.

If the engines are located so that you have not the ground area, there are a number of tower cooling systems on the market, among the best of which are the Barnard, a system built by the Sturtevant Company, and the Boston Blower people also build a very good system.

Another good method is to discharge the water over a basin through ordinary spray pipes, like a spray fountain; this is cheap and very effective. Scrubber water can be used over again if the coal is not too high in sulphur, and if it is too high it can be neutralized by soda.

Usually 140° is the maximum jacket-water temperature allowed as the temperature of discharge of gas engines, that is, the maximum temperature under which the engine is entirely safe. There is no doubt, however, that a higher temperature than this can be maintained with perfect safety, but by keeping the temperature too high or too near the maximum, any intermission or short stoppage of water supply, or extra heavy load on the engine brings it too near the danger point. The temperature of the jacket water mostly effects the lubricants. Of course where water-cooled pistons are used, it is very dangerous indeed to allow the temperature of the water in the piston to suddenly rise for the reason that it expands the pistons and is liable to cause it to stick; so we would advise running the discharge water through the piston of the engine at a lower temperature than that of the jacket water. The very best results would be obtained by running the water at its maximum temperature at all times, because all the heat that is wasted through this medium is against the economy of the engine. General practice, however, seems to set this temperature, as stated, although some have had excellent results with 160°.

Our experience goes to show that the consumption of ten gallons of water is required as an average for water jacket and scrubbers per h.p. capacity. Where open tanks are used for cooling the evaporation loss may be figured at about 10%. Others say that where cooling water is running, a waste allowance of 8 to 10 gallons of water at 60° F. should be made per b.h.p. hour. Where cooling towers are used, from ¾ to 1 gallon per hour will take care of the evaporation. Sometimes the circulation is due to the temperature of the water and sometimes it is obtained by rotary pumps.

CAPACITIES OF ROTARY PUMPS—(Siebel)

Dimensions of Shell.	Diameter of Suction and Discharge.	Revolutions per Minute.	Size of Pulleys.	Gallons per Minute.
4×4.............	1½	130 to 150	2¼×7	30
4×4.............	1¼	130 to 150	......	25
4×4.............	1	130 to 150	......	20
6×6.............	2	120 to 140	3¼×12	40 to 50
6×6.............	1½	120 to 140	3½×12	50 to 60
6×6.............	2	120 to 140	3½×18	75 to 100
Brewers.				Barrels per Hour.
6×6.............	2	100 to 120	5 ×20	120
7×8.............	3	100 to 120	4½×18	150 to 200
8×8.............	3 or 4	100 to 120	5 ×20	200 to 250
8×8.............	3 or 4	100 to 120	6 ×24	200 to 250
8×12...........	4	100 to 120	6 ×24	300 to 350
Soap.				Pounds per Minute.
8×12...........	4	100 to 120	6 ×24	1200

Anti-Pulsators.—When a gas engine is connected on city gas, and to a comparatively small street main, its operation will, unless special precautions are taken, cause a fluctuation in pressure which may effect the use of lighting and cooking appliances in the neighborhood. What means would you employ to prevent such a fluctuation in pressure from being produced in the street main when the engine is running?

The question was brought up and discussed at a meeting of the American Gas Light Association and several methods of overcoming the fluctuation of pressure were described.

The simplest method which only applies, however, where the lead is fairly constant, is to put a stopcock on the inlet to the gas bag and by partly shutting the cock, compel the gas to pass into the bag at a practically uniform rate, just sufficient to supply the quantity of gas required by the engine. The bag acts as a reservoir, which is emptied when the engine draws gas, and is filled again during the interval between explosions, and as the pull on the portion of the pipe in front of the stopcock is kept more constant the fluctuation in pressure is reduced. This method will give slightly better results when two bags are used in tandem instead of one. When it is employed care should be taken not to shut off the stopcock to such an extent as to prevent the engine from getting all the gas it requires and thus to prevent it from developing the power needed.

A small gas holder will, under the same conditions, absolutely prevent the passing back to the street main any fluctuation in pressure no matter how much the lead varies, but such a holder is comparatively expensive.

All of these methods employ the same principle: that of having a store of gas fed to an accumulator from which the engine can draw its supply without reducing the pressure as much as if it drew directly from the service.

Lubrication.—Gas engines require more lubricating oil than steam engines, especially in the cylinders. The amount of oil used in gas engines per h.p. hour runs, in small units, about 0.001 gallon per b.h.p. hour.

It can be stated that the gas engine in its bearings, crank pin, etc., will not use any more oil than a steam engine, but that the cylinders, if single acting, will use four times as much oil. The reason for this is because each cylinder, whether steam or gas engine, requires practically the same amount of oil to lubricate it, the gas engine being four cycle. It takes four times the displacement to give the same power as the steam engine. Therefore in proportion to power the cylinder oil consumed in a gas engine would be four times that of a steam engine. As an average throughout, 0.2 gallon per 200 b.h.p. hours is a very fair statement and is easily accomplished.

Our most successful operation has been with Enterprise gas engine oil.

Viscosity of Mineral Oils.—The following two tables contain the results of a number of experiments in the viscosity of mineral oils derived from petroleum residues and used for lubricating purposes:

VISCOSITY OF MINERAL OILS

Density, Water=1.	Flashing Point, Degrees C.	Burning Point, Degrees C.	Specific Viscosity, Water at 20° C. =1.		
			20°	50°	100°
0.931	243	274	....	11.30	2.9
0.921	216	246	....	7.31	2.5
0.906	189	208	....	3.45	1.5
0.921	163	190	....	27.80	2.8
0.917	132	168	....	.....	2.6
0.904	170	207	8.65	2.65	1.7
0.891	151	182	4.77	1.86	1.3
0.878	108	148	2.94	1.48	...
0.855	42	45	1.65	.....	...
0.905	165	202	....	3.10	1.5
0.894	139	270	7.60	3.60	1.3
0.866	90	224	2.50	1.50	...

The several groups in this table are from the different distillates.

VISCOSITY OF OILS BY TRADE NAME

Name of Oil.	Density.	Flashing Point, Degrees C.	Burning Point, Degrees C.	Viscosity at 19° C., Water=1.
Cylinder oil......................	0.917	227	274	19.1
Machine oil......................	0.914	213	260	10.2
Wagon oil.......................	0.914	148	182	8.0
Wagon oil.......................	0.911	157	187	7.0
Naptha residue..................	0.910	134	162	5.5
Oleo naphtha....................	0.910	219	257	12.1
Oleo naphtha....................	0.904	201	242	6.6
Oleo naphtha....................	0.894	184	222	2.6
Oleonid.........................	0.884	185	217	2.8
Oleonid, best quailty............	0.881	188	224	2.0
Olive oil........................	0.916	...	...	2.2
Whale oil.......................	0.879	...	...	0.9
Whale oil.......................	0.875	...	...	0.8

Engine Tests.—The following tabulated data have been compiled by L. L. Brewer from a report on general European practice:

WEIGHTS AND FLOOR SPACE

B.H.P.	R.p.m.	Builder.	No. of Cylinders	Strokes per Cycle.	Single or Double Acting.	Cylinder Arrangement.	Weights. Eng. without F. W.	Flywheel. For Blow.	For Dynamo.	Square Feet Floor Space per B.H.P.
100	150	Cockerill	1	4	S.	Sc	45000	9000	21100	2.05
200	105	"	1	4	S.	Sc	83000	25000	58500	1.81
250	150	"	2	4	S.	Td	65000	10000	23400	1.24
300	120	Deutz	1	4	S.	Sc	83500	35000	81800	2.07
300	120	"	2	4	S.	Tw	101000	14000	32800	1.52
300	140	"	4	4	S.	d. tw	110000	3500	8200	1.32
600	80	Cockerill	1	4	S.	Sc	207000	100000	234000	0.99
600	130	"	2	4	S.	Td	185000	46000	107500	1.13
600	110	Oechelhaeuser	1	2	S.	Sc	143000	48000	112000	1.23
600	130	Deutz	2	4	S.	Tw	158000	28000	65500	1.67
600	130	"	4	4	S.	d. tw.	189000	7000	16400	1.08
600	110	Körting	1	2	D.	Sc	136500	18000	42200	1.11
750	90	Nürnberg	1	4	S.	Sc	297000	115000	26900	1.03
1200	80	Cockerill	2	4	S.	Td.	365000	95000	222000	0.68
1200	130	Deutz	4	4	S.	d. tw	354000	14000	32800	1.01
1200	120	Nürnberg	4	4	S.	d. tw	280000	16000	37400	0.94
1200	110	Oechelhaeuser	2	2	S.	Tw	260000	16000	37400	0.90
1200	110	Körting	2	2	D.	Tw	250000	4500	10500	0.90
1400	110	Cockerill	2	4	D.	Td	374000	8600	20000	0.42

GAS CONSUMPTION

Engine.	Cubic Feet per B.H.P. Hour.	Heat Value in B.T.U.	B.T.U. per B.H.P. Hour.
Deutz	135	100	13500
Cockerill	116.5	110	12800
Oechelhaeuser	107.5	103	11050
Körting	87.6	130	10620
Auhalt	95.2	101	9620
Premier	70	135	9100

AVERAGE AMERICAN PRACTICE

Load, per cent	125	100	80.	50	25
Cubic feet per b.h.p. hour	115	122	137.5	163	200

The main considerations affecting the consumption of lubricating oil and cooling water are the dimensions of the engines, the larger the dimensions the greater disadvantage to the engine. The average cooling water consumption is 20 gallons per b.h.p. hour. Lubricating oil varies between 0.0045 to 0.0055 pint per b.h.p. hour. The ability of the engineer in charge, however, has considerable effect on the above results.

The following figures give the average efficiencies:

SINGLE-ACTING FOUR-CYCLE ENGINES
One cylinder . . . . 85 to 90%
Two cylinder . . . . 80 to 85%
Four cylinder . . . . 75 to 85%

SINGLE-ACTING TWO-CYCLE ENGINES
One cylinder . . . . 78 to 82%

DOUBLE-ACTING TWO-CYCLE ENGINES
One cylinder . . . . 70 to 75%

Load Factors.—A committee of the Institute of Civil Engineers in 1906 made a report declaring that, on account of the difference in their operation, different standards from those of steam engines should be used in comparing gas engines. The report recommends comparing the engines to an ideal fulfilling the following conditions: (1) The reception and rejection of heat should take place as nearly as may be in the same way as in the actual engine; (2) there should be no heat losses due to radiation, conduction, leakage, or imperfect combustion; (3) data for numerical evaluation of the standard should be ascertainable by simple measurements; (4) the expression for the efficiency should be a simple one.

The committee recommended that the ideal standard engine be taken to work with a perfect gas of the same density as air, and that it be a perfect air-gas engine operated between the same maximum and minimum volumes as the actual engine, receiving the same total amount of heat per cycle, but without jacket or radiation loss, and starting from one atmosphere and the selected initial temperature of 139° F. The actual efficiencies of all ordinary gas engines vary between 0.5 and 0.6 of the efficiency of the air-engine standard.

Three engines were tested, from the results of which tests the following figures were taken:

Size engine	5 I.H.P.		25 I.H.P.		56 I.H.P.	
Load	Half	Full	Half	Full	Half	Full
I.h.p.	3.6	5.72	14.5	25.9	34.1	56.3
B.h.p.	2.87	5.20	10.82	20.9	27.9	52.7
Mechanical efficiency	0.80	0.90	0.75	0.80	0.82	0.94
Net B.T.U. per hour	32260	49630	117200	187700	267500	450600
Thermal, i.h.p., efficiency, per cent	28.0	29.0	31.5	35.0	32.5	31.8
Thermal, b.h.p., efficiency, per cent	22.4	26.1	23.6	28.0	26.7	29.9
Thermal efficiency, standard	0.496	0.496	0.496	0.496	0.49	0.49
Relative efficiency, i.h.p., per cent	56.4	58.4	63.5	70.6	66.3	65.0
Relative efficiency, b.h.p., per cent	45.2	52.6	47.6	56.4	54.5	61.0
Cubic feet per i.h.p.	15.78	15.33	13.77	12.78	13.67	13.94
Cubic feet per b.h.p.	19.80	16.87	18.45	15.84	16.70	14.90
Air: gas, ratio	8.49	9.15	8.42	9.17	7.97	8.27

GUARANTEED AVERAGE THERMAL EFFICIENCY OF A GAS ENGINE

Load Factor.	Effective B.T.U. per b.h.p. hour.
Single-cylinder engine, at rated load	11,000
75% load	12,000
50% load	13,000
33% load	17,000
Double-cylinder engine, rated load	10,700
75% load	11,500
50% load	12,700
33% load	15,000
Four-cylinder engine, rated load	10,500
75% load	11,300
50% load	12,500
33% load	14,500
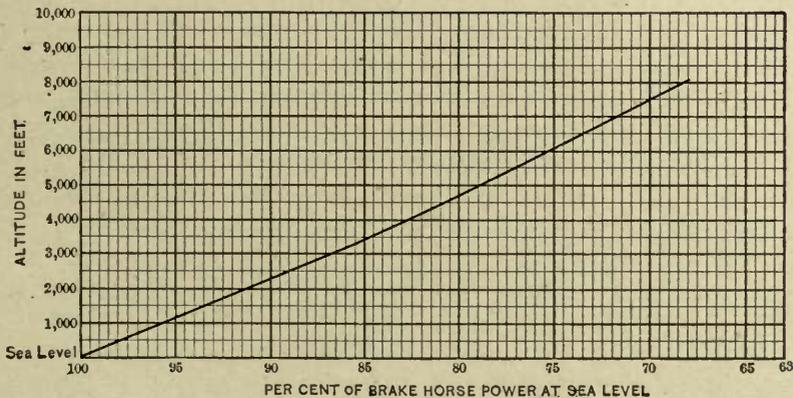
FIG. 127.—Influence of Altitude on Horsepower.

Utilizing Exhaust Gases.—By the use of engine exhaust gases in suitably designed heaters attached to the engine exhaust pipe, from 2 to 3 lbs. of steam per b.h.p. per hour can be raised up to 60 lbs. pressure. The author's practice is to raise to about 5 lbs. pressure and by use of engine jacket water possibly 5 lbs. per b.h.p. can be attained. Where hot water is required, as around chemical works, etc., this is added economy to the gas plant.

Cecil Poole, in his article upon the regeneration of exhaust gas from gas engines, says:

" A hot-water heating system, as an adjunct to a gas-power plant, could easily utilize between 60 and 70% of the exhaust heat and all of the heat in the discharged jacket water. Such an auxiliary system would bring the gas engine nearer to the steam engine in applicability where sensible heat must be supplied by the power plant. There would still be the drawback, however, that a gas-power plant would not furnish as much heat as a steam-power plant of the same output. For example, with 35 lbs. of jacket water per b.h.p. hour discharged at 140° F., and the exhaust gases containing 3800 B.T.U. at 1600° absolute temperature, the following figures are obtained for the gas plant:

Heat to raise 35 lbs. of water from 140 to 190° F. . . . . =1750 B.T.U.

$$1750 \div 0.85 = 2059 \text{ B.T.U.}$$

Temperature range of exhaust gases in the heater.. $= 1600 - 655 = 945°$

Heat available in gases. . . . . $= 3800 \times 945 \div 1600 = 2244$ B.T.U.

Heat rejected by heater. . . . . =185 B.T.U.

Assuming that the water was cooled in the radiating pipes to 70° F., the heat units delivered in sensible heat to warm the building would be 4200 B.T.U. per b.h.p. hour of engine output at full load.

A non-condensing steam engine of high efficiency will easily furnish 25,000 to 26,000 B.T.U. per b.h.p., in the latent heat of evaporation contained in the exhaust steam. This is obviously about six times as much heat as the gas engine could supply. However, a condensing steam engine can supply no heat whatever, while the gas engine is able to supply about 4000 heat units per b.h.p. hour and do the same amount of work, with a consumption of only one-third the quantity of fuel.

In a gas engine the exhaust leaves the cylinder at a high temperature and thus carries away the latent and sensible heat of the water it contains. Opinion differs as to which heat value should be used in estimating the heat efficiency in a gas engine. In Germany, England, and America the low value is used largely; in France the high value, on the basis that the producer should be credited, as is the boiler, with the heat value it gives the gas. To utilize more fully the heat of the gas or steam is considered a function of the engine, and a loss not chargeable to the producer.

CHAPTER XII

INDUSTRIAL GAS APPLICATIONS

Comparison of Industrial Fuels.—The following table is given by the Morgan Construction Co. showing the comparison between the cost of a ton of coal and 1000 cu.ft. of natural gas:

Cost of 2000 lbs. of Coal.	Value of 1000 cu.ft. of Natural Gas, Cents.	Value of One Gallon Fuel Oil, Cents.
$0.75	$5\frac{1}{4}$	1
1.00	$6\frac{1}{2}$	. . . .
1.25	$7\frac{3}{4}$	. . . .
1.50	9	1.35
1.75	$10\frac{1}{4}$	. . . .
2.00	$11\frac{1}{2}$	1.7
2.50	. . .	2.1
3.00	. . .	2.5

It is estimated that where a furnace temperature of say 2700 degrees is to be obtained, at least 50% in fuel economy is obtained through the use of gas firing, by reason of the heat regained through the regenerator or recuperator. This of course is impracticable with oil or direct coal firing.

The Industrial Gas Co. make the following comparison between the value of fuels; in each instance the figures are based upon fuel, air and gas regenerators for the producer gas:

Coke and anthracite: One ton of 2000 lbs. when burned directly in connection with heating operations is displaced by 1000 lbs. bituminous slack or run of mine coal burned in the producer.

Pea, anthracite, and bituminous coal: One ton of 2000 lbs. when burned directly in connection with heating operations is displaced by 900 lbs. bituminous run of mine or slack burned in the producer.

Fuel oil: One gallon fuel oil burned without regeneration is displaced by $9\frac{1}{3}$ lbs. bituminous run of mine or slack coal burned in the producer.

Natural gas: One thousand cubic feet of natural gas burned without regeneration is displaced by 75 lbs. bituminous run of mine or slack coal burned in the producer.

For bending heats, tempering, hardening, annealing, baking, roasting, drying, soldering, tinning, galvanizing, singeing, and other processes requiring heats no higher

than 1800° F., other fuels are displaced by the following amounts of "buckwheat" anthracite coal, in the producer and burned with full recuperation.

Natural gas: 1000 feet displaced by 150 lbs.

City gas: 1000 ft. displaced by 100 lbs.

Anthracite coal and coke: 1 ton of 2000 lbs. displaced by 1800 lbs.

Pea coal and bituminous coal: 1 ton of 2000 lbs. displaced by 1620 lbs.

Fuel oil: 1 gallon displaced by 19 lbs.

In firing furnaces with producer gas, the Hawley Down-Draft Furnace Co. recommend that the gas be admitted at $\frac{1}{4}$ lb. more pressure than the air from the blower. The company rates their furnaces at one-third the capacity, when firing with producer

Fig. 128.—Mixing Burners for Hawley Down-Draft Kilns.

gas as when firing with oil, the oil pressure being about 30 lbs. The air being 12 to 16 ounces pressure when melting copper or bronze and 11.5 lbs. when melting iron or steel. The section shows how the pressure of air and gas are regulated.

Heat Recovery.—In considering any gas fuel, the first question is what percentage of the energy of the fuel converted is delivered with the gas? Producer gas, though the lowest in energy, can be produced more cheaply per unit of heat than any other. Yet in the old Siemens producer, practically all the heat of primary combustion—that is, the burning of solid carbon to carbon monoxide—was lost, as

little or no steam was used in the producer, and nearly all the sensible heat of the gas was dissipated in its passage from the producer to the furnace, which was usually placed at a considerable distance.

Modern practice has improved on this early plan, by introducing steam with the air that is blown into the producer, and by utilizing the sensible heat of the gas in the combustion furnace. One pound of carbon, burned to 2.33 lbs. of carbon monoxide, CO, develops 4400 heat units, or about 30% of the total carbon energy; in the secondary combustion, 2.33 lbs. of carbon monoxide burned to 3.66 lbs. of carbon dioxide develop 10,100 heat units, or 70% of the total energy; making in all 14,500 heat units for the complete combustion of the original pound of carbon. Now, it is evident that if the heat of the primary combustion is not employed either to dissociate water or to impart a *useful* high temperature to the gas 30% of the energy will be practically lost, i.e., the gas will carry into the furnace only 70% of the total energy of the carbon. It is equally evident that if all the heat of primary combustion could be applied to the dissociation of water, there would be little effective loss of energy in conversion; or if, instead of dissociating water, all the sensible heat of the gas (representing the heat of primary combustion) could be utilized, the loss would similarly be reduced to *nil*. But the complete realization of either alternative is impossible, for the loss by radiation from the producer is an important item, and the unrecovered energy expended in blowing the producer with air and steam amounts to from 3 to 5 per cent.

Good practice does, however, recover a considerable percentage of the heat of primary combustion by the use of both of these means, i.e., by utilizing the sensible heat of the gas through close attachment of producer and furnace, and by introducing with the air blast as much steam as the producer will carry and still maintain good incandescence. In this way about 60% of the energy of primary combustion should be theoretically recovered, for it ought to be possible to oxidize one out of every 4 lbs. of carbon with oxygen derived from water vapor. The thermic reactions in this operation are as follows:

Heat Units.

4 pounds C burned to CO (3 lbs. gasified with O of air and 1 lb. with O of water) develop.... 17,600
1.5 pounds of water (which furnish 1.33 lbs. of oxygen to combine with 1 lb. of carbon) absorb
     by dissociation 10,333
The gas consisting of 9.333 lbs. CO, 0.167 lb. H, and 13.39 lbs. H, heated 600°, absorbs.... 3,748
Leaving for radiation and loss 3,519

————

17,600

(It may be well to note here that the steam which is blown into a producer with the air is almost all condensed into finely divided water, before entering the fuel, and consequently is considered as water in these calculations).

The 1.5 lbs. of water liberates 0.167 lb. of hydrogen, which is delivered to the gas, and yields in combustion the same heat that it absorbs in the producer by dissociation. According to this calculation, therefore, 60% of the heat of primary combustion is theoretically recovered by the dissociation of steam, and even if all the sensible heat of the gas with radiation and other minor items be counted as loss, yet the gas must carry $4 \times 14,500 - (3748 + 3519) = 50,733$ heat units, or 87% of the calorific energy of the carbon. This estimate shows a loss in conversion of 13%,

without crediting the gas with its sensible heat, or charging it with the heat required for generating the necessary steam, or taking into account the loss due to burning some of the carbon to carbon dioxide. In good producer practice the proportion of carbon dioxide in the gas represents from 4 to 7 per cent of the C burned to CO_2, but the extra heat of this combustion should be largely recovered in the dissociation of more water vapor, and therefore does not represent as much loss as it would indicate. As a conveyor of energy, this gas has the advantage of carrying 4.46 lbs. less nitrogen than would be present if the fourth pound of coal was gasified with air; and in practical working the use of steam reduces the amount of clinkering in the producer.

In a paper read by W. K. Eavenson before the second annual meeting of the American Gas Institute the subject of air-blast gas appliances was ably treated. He referred to burners as follows:

Air Injector.—In the different types of burners to be described, used with Philadelphia city gas, the gas and air are mixed by an injector. The air nozzle is
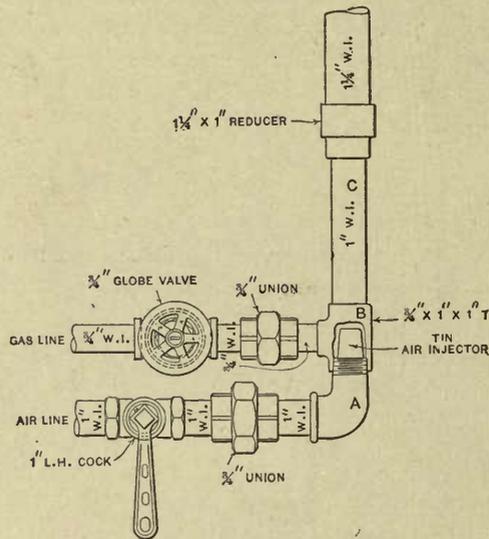
Fig. 129.—Blast Connection for Furnaces.

soldered on the service ell A and extends in the tee B, slightly beyond the center line of the side outlet, carrying the air past the gas way, the air creating a slight suction on the gas line. The air and gas are mixed in the pipe C on the way to the burner. The air nozzle is made of tin and can easily be replaced by another of different diameter, if adjustment is needed. Satisfactory results cannot be obtained by attempting to ram or contract the nozzle. The air nozzle should be so adjusted as to derive the full benefit of the injector effect. For instance, after the fire-brick linings have become sufficiently heated to bring a furnace to its maximum heat, when the lever-handle air cock is wide open, a reducing or gas flame should issue from the furnace vent. The pressure in the gas pipe need not be more than twenty-tenths.

Forms of Burners.—Some types of burners used are described below. In these burners no outside or secondary air is required for complete combustion, and, as a rule, any furnace will give better results if it is closed tight at the bottom.

One of the eight burners used in the No. 1 oven furnace illustrates the general method of putting blast burners in oven furnaces having a fire-brick lining, into which the burners are inserted. This recessing of the burners serves the double
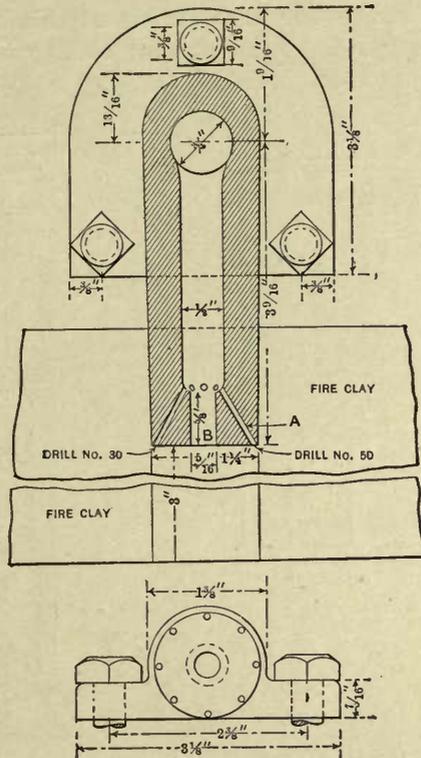
Fig. 130.—Burner Used in Oven Furnace.

purpose of protecting it from the heat, and also of maintaining the flame, as it has been found that this type of burner cannot be kept lit, if in the open. One of the most interesting features of the use of gas with air pressure is the devices that are used under different conditions for the purpose of keeping the flame lit.

In the burner shown, attention is called to the small radiating orifices *A*, which surround the main burner opening *B*. Without these orifices, the main flame would blow out, and even with the orifices, the flame is maintained only when the end of the burner is surrounded by a projecting hood like the fire-brick shown. Why the orifices and projecting hood act as they do is a matter of theory. Probably the small size of the tubes and the fact that the mixed air and gas issuing from them impinge on the hood, so reduce the speed at the point of combustion that there is less tendency to blow out. Then, too, the walls of the projecting hood, protect the tender flames from side drafts.

The gas and air mixture can be kept lighted, when it issues from one central opening at the burner nozzle, provided the flame plays against a fire-brick or other surface, located close in front of the nozzle; but it is not as certain to stay lighted as the construction described above. Also, in some circular furnaces, burners of simple nozzles are used, by arranging two or more burners around the circumference, so set at a tangent, that the flames play around the circular wall in the same direction and thus tend to keep each other lighted.

Ferrofix Brazing Head.—The construction of this burner permits of keeping the burner lit in the open. The principles are the same as in the former burner.

Fig. 131.—The Ferrofix Brazing Head and Machlet Burner Tip.

The secondary flame issues from the annular slit A, instead of from small orifices, and the projecting hood is the wrought-iron pipe B instead of fire-brick.

When using the "Ferrofix" head in constructing home-made brazing furnaces, it was found that the head burned out very quickly. To overcome this, it was protected from the heat by cold-driving it in a cast-iron collar. This collar is 3 ins. long and $\frac{1}{2}$ in. thick. The face of the wrought-iron hood B is recessed i in. in the collar.

When fitting a collar to a head, care must be taken not to close the circular space A. The Ferrofix head has been put to the following uses:

Home-made cylindrical brazing furnaces equipped with five heads (the protectors) are being used for brazing flanges on the large copper steam pipes of locomotives. They also used one head in a small furnace for the smaller copper pipes.

Two heads were placed under the vaporizing cap of a 125-h.p. Hornsby-Akroyd oil engine. The cap must be heated to a dark red before the engine can be started. The two burners enable the consumer to start the engine in 15 minutes. Ten sets of these burners were installed for this purpose. These burners replace the oil lamps originally furnished by the engine manufacturers.
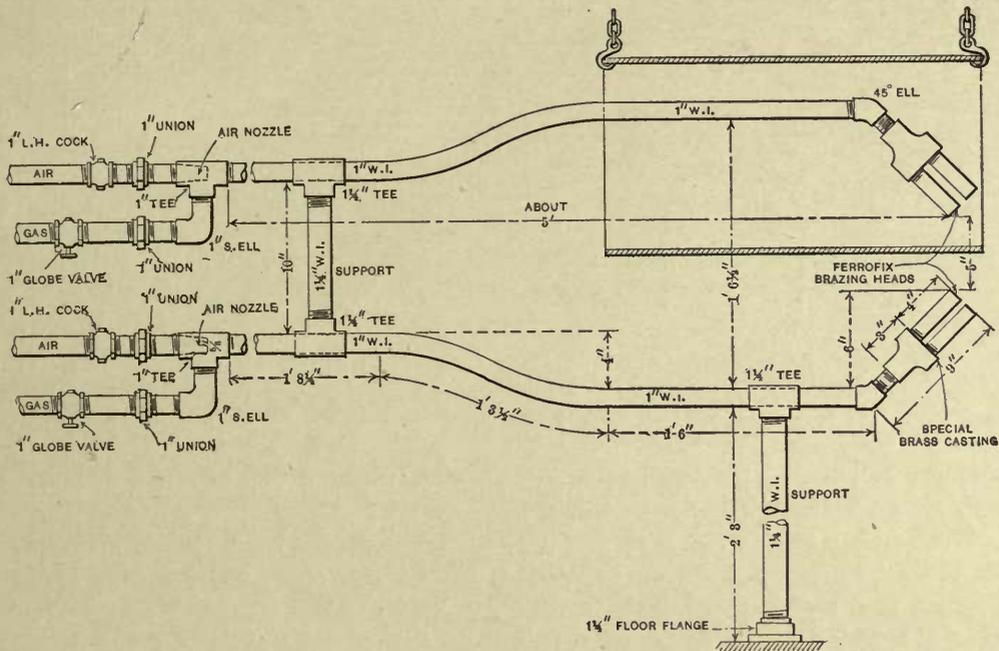
Fig. 132.—Special Brazing Burner.

Three heads were put in the fire-box of an old charcoal brazing furnace. It is used for brazing the bottoms in copper pans of all sizes. Two heads were adapted to braze the joints in ice-cream cans. The next illustration of special brazing burner shows the Ferrofix head adapted to braze the copper cylinders of chemical engines. They used four heads here as some of the cylinders are made of $\frac{1}{4}$ in. copper, and a large volume of flame is needed. They also put a ring of heads around a very large cauldron previously heated by steam. This cauldron is used for manufacturing axle grease.

Machlet Burner.—The construction permits of keeping the bruner lit in the open. The principle of maintaining the flame of the burner is similar to that used with the Ferrofix head. The ribbons A are recessed $\frac{1}{8}$ in. in the shell B. This prevents the draft of air from blowing or sucking out the small flames which burn

from the ports *C* and *D*. The pressure of the gas and air is probably sufficiently cut (due to its impinging on the part *E*) to hold the flame to the burner. With this burner it appears that the small flames burning at *D* act as pilots to the flames burning at *C*.

The tips are made of one size, $\frac{3}{8}$ in. diameter, and can be set in rows in pipe burners of straight or circular form, or arranged in clusters, etc. In Philadelphia they have used the Machlet tip in the following home-made appliances: In japanning ovens for enameling the frames of baby carriages and velocipedes and skylight frames. Under tinning furnaces and sawdust driers.

Singeing Burner.—The feature of the ribbon burner is that it gives from end to end a continuous line of flame of uniform size, thus rendering it useful for such
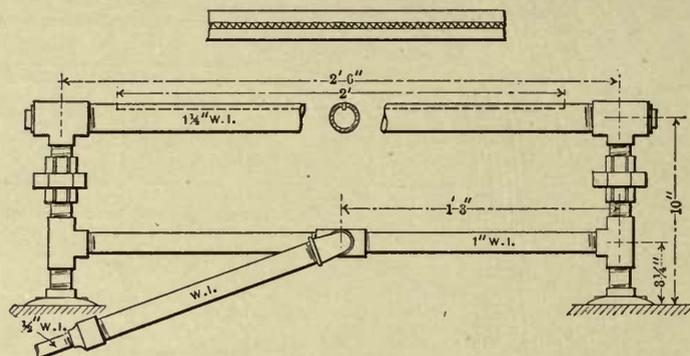
Fig. 133.—Ribbon Singeing Burner.

purposes as singeing fabrics, and roasting coffee, where a line of separate burners, with spaces between the flames would not answer.

The ribbon burner has been utilized as follows: Under the 6-foot cylinder of an old coffee roasting machine, the capacity of the cylinder being 350 lbs. Two ribbons were set in a pipe paralleling the cylinder, so that the two lines of flames impinged on the cylinder at an angle to each other. One of their customers was using a machine of German manufacture for singeing tapestry. The gas flame issued from a slot about 4 ft. long, the slot being formed by two bevel-edged plates which could be adjusted and held by set-screws. The flame was uneven and at places intermittent. To overcome this trouble one of the ribbons was taken out of a ribbon burner and set it in the slot, holding it by squeezing it between the beveled plates. The result was a steady, even flame which produced satisfactory results.

Soft Metal Burner.—Still another burner is the soft-metal burner. With this burner an intense heat can be maintained under cauldrons for melting metal, candy, etc. The illustration shows one of the sixteen stoves of their own design sold to a consumer. It gives quicker results than any stove treating 40 lb. batches of candy in 15 minutes, instead of 30 for the stove replaced. The stove is equipped with the No. 6 soft-metal burner. The construction of the burner permits of its being lit in the open. The bottoms of the pans come within 8 ins. of the top of the plug *C*. A half-inch sheet-iron flare prevents the flame from touching the pan above the level of the syrup, thus preventing scorching.

The sight holes G are used to determine the condition of the flame when the pan is in place. When the stoves are not in use, the burners are protected from the dust peculiar to a candy shop, by sheet-iron caps.

An old charcoal furnace, used for tinning objects and for annealing copper pans, was equipped with this burner. This burner was also used under pots of old coal furnaces, for melting metal, under potash kettles, under kettles for supplying hot water, and in the frames of old coal candy furnaces.
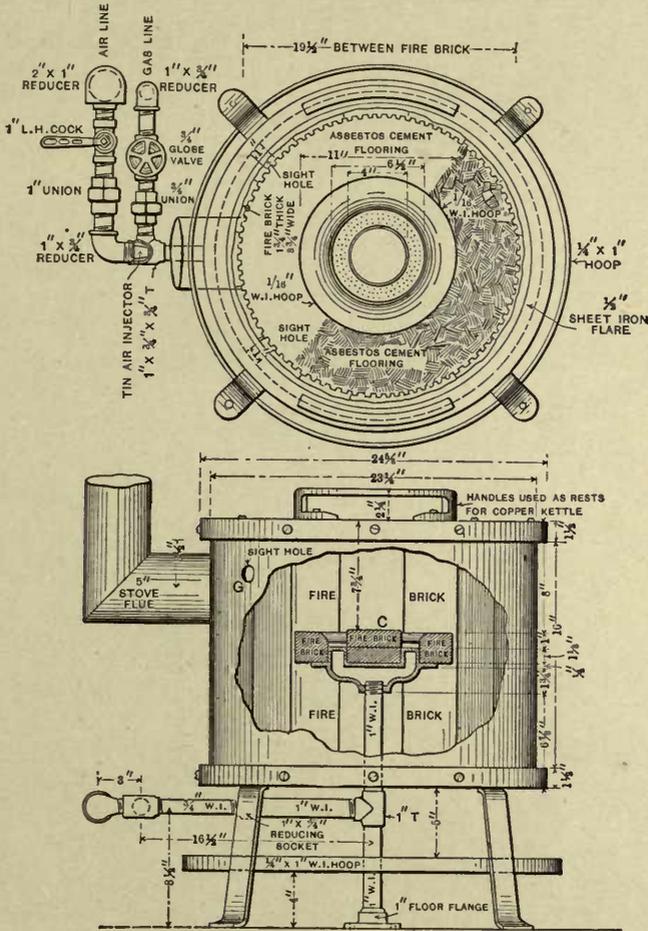
Fig. 134.—Blast Confectionery Stove.

Blow Torch.—The brazing torch is a type of burner on the market which is useful for certain purposes. It will stay lit in the open, apparently because the gas and air mixture is burned at a point close to the injector. As already described, if the mixture is piped any distance from the injector, one of the several special types of burners, as described, must be used in order to maintain the flame.

This torch was used in a glass-bending furnace. The flat pieces of glass are placed

on the molds which set in the furnace on a slab. The heat is then applied through the torch held in the hand of the operator until the glass forms to the mold. It is

Fig. 135.—Blast Blow Torch.

SINGLE BURNER.

DOUBLE BURNER.

TRIPLE BURNER.
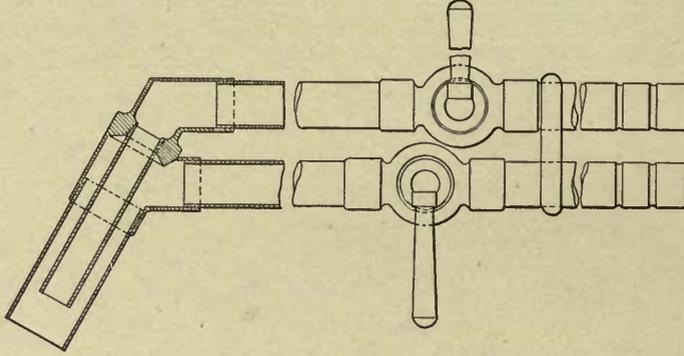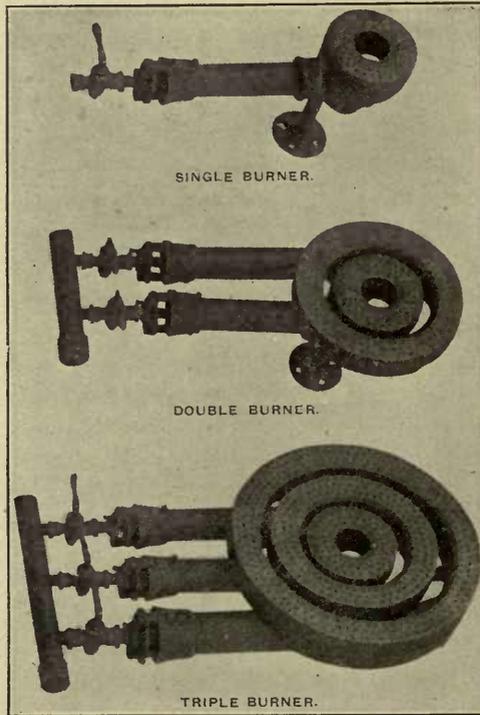
Fig. 136.—Cyclone Annular Burner.

then removed and placed in an annealing oven to cool. The molds vary in size, the largest one being 14 by 24 ins. To take care of the large molds, the end of one of the torches had to be flattened out to a 2-inch oblong opening, thus enabling

the operator to cover the mold with a solid sheet of flame. The flame must cover the mold, otherwise the glass will break.

These industrial burners are applied to many purposes and are a durable and efficient type. They are designed to intensify flame propagation and are especially effective with gases having high ignition points.

Pressure Blowers.—Because burners utilizing producer gas must be operated under pressure, both gas and air blowers are necessary, a separate one for each, since they must be kept separate until they mix at the burner. The gas should be delivered under a slightly lower pressure than the air to secure the best results
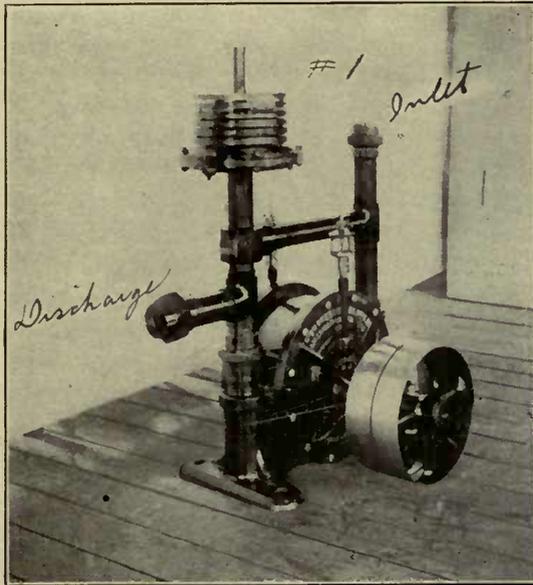
Fig. 137.—Pressure Blower for Gas.

and the exact regulation is possible by having two blowers. The gas booster is of somewhat different construction from the air blower. The American Gas Furnace Co. make a gas blower running at 25 r.p.m. and delivering gas under a pressure of 0.5 to 2 lbs. pressure per square inch. The one here illustrated has a pulley 8 ins. diameter and 2 ins. face. The pressure is regulated by the weights above the discharge pipe; no weight delivers $\frac{1}{4}$ lb. and each weight added increases the pressure by $\frac{1}{8}$ lb.

Forge Work.—Small furnaces for this industry have been operated for some time on fuel oil or gases more expensive than ordinary producer gas. Because of its lower heating value and consequently necessary large volume, the application of producer gas requires special treatment. The system is, however, in successful service, giving good, quick forging heats, with large economy over oil or other methods of firing, and with absence of the smoke and dirt of ordinary coal fires. The gas

serves heating furnaces for bending, heading, bolt and rivet machines and a variety of miscellaneous work. In such installations, however, it is best to concentrate the furnaces as much as possible. It is difficult and often impracticable to pipe the gas to scattered furnaces at great distances from each other. With properly designed flues and connections, the soot can be cared for without trouble.
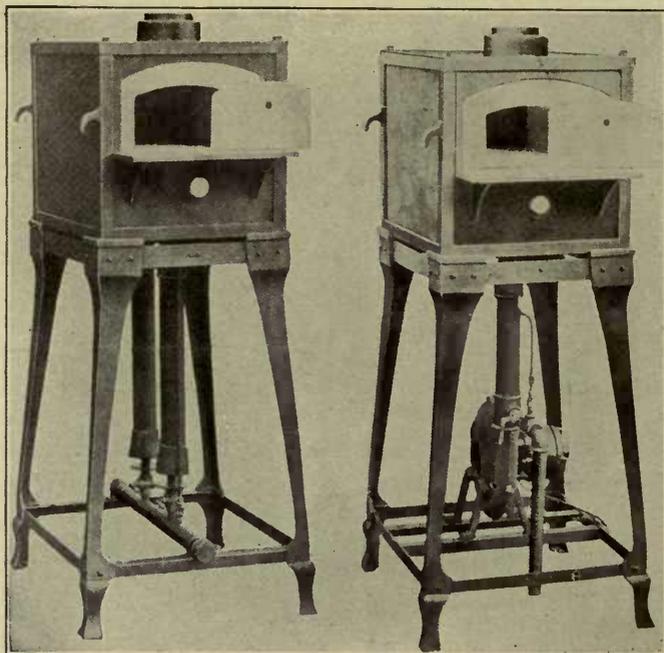
FIG. 138.—Muffle Furnace Using City Gas.

With holder pressure, a temperature of 2000° F. was obtained, which was raised to 2500° F. by blast from an attached fan.

The furnace hearths may be as small as 6×12 ins. or as large as desired. They may be so designed for the particular class of work they do that the heat will be well centered on the iron being heated, and are therefore economical in fuel. For obtaining welding heats reversing regenerative furnaces must be used, giving the best welding heats obtainable. One furnace will readily supply four to six men with work, so that considering the amount of work heated the cost of the furnace is low. The type of furnace and the character of the gas best suited to any case can be determined only by a study of the conditions of each installation.

Various Applications.—The accompanying illustrations show a large variety of uses to which gas heating is applied.
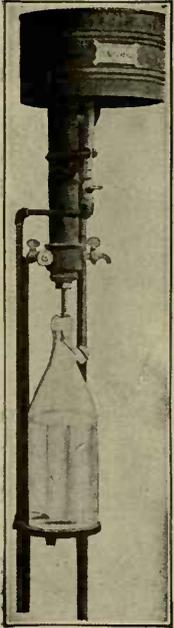
FIG. 139.—Water
Still.

FIG. 140.—Producer Gas Heating Furnace for Heating Plates for
Pressing into Shapes.
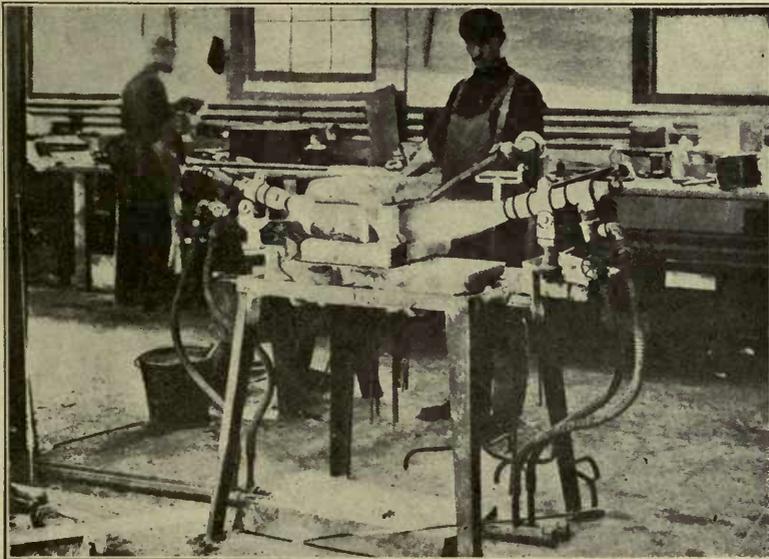
FIG. 141.—Brazing by Producer Gas.
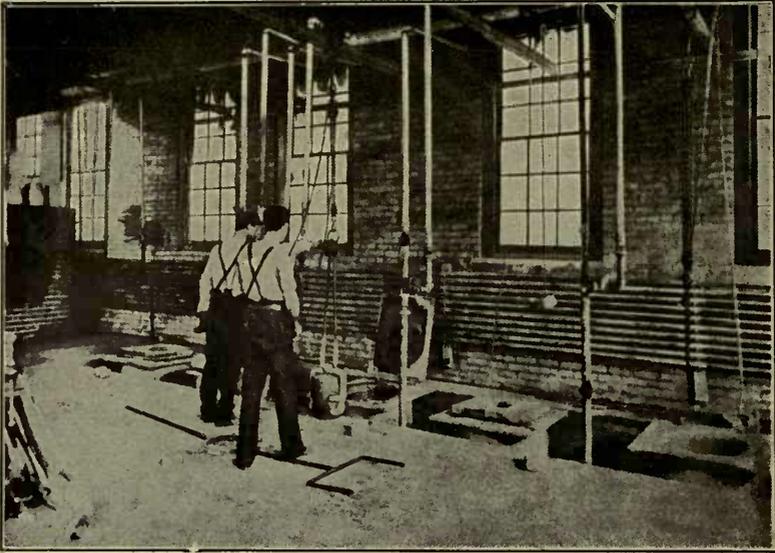
FIG. 142.—Producer Gas-fired Crucible Furnaces for Heating Brass and Aluminum. Capacity, 9 melts per 10 hours.
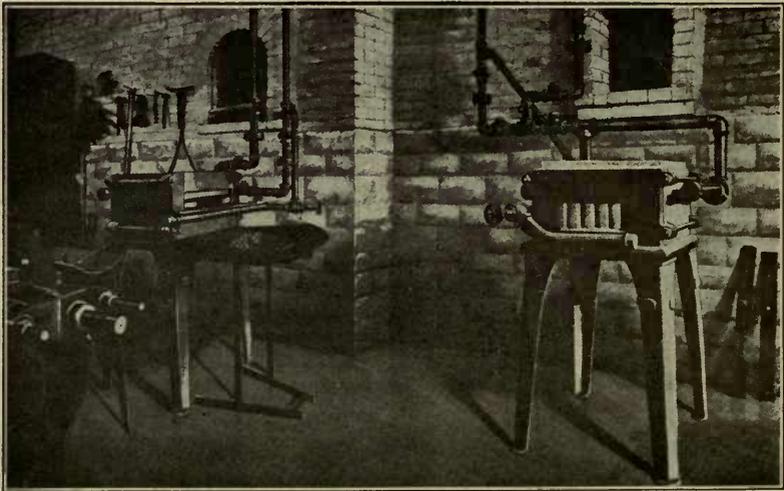
FIG. 143.—Producer Gas Forge Furnace.   Heats 14,500 ½-inch bolts in 10 hrs.
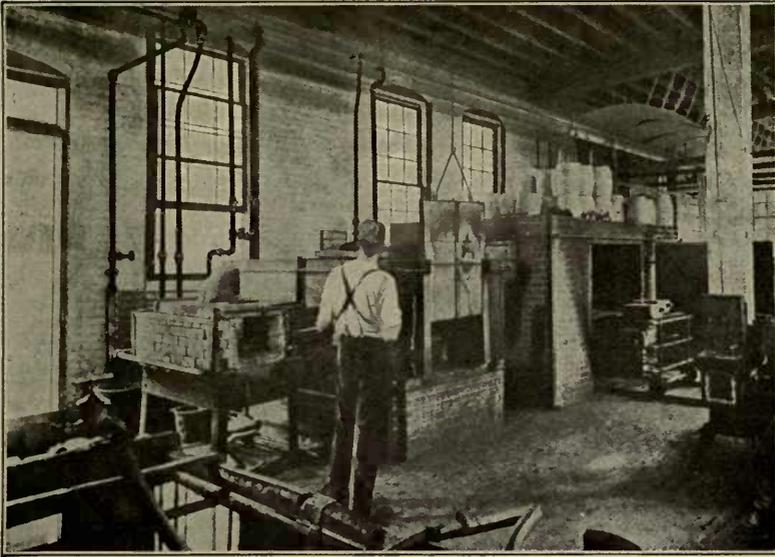
Fig. 144.—Producer Gas-fired Furnaces. Case Hardening, Annealing and Core Ovens.
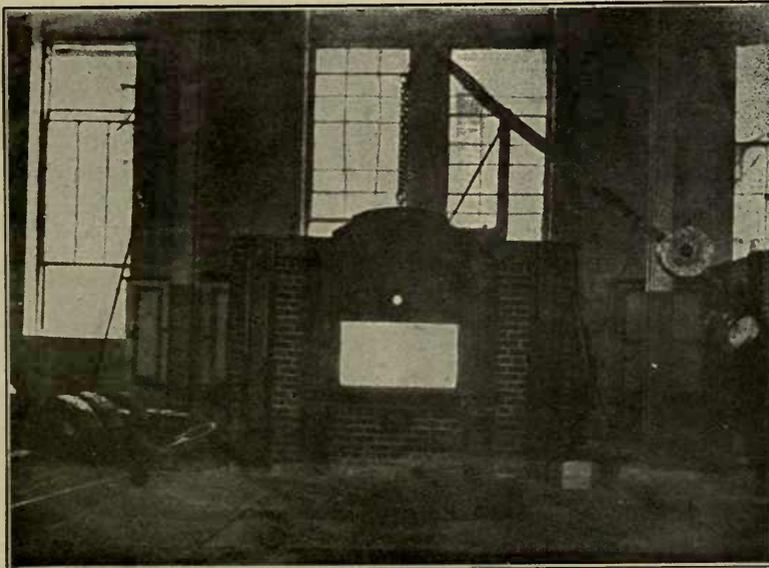
Fig. 145.—Large Producer Gas-fired Furnace for Heating Steel Ingots up to 5000 lbs. There is no flue for waste gases and the temperature is about 3000° F.
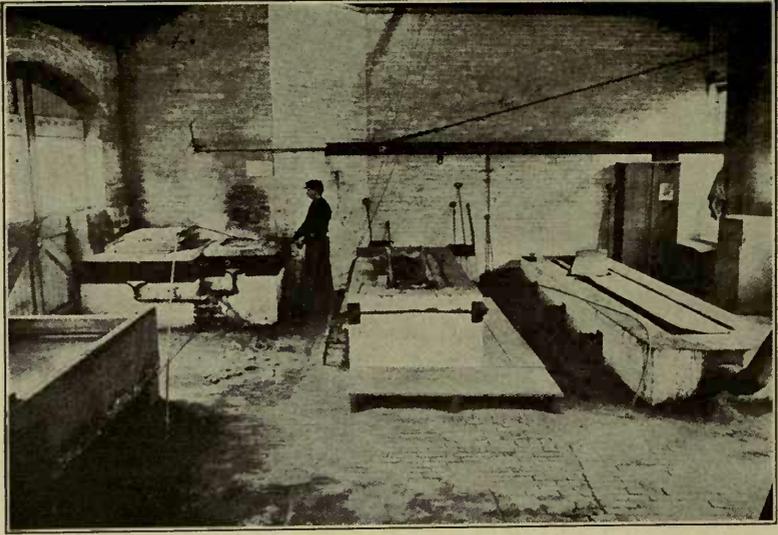
Fig. 146.—Galvanizing with Producer Gas Heat.
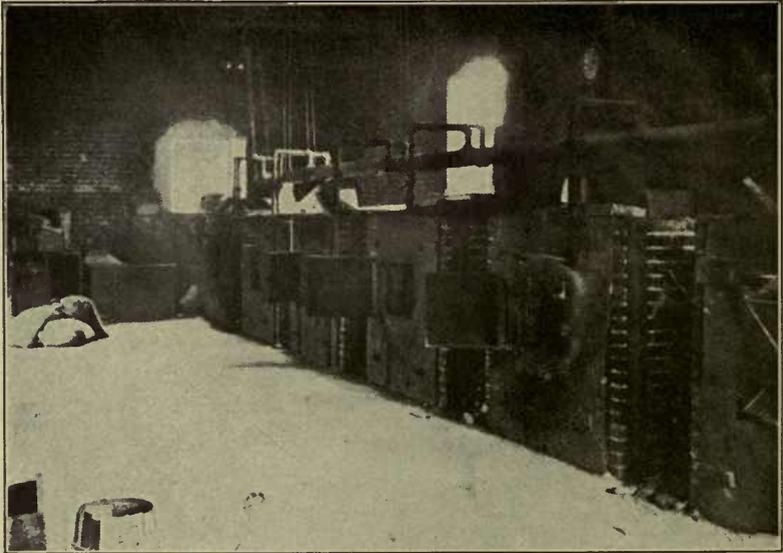
Fig. 147.—Producer Gas-fired Annealing Ovens. Built for natural gas but changed over to producer gas.
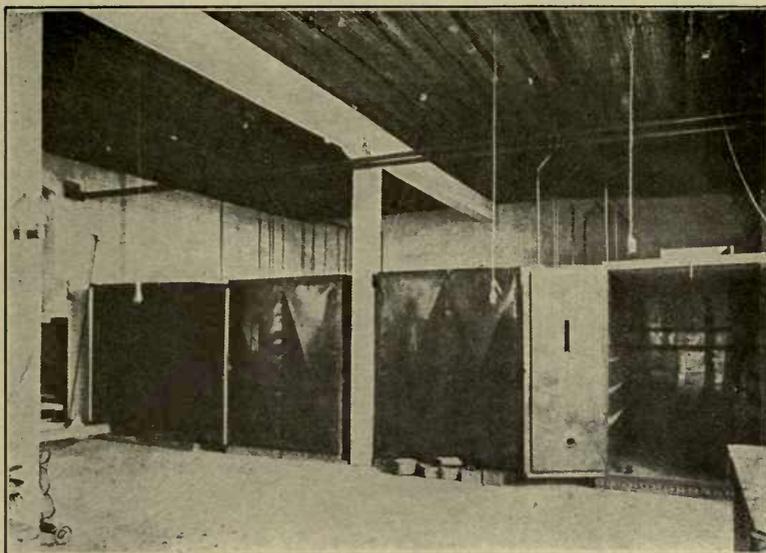
Fig. 148.—Producer Gas-heated Japanning Ovens Used on Sewing Machine Heads. They are heated to 500° F. in 20 minutes. Natural gas had been used previously.

Gas Firing of Steam Boilers.—The Kirkwood burner and mixer has proved one of the most successful in the natural gas fields and has also been extensively used in the firing of cement kilns with gas; the action of the burner secures an especially good mix. The best results are obtained from the use of any burner by applying the flame to the water leg of the boiler at an angle of 45°. With natural gas the first half of the flame should be a decided green, changing to blue. A cherry streak in the flame is not objectionable, but any yellow color should not be permitted. A burner designed to throw a flat jet of flame say 10 ins. wide at an angle of 45° against a water leg will be found particularly efficient.

The gas should be supplied with plenty of force, and where this is not otherwise available, can be furnished through the medium of an inductor operated by air under pressure. This pressure may safely run from 1 to 1.5 lbs. Where small water heating boilers are used, burners of the Cyclone type, the invention of Henry L. Doherty, designed to secure rapid flame propagation through the return of flame to the point of ignition, will be found very satisfactory. Producer and natural gas fire-brick gratings, in connection with a gas mixture chamber will be found good. The nipples from valves to burners which constitute the mixing valve in small burners should not be less than 8 ins., as the lesser length creates a liability to back firing or flashing. Ordinarily burners should be located from 1 to 2 ins. from the water leg of the boiler unless annular burners, or burners of the perforated pipe type, are used, which would not be located less than 3 ins. from the water leg. This is for the reason that the flame from annular burners cannot be impinged at an angle and there is a tendency for the flame to reverberate and striking the fire surface reflect back upon the burner. This should at all times be prevented.
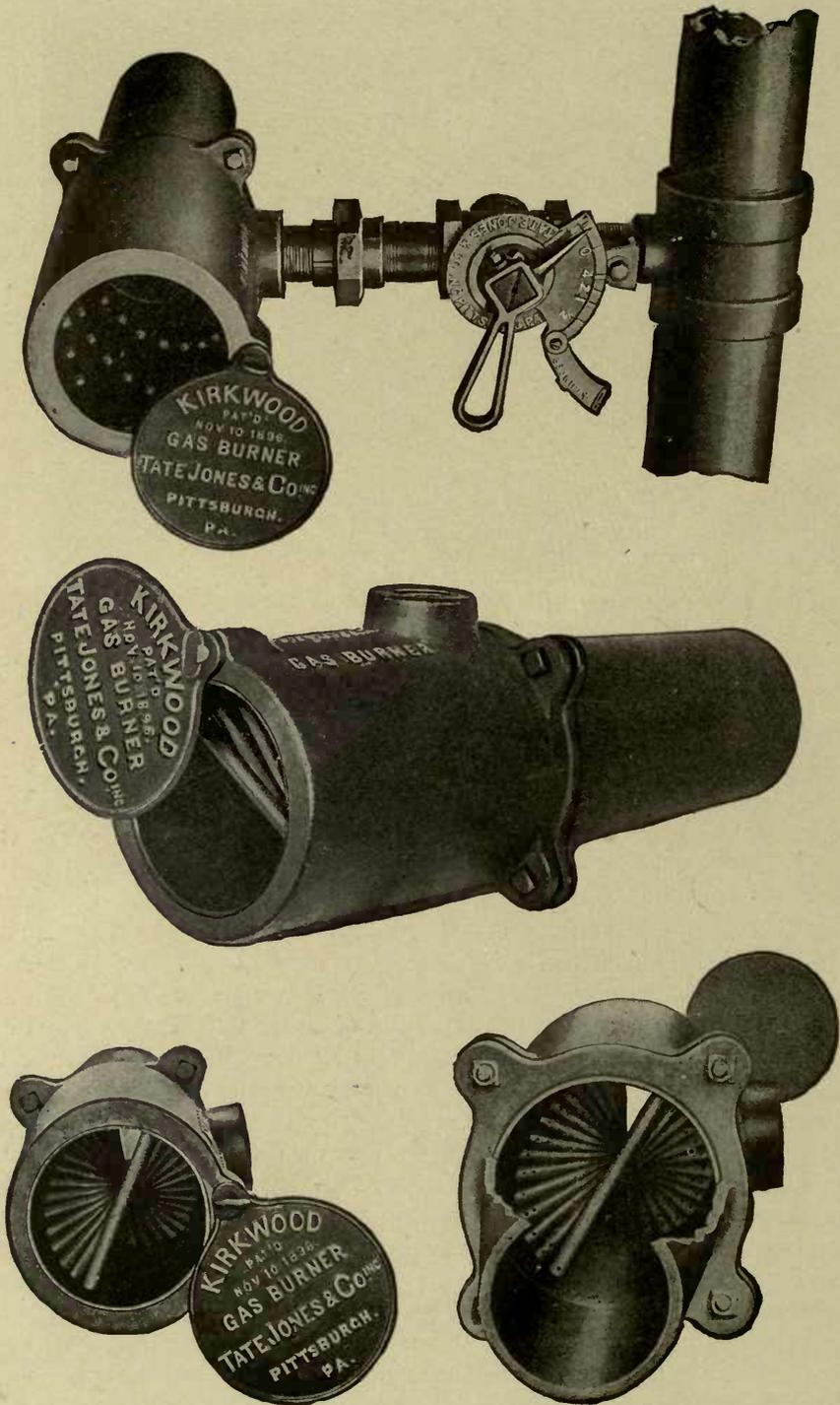
FIG. 149.—Kirkwood Natural Gas Burner.

As in ordinary boilers, sheet iron dampers should be used and the damper so adjusted as to allow only enough to escape through the flue to
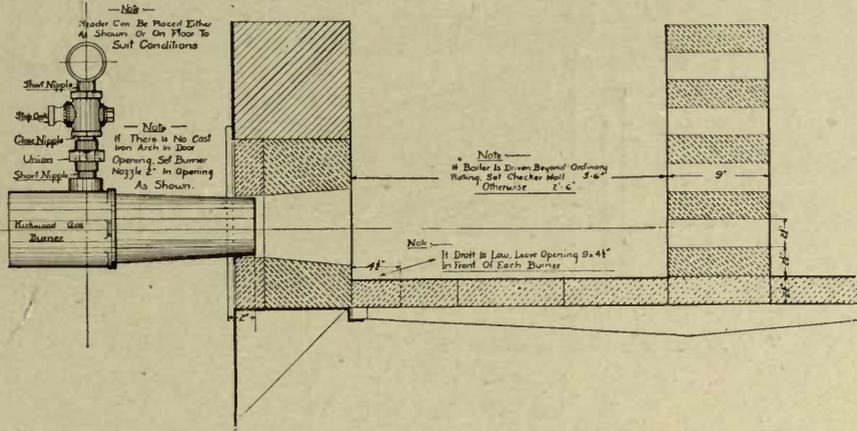
FIG. 150.—Position of Burner and Fire-wall in Furnace.

carry off the products of combustion. The flame is usually so regulated as to travel as far as possible along the sections of the boiler.

It is claimed by some engineers that the best practice is to direct the flame into a network of fire-brick, so that it is thoroughly diffused and spread before coming into contact with the heating surface of the boiler, rather than to allow the flame from the several burners within the furnace to impinge directly against any part of the heating surface, which might in that way cause damage by reason of inequality of temperatures. The gas
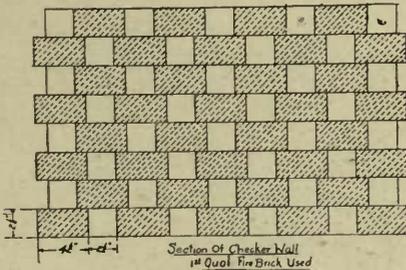
FIG. 151.—Front of Fire-wall.
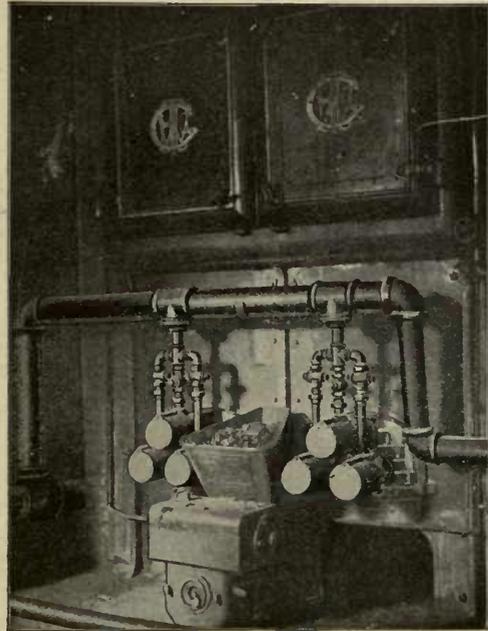
FIG. 152.—Kirkwood Burners Applied to Water-tube Boilers without Disturbing the Stoker.

is impinged into a lattice or checker-work pen, built up of fire-brick. The interstices (made by use of " soaps " or half brick), regulating the intimacy of the mixture.
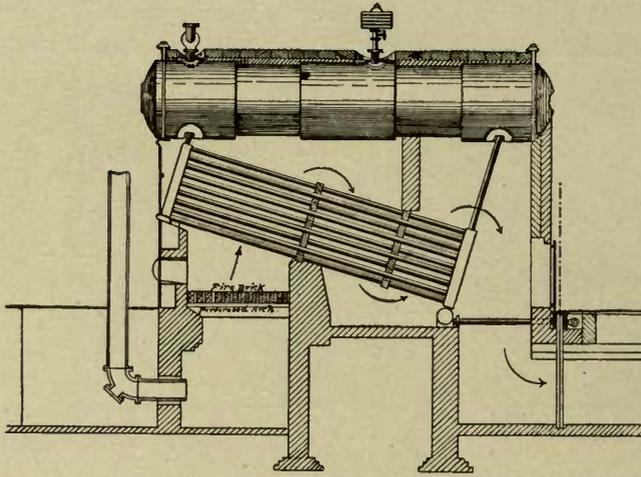
FIG. 153.—Gas-fired Water Tube Boiler.
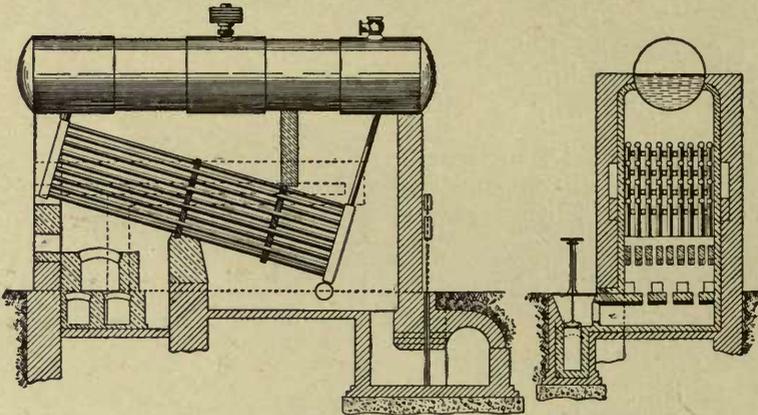
FIG. 154.—Another Gas-fired Water Tube Boiler.
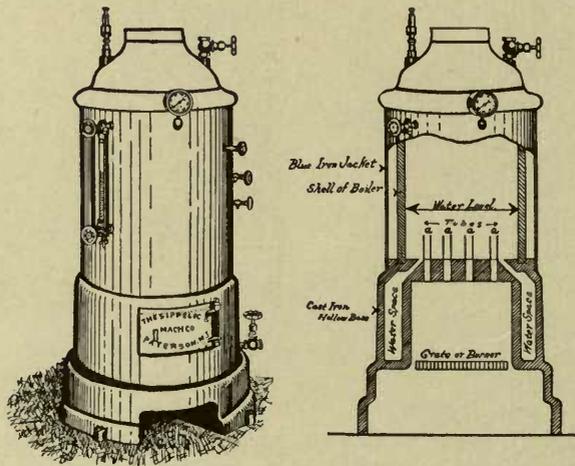
FIG. 155.—The Sipp Gas-fired Steam Boiler.

The use of producer gas-firing of boilers is only to be advocated under conditions of low grade fuels, with particular reference to lignites. With this character of coal the efficiency of direct firing is largely reduced in the average type of boiler by the loss of a portion of the high volatile matter. This gas escapes from the combustion zone more rapidly than it is consumed, that is to say, it passes the ignition area prior to its ignition.

The flame propagation of lignite is so rapid as to make its direct firing by hand a matter of extreme difficulty. Moreover its tendency to " fine " makes close grates impractical, while in using wider grates or voids the grate loss is materially increased. With coal of this character it is therefore economical to use two-stage combustion and gasify it prior to its admission into the combustion chamber.

Boilers Using Waste Gases.—The proportioning of boilers for blast furnaces is discussed as follows by Kent, who says that Mr. Gordon's recommendation for proportioning boilers when properly set for blast furnace gas is, for coke practice, 30 sq.ft. of heating surface per ton of iron per 24 hours, which the furnace is expected to make, calculating the heating surface thus: For double flued boilers, all shell surface exposed to the gases, and half the flue surface; for the French type all the exposed surface of the upper boiler and half the lower boiler surface; for cylindrical boilers not more than 60 ft. long all the heating surface. To the above must be added a battery for relay in case of cleaning, repairs, etc., and more than one battery extra in large plants, when the water carries much lime. For anthracite practice add 50% to above calculations. For charcoal practice deduct 20%.

In a letter to the author in May, 1894, Mr. Gordon says that the blast furnace practice at the time when his article (from which the above extract is taken) was written was very different from that existing at the present time; besides, more economical engines are being introduced, so that less than 30 sq.ft. of boiler surface per ton of iron made in 24 hours may now be adopted. He says further: Blast furnace gases are seldom used for other than fuel requirements, which of course is throwing away good fuel. In this case in a furnace in ordinary good condition, and a condition where it can take its maximum of blast, which is in the neighborhood of 200 to 225 cu.ft. atmospheric measurement per sq.ft. of sectional area of hearth, will generate the necessary horsepower with very small heating surface owing to the high degree of the escaping gases from the boilers which is frequently 1000°.

A furnace making 200 tons of iron per day will consume about 900 h.p. in blowing the engine. About a pound of fuel is required in the furnace per pound of pig metal.

In practice it requires 70 cu.ft. of air piston displacement per pound of fuel consumed or 22,400 cu.ft. per minute for 200 tons of metal in 1400 working minutes per day at say 10 lbs. discharge pressure. This is equal to $9\frac{1}{4}$ lbs. m.e.p. on the steam piston of equal area to the blast piston or 900 i.h.p. To this add 20% for hoisting, pumping and other purposes for which steam is employed around blast furnaces, and we have 1100 h.p. or say $5\frac{1}{2}$ h.p. per ton of iron per day. Dividing this into 30 gives approximately $5\frac{1}{2}$ sq.ft. of heating surface of boiler per horsepower.

Water tube boilers using blast furnace gases are described by D. S. Jocobus (Trans. A. I. M. E., xvii, 50) who reports a test of a water-tube boiler using blast furnace gas as fuel. The heating surface was 2535 sq.ft. It developed 328 h.p. (Centennial standard) or 5.01 lbs., of water from and at 212° per square foot of heating surface

per hour. Some of the principal data obtained were as follows: Calorific value of 1 lb. of the gas 1413 B.T.U. including the effect of its initial temperature, which was 650° F. Amount of air used to burn 1 lb. of the gas equals 0.9 lb., chimney draught 1⅓ ins. of water. Area of gas inlet 300 sq.ins.; of air inlet 100 sq.in. Temperature of the chimney gases 775°. Efficiency of the boiler calculated from the temperatures and analyses of the gases at exit and entrance 61%. The average analyses were as follows, hydrocarbons being included in the nitrogens.

Blast Furnace Gas	By Weight.		By Volume.	
	At Entrance.	At Exit.	At Entrance.	At Exit.
CO_2	10.69	26.37	7.08	18.64
O	.11	3.05	.10	2.96
CO	26.71	1.78	27.80	1.98
Nitrogen	62.48	68.80	65.02	76.42
C in CO_2	2.92	7.19	. . . . .	. . . . .
C in CO	11.45	.76	. . . . .	. . . . .
Total C	14.37	7.95	. . . . .	. . . . .

Steam Boilers Fired with Waste Gases from Puddling and Heating Furnaces.— The *Iron Age* (April 6th, 1893) contains a report of a number of tests of steam boilers utilizing the waste heat from puddling and heating furnaces in rolling mills. The following principal data are selected. In Nos. 1, 2 and 4 the boiler is a Babcock and Wilcox water tube boiler, and in No. 3 is a plain cylinder boiler 42 ins. diameter and 26 ft. long. No. 4 boiler was connected with a heating furnace, the others with puddling furnaces.

	No. 1.	No. 2.	No. 3.	No. 4.
Heating surface, sq.ft.	1026	1196	143	1380
Grate surface, sq.ft.	19.9	13.6	13.6	16.7
Ratio heating surface to grate surface	52	87.2	10.5	82.8
Water evaporated per hour, lbs.	3358	2159	1812	3055
Water evaporated per sq.ft. lbs. per hour, lbs.	3.3	1.8	12.7	2.2
Water evaporated per lb. coal from and at 212°	5.9	6.24	3.76	6.34
Water evaporated per lb. fuel from and at 212°	. . . . .	7.20	4.31	8.34

In No. 2 1.38 lbs. of iron were puddled per lb. of coal.

In No. 3 1.14 lbs. of iron were puddled per lb. of coal.

No. 3 shows that an insufficient amount of heating surface was provided for the amount of waste heat available.

Gas Firing, Rust Boiler.—An arrangement is here illustrated for the firing of a Rust water-tube boiler by means of blast or producer gas, the gas being admitted through an over head flue, and there being no anticipation of burning coal. The burners enter the front above the fire door so that, should it be desired, the usual grates and accessories may be supplied and the boilers fired with coal in addition, or by coal or gas interchangeably.

Breeching
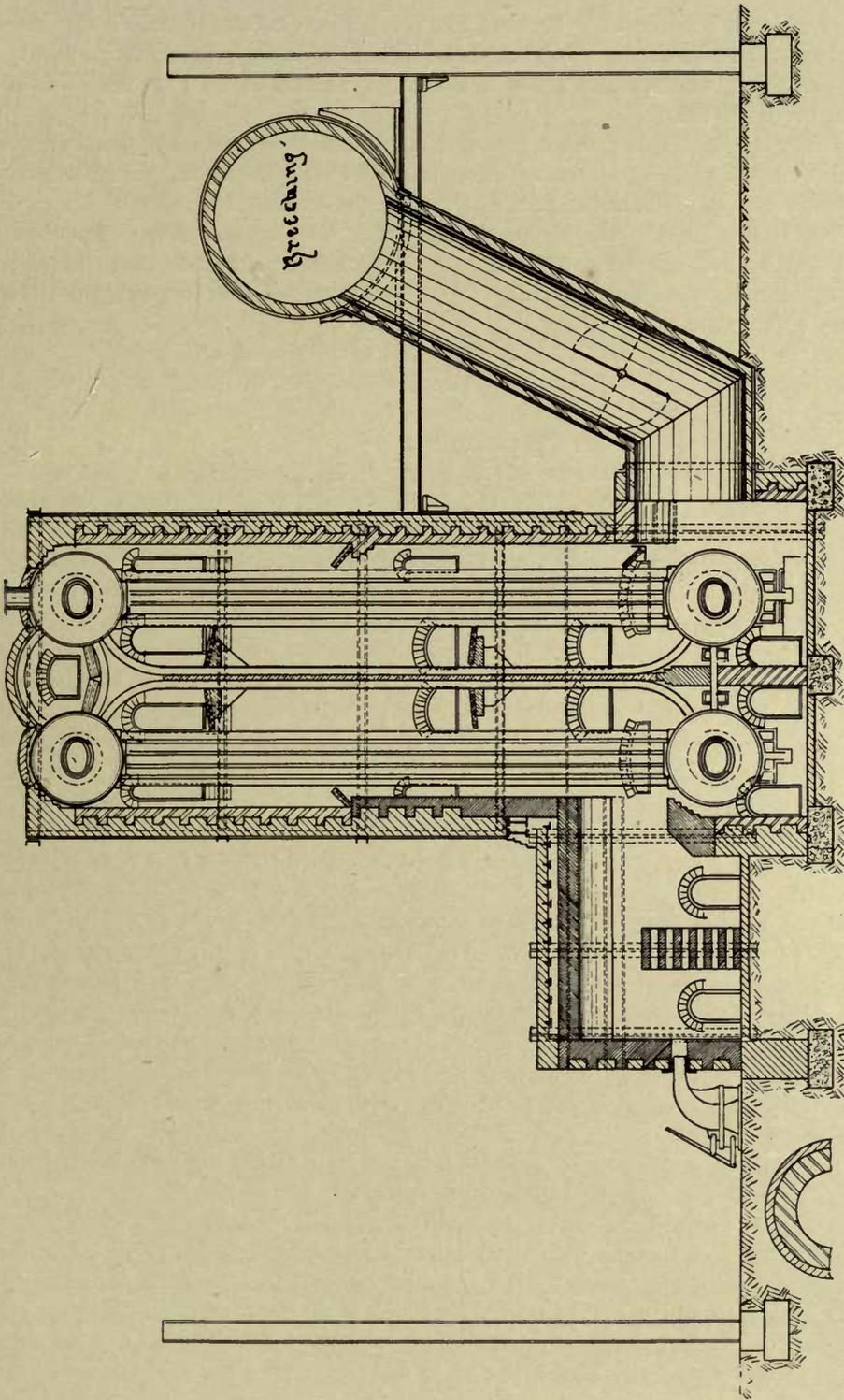
Fig. 156.—Rust Boiler Fired with Producer Gas.

Natural gas burners may be used for firing these boilers if sufficiently large, in which case there should be considerable additional area by reason of this latter heat value. In firing with natural gas a much larger volume of air per cubic foot of gas may be prepared for.

In using producer gas or blast gas some advantage in reverberation and combustion is obtained by impingeing the gases on or into checker brick-work. The former being particularly the case where the area of the combustion chamber is limited.

With low value gas the flame should never be allowed to impinge upon any portion of the heating surface of the boiler. This is for the reason that the relatively low temperature due to water cooling tends to reduce the flame temperature of certain portions of the gas below the point of igniiton whence it escapes unburned, with considerable consequent loss. Ample time and space should be allowed for complete combustion of the gas before striking these surfaces. In an installation, such as that indicated with a Rust boiler, 7 or 8 ft. should be allowed between the gas burner and the nearest portion of the heating surfaces.

Gas Firing, Lester Boiler.—A paper by J. H. Lester, M.Sc., published in the *Journal Soc. Chem. Industry* (May 15, 1908) describes a remarkable experimental form of gas-heated steam boiler which, if it can be copied on a large scale, will be likely to revolutionize the present methods of steam generation.

As an example of the high duty obtainable in steam production with this form of boiler, Mr. Lester states that a series of his gas-heated tubes built up into a block occupying only 1 cu.yd. of space, would evaporate as much water as a Lancashire boiler measuring 30 ft. by 8 ft. diameter and that the efficiency of the new boiler would be as high as that of the Lancashire boiler when worked with economizers.

The experimental boiler designed by Mr. Lester consisted simply of a copper tube of $\frac{3}{16}$ in. internal diameter, and 20 ins. in length, surrounded by a jacket allowing $\frac{1}{16}$ in. space between the two tubes.

The gas and air mixture entered at the top of the inner tube, and by careful regulation a flame 7 ins. in length, showing less than 0.50% of free oxygen, and less than 0.50% of carbon monoxide in the exit gases, could be obtained. The water entered the annular space between the two tubes and flowed upward in the opposite direction to that of the gas mixture. The cooling of the gas by the adoption of this principle of counter-current circulation was so effective that the latent heat of condensation of the water produced by the combustion of the gas was recovered; and the total loss of heat at the base (or chimney end) of the combustion tube never exceeded 5%. Mr. Lester, in fact, believes that by lengthening his tubes he could recover 100% of the calorific value of the gas in the water, and thus convert his boiler into a calorimeter.

The steam passed away by an outlet in the side of the upper part of the outer tube. The restricted space available for water was purposely adopted in order to prevent any downward current of water in the annular space.

The burning of the gas with the minimum of oxygen supply, of course increased the final temperature attained by the gas mixture, and therefore the efficiency of the boiler. It was found experimentally, that the production of a rapid series of gas explosions, or musical notes, appeared to be coincident with the conditions required for this perfect combustion, and that the mixture giving the highest musical note

when ignited gave the most satisfactory results as regarded low percentages of free oxygen and carbon monoxide in the exit gases.

A boiler constructed upon this principle, using producer gas, might therefore convert 95% of the heating value of the gas into the thermal energy of steam; and, as Mr. Lester remarks, the construction of such a boiler does not offer insuperable difficulties.

The theory of Mr. Lester's boiler is unquestionably correct, embodying as it does the well known principle of heat absorption from reverse currents.

However, it has certain mechanical difficulties which must be obviated. Principally that of the fact that the hot gases come in contact with the steam heat of the boiler instead of the water leg and it will be difficult for the tubes to resist the heat of same, there being no water cooling to protect them.

When experiments of this kind have been tried under commercial conditions, it has been found that not only have the tubes resisted the intense heat of the gas very badly, but it has been almost impossible to keep them tight within the tube sheet.

CHAPTER XIII

FURNACES AND KILNS

THE sensible temperature of the effluent gases from a pressure producer vary from 300 to 1500° F., according to the type of the producer and the nature of the fuel, rarely exceeding, however, 1000° F. The pressure maintenance upon the gas mains varies in practice from practically zero up to 4 ins. of water, equivalent to 2.4 ounces.

There is, of course, liability of explosion in such an application as to a gas-fired kiln, but there being practically no compression the resultant damage is usually trivial, and the danger practically confined to the possible scorching of attendants. Even this may be obviated by a reasonable degree of care in operation. All chances of asphyxiation must also be guarded against.

There are conditions for which the continuous kiln is not adapted and in such cases unit kilns must still be used. A scheme that has given good results in Germany is to build the individual fire boxes of such a form as to have the condition of gas firing, i.e., have a thick fuel bed and admit an auxiliary air supply over and above the surface of the fuel, in such a way as to secure a mixture of the air and gases before the latter are burned in the combustion chamber. With this arrangement it is possible to secure perfect combustion—eliminating the smoke nuisance—higher temperatures and better conditions in the kilns. The arrangement is simply the conversion of the usual fire box into a small gas producer. The Christy Fire Clay Company, of St. Louis, has introduced this method on some of its unit kilns for burning fire-brick.

Brick burning with natural gas, has reduced the length of the operation one-third, and the same decrease in time should be true of producer gas firing.

The German practice is to have one or more little producers built into each kiln, but the American system of centralizing the producer, or segregating the producers, is much more efficient, convenient, and economical of fuel, the latter showing in some instances a saving of $33\frac{1}{3}\%$.

If the gas is to be used in ordinary down-draft kilns, there should be a branch pipe leading into each of the fire-places already existing. In this pipe there should be a valve for regulating the amount of gas admitted. Just above where the gas enters, the air for supporting the combustion must be admitted. The two will combine behind the bag wall and the flame go up over into the combustion chamber, just as it does with the ordinary direct coal fire, except that the quality of the flame would be more like that from wood, being longer and softer and more easily diffused throughout the kiln than a coal flame. At the same time any desired temperature can be obtained, even great enough to melt fire-brick.

312

It may be noted, as an item of significant importance, that the majority of shaft or vertical kilns have not been particularly economical when operated by producer gas, as compared with kilns of horizontal type. This may be by reason of the reverberatory features with the latter type, or by reason of the increased rate in the flow of gases in the former due to both draft and convection, or it may be due to a combination of the several features noted.

Producer Gas Furnaces.—Producer gas being so low in caloric energy, cannot be used to advantage in high-temperatrue furnaces, without at least pre-heating the air for combustion. When both air and gas are properly pre-heated, as in the best regenerative furnaces, a very high economy can be obtained, and only a half or a third as much fuel is required to do a given amount of work as when the coal is burned direct.

The essentials for the economical heating of a high-temperature furnace are, a good quality of gas (preferably rich in hydrocarbons), properly mixed with just the right amount of air, both having been heated to as high a temperature as possible. The amount of air required is dependent upon the temperatures of gas and air. The proper mixing of the gas and air is very important. To obtain the best results, the mixture should be as rapid and intimate as possible, thus causing a high temperature in the shortest time after the air and gas come together. It is also important that the furnace should be of the proper shape and proportions, so as to utilize the heat generated to the best advantage.

The modern practice of heating by radiation instead of by contact is undoubtedly right; hence the high roof of the so-called regenerative gas furnaces, and the large volume of luminous gas with its powerful radiating properties over the bed of iron or other material to be heated. It is certainly a fact that we require a very much greater volume of non-luminous gas than we do of luminous gas to do a given amount of heating at high temperatures.

In many works we find the waste heat from the furnace used in making steam, and this plan is advocated by some high authorities. But, if there were no other objections to it, the waste heat from the furnace heating iron for instance, would be very much more than is necessary for furnishing the power to roll the product. For this reason alone it is better to recover the waste heat and return it to the furnace, generating steam in a separate apparatus as required; for it will be impossible to arrange any works so as to utilize all the waste heat direct from furnaces.

Regenerative furnaces have been much improved of late years by making the roofs higher and working on the radiating principle. Maximum economies can only be obtained from these furnaces, however, by running them continuously, say for a week at a time, as it takes a large expenditure of energy to heat them up when they are once allowed to cool.

In many cases, where a very high temperature is not required, producer gas can be used with considerable economy over direct firing, by pre-heating the air only, up to a temperature of 500° or 600° in " continuous regenerators." These are usually composed of iron pipes, through which the air is blown or drawn, and which are heated from the outside by the waste gases from the furnace. While these do not give as great economy as the alternating brick regenerators, they are much less expensive and troublesome to operate. Of course they cannot be used when the temperature of the

escaping gases is high enough to destroy iron pipes. Terra cotta pipes and fire-brick flues have been used in place of iron pipes for continuous regenerators, but they do not conduct heat well, and are very liable to crack.
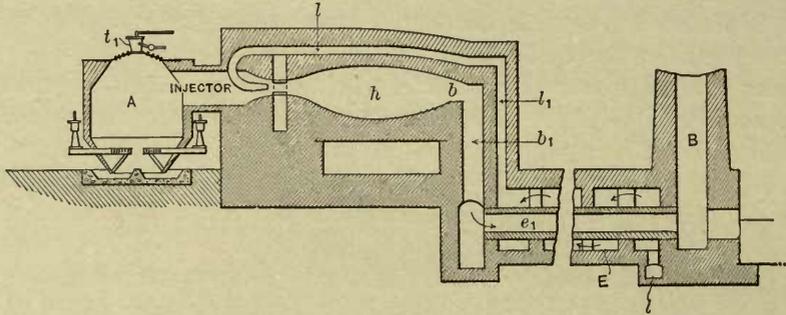
FIG. 157.—Producer Gas-fired Metallurgical Furnace. The pre-heated air is admitted under pressure.

Although regeneration should always be employed when practicable, especially where the waste gases escape at a high temperature, in many kilns and furnaces, when
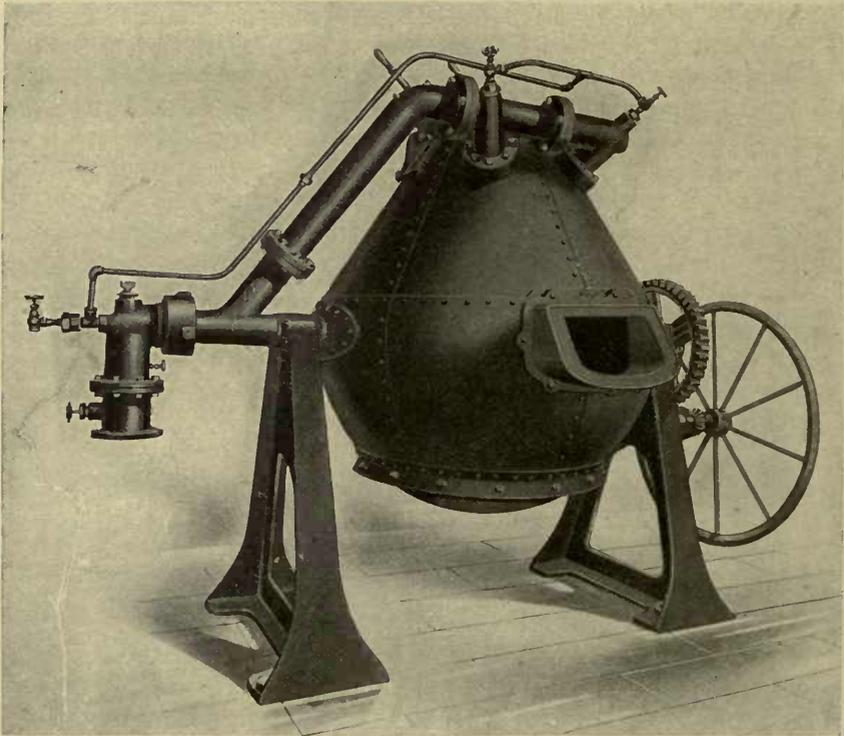

FIG. 158.—A 60-inch Schwartz Gas-fired Furnace.

the temperature required is not very high, producer gas may be used with marked economy without regeneration. This economy is principally due to the better facili-

ties for perfect combustion, the fact that less air is necessary, the saving of coal from the ashes, and especially where the producer is fed automatically and continuously, the improved and uniform quality of the gas and consequent great regularity of the heat obtained. Besides these the absence of dust, the smaller amount of labor required, and the substitution of a cheap for an expensive fuel, are often important points. But producer gas cannot be burned satisfactorily in very small quantities, where both gas and air are cold. The flame is very easily extinguished, and even a low red heat is reached with difficulty.
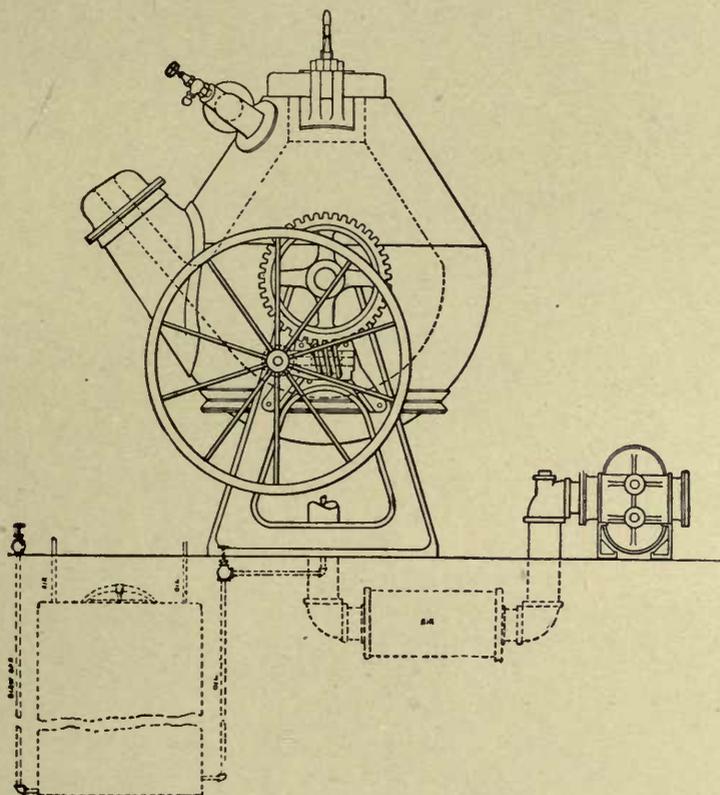
FIG. 159.—Gas Connections to Schwartz Furnace.

In Europe producer gas has been applied much more generally than in this country. We have become thoroughly familiar with its use, in the heating furnaces of our iron and steel mills, but it is fast working its way into other industries, such as glass furnaces, brick, pottery, and terra-cotta kilns, lime and cement kilns, sugar house char kilns, silver chlorination and ore roasting furnaces, for power purposes in gas engines, etc. The introduction of producer gas has conclusively shown that when made in a good producer and applied with a proper attention to the laws governing combustion, a considerable saving is effected over the former wasteful methods.

The illustrations of tilting furnaces show how producer gas firing can be used on both a large and small scale and on a practical basis.
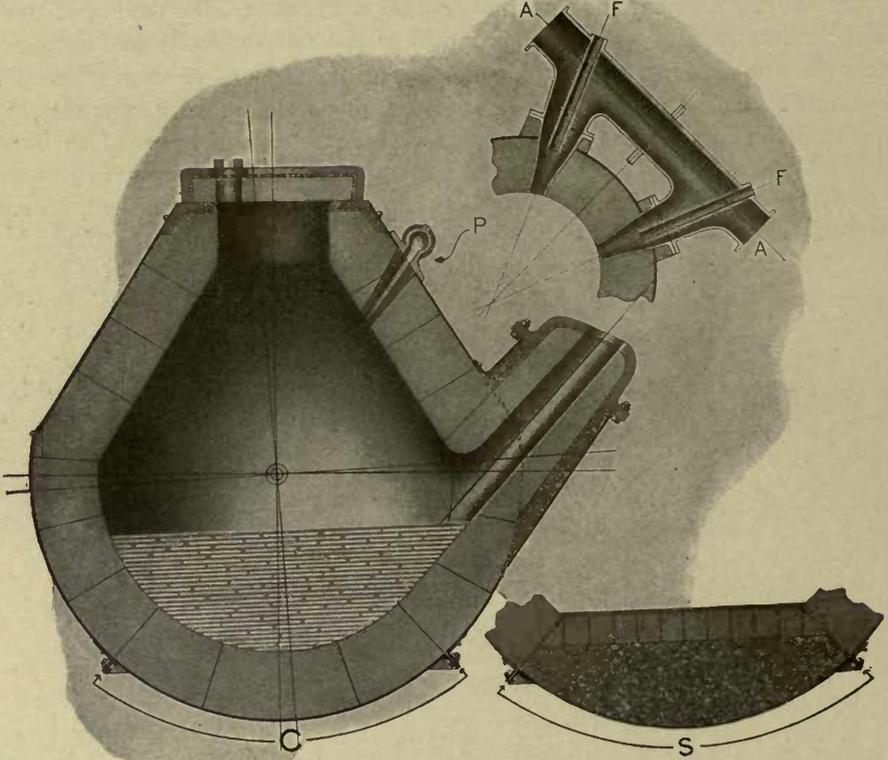
FIG. 160.—Fire Tile Lining of Furnace.
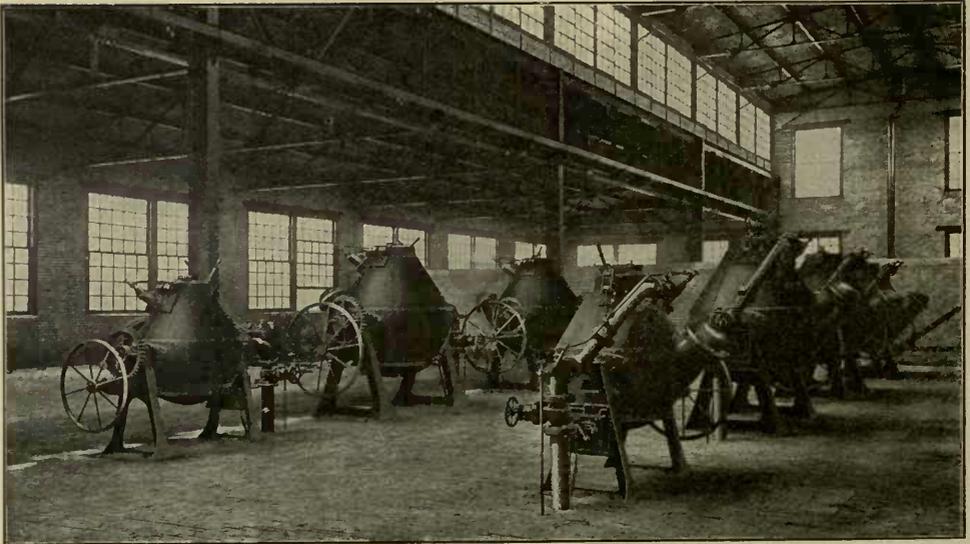
FIG. 161.—Schwartz Furnaces of 45 Tons Capacity per day at the Plant of the Magnus Metal Co
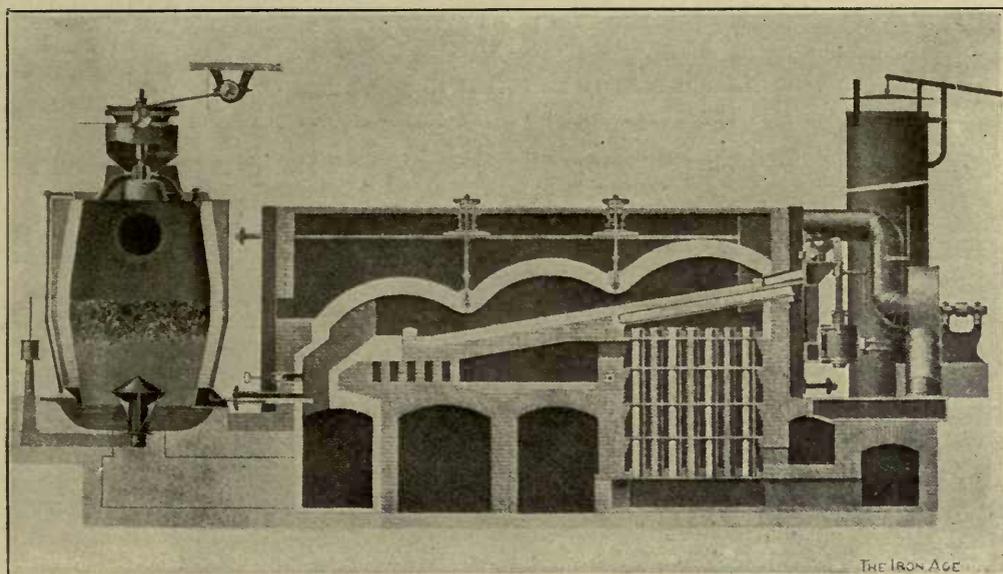
Fig. 162.—Morgan Producer and Furnace for Heating Billets 30 ft. long.

Gas Firing of Kilns.—In the matter of gas firing of ceramic ware we would recommend the advantages as being:

1. An attainment of more perfect combustion, as the fuel in the gases formed burns quickly and perfectly. Again the transformation of heat into a potential form allows the combustion to take place more nearly at the point where the heat can be applied with the highest efficiency, instead of a consumption of fuel in the furnace itself, with the resultant waste of radiation.

2. Gas firing permits the use of regenerators for restoring a large portion of the waste heat, in the form of sensible heat, to the gas and air, prior to their admission into the furnace. This fact, taken into combination with the foregoing, creates a considerable resultant economy.

3. As an advantage on the side of gas firing, is the uniformity of heat obtained, which is impossible with the direct furnace, due to variations and fluctuations, as to cooling apparatus, cleaning, etc.; although this, of course, occurs to some extent with producer work, such variations are reduced to a minimum by reason of the intervening medium of transmission and of equal fuel bed.

4. In metallurgical work the loss by oxidation where producer gas is used rarely exceeds 1% in some instances, with a low hydrogen gas being even less, while the common practice of furnace work will average 3%.

Finally and perhaps most important, is the saving in labor, which is materially diminished in producer work, by the concentration of firing, the ability to use mechanical devices, and the reduction of actual coal handled.

Brick and Tile Manufacture.—In the manufacture of tile and brick, five items are of particular importance:

1. The time or period of the operation.

2. The continuity of operation of a plant capable of manufacturing at all seasons of the year and under all conditions of weather and temperature.

3. The question of labor and its reduction to a minimum.

4. The waste, and the manufacture of the finished product with a minimum of material including fuel.

5. The quality of the product.

One of the most important features in the manufacture of a product of this kind consists in the pre-drying of material. Inasmuch as a pre-heating of the air or elements of combustion tends to shorten the flame, creating a short, stubby, cutting flame through the increase of flame propagation, when a more voluminous flame of uniform temperature or combustion occupying a relatively large area is required by the conditions of heat expulsion and the physical character of the material it is manifestly best to utilize all of the waste heat possible for this pre-drying process.

In pre-drying material two conditions are requisite, the first being the application of heat together with its circulation throughout the material. The second the escape of the products of condensation or aqueous vapor expelled, distilled or vaporized through the action of the heat thus applied.

To accomplish this it is manifestly necessary to turn water into vapor, which process requires absorption of a definite amount of heat. For example, to evaporate a pound of water into vapor at the temperature of 60° requires 1070 B.T.U., the vapor thus evaporated having a pressure of one-quarter of a pound per square inch and 1000 cu.ft. of the vapor weighing 0.82 pounds.

The presence or absence of air has no effect upon the production of aqueous vapor. At 60° F. evaporation will proceed until 1000 cu.ft. of space contains 0.82 lbs., when evaporation will cease until the vapor is removed. If air is present it is said to be saturated when that condition obtains in which no further evaporation takes place.

Inasmuch as air has no chemical affinty for water vapor, it is manifest that it must be kept in motion to sweep away through physical action the water vapor already formed, the escape of which would otherwise be extremely slow.

Of course at and above a temperature of 212° F. the pressure of aqueous vapor is above atmosphere and its expansion is such as to force aside atmospheric or air pressure without additional force.

Conversely, therefore, it will be seen that unless drying is conducted at a boiling temperature, or that of 212° or over, a continual renewal or movement of the air is advantageous or from a practical standpoint an essential condition, in order that the displacement may be created for the formation of more vapor or continued vaporization.

Again the action is dual: not only is vaporization accelerated, but fresh supplies of heat are brought in contact with the material to be dried in the process of the circulation thus maintained.

There is also a cooling effect upon material from which moisture is evaporated. According to one authority, the evaporation of one ounce of water from a pint would reduce the temperature of the whole pint from 96° F. to 32° F. or freezing point, were no extraneous heat supplied.

In sun-dried brick or tile the evaporation occurs through the radiant heat from the sun and by contact with surounding objects, principally that of the enveloping air. In an artificial drying of brick and tile the heat for drying has been heretofore

supplied by the combustion of fuel and very considerable expense. The usual drying may be divided into three classes:

1. Drying due to products of combustion circulating among the material which in driving off aqueous vapor is termed " water smoking."

2. By imparting heat from the products of combustion to clean air and allowing the latter to dry the brick, as in the case of the hot air or hot blast drier.

3. The utilization of heat primarily created in burning or calcining the material within a kiln; then drawing through the burned or calcined mass left, at a high temperature, a volume of fresh air, while the kiln is in a cooling state, the air being induced or forced by means of fans; the air becoming heated in this passage performs the dual function of cooling the kiln and material, and of heating or drying the green material in the second kiln through which it is forced, known as the " green kiln," this being termed the " waste heat " process.

4. The fourth plan is that of using the heat of combustion to generate steam in the boiler and passing this steam through the medium of pipe coils underneath the drying floor, and through pipe partitions where it heats the air which in turn circulates through the material to be pre-dried, its action being both by radiation and conduction. It is termed the old style " hot floor " or " direct dryers " method.

5. The fifth method is that of generating steam which is used in heater coils to heat air within a chamber, which being brought up to a certain temperature is forced by fans through the material to be dried. This is known as the indirect or hot blast system and while efficient is most extravagant in cost.

In the last two systems exhaust steam may be used, as it contains from 80 to 90% of the heat originally contained by the live steam, it, however, possessing the drawback that the amount of exhaust steam necessary for the purpose is not usually available, as it is disproportionate in its volume or amount with the boiler installation necessary to be maintained in a plant of this character, or for the mechanical load factor.

It is evident that the economic adoption suggested by a comparison of these systems will show the rational method to be the third type or " waste heat process " inasmuch as it permits the regeneration and use of a by-product of heat which must be otherwise totally lost.

The method of interchangeable connection between the kilns permitting any combination of series or multiple to be made, enables each green kiln in burning to act as a regenerator or economizer for its predecessor in a cooling state, also the blast of cool air induced or forced through the cooling kiln increases the cooling process, effecting a time economy of not less than 25%, hence materially increasing the output of the plant per kiln.

Large fans of the Green fuel economizer type especially designed for the handling of heated gases are usually used. They run at a comparatively low speed, and the power required is relatively small.

Instead of the piping shown in the illustration, it is possible to use flues or tunnels underground with proper valves and by-passes, which have perhaps a higher insulating quality. They have, however, the disadvantage of becoming readily water trapped, unless made with great care and with expensive construction.

Spiral pipe, riveted pipe, or even No. 12 galvanized blast pipe, the latter being duly supported, may be used in connection with the arrangement mentioned, and

it is even possible to line this pipe with fire-brick, or in cases, to cover it with some insulating material, the former being the better arrangement to reduce its radiation losses.

　　Another salient feature is reduction in cost of firing, and its attendant labor. This is due to the fact that while the producer requires a crew of but two men per shift, and may be fed by a satisfactory conveyor or feed hopper, or some other device,
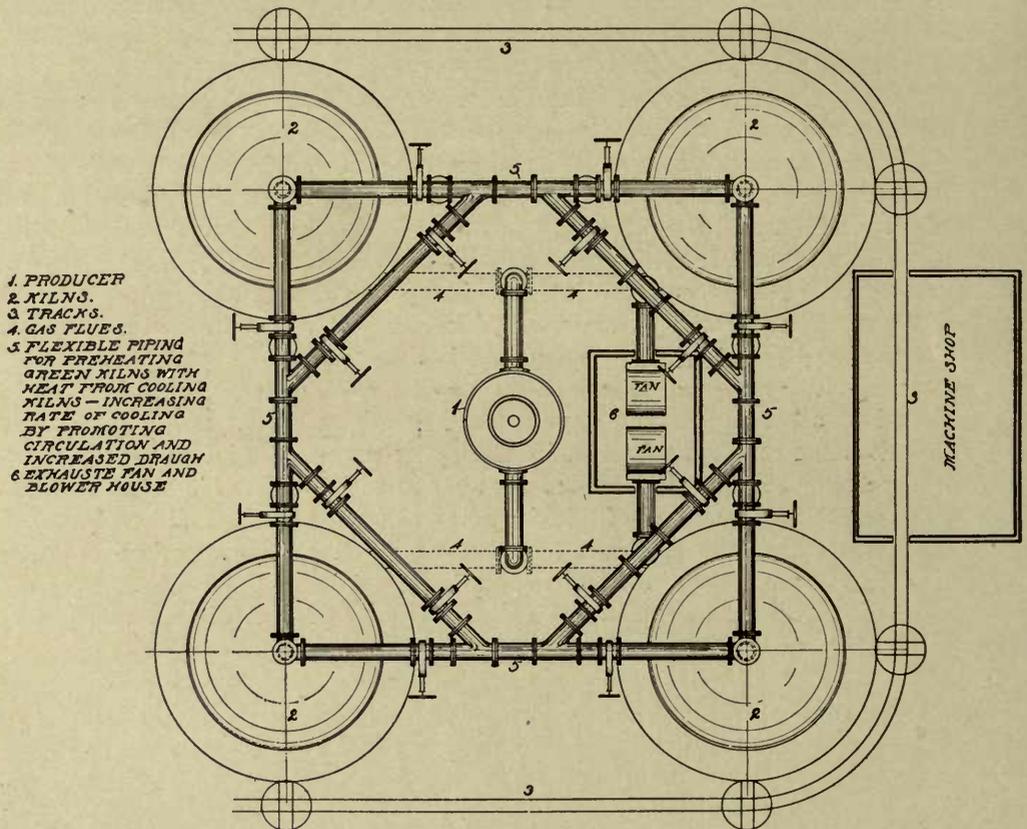

Fig. 163.—Brick Plant Heated by Producer Gas.　Arrangement and connections.

the direct fired kilns have all the way from two to eight furnaces and rarely ever have less than two men per kiln per shift, hence it will be seen that the reduction of labor is about 75%.

　　Again the operation of burned kilns under direct firing is exceedingly difficult, due to slagging and the formation of clinker. This may be to a great extent obviated in the producer by the manufacture of gas at a lower temperature than that of the fluxing point of fusible ash.

It is of course admitted that this condition is materially dependent upon the nature of the coal. In any case, however, it may be relatively reduced.

Again the other losses relative to gaseous combustion, especially those regarding localization of temperature and the accomplishment of combustion without air excess, are particularly emphasized in this application.

Consequent upon the former the uniformity of the product is materially enhanced, the " burn " due to a voluminous combustion instead of a high localized temperature or reducing flame is much more even throughout, resulting in less over-burned brick at the sides, crocking and vitrifying, and less green or unbaked brick at the center or remote from the flue passages.

The installation cost of down-draft kilns in connection with an arrangement of this kind, is comparatively high, but when its continuity of service is taken into
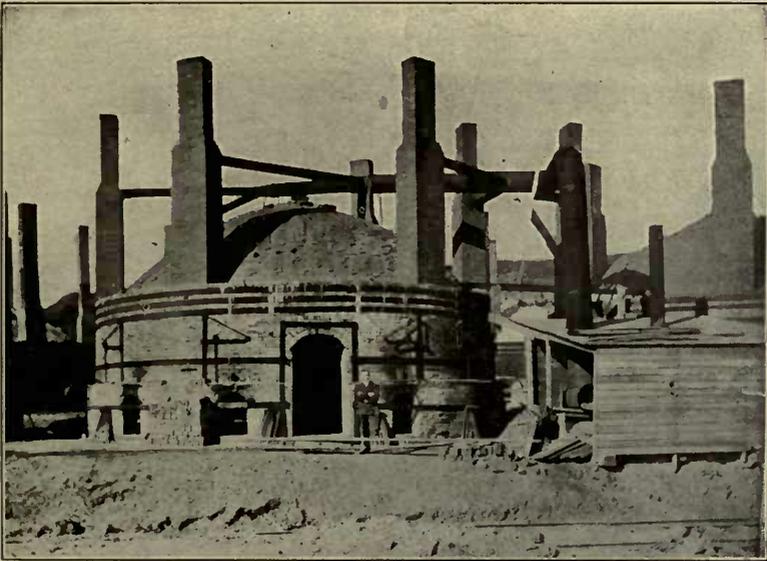
Fig. 164.—Brick Kiln with Mechanical Draft.

consideration (the service of the Scotch or Summer kiln will not average through the United States more than four months per annum), together with the increased cost and scarcity of wood, there is but little doubt that this arrangmeent will be shortly adopted exclusively, with the exception of certain southern territory where the winters are open and wood fuel yet plentiful. For fire-brick and other tile requiring any degree of perfection or uniformity of product, this mtehod has become well established.

Taking into consideration comparative industrial work, the down-draft kiln is certainly extremely effective. This is due to the dissemination of gases and combustion throughout its area and the reverberatory effect of its conical dome. The lines of this dome by the way should be so calculated as to prevent extreme convergency of the reflected heat rays, as such an error frequently occasions concentration and irregularities of temperature.

It should be borne in mind in the designing of these kilns that the law of area to volume is particularly potent, that is to say, while the contents of the kiln increase as the cube of the dimensions the radiating surface varies only as the square; hence within certain structural limits the larger the kiln the more efficient, for the mass of contents once heated acts as a most efficient burner and the principal heat loss of the kiln is due to radiation.

The gas is usually conducted to the various portions of the kiln through brick flues, the main flues being permanent in structure. Great care should be taken in making the main conduits and walls of the kiln extremely tight as any leakage is promotive of air excess and consequent economy less in combustion. The best results of this combustion has generally been obtained when an analysis of the flue gases shows just a trace of CO, say, half of one per cent; this, however, is rarely possible by reason of the kiln leakage.
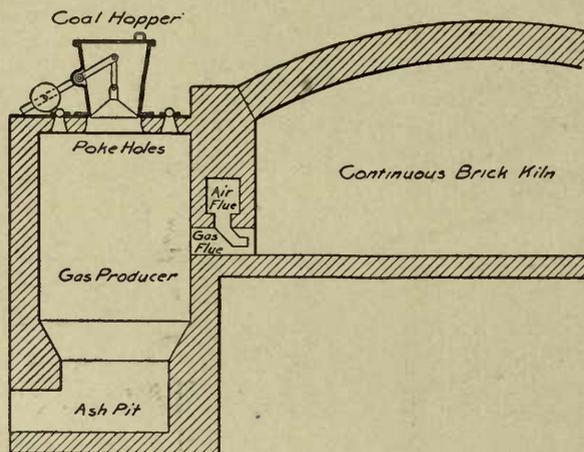
FIG. 165.—Arrangement of Pre-heated Air Flue.

Youngren Kilns.—The continuous kilns, of which the Youngren is one of the most prominent types, is built of a series of communicating chambers (see illustration), and is divided into two general glasses known as the "tunnel" and "chambered" kiln, the former being cheaper to construct, but the latter requiring much less labor in operation, together with making a more uniform product.

The number and size of the chambers is regulated by the capacity of plant, the nature of the clay, and the length of time it takes to set, dry, water smoke, burn, cool and empty a chamber. The combined holding capacity of all the chambers should be from sixteen to twenty times the daily capacity of the plant. A continuous kiln is especially adapted to the burning of all kinds of the better grades of clay ware which are usually burned in "down-draft" kilns, such as face-brick, paving-brick, terra cotta, fire-proofing, drain tile, etc., as well as for common building brick.

The cycle of operation on a 12-chambered kiln, such as that shown in the illustration, is as follows:

Bricks are being alternately set and dried in chambers Nos. 1 and 2.

No. 3 is being emptied and cleaned out preparatory to setting when No. 1 is filled.

No. 4 is nearly cool, the caps having been removed from the crown, the doors and wickets being open.

Nos. 5, 6, and 7 are in their various stages of cooling.

Air for cooling is admitted into chamber No. 4, and is circulated through Nos. 4, 5, 6, and 7; it then passes through No. 8, which is red hot, the firing having recently ceased; this hot air then goes on to supply combustion for firing in chambers Nos. 9 and 10; the products of combustion given off by these latter two chambers pass through No. 11 and raise its temperature to a straw heat, ready for direct firing, after which the gases pass on through No. 12, which has just been sealed up.

Surrounding the chambers is a hot air or waste heat duct, to which is attached an induced draft fan. In the cycle just described, this fan pulls directly on No. 12,
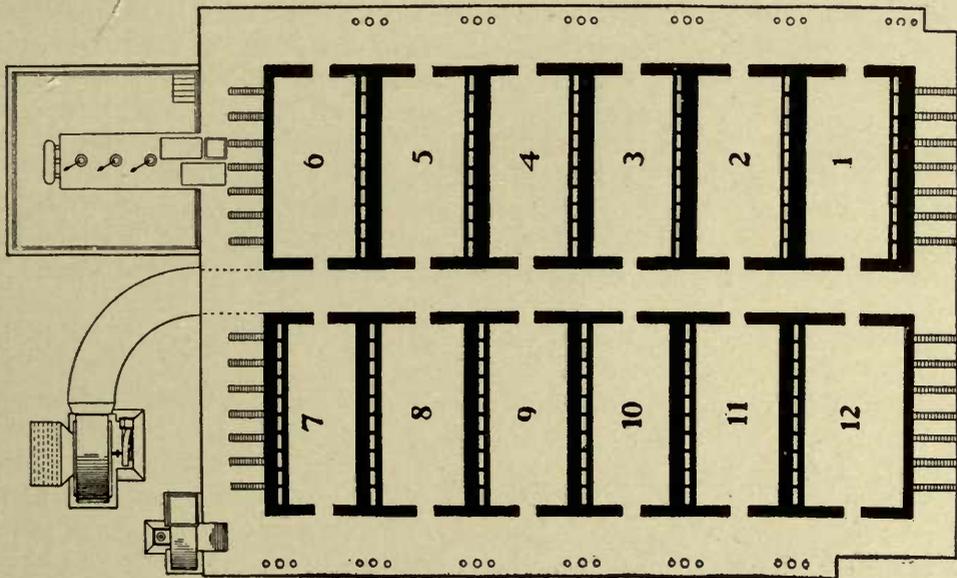
Fig. 166.—Diagram Plan of Youngren Continuous Producer-fired Brick Kiln.

discharging freely into the atmosphere. The draft thus created causes the circulation just described through all the other chambers back to and including No. 4, where the air is first admitted.

Supposing the start is made in chamber No. 1, and further, that the chambers are of such size that a tier of brick will equal half a day's output; then at noon the setters will shift over to chamber No. 2 for the afternoon, heat and air being turned into No. 1 to dry the bricks set therein. The next morning the setters start in No. 1 again, this alternate setting and drying being repeated and the conveyors remaining in their respective chambers until the kiln is filled.

The heat and air for drying the bricks are obtained from a bank of encased steam coils and a blower. The coils are supplied with exhaust steam from the main engine, blower engines, feed pumps, etc., this being supplemented by whatever live steam is required. The duct which conveys the air to the chamber passes between the two rows of chambers, suitable dampers being provided for opening and closing communi-

cation between this duct and the chambers on either side of it. Single battery kilns can be constructed when local conditions warrant it, the process being made continuous by a return duct from the last to the first chamber to convey the heat and gases.

The gas producer is preferably located at one end of the kiln. The main gas duct is carried across the end and along both sides of the kiln outside the hot air duct. From the bottom of the duct smaller ducts extend across beneath the hot air duct, exactly opposite the walls between the chambers. These latter ducts lead to short flues in the division walls, at the tops of which are distributing passages to convey the gas to the openings leading into the combustion chambers behind the flash walls. The gas ignites immediately upon entering the combustion chamber, the intensity of the heat being regulated to a nicety by a valve operated by the wheel on the controller column.

As already mentioned, the fresh air which supports combustion is heated to a very high temperature by first passing through the chambers which have been burned and are being cooled off. The amount of air can also be controlled by dampers operated from the top of the kiln so as to get the highest combustion efficiency. The air and gas are mixed in their proper proportion just before entering the combustion chamber.

The induced draft fan not only gives the required draft for combustion but also maintains the proper circulation of air through the chambers which are cooling off, and draws the products of combustion through the chambers which have been set, thus doing the water smoking and raising the temperature up to the point where firing can begin.

In the crowns of the kilns are vents, the covers of which can be removed to accelerate the cooling of the chambers.

The heat for drying is obtained from the bank of steam coils which are enclosed in a steel jacket. The blower draws fresh air across the coils and discharges into the warm air duct.

The air for drying is admitted to the chambers through openings in the end walls, and the heat given off by the bricks in cooling is drawn through openings at the opposite end of the chambers. The blower can be driven by a direct-connected engine or by a belted engine or motor. Manhole plates are provided for easy access to all the ducts.

The main conveyer is suspended from cables, which latter wind around a shaft for raising and lowering the conveyer, according to the height of the courses of bricks as the setting progresses. The cross conveyer, which carries the bricks from the main conveyer into the chambers, is simply a light, ball-bearing, gravity conveyer, one end of which is supported by the main conveyer, the other end resting on a tripod inside the kiln.

Owing to the very high temperature of the air which supports the combustion of the gas, the general atmosphere in the burning chambers is usually highly oxidizing. Should this be undesirable, the required chemical reactions during the burning process can be readily produced. This is accomplished by maintaining a reducing atmosphere periodically, which is brought about by shutting off the air supply in the connecting passages between the cooling chambers, by suitable dampers provided for that purpose.

The condition within the kiln can be changed in less than two minutes, from an oxidizing character to a neutral or more or less powerful reducing character, by a

simple manipulation of valves. No rules can be laid down as a guide for the treatment of different clays, during the various stages of making into bricks. By this arrangement a saving of from 24 to 36 hours is effected in drying time, besides the drying being made more effective. The water smoke period is reduced about one-half.

The bricks are set in about the same manner as usual, except that the number of courses high has to be regulated according to the stiffness of the clay and the ability of the bricks in the lower courses to support the weight of those above. This varies from six to thirteen courses with different clays.

When the entire bottom of the kiln has been covered with bricks, set as many courses high as has been found practicable, the setters raise the conveyer to the proper height for the next tier, and then go into another kiln or chamber to repeat the operation while the bricks previously set are allowed to dry.

When the bricks in the first tier have dried, the setters begin setting another tier on top of them. This is repeated until the kiln is filled, when the conveyer is withdrawn and moved to another kiln or chamber. The last tier dried, the kiln door is then cased up, and the kiln burned in the same manner as though the bricks had been dried in a typical car system or tunnel drier.

The first tier need only be dry enough to support the weight of the second. The heat passes over the first tier before reaching the second, when the latter is ready for drying, and over the first and second to dry the third, and so on until it finally reaches the top tier. When the top course is dry, the bottom courses are thoroughly dry and as hot as the hot air will make them, the kiln being in a perfect condition to start firing without water smoking.

The circulation of air is necessary to carry off the moisture is produced by one or more fans or blowers. The motive power can be either a steam or gas engine, or an electric motor.

The air for supplying combustion is heated to a very high temperature while performing the service of cooling the chambers already burned. The hotter the air is, the less fuel is requred.

In metallurgical furnaces of the open-hearth type a saving of 30% is assumed to be effected where furnace is of the full muffler type with complete regeneration. Where over 2000° F. is required and up to 3000°, the secondary air must be highly pre-heated. Above 3000° air and gas should be pre-heated to the maximum.

The saving in brick or ceramic kiln gas firing over direct firing is usually estimated at 40% under conditions of proper applications. Temperatures in kilns or furnaces of this kind are relatively low.

Schmatolla High Temperature Kiln is based on the Siemens system, which had been in use a long time, for example, in the steel industry. The system chiefly consists in the particular connection of the heating chamber a with two or more heat collectors or accumulators b, and a generator, which is arranged beteewn the heating chamber and the regenerating chambers in such manner as to form a single block of masonry with the former, and with the latter, so that losses of heat from the generator or in the gas conduits or flues are quite impossible. The furnace c is constructed in such manner that it can be first used as a directly fired chamber furnace, and then gradually changed to gas firing from the same furnace c. The gas generator c, which is built in a similar way as a grate furnace, but with a higher shaft, is arranged below

the burning chamber a, and the two heat collectors or accumulators reach approximately from the bottom end of the gas generator to the upper end of the heating or burning chamber. The gas generator is connected to the chamber at both sides by means of conduits or flues $d\ e$, between which are arranged dampers f, the latter enabling to close the one or the other of the flues d. The two heat collectors b are connected to the heating or burning chamber a by means of conduits g and openings h. The heat collectors, which are provided with a grating of refractory stones or other material, are connected at the bottom end to conduits b^1, b^2, b^3, b^4, which can be brought into communication either with the chimney channel b^5, or with the outer air, by means of a device consisting of a box k, shown in the lower part. Assuming that the damper f on the left-hand side is closed, the corrseponding damper f on the
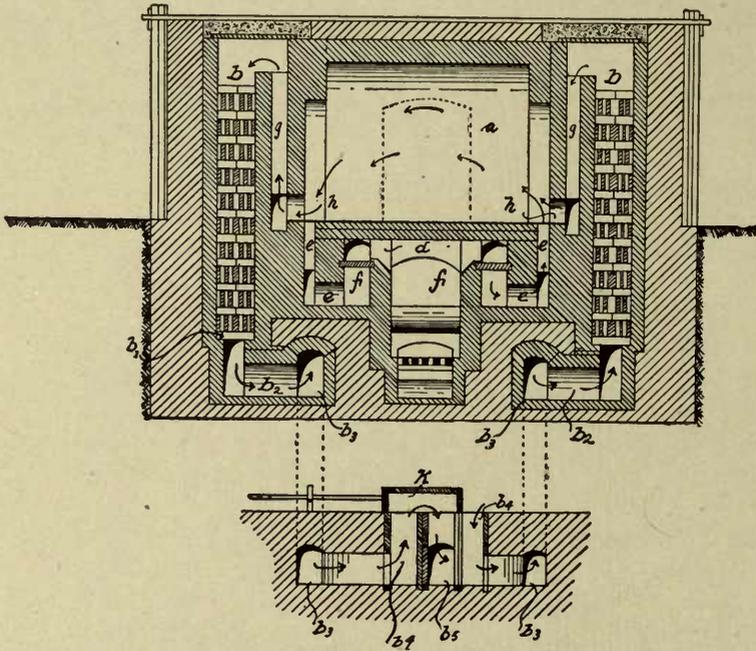
Fig. 167.—The Schmatolla High Temperature Ceramic Kiln.

right-hand side being open, and the box stands as shown in the drawing, the conduit b^4 on the right-hand side is in connection with the outer air, and the conduit b^4 on the left-hand side is connected with the chimney; and, assuming further that the generator is filled with coal and that the whole furnace is already incandescent, the generator-gas will then pass through the right-hand conduit system $d\ e$ into the heating chamber a, and the air through the right-hand conduit system b^4, b^2, b^3, b^1, the grating of the right-hand heat collector and the conduits $g\ h$ also into the heating chamber. Gas and air become mixed at the right-hand end of the chamber, burn in the interior of the chamber a, and pass at the other end through the conduits $h\ g$ and the heat collectors h, as well as the conduits b^1, b^3, b^2, b^4 on the left hand into the chimney. The combustion gases escaping from the chamber give off the greatest portion of their

heat to the grating of the heat collector arranged on the left-hand side. When the latter is saturated with heat, that is to say, already highly heated, so that the combustion gases begin to escape through the flues b^1, b^3, b^2, b^4, with a high temperature, the box k is drawn to the right side, so that the left channel b^4 be open and right channels b^1, b^2, b^3, b^4, with the chimney are closed, whilst the right-handed flue system b^1, b^2, b^3, b^4 is connected to the chimney. If, then, the right-hand damper f be closed, and if thereupon the left-hand damper f is opened, the generator gas will pass through the left-hand side flues e and g into the chamber, and the air will pass thrugh the left-hand side flues b^4, b^3, b^2, b^1, the grating of the left-hand side heat collector b, and the left-hand side flues g, h into the chamber a'. The flame in the latter will follow the opposite path as before, and pass on the other side through the flues g, h, the grating of the heat collector, and, after having given off to the latter the greater portion of its heat, through the right-hand flues b^1, b^2, b^3, into the chimney. The air is, of course, highly heated on the way by the previously highly heated grating of the left-hand side heat accumulator and passes into the chamber with a very high temperature. Assuming that coal or some other high-grade fuel is used, the generator gas will pass into the heating chamber with a very high temperature, since it has to traverse only a short conduit, and thus it is possible to increase the temperature in the said chamber to a much higher degree than was hitherto possible in the furnaces generally used in various industries, for instance, for burning or heating highly refractory materials. As the direction of the flames can be altered at given time intervals, the temperature in the chamber can be raised as much as desired up to the limit of the dissociation temperature of carbonic gas, that is to say, up to 2000° C.

CHAPTER XIV

BURNING LIME AND CEMENT

Lime and Calcining.—A difficulty in the use of gaseous fuel in the ceramic and calcining industries has been largely due to a lack of coöperation of the gas engineer and the kiln designer. Upon the part of the former there has been a lack of incomplete knowledge of just what is required in the way of degree of temperature, conditions of regulation and quantity of heat. Upon the part of the latter there has been an inexact understanding of the laws and actions of gaseous fuel. There can be but little doubt that when these are brought together and harmonized that the adoption of gaseous fuel will be the logical act of all of these industries, principally for the following reasons:

1. Foremost will be the utilization of low grade fuel, which under conditions of direct firing, by reason of its content of water, ash, and its tendency to clinker, will not supply the requisite heat effect.

2. With a proper application an almost unlimited heat intensity can be obtained.

3. More important, the regulation of this heat can be made positive and with complete facility.

4. The action of the gas flame is more mild and diffused than that of the direct flame and the tendency is for a more extended and distributed combustion, and less intense localization of heat which, when occurring in the arches through the medium of coal burning, is so objectionable a feature and so wasteful of fuel.

5. The centralization of the producers permit a reduction of labor and an ease of operation over the firing of separate and several arches.

6. The uniformity of the heat and the diffusion of its combustion tends to a more uniform burning of the product.

7. Clinkering in the grates of the arches is eliminated with its consequent loss of fuel and wear upon the linings.

8. A cleaner and more uniform product.

Finally the combustion is more thorough. To quote from Orton, "Another source of economy lies in the fact that it is possible to approximate much more closely to the theoretical perfect combustion. To burn a pound of coal requires an average of about 11 lbs. of air, yet we often use 22 or 33 lbs., or even 55 lbs. of air per pound of coal in actual operation. An excess of 300% of the theoretical amount of air required is not uncommon. With the use of producer gas, it is quite safely possible to cut down the excess of air in cases where it is the intention merely to consider the efficiency of heat production. In clay burning the chemical condition of the atmosphere is

328

often most important, and all questions of fuel economy must be considered as secondary to this. But it is possible in the use of gas to limit the excess of air very much more than with solid fuel, while still maintaining an oxidizing fire, and consequently there is much less heat carried out as sensible heat of the waste gases, and so economy may come in that way."

It must be borne in mind that for the dissociation of $CACO_3$ there must be a minimum temperature of about 900° C. or something over 1800° F. The application of producer gas whose flame temperature is normally only about 1200 to 1400° F., so as to attain this temperature must be a matter of careful and special design, and it is safe to allow at least for the obtaining of a temperature as high as 1000° C. permitting thereby a factor of safety or a reserve of power.

Of course a highly silicated lime will not stand a heat much over say 1900° F., but in the opinion of the writer the degree of heat should only be limited by the amount of silicate contents in the limestone.

Another thing which must be borne in mind is that the cooling chamber of a lime kiln affords exceptional opportunities for pre-heating the secondary air for combustion. This secondary air, however, should not be raised to a temperature above 300 to 400° F. inasmuch as a higher degree of temperature tends to shorten the flame to a point which is impracticable for lime burning.

This pre-heated air when so used may be admitted for combustion of the gas in an amount not over 10% in excess of the theoretical requirement; this 10% excess of course including the leakage of the kiln and such air as may work up through the dumping hopper and cooling chamber.

In any operation certain data must be secured, in order that the demands of each particular condition be specifically known. Primarily this information consists as follows: First, the character of the limestone to be burned, the temperature at which it calcines most completely, the amount of heat required to calcine a given amount of limestone, the type of kiln required for the operation, the nature and character of the fuel available. Now, when this information is secured it is only necessary to comply with these requirements or demands to secure positive results. To the failure in considering these several conditions I would attribute the failure of burning lime with producer gas, almost universally met with hitherto in the United States.

There can be no doubt, however, that where the conditions are intelligently considered, that plants can be designed where the demanded heat conditions can be supplied and the results obtained will be the highest degree of efficiency, both from economy of production and quality of product to which the art of limestone burning may attain.

Lime Burning with Natural Gas.—A lime-burning operation with natural gas has been successfully conducted at Sugar Rapids, O., for Mr. Peter Martin, of the Ohio & Western Lime Co., for some fifteen years, a brief description of which is as follows: The arches being originally designed for wood are about 3 ft. wide and 2 ft. high, and although giving satisfactory results, are unnecessarily large. It is not necessary in fact that the arches be larger than 2 ft. wide and 20 ins. high, which would answer all purposes. Within the arches, 2 in. pipes are laid, one on each side of the arch. Into these pipes the gas is induced from ¾ in. pipes, with a mixer at the end, making a form of Bunsen burner similar to the type used in the oven of a gas range.

The mixers are equipped with slides for air regulation, and the whole arrangement is similar to the natural gas supply to a gas range.

The arches are 5 ft. in length inside, and the pipes are laid so that they reach within about 4 ins. of the inside of the arch or shaft of the kiln. The ash pits underneath the kiln are filled in tight with air-slaked lime, so that no air can get into the ash pits. The maintaining of the kilns tight is particularly important to prevent over-ventilation or an excess of air.

The great difficulty in regulating the combustion in a kiln of this type lies in too intense a temperature, and in over-burning or in case-burning the lime.

Mr. Martin recommends a kiln about 22 ft. in height from the arch to the top, and about 6 ft. in diameter. He also states that a moderately low kiln possesses a better draft than a kiln that is too high, this probably being dependant, however, upon the ratio of the height to the diameter, in proportion to the total voids in the charge.

Vertical Lime Kilns.—In the burning of limestone ($CACO_3$) to lime (CaO) a paradox presents itself in the fact that the softer the limestone and the more ameanable to heat, the more difficult is its complete calcination. This is by reason of the fact that at an early stage of the process the limestone disintegrates, powders, pulverizes, or " fines," forming a compact mass comparatively impenetrable to both heat and gases, which retards the further calcination and additional expulsion of CO_2. The physical structure of the limestone, in the opinion of the writer, has much more to do with the conditions of quality of burning than that of its chemcal analysis, principally for the reason above cited.

In the use of shaft kilns these conditions can be somewhat regulated by the size of the stone or ore charged. By experimental determination of the relative draft of each kiln in connection with the stone to be used, the most economic size may be ascertained. Generally speaking the writer favors limestone fragments of approximately $8 \times 8 \times 12$ ins., for it has been his experience that whereas the large stone means a slight increase in fuel per kiln, yet there is a more than commensurate output per kiln and a reduction of fuel per unit of lime manufactured.

The use of exhausts in connection with shaft kilns may be advocated where such kilns have naturally bad drafts, in which case not only the process of combustion, but the CO_2 evolved from the dissociation of the limestone may be more readily and speedily removed, although under ordinary circumstances the degree of draft can be largely regulated by the size of stone charged as aforesaid and any advantages attained from the use of the exhauster are offset by the tendency of the exhaust to wire-draw or channel the gases through the charge and to over-ventilate the kiln, that is to say, produce air excess through superinduced leakage, there being leaks in nearly all kilns, especially in the neighborhood of the dumping hoppers.

Many experienced lime burners believe that the advantages so well known, as accruing from wood or flame burned lime, are caused by the large moisture content in the wood fuel. It is extremely possible that there is some eruptive or disintegrating action between such moisture and the limestone, although such action is probably more physical than chemical.

Should this effect be desirable with any particular quality of stone, it is easily obtained by using gas with the low pressure steam or moisture endothermic; such
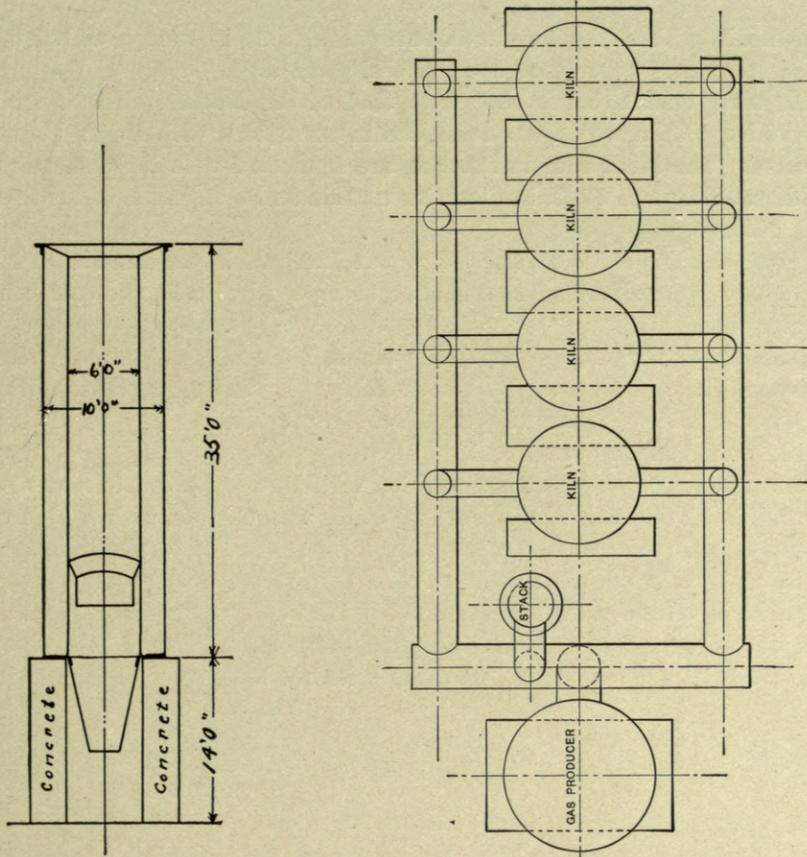
Section of the Duff Kiln.   Plan of Duff Kiln Plant.

FIG. 168.
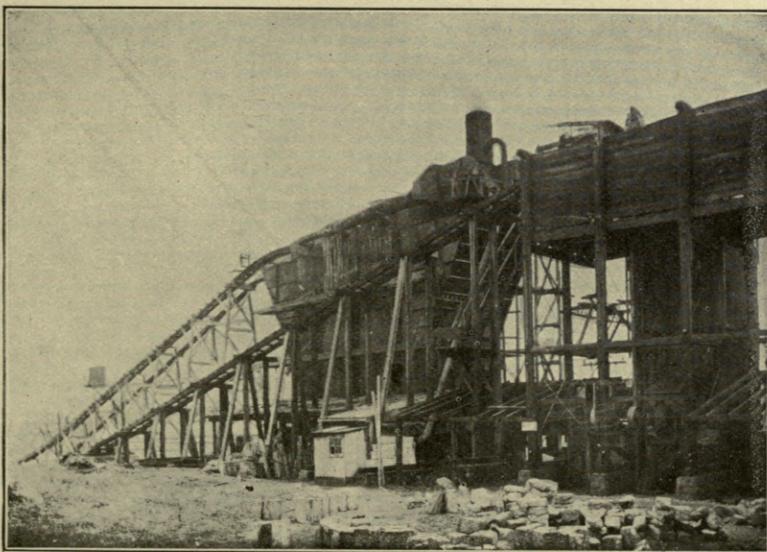
FIG. 169.—Typical Shaft Lime Kiln showing Runway for Charging Limestone.

gas can be made with a high degree of saturation, that is to say, with from eight-tenths to one pound of water per pound of coal gasified.

The following installation is similar to that of the National Mortar and Supply Co., of Gibsonberg, Ohio, which was furnished in connection with Duff's Patent Water Seal Producers. The kilns, four in number, are connected with the producer between lateral headers. They are 10 ft. in diameter outside and 6 ft. inside of brick-work and are 25 ft. high.

Each of these kilns has a capacity of about 125 barrels per kiln for 24 hours and the fuel economy approximates 6 lbs. of lime to a pound of coal, the coal being a fair Pennsylvania grade.

This economy is a saving of practically one-half over that obtained under similar conditions with the same stone, by direct firing. By increasing the height of the kilns to 35 ft. an additional capacity of 25 barrels per kiln per day could be obtained with possibly more economic fuel consumption.

Another successful lime plant in operation with Duff producers is that of the Ohio and Western Lime Company of Gibsonberg, Ohio, who operate with a high degree of economy and efficiency. The same company have a number of plants in satisfactory operation in connection with the Bauxite ores, lime roasters and rotary kilns.

Rotary Lime Kiln.—The following notes are made upon a rotary kiln for the production of lime. Length of kiln 100 ft. Diameter of kiln 6 ft. Thickness of lining 6-in. fire-brick for first 60 ft., 9-in. fire-brick for balance of distance.
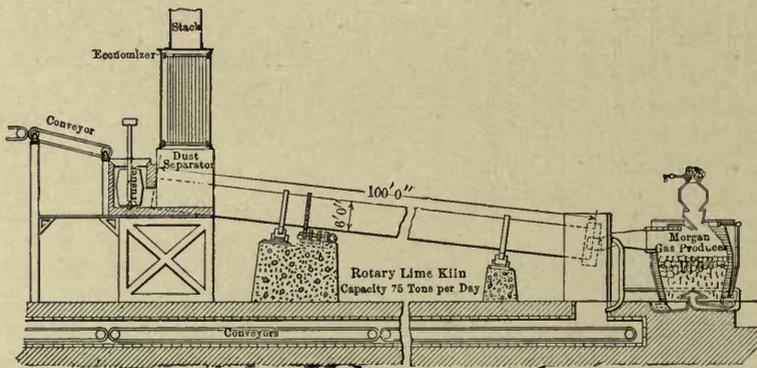
Fig. 170.—Producer-fired Rotary Lime Kiln.

The kilns are supported by three bearings, being driven by the center bearing. Inclination of kiln ¾ in. to the foot. Number of revolutions of kiln, one revolution in 2 minutes and 10 seconds. Size of producer, 10 ft. diameter, Morgan type. Total power used for revolving kiln, conveyors, crushers, and other mechanical devices, 50 h.p.

In this type of kiln the stone is charged through a conveyor into the crusher, where under the Jones patent it is reduced to a 2-in. mesh. The stone is then carried the length of the kiln. Period of calcination about 3½ hours per unit of stone. Maximum temperature of lime kiln, 2020° F. Temperature of gas in settling chamber or dust separator at end of kiln, 630° F. These gases are passed through a boiler and their heat recuperated by raising steam.

The primary and secondary air for the manufacture of the gas and its combustion, respectively, is drawn through the cooling chamber along the conveyor and up through the collecting or receiving vat, situated at the base of the kiln, thereby securing a fair degree of pre-heat. The yield of this kiln runs from 5 to $6\frac{1}{2}$ lbs. of lime per pound of fuel.
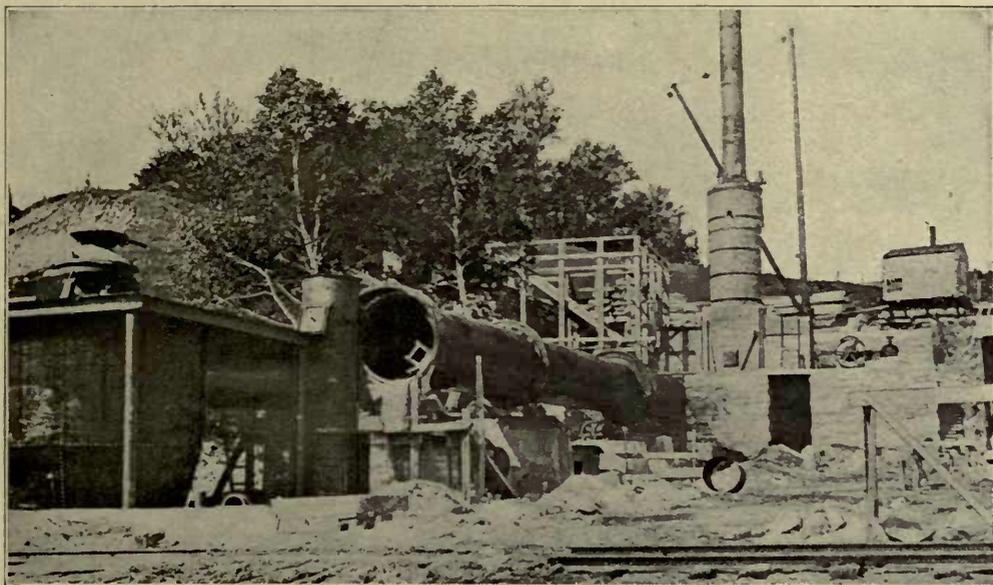
FIG. 171.—Rotary Kiln Plant of the New England Lime Co. under Construction.

German Lime Kilns.—German gas-fired lime kilns have attained an economy of 25 to 50% over the direct-fired kiln. That is to say, a production of from 4 to 6 units of lime per 1 unit of fuel. This can only be attained by utilizing the heat of the cooling lime in the pre-heating of the secondary air.
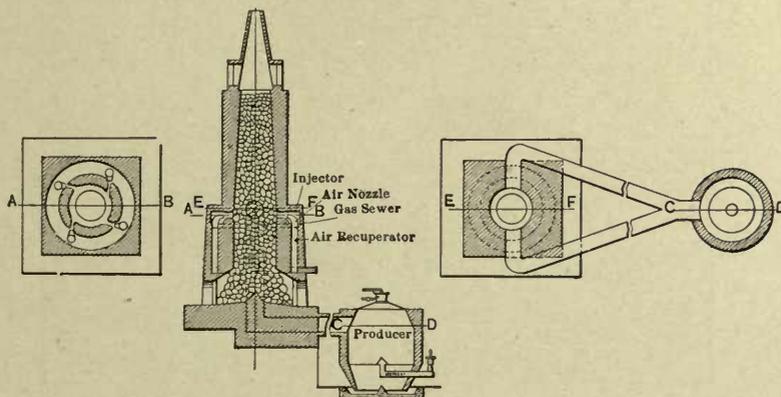
FIG. 172.—Vertical and Horizontal Sections of a German Gas-fired Lime-kiln.
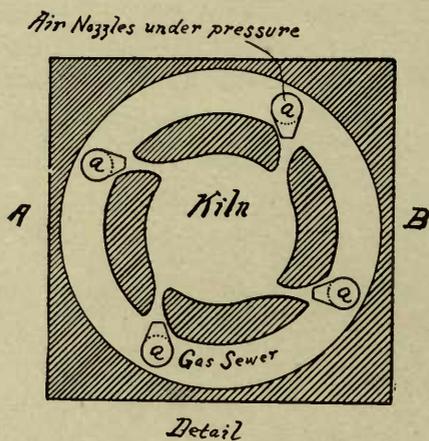
FIG. 173.—Section showing Pressure-air Nozzles (a).
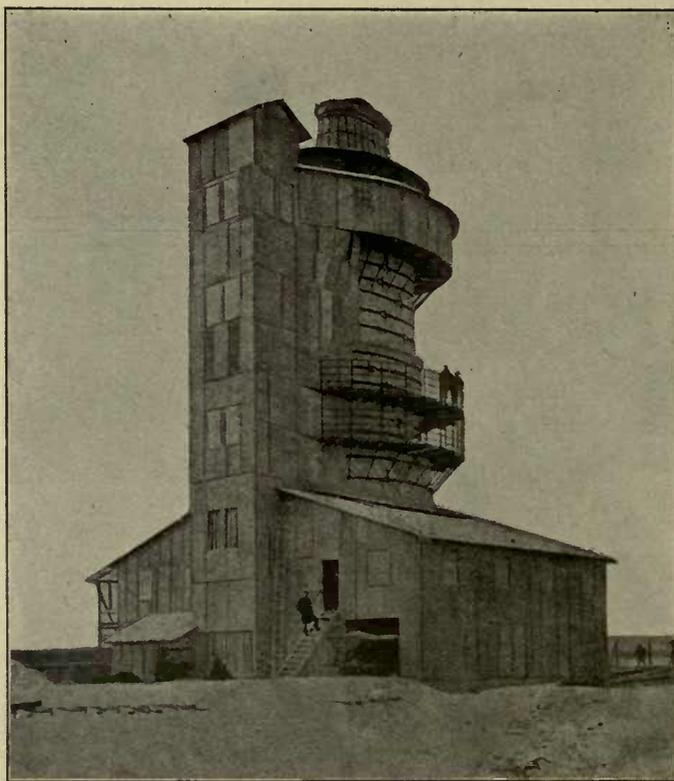
FIG. 174.—View of German Gas-fired Lime-Kiln.

Cement Kilns.—In the manufacture of cement where producer gas is burned in rotary kilns, it is necessary for economic work to recuperate a large amount of sensible heat from the incandescent clinker. This may be done by passing through the clinker the secondary air, and temperatures as high as 800° F. can thus be obtained.
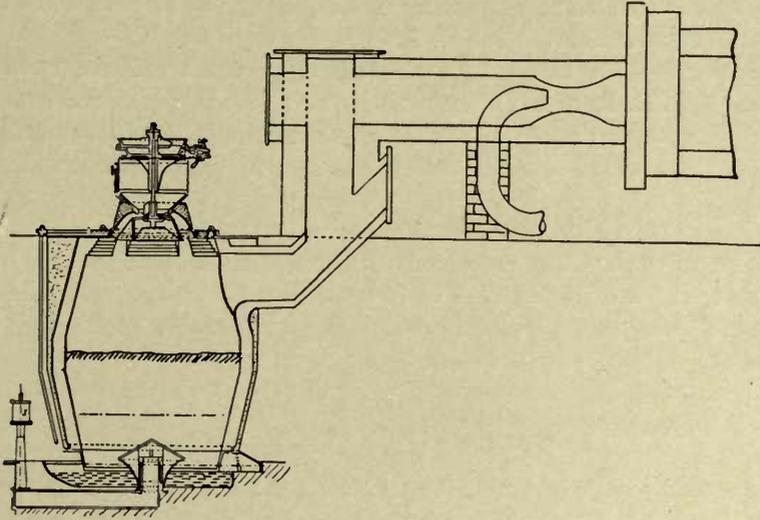
Fig. 175.—Gas-fired Rotary Cement Kiln.

The temperature of these kilns generally run from 2000 to 2700° F. which can be readily obtained with this degree of recuperation, when it compares very favorably with coal-dust firing, supplying a clean finished product.

The Eldred Process of Cement Clinkering.—The following outline of a cement clinkering gives the data upon which a maximum thermal efficiency system is based. Although this system is as yet only in a tentative form, the data herewith given is derived from practical experiments and from calculations of the best authorities in this country and in Europe. The figures therein contained may therefore be taken as representing a fairly accurate basis of computation.

In the modern practice of producing Portland cement in the United States, it is practically all burned in a rotary kiln fired usually by the burning of a flame plume of pulverized coal axially with the kiln, but oil and natural gas are sometimes used. The raw materials used in the manufacture may be divided into three groups, as follows:

First Group.—This consists of what are called cement rocks, from their having been formerly used in the manufacture of natural cement. These consist of rocks having nearly the composition of Portland cement, and with the lime, alumina, and silica already in combination to some extent. To these rocks is added usually enough limestone to produce cement of the proper analysis and this mixture is dried, ground, and fed into a rotary kiln.

Second Group.—In this may be placed a mixture of limestone and silicious clay, dried and ground and fed into the rotary kiln. In burning this mixture, the water

of hydration must be dissociated from the clay, the mixture must be raised to the dissociation temperature of limestone, say 900 to 1000° C., the carbonic acid must be then driven off and the resulting lime and baked clay brought to the temperature at which sintering takes place, say 1300° C. At this temperature combination of the lime with the silica takes place, forming among other compounds tri-calcium silicate ($3CaO.SiO_2$) and di-calcium aluminate ($2CaO.Al_2O_3$), which are considered as the active substances in cement. (See U. S. Geol. Survey Report.)

Third Group.—This is marl, which is finely divided calcium carbonate, being the remains of sea shells or fresh water shells, and with this is mixed enough clay and sand to give the proper proportions of lime, alumina, and silica; this mixture is ground wet into a slurry and fed into the rotary kiln in a semi-liquid form and is there dried and burned.

In the mixtures of the first group the amounts of lime combined with the silica and alumina and the amount combined with the carbonic acid to form limestone, are quite variable, so that the amount of heat necessary to produce cement from this mixture would differ in each case and cannot be accurately determined until all the elements of the mixture are analyzed.

In the third group the amount of water is so much and so variable that the fuel requirements cannot be determined until the amount of water present is known.

In the second group, however, the constituents are assumed to be pure, and these we will select as the mixtures on which the heat determination will be calculated. We will assume that the theoretical cement produced is to have the following composition corresponding with Ca_3SiO_5 and $Ca_2Al_2O_5$:

Lime, CaO.	68.25%
Silica, SiO_2.	19.72%
Alumina, Al_2O_3.	11.93%

All the other constituents found in commercial cement are accidental impurities, and it is well settled that they do not improve the cement, and most of them must be guarded against less any excess impair the quality of the product.

To produce a cement of this quality requires that the following ingredients be used in the proportions given:

Limestone, $CaCO_3$.	121.2 Kgs.
Clay, $Al_2O_3.2SiO_2.2H_2O$.	32.0 Kgs.
Sand.	4.8 Kgs.
Total weight of mix	158 Kgs.

Therefore 158 kgs. of raw mixture will make 100 kgs. of cement. The operation may be divided into two stages, and the heat requirements will be here calculated

for the two operations of calcining and clinkering, the first of these consisting of heating the mixture to 900° C. thus dehydrating the clay and decomposing the limestone.

Calcining Kiln.—The heat requirements for producing calcines are as follows: For dehydrating the clay there will be required 1218 calories per gram of water dissociated from the clay; H_2O, 4.5 kgs.

For dissociating CO_2 from limestone requires 1026 calories per kg. of CO_2. For heating the charge it will be assumed that the specific heat of the mix is at lower temperature, about 0.25:

$$158 - 4.5 = 153.5 \text{ kgs.}; \quad 153.5 \times 0.25 \times 900 = 34.537 \text{ calories for heating.}$$
$$4.5 \times 1218 = 5.480 \text{ calories for dehydrating clay.}$$
$$121 \text{ kgs. } CaCO_3 = 53.2 \text{ kgs. } CO_2; \quad 53.2 \times 1026 = 54.600 \text{ calories for dissociating limestone.}$$

Total.......................... 94.617 calories for producing calcines.

For sintering, the heat requirements are very much less; in fact the exothermic reactions produce one-third as much heat as is absorbed in heating the calcines to the sintering temperature, hence the advantages of dividing the process into two stages. The heat of combination of lime with silica and alumina in cement does not seem to have been accurately determined by Le Chatelier, who determined that in the combination of $3CaO.Al_2O_3.2SiO_2$ that there were 150 cals. developed per unit of $Al_2O_3.2SiO_2$ and as the silica and alumina exist in about that ratio in the cement, their sum multiplied by 150 cals. will give the heat produced.

In heating the calcines from 900 to 1300° C. their specific heat is assumed to be 0.30, therefore:

$$100 \times 0.3 \times 400 \ (1300 - 900) = 12.000 \text{ calories absorbed by clinker.}$$
$$31.65 \ (SiO_2 \text{ and } Al_2O_3) \times 150 = 4.747 \text{ calories produced.}$$

Difference.................. 7.253 calories absorbed from fuel.

The total heat units in the clinker as discharged would be as follows:

$$100 \text{ kgs.} \times 0.3 \times 1300 = 39,000.$$

The above represents the heat requirements, provided that the combustion, gases left the kilns cold and the carbonic acid gas from the limestone left the kiln at the temperature of dissociation. Practical working tests with a gas-fired rotary kiln 100 ft. long ×6 ft. in diameter, burning limestone crushed to 2 in. size, such limestone containing 98% $CaCO_3$, have shown that it is safe to assume an output of six parts of lime to one part of good gas coal. Therefore 66 kgs. of lime would require 11 kgs. of fuel, and as there is 66 kgs. of lime in 100 kgs. of cement, 11 kgs. of coal would calcine all

of the lime to produce 100 kgs. of cement. There remains only the heat requirement for bringing 33 lbs. of SiO_2 and Al_2O_3 to the required temperature at which the lime is formed.

$$SiO_2 + Al_2O_3 = 33 \text{ kgs.}; \quad 33 \times 0.25 \times 900° \text{ C.} = 7425 \text{ cals.},$$

which would be equivalent to not more than 1 kg. of coal per 100 kgs. of calcines, therefore the requirements for the calcining kiln will be:

11 kgs. of coal for heat to produce 66 kgs. of lime.
1   kg. of coal for heat to raise temperature of clay.
0.5 kg. of coal allowance for heat losses in heating up clay.

_____

12.5 kgs. coal per 100 kgs. calcines or 1 part coal to 8 parts calcines.

Clinkering Kiln.—For clinkering, estimating that the calcines are discharged directly from the primary kiln in the clinker kiln at 900° C., and are therein heated to 1300° C., a range of 400° rise in temperature, $100 \times 0.3 \times 400 = 12.000$ calories absorbed.

The clinkering operation is exothermic. Since Le Chatelier has determined that 150 calories are evolved per unit of combined $SiO_2Al_2O_3$, therefore 31.65 kgs. (combined silica and alumina) $\times 150 = 4747$ calories.

Subtracting this from the 12,000 calories absorbed by the calcines in the clinkering kiln there remains 7253 cals. per 100 kgs. to be furnished by the fuel. This represents slightly less than 1% fuel for clinkering.

Assuming that 180 tons are to be clinkered per day in one clinkering kiln, 180 tons = 18,000 kgs. divided by 100 = 1800 kgs. coal or 1%. There remains 39,000 cals. in the discharged clinker and, assuming that one-third of this heat can be taken up by cooling with air and supplied to the primary or calcining kiln, 13,000 kgs. would be afforded per 100 kgs. or 1½ kgs. coal, or 1.5%, which, subtracted from 12.5 kgs. coal used in calcining, gives 11 kgs. or 11% fuel, or 1 part of coal to 9 parts of calcines.

Assuming an efficiency of only 25% in the clinkering kiln, or 4 kgs. per 100, 1800 kgs. $\times 4 = 7200$ kgs. This would be 4% of the fuel consumption, or 4 kgs. per 100, which, added to the 11 required for calcining, equals 15 kgs. per 100 or 15%, or 1 part of coal to 6.6 parts of cement.

A regenerative system is capable of utilizing 84.2% of the total heat of the gas and the producer should have an efficiency of 80%, thus giving 64% efficiency for the combination of the producer and kiln, not allowing for radiation loss. I believe that it would be safe to assume 50% efficiency for the clinkering kiln outfit, allowing 14% for loss by radiation. If this result is realized the process would yield 7.69 kgs. of cement for each keg of coal consumed. This, as will be seen, effects a saving of more than one-half of the present fuel consumed under average direct firing practice or an increased efficiency of over 100%.

The Eldred Process of cement burning is as yet in a more or less tentative state, and inasmuch as its discussion embodies pro and con practically all the principles

involved, and such a discussion necessarily involves a recapitulation of the elementary data, it has been thought worth while to insert it here.

The general principles claimed by Mr. Eldred are undoubtedly correct, there being however, certain variables relative to the fuel and materials used. Also there is a question in the mind of the writer as to the possibility or practicability of the use of flue gases in this process.

Should they be used, their confining limits must be along the following lines:

(a) It is questionable whether it is well for high temperature work to use CO_2 or the resultant products of combustion as an endothermic agent by reason of the low flame temperature derived from the combustion of the gas consequent upon its small calorific value. For while hydrogen is unsuitable as a power gas, it has a high flame temperature and displaces about twice its own volume of nitrogen in a constituent gas, hence its presence is highly valuable in an operation of this kind.

(b) Again as to the obtaining of a voluminous gas through the use of secondary dilution or retarding of the flame, this again is only obtained at the expense of flame temperature. Hence it will be manifest that, in order to obtain its dilution, it will be necessary to considerably " boost " the flame temperature by a high degree of regeneration and pre-heating of the elements of combustion.

When, however, it is considered that such pre-heating is merely a function of the original flame temperature, the question becomes cyclic and must be determined by absolute experiment.

It is of course a fact that the voluminous or elongated flame function of retarded or prolonged combustion, due to the dilution of the air, has been successfully used in connection with the manufacture of cement in rotary kilns, but it must also be remembered that the combustion in this case was that of powdered fuel possessing a third greater flame temperature than that possessed by ordinary fuel gas.

A general outline of the Eldred process, which is interesting particularly as it reflects the subjects of two-stage calcining and complete heat recuperation, is as follows:

It has been the modern practice to burn cement with a long blast-flame in a rotary kiln, but to employ the same flame for both the calcining and sintering or final vitrifying of the material, although the temperature requirements are very different in the two cases, the calcining step or expulsion of carbon dioxide and water being an endothermic process, requiring a comparatively low temperature (about 1200 to 2000° F.) and a large volume of hot gases, while the clinkering reaction absorbs but little heat and is really exothermic, and should take place under high temperature conditions (about 2500° F. or higher). It is very difficult in practice with a single flame to obtain and maintain a proper balance between these two effects, so that in the one case the calcining shall be sufficiently performed before fusion sets in and in the other case the desired degree of fusion shall be effected before the material leave the kiln or passes beyond the influence of the clinkering flame. In practice the kiln-tender attempts to control matters by regulating the speed of the cylinder and the quantity of cement material fed in at the upper end per unit of time; but this requires the greatest skill, in spite of which the feed or travel of the material will, on the one hand, often be too slow in respect to the temperature of the flame, which means that too much heat is devoted to clinkering and too little to calcining, giving premature fusion of under-calcined material, while on the other hand if the speed is too fast the clinkering zone

retreats toward the discharge end and too much of the heat goes into calcining and
too little into clinkering, so that the cement may be under-fused. The flow of the
material through the calcining zone can be regulated only by varying the flow through
the clinkering zone. When variations in the composition of the cement material
are encountered, a change in the feed or in the flame must often be effected, and this
will frequently destroy the proper balance of operations in the kiln.

In the method under discussion, two or more separate flames are employed for
the calcining and clinkering operations, respectively, and each flame is regulated to
a temperature corresponding to the operation in which it is engaged instead of, as
formerly, trying to regulate one flame for both operations.   The two steps of the burning
process are preferably carried on in chambers more or less separate, one of which may
deliver material into the other and maintain the heating influences in the two opera-
tions substantially independent.   The conditions of combustion and rate of feed may
then be independently regulated for each stage of the process, and the delicate balance
of operations no longer exists.

It has been found that one of the most important consequences of this method
is that it now becomes possible to employ a profitable and dustless fuel, such as a
producer gas, thus avoiding the expense and danger of powdered coal, for by carying
on the two stages in separate chambers it is possible to regenerate or recuperate the
materials of combustion and obtain a very high temperature in the clinkering chamber,
while also employing a flame in the calcining chamber especially suited to the calcining
operation.   Heretofore regeneration has not been found practicable, because the gases
at the upper end of the kiln would be so full of dust as to clog the regenerators and so
far cool down in consequence of the absorption of their heat by the materials under-
going the endothermic calcining operation as to be of little use in obtaining a high
clinkering temperature.

In the calcining stage, the gas and air may be used with or without regeneration,
while in the clinkering stage the gas or air, or both, are preferably regenerated, so as
to obtain a very high temperature and great economy in fuel.   The gases for heating
the regenerators for the clinkering stage are abstracted from the clinkering chamber
where they are very hot and comparatively free from dust.   Thus for clinkering, the
fuel heat is used in a very high temperature form and only a small quantity of gases is
required, while for calcining the volume of gases is perferably large and their temper-
ature low.   The calcining takes a longer time than the clinkering, and for that stage a
producer gas flame of moderate temperature and large volume is well adapted and is
preferably carried well down into contact with the material.   The temperature of
the calcining flame, however, may be raised to absorb more of this heat by passing
more material in a given time.   The gases at the end of this stage are hot enough to
yield a moderate regenerating heat for the calcining flame if it be desired to carry a
hotter flame than one unregenerated.   Since the chambers may each be made shorter
than the usual length of a cement-kiln and the strong blast current required to keep
powdered fuel in suspension is no longer necessary, a weaker blast may be used and
less dust produced in the calcining chamber.

The operation in the calcining chamber is advantageously carried to a point at which
incipient fritting or softening of the material occurs, so that it enters the clinkering
chamber practically free from dust.

1 PRODUCER.
2 CALCINING KILN.
3 CLINKERING KILN.
4 DUST SEPARATORS.
5 FEED HOPPER.
6 RECEIVING VAULT
7 REGENERATORS.
8 REVERSING VALVE
9 RECUPERATOR
10 ECONOMIZER

Fig. 176.—Rotary Cement Kiln Designed for Highest Thermal Efficiency.

Among other advantages which may be named are the ability to force the feed, if necessary, especially in the clinkering chamber, enabling a smaller clinkering kiln to handle the material and enabling several calcining-kilns in parallel to feed a single clinkering kiln. Conversely several clinkering chambers might take the product of a single calcining chamber.

Since there is a relatively moderate temperature in one chamber and a relatively high temperature in the other with no intermediate temperature, the formation of "rings" adhering to the lining of the kiln is avoided. The material is accessible between stages for withdrawing samples for the purposes of analysis. Wear and tear due to sudden changes in temperatures and to widely different temperatures in different parts of the same chamber is avoided.

The material to be calcined is fed in at 5, passes through the rotary kiln 2, drops from its end by a chute into rotary kiln 3 of higher temperature and from its end by a chute to a platform to pre-heat the entering air, and is discharged by a conveyor. The gas is made in the producer 1 and sent out by two pipes, one to the lower end of kiln 2, the other to the reversing valve and through flues 7 and checker brick. The air is delivered by a fan shown at the left hand, one branch passing down to the calcined clinker platform, the other going through recuperator pipes 9 in the stack and thence to the lower end of kiln 2. The baffle chambers 4a and 4b intercept the dust and the water tube boiler 10 makes steam for the producer blast.

In the operation of this process the raw material is introduced into the kiln at 5 and is there subjected to a calcining flame by the combustion of the producer gas with the air admitted into the lower part of the kiln, as above indicated. A long voluminous flame is here produced, giving that "soaking" heat or slow heat undulation requisite for the dissociation from the material of the carbon dioxide chemically combined with the lime and magnesia. The material which passes through the chamber 2 is freed by the application of this specifically calcining flame from its carbon dioxide and falls through the chute into the clinkering kiln 3. Here a high temperature is maintained by means of the regenerative system employed, the material being maintained at or rapidly brought to the temperature at which the clinker forming exothermic reaction occurs. The material is finally discharged into the clinker cooler over which a current of air is caused to flow. As soon as the material is sufficiently cooled it may be ground to the fineness required.

Various apparatus may be employed to carry out the process. For example instead of a rotary kiln for clinkering, a furnace equipped with a shaking hearth may be employed. Different kinds of fuel may be employed, suited to the particular character of furnace, although producer gas is preferred for the reasons already stated.

In operating the furnace the transition point between the calcining and clinkering stages may to some extent shift from one chamber to the other, it being one of the advantages of the invention that great latitude of operation is possible and little skill required; where formerly the reverse was true. Under some conditions it may be found desirable to perform the calcining and clinkering at different times, that is non-continuously. This invention enables this to be effected. The main purpose of passing the calcines directly into the clinkering kiln is of course to conserve the heat of the calcines.

It will be understood that this invention does not claim to have originated the separate performance of the calcining and clinkering operations in cement manufacture; but it is the first to utilize the two-stage method with reference to the regulation and control of temperatures by internal heating in reverberative chambers with special fuels, and more particularly with regard to the advantages of using producer gas and other weak gases in both or either of the stages and successfully regenerating the materials of combustion.

CHAPTER XV

PRE=HEATING AIR

Blast Stoves.—In a general way, with the average conditions as they obtain throughout the country, with lower-priced fuel adapted for heating air in the U-pipe stove for pre-heating blast, as compared with the high-priced coke that must be used in the blast furnace, air may be heated as cheaply, pound for pound, to a temperature of 800 or 900° F. in a well-designed stove as in the smelting zone of the blast furnace.

U-pipes of cast iron will stand a long while at a low red heat (about 800° F.) without distortion or other damage, if properly designed and made of suitable material. Any number of sections, consisting as above of four series to the section and 6, 7, or 8 pipes in each series, are attached or coupled together, through flanges on the mains, to make a stove of any size required. The elbows and flanges, which serve to couple the U-pipes together, as also the rectangular main blast pipes of the stove, which serve respectively to conduct the cold air into the various series of U-pipes and the hot air out of them, and to which the several series are connected by flanges, are rectangular, of suitable size, three-quarters of an inch thick, rest on the end walls of the heating chamber, and are all above it. These mains are usually bricked in, or else covered with asbestos cement to prevent loss of heat by radiation. There are flanges below the elbows on the U-pipe, as high up as practicable and completely encircling them, and on these flanges are placed fire tiles of suitable form, which constitute the roof or top of the heating chamber, down into which project the main portion of the U-pipe for heating. The roof of the heating chamber, including the top elbows of the U-pipes, are usually covered with ashes a foot or a foot and a half deep, to prevent heat radiation from the roof and from the top elbows.

This system of covering and insulating the top, and thus conserving heat that would otherwise be radiated into the atmosphere and lost, is the best, simplest, and cheapest possible, admitting of ready access to the flanged elbows where the U-pipes are bolted together.

All joints are machined true, and provided with asbestos gaskets, and are thus capable of being always screwed up air tight, and must always be so, for a leaky stove entails great loss. Every joint and every bolt in the stove is readily accessible from the outside, and no joint or bolt is exposed to the fire or to the heat of the heating chamber.

U-pipes can be detached, taken out when necessary and replaced with new, without drawing the fires or cooling the stove, other than to close all draft doors tight and shut off the blast. In case of necessary repairs, the cold-air blast is turned off the

344

stove and directly into the blast furnace. A burned-out U-pipe can be taken out, a new pipe put in, and the air blast turned through the stove again in an hour, without cooling down the stove.

Expansion and contraction strains are so compensated that no pipe or other part of a U-pipe stove can ever fail by reason of such strains. A U-pipe stove, properly
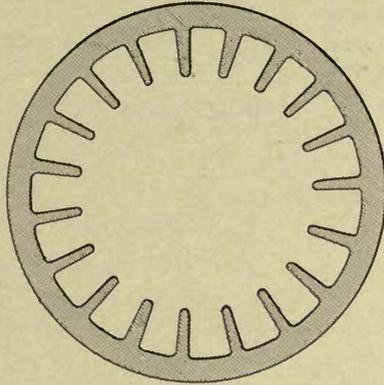
Fig. 177.—Section of Blast Pre-heater Pipe.

managed, is as durable as the average smelting furnace. The only possible danger is in burning, and, with the present system of constructing the heating chamber and protecting all U-pipes from the direct action of currents of flame and heat impinging
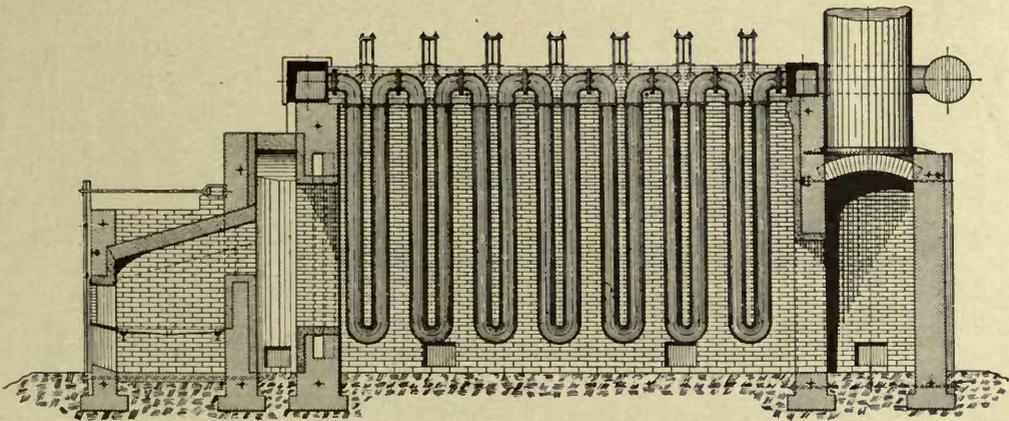
Fig. 178.—Longitudinal Vertical Section of U-pipe Hot-blast Pre-heater.

upon them, they never should burn, and never can do so except through the grossest carelessness.

U-pipes must not be subjected to the direct action of violent currents of flame and incandescent products of combustion from the reverberatory roofs of the fire boxes that would melt or burn them.

Practically, air heats very little by radiation, but by contact with heated surfaces, and, for this reason, to heat air economically, ample heating surfaces must be provided. To increase the heating surfaces of U-pipes, they are sometimes cast with longitudinal ribs on the inside, as shown in detail in the drawing.

Iron is a very active conductor of heat, and, projecting inward from the body of the pipes, as they do, these ribs become heated, and the air coming in contact with them, as well as with the balance of the inside surface of the U-pipes, the area of the heating surface and hence the efficiency of the stove, is very greatly increased, doubled in fact. U-pipes of cast iron will stand far more heat without distortion or other damage than pipes made of steel or wrought iron.
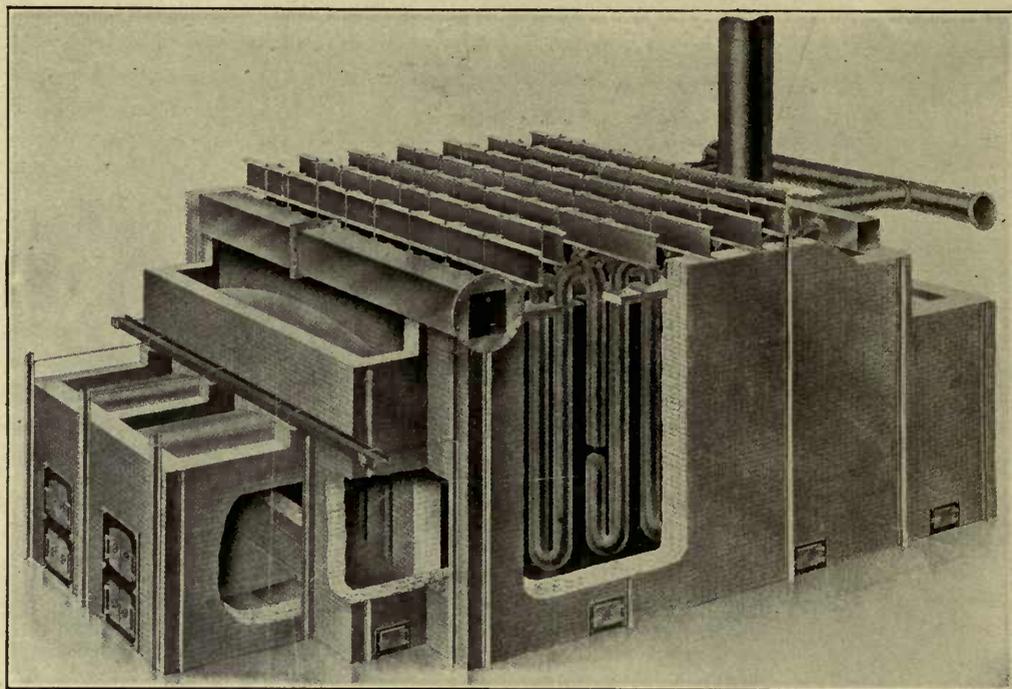
Fig. 179.—U-pipe Hot-blast Stove.

The heating surface necessary for heating an air blast to 600° F. may be taken as .4, and to 800° .5 of a square foot for each cubic foot of air to be heated per minute. The extreme ultimate velocity of heated air on leaving the stove and in the pipes to the furnace should not exceed 5000 ft. per minute.

Air expands 0.002036 of its volume for each Fahrenheit degree added; therefore, when heated to 600° F. from 60° normal atmosphere, its volume has become 2.1 times its original volume, and hence all pipes and tuyeres must have more than double the area required for cold air of given amount in weight.

Sturtevant Pre-heater.—This pre-heater will absorb from 1 to 1.25 B.T.U. per degree mean difference between the temperature of gas and air per hour per square foot of heating surface, the temperature of the gas being about 500 or 600° F., and

the temperature of the air entering the heater being 100° F. Of course, with a higher temperature of gas, say, between 1000 and 1500° entering the heater, the air entering the heater 100° F. or less, the absorption would be between 1.5 and 2 B.T.U.
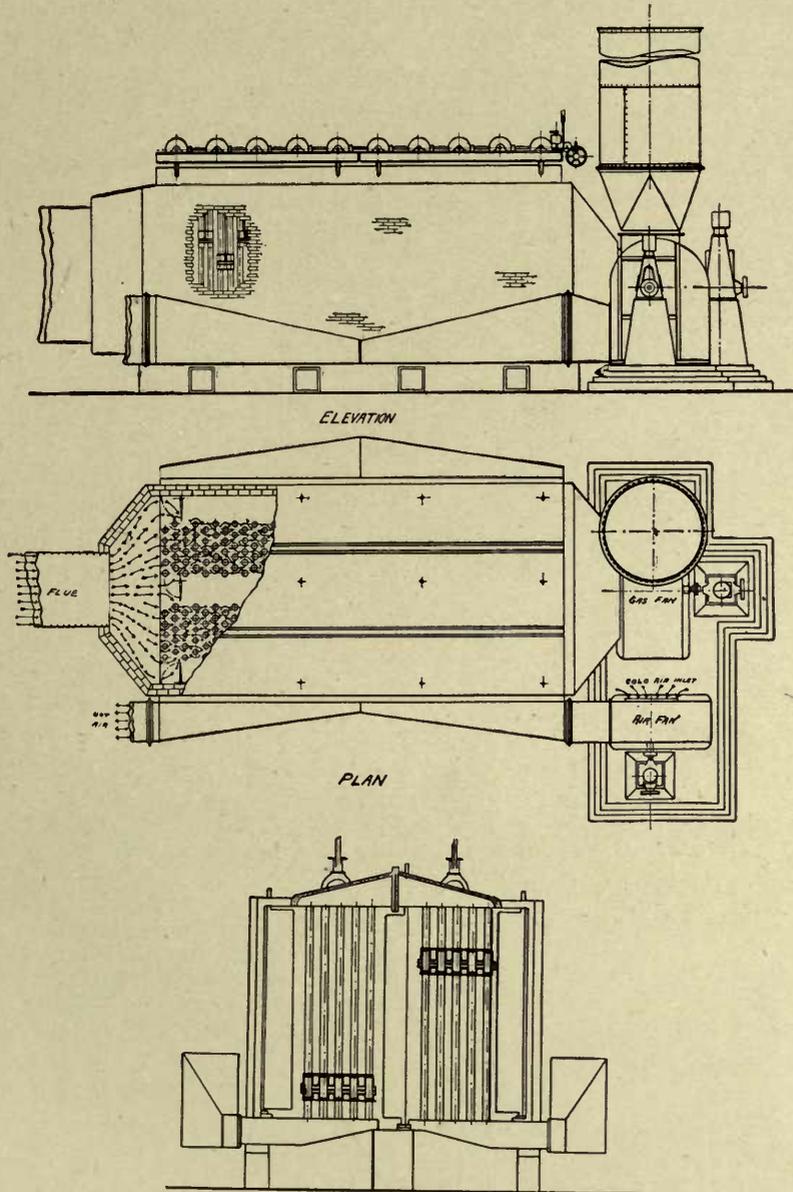
FIG. 180.—Sturtevant Air Pre-heater Plant (Elevation, Plan and Cross-section.)

Under the former conditions, the Sturtevant Co. suggest the use of the following formula for estimating purposes:

$$T = 1.25H\left[\frac{(G+g)}{2} - \frac{(A+a)}{2}\right].$$
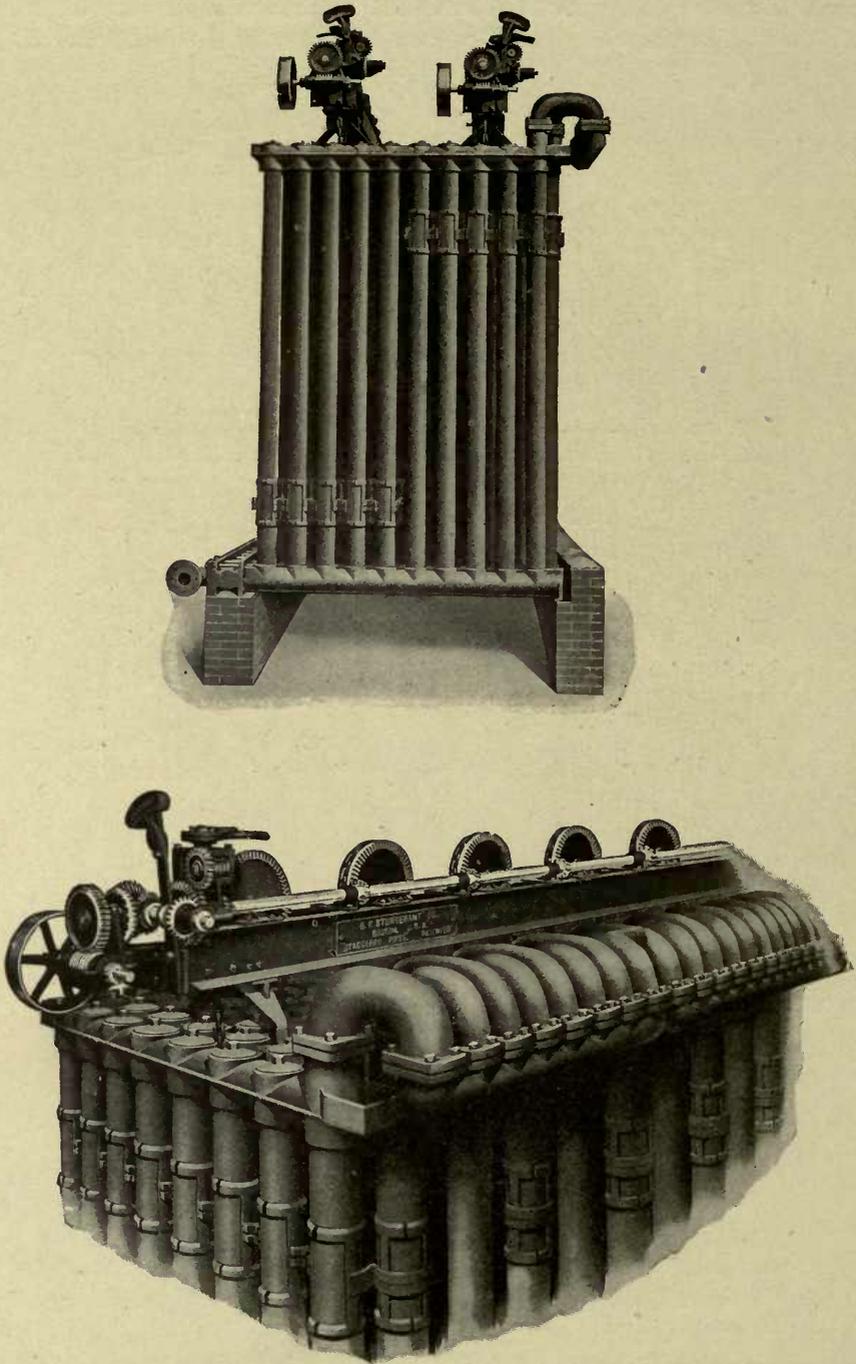
FIG. 181.—Air Pipes and Scrapers to Remove Flue Dust.

Where T = the total heat transmitted or absorbed, 1.25 is the factor; H is the heating surface in square feet; G is temperature of gas entering air heater; g the temperature of gas leaving the air heater; A is the temperature of the air leaving the air heater, a the temperature of air entering the air heater. The velocity of air flow in the above is assumed to be approximately 2000 ft. per minute.

The advantages claimed for the heater over that of other types, are: The pipes are arranged in staggered rows, instead of straight rows; there are no gaskets in the gas chamber; the heater can be easily connected up in several different ways, and for different volumes of air; it can be made up in sections of a size that can be easily transported and installed; there are baffle plates on each side, also in the center, in order to give accessibility to all parts of the apparatus; the driving shaft runs lengthwise of the apparatus, which requires a less number of driving heads, and less power to operate the scraper mechanism.
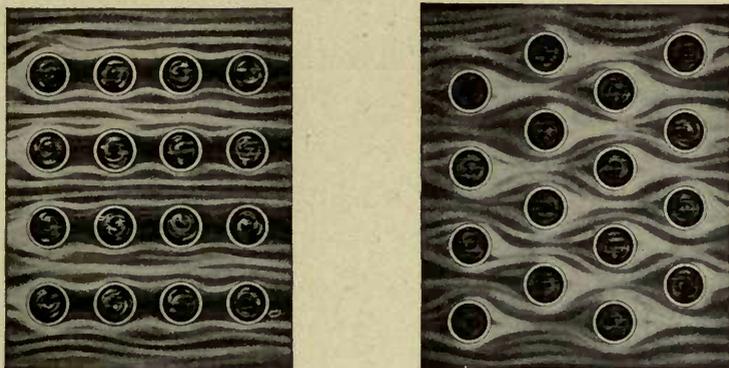
Fig. 182.—Passage of Gases among Straight Rows and Staggered Pipes.

Green Air Heater.—This heater consists of a group of vertical cast-iron tubes, 9 ft. long between the headers and $3\frac{7}{8}$ ins. internal diameter. These tubes are forced by a hydraulic press into top and bottom boxes to form six-tube units. These units, or sections, are assembled side by side. The blow-up gases from the superheater of a water gas set, for example, pass in among the tubes, while at the same time the air supply for the generator is forced through the tubes by a blower and take up heat from the gases, returning it to the generator. The result is that it is not necessary to blow the generator so long to bring it up to the required temperature and not so much fuel is required in the blowing-up process, with a resulting saving in the present case of about one-fifth of the fuel required for the generators. The outsides of the tubes are kept clean of soot by automatic scrapers, which travel slowly up and down.

The net result is that there was an average saving of about 17.3% of generator coal for this period of three months, with a maximum saving of 19.8% in June. As the monthly output runs at about 5,000,000 cu.ft. of gas, and as on an average 8 lbs. of coal per 1000 cu.ft. of gas were saved, the monthly saving of coal amounts to 20 tons.

Triple Recuperation.—As an application of the triple recuperation of the gas, secondary air and primary air, the system of A. A. Queneau is described in " Industrial Furnaces," by E. Damour and A. L. Queneau. The apparatus has the ordinary
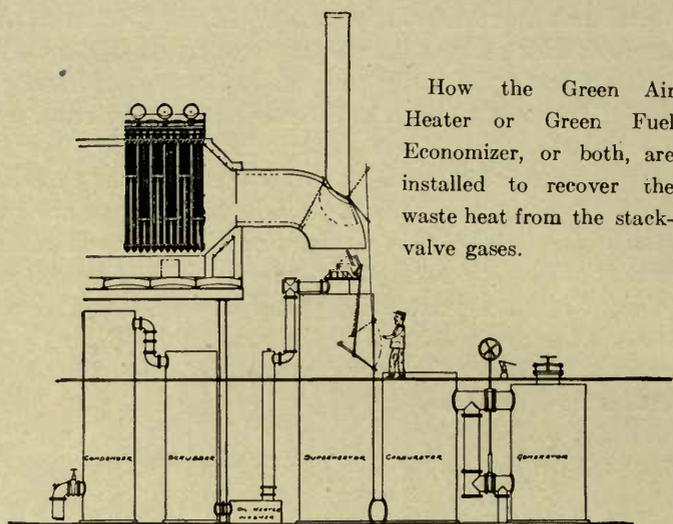
How the Green Air Heater or Green Fuel Economizer, or both, are installed to recover the waste heat from the stack-valve gases.
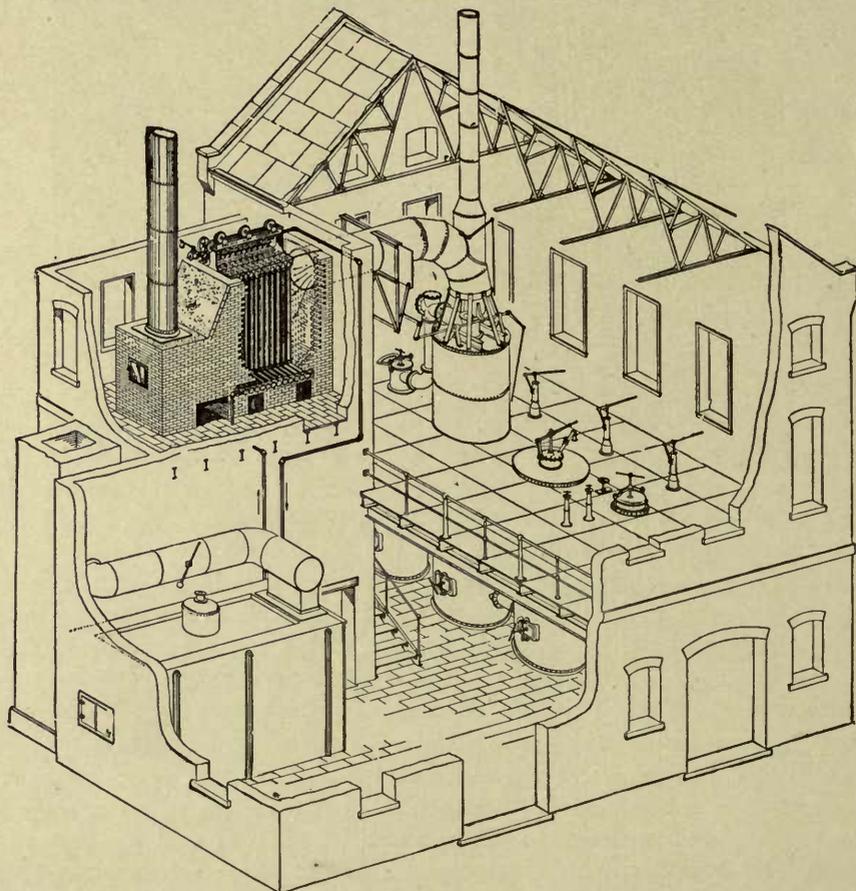
FIG. 183.—The Green Fuel Economizer in Poughkeepsie (N. Y.) Gas Works, where it is saving 25% of the boiler fuel.

Plan of New Haven (Conn.)
Gas Works, showing Green Fuel
Economizer fitted to three 8-ft.
U. G. I. sets.

Cross - sectional Elevation New
Haven Gas Works. This Economizer
supplies the boilers with water at a
temperature of 340 to 350° F., saving
25% of the boiler fuel.
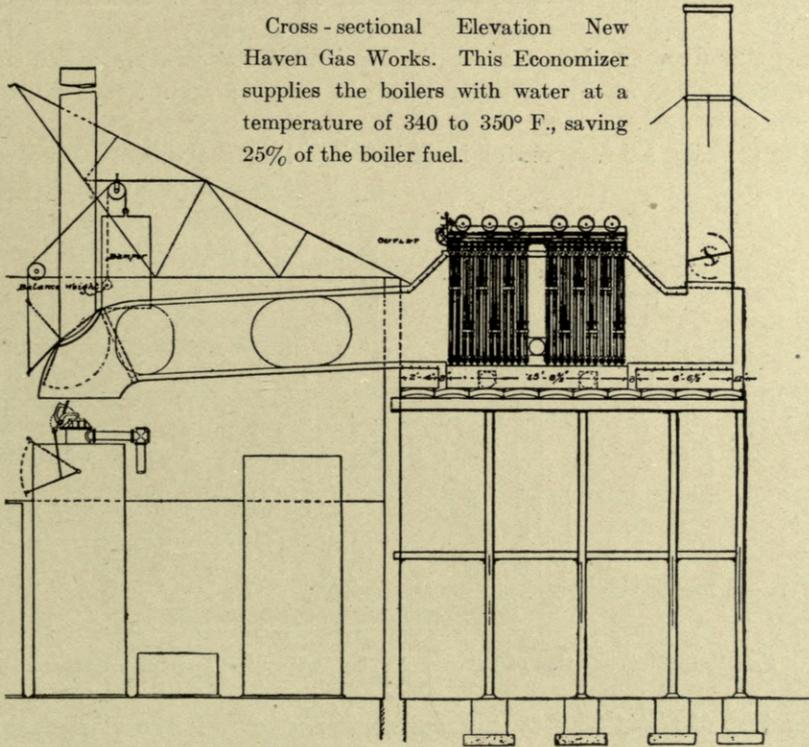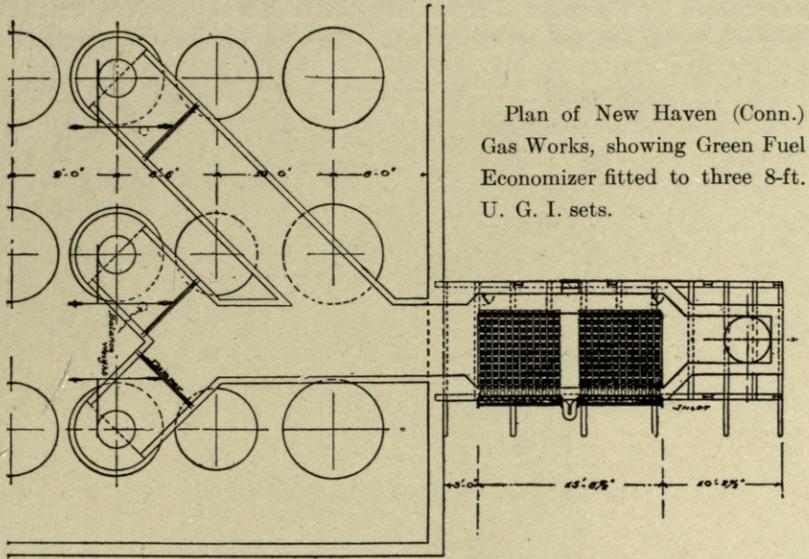
Fig. 184.—Air Pre-heater on Water-gas Machine.

Siemen's chambers for the gas and secondary air, with a single chamber of the parallel counter-current type for the primary air. Usually the waste products leave the
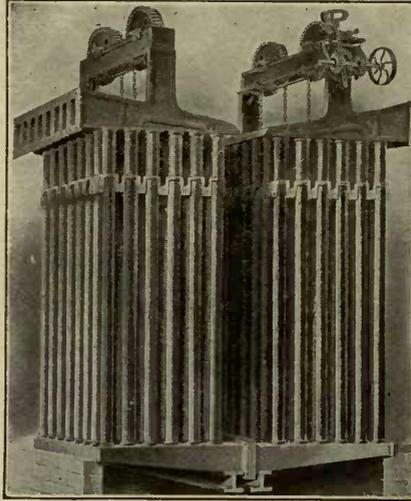
FIG. 185.—Air Pipes and Scrapers on Green Pre-heater.

Siemens chambers on their way to the stack at a temperature which allows the use of cast-iron pipes for the recuperator. In case of high temperatures a fire-brick recuperator is used.

The primary air recuperator is designed so that the waste products leave it at a
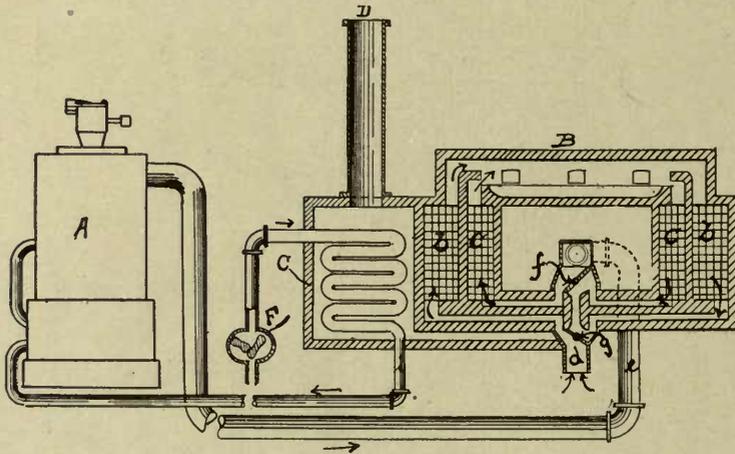
FIG. 186.—Recuperation of Primary Air, Secondary Air, and Gas—Queneau System.

temperature of about 200° C., a temperature necessary for an efficient draught in the stack. The primary air is forced through the recuperator by means of a positive blower, while the heated air is led to the producer through a brick-lined flue. In order to utilize the calories of the primary air to the best advantage, without endangering

the producer, the primary air meets a system of water-sprays (the steam injector being entirely dispensed with). The vaporization of the water injected is obtained wholly at the expense of the recuperated waste heat (doing away with the boiler plant). By injectng the water in liquid form in the producer and obtaining its vaporization thereby, the fire zone of the producer is cooled more efficiently than by steam injection. The amount of injected air and water can be varied independently at will, since they are not interdependent, as in the case of the steam injector. The use of the parallel counter-current system for the primary air does away with the complications of a third set of valves. The regulation of the temperature of the primary air recuperator is automatically obtained by the regulation of the temperatures in the Siemens chambers. Two conclusions may be noted:

1. The very high efficiency of furnaces wth triple recuperation.
2. The very small influence of the ruling temperature on the heat utilization.

This system of recuperation is, then, particularly suited to high temperatures; its use would result in a fuel economy of 10% over that of the Siemens regeneration furnace.

There is a case where the use of triple recuperation would give an economy even greater than 10%; it is in its application to industrial operations in which the waste products consist of the products of combustion of the fuel, and of gases liberated by the materials under treatment in the hearth, that is, water vapor, carbon dioxide, sulphurous dioxide, etc. Usually the calories carried by these gases would be utterly lost, since the products of combustion of the fuel have higher thermal capacity than the recuperating gases. In the case of triple recuperation the contrary is true, and therefore these extra calories can be brought back to the hearth.

Glass furnaces present the typical example of this supplementary recuperation. The materials charged in the furnace carry as much as 45% of volatile products; the coal required for the fusion of the glass weighs about 60% of the weight of the fused glass. The mass of the volatile products is, therefore, mathematically speaking, a quantity of the same order as that of the products of combustion of the fuel. The ratio of the masses may be as high as $\frac{1}{20}$, corresponding to a loss of $\frac{1}{20}$ of the available calories. The recuperation of these lost calories added to the increased economy resulting from triple recuperation proper, would bring an increase of 15% in the fuel efficiency by the application of this system to glass furnaces.

CHAPTER XVI

THE DOHERTY COMBUSTION ECONOMIZER

The success of this apparatus is due to two features:

1. The elimination of clinkers due to the ability of the bench to use a large volume of flue gas as an endothermic agent. The large amount of the volume subtending general and thorough saturation of the fuel bed.

2. High fuel economy due to the same large volume of flue gas being converted to fuel gas through the reaction or regeneration of the fuel bed.

The large volume (about 50% of the total flue gas) above stated is made possible only on account of the high temperature at which the flue gasses are returned from the outlet of the bench, it being a fact as before stated, that the endothermic powers of CO_2 diminish with temperature and hence a large quantity at high temperature may be used without reducing the fuel bed below the temperature of gasification or reaction.

In order to handle the gases at this high temperature an air injector is used, the primary air being sent into the injector at a pressure of about 25 ounces of mercury by a positive blower. This primary air when mixed with the flue gas which it induces, is charged to the extent of about 9% CO_2 on an average running variously from 8 to 12%. The fuel gas as a rule shows an analysis of about 17 to 19% CO_2 when the temperature of a bench is at its working heat, approximating 2100° F. In these benches the depth of fuel bed runs from $2\frac{1}{2}$ to 5 ft., depending upon the nature of the fuel used.

Retort Bench Firing.—A key to the drawing herewith shown, where the principle is applied to a gas-works retort bench, is as follows:

It will be noted that the arch walls (A) are built entirely of fire-brick; no red brick whatever being used in their construction. The back wall (B) when two benches are not built back to back is constructed of "9's" of fire-brick backed by a good quality of red brick laid in lime mortar well tempered with Portland cement.

The arches (C) are constructed on heavy forms, the least possible amount of fire-clay being used in laying. The arch tile are made of special fire-clay material to withstand the high temperature to which they are subjected. The arch (E) is constructed of fire-clay tile arched in form and made hollow to reduce the weight and also to prevent loss of heat by radiation. The air space (D) between the two arches forms an additional insulation against radiation and also relieves the arch (C) of any unnecessary weight, thus avoiding any sagging of the arch.

The insulation filling (F) of fine ash is for the purpose of lessening the weight on
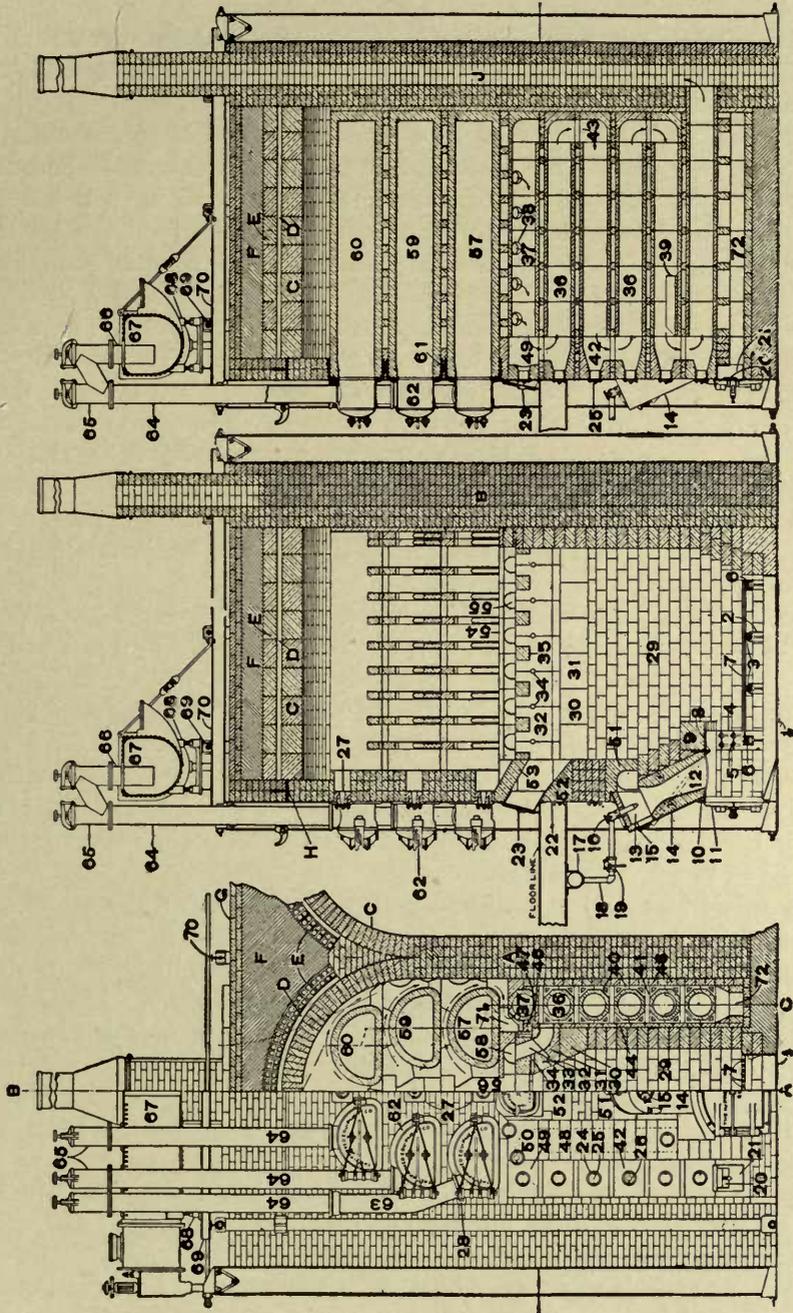
Fig. 187.—Gas Bench Producer adapted to Flue-gas Blast—Doherty System.

the hollow arch and forms an excellent insulation on top of the bench, covered as it is by two courses of brick (G) which make the top of the bench flat and smooth, and readily kept clean in addition to being cool.

The arch lintel (H) is made of cast iron heavily ribbed and supported by the arch walls, the brick-work above being constructed in such a way as to avoid twisting the lintel and necessitating periodical repairs at this point.

The flues (J) are carried up the back wall and are of large proportions lined throughout with fire-brick ending with a short fire-brick stack, steel bound. This stack may readily be extended through the retort house roof by a length of steel stack if desired. No stack dampers whatever are used on top of the bench. The dampers are placed in a more convenient position where there is little likelihood of their being moved through carelessness.

All binding steel is supported from the foundation direct, heavy iron sole plates being used to insure a firm footing. This binding steel may be either of heavy channel iron or I-beam sections, as local conditions may warrant. The lower anchor bolts are tied in the foundation and not in the arch walls. The steel cross ties above are supported by the binding. Whenever necessary the back walls and the end walls are reinforced with steel to prevent warping and bulging.

The ash pan (1) extends flush with the front of the bench.

The bearing bar supports (2) are firmly tied in the brickwork and permits the steel bearing bars (3) to be removed.

The side plates (4) are supported and ribbed to avoid breakage and prevent the removal of the step bars (5) which they support and also the steel and end bearing bars (6).

The grate bars (7) are of bar steel supported on four bearing bars as shown. The end bearing bars (6) are of steel and easily removed if desired, but when in place support the grate bars and keep them properly placed.

The ash door lintel (8) is a single casting ribbed and arched in form, supported on each side by the brick-work and relieved of all unnecessary weight by the fire-arch (9) as shown in the cross-section.

The ash door frame (10) is bolted to both the ash pan and the ash door lintel, forming an additional means of support for the ash door lintel. The ash door (11) is very large, permitting the ashes to be shaken down and withdrawn, is ribbed to prevent warpage and is finished on the face to prevent leakage. The ash door is equipped with a steel liner to prevent radiation. The whole door is fastened tight by means of a light steel cotter bar with latch and cam tightener.

The injector throat (12) is fire-clay as is also the top lining (13) the whole being inclosed in the cast-iron injector housing (14) tied firmly to the ash lintel door by means of tie rods as shown. This injector housing is equipped with an injector damper (15) as shown for the admission of primary air when required. The injector nozzle (16) is clamped fast to the injector housing by means of the small collar and yoke shown and may be removed when necessary.

This injector nozzle is so designed that while the volume of air passing through it may be varied the pressure and velocity remain substantially the same. This adjustment of the injector nozzle opening is by means of a handwheel on top, which is connected to a non-rising stem.

The bustle-pipe (17) which may be either placed underground or supported by the charge floor beams in some similar manner to that shown, carries air from a positive pressure blower (not shown) installed at any suitable point in the plant. The laterals (18) conduct the air from the bustle pipe to the injector nozzles, a quick closing lever-handle gate-valve (19) being installed in each lateral for the purpose of cutting off the supply of air to the bench without changing the adjustment of the injector nozzle.

The secondary dampers (20) and frames (21) are of cast iron, the frame being laid in the brick-work, but may be removed should occasion require. The form of the frame is such that the opening is elevated and protected by a small hood above, which gives protection from dirt and coke and protects the damper with its cap-screw clamp.

The coke chute frame (22) and cover (23) is firmly attached to the front of the bench.

All recuperator flues and other points for cleaning out the bench are equipped with cast-iron peep-hole frames (24) and covers (25) a number of the latter being supplied with swing-sight covers (26) for the convenience of the operator. These peep-hole frames are embedded in the front wall, and at points of high temperature are protected by fire-clay blow-plugs (27) as shown. The peep-hole covers hang on trunnions engaging hooked lugs on the frame in a similar manner to that employed in hanging the coke chute cover.

The blow plugs (28) are cast iron with an eye in each for removal when the combustion chamber requires cleaning. The fire-clay blow-plugs (27) are removed for cleaning, but the swinging sight covers in the peep-hole permit the operator to view the interior of the combustion chamber without the removal of the entire blow-plug.

Referring to the bench filling details, the producer or furnace (29) is built entirely of large producer blocks of a special quality of fire-clay, insuring a tight and durable producer having a minimum number of joints. The producer arch is composed of a key and three sets of fire-clay blocks on each side, the lower being the caps (30) on top of which rest the skewbacks (31) supporting the springers (32). It will be noticed that the ducts (33) pass through the skewbacks and springers and carry the secondary air from the recuperator. The springers contain a small secondary tuyere (34) each as indicated. The producer key (35) spans between the springers on each side and forms the key of the arch. The entire interior of this producer is coated with a flux mixture which when hot glazes the surface binding the tile together thus insuring the stability of the whole mass and the tightness of all the joints.

The recuperator tiles (36) are made in convenient lengths of one piece, having a circular bore and an octagonal exterior. The top recuperator tile (37) are similar in every respect to the recuperator tiles except that they have a hole (38) in the side to permit the products of combustion to enter after they pass beneath the lowest retorts.

The stack dampers (39) are located in the second row of recuperator tiles from the bottom as shown, thus placing them out of the way and impossible to move by accident although readily adjusted with a hook when required.

The miters (40) are light but strong and tightly cover the joint between adjacent sections of the recuperator tile form the spacers for the passage carrying the

secondary air and constitute columns of rigid support aside from the column effect derived from the recuperator tiles themselves.

The spacers (41) are the same width as the miters and also cover a portion of the recuperator joints, and insure alignment in the complete work.

The front returns (42) which connect one row of recuperator tile with another, form a part of the front wall and are fitted with the peep-hole frames mentioned. These front returns are not tied in any way to the recuperator tile, thus permitting difference in expansion to both recuperator and front returns, resulting in a continually tight recuperator.

Recuperators of Doherty Benches.
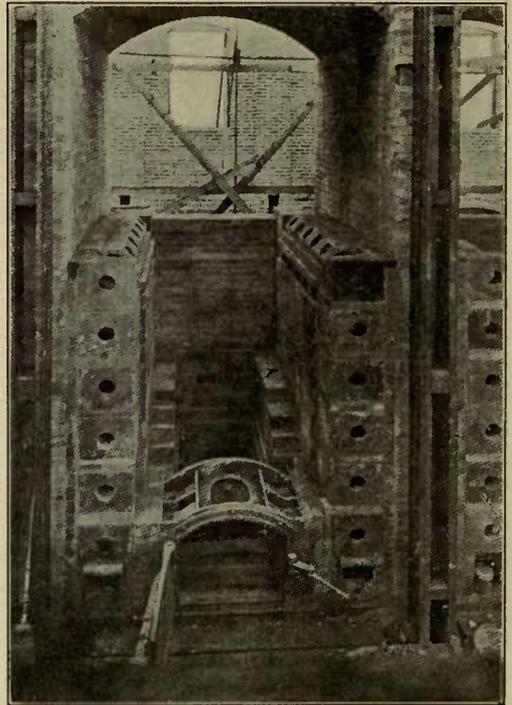
Bench Furnace in Process of Construction
Large blocks are used instead of brick.

Fig. 188.

The back returns (43) are similar to the front returns except that they are lighter in construction and are not fitted with peep-hole frames.

They also connect one row of recuperator tile with another, but like the front returns are not tied in any way to the recuperator tile.

The shims (44) span between the miters and form a backing for the blocks of the producer and form an additional protection against leakage between the producer and the secondary air passage.

The liners (45) are laid close against the arch wall and form a column of support for the setting above, thus relieving the recuperator of excessive weight in addition to insuring protection to the arch wall.

The step miters (46) together with the skewbacks (31), springers (32), and fillers (47) form an elastic or slip joint thus relieving the recuperator from liability of damage through a possible difference in expansion between the recuperator proper and the walls of the producer.

In this type of construction recuperator leakage is reduced to a minimum.

The front wall is constructed almost entirely of special blocks of suitable size. The injector housing with its fire clay lining is placed immediately above the ash door lintel in the center of the bench. The down-takes (48) and the shunt returns (49) connect with the down-flue blocks (50) leading to the injector inlet (51). This injector inlet in turn opens into the top lining (13) above the injector throat (12).

The coke chute bottom (52) rests above the injector inlet and may be renewed if necessary, together with the coke chute top (53) immediately above. These tiles are subjected to wear and are heavy enough for this purpose, but may be removed and new ones installed should the wear be excessive.

The fire arch (9) is massive and thoroughly protects the ash door lintel from excessive heat and load.

The tuyere blocks (54) contain the secondary openings (55) which open into the combustion chamber (56), support the lower retorts (57), and form a secondary cleaning and equalizing duct (58). This equalizing duct is accessible through one of the peep-hole frames shown in the front of the bench. The tuyere blocks also form a support for the lower central setting blocks and have a lip which prevents the clogging of the tuyeres from a collection of slag.

The retorts (57), (59), and (60) are made of fire-clay material thoroughly tamped and hard burned, great care being taken that they are of uniform size and shape and of uniform quality throughout.

The setting tile are light, but their combined supporting area is in excess of that usually used, which results not only in better support for the retorts, but adds to the effective radiating surface, insuring a more uniform distribution of heat with less likelihood of damage resulting from quick changes of temperature.

The patent retort collars (61) are cast in two sections and clamped firmly around the mouth of the retort with a packing between of rust joint material. On page 26 are two views of these retort collars attached to a retort which is ready to be installed. The flange on the face of the collar is tapped to suit the mouthpiece to be used and which is fastened to the collar by means of studs. It will be readily seen that this method of attaching a mouthpiece to a fire-clay retort is far superior to the antiquated method of using bolts exending into the retort itself. These bolts burn off and give trouble by allowing the mouthpiece to sag and pull away from the face of the retort. The use of this retort collar permits a retort of uniform cross-section throughout and also allows removing and replacing a mouthpiece at will without damage.

The bent pipes (63) and stand-pipes (64) are of cast iron, the latter being furnished of steel if desired.

The bridge pipes (65) are of standard design as are also the dip pipes (66) and the hydraulic main (67).

The hydraulic main is supported on adjustable chairs (68) resting on I-beams (69) spanning between the cross-ties (70) supported by the binding.

The gas rising from the fuel bed of the producer (29) passes between the keys (35) as indicated by the arrows into the combustion chamber (56). In this chamber the gas passes between the setting and around the retorts, down to the open spaces (71) immediately beneath the bottom retorts; thence through the openings (38) in the top recuperator tile into the recuperator proper. Then forward to the shunt return (49) where a portion enters the next lower row of recuperator tile and a portion is drawn into the down-flue blocks (50).

That portion of the gas which enters the second row of recuperator tile passes to the back returns and then down and forward again to the next front return and so on until it finally enters the stack (1) and then to waste.

The secondary air enters through the damper frames (21), passes back through the ducts (72) and rises between the rows of miters and spacers and completely surrounds the recuperator flues until it enters the ducts (33) leading to the equalizing duct (58). A portion of this secondary air is short-circuited through the small secondaries (34) below the keys (35); the remainder entering the combustion chamber (56) through the tuyeres (55) leading from the equalizing duct.

The primary air under pressure, and issuing from the injector nozzle, enters the throat of the injector, producing a partial vacuum or inductive effect in the space immediately above the throat, which effect results in a certain percentage of the gases entering the space beneath the lowest retort, being drawn into the shunt return, then through the down-take blocks, into the down-flue blocks to the injector inlet. The gases thus induced into the injector top are forced by the air issuing from the injector nozzle through the throat and injected into the ash pan beneath the grate bars of the producer.

At the same time these gases are thoroughly mixed with the primary or injector air issuing from the injector nozzle before they pass up through the fuel bed.

Chemical Reactions.—As the hot coke is usually used for fuel in a gas-bench producer, we will consider coke as the fuel used in this case. The depth of the fuel bed should be 4 or 5 ft., leveled off on top. The stack dampers should be so adjusted that the pressure in the producer is as near atmospheric pressure as possible, so that there will be neither a tendency for the producer gas to blow out when the coke chute cover is removed nor a tendency for the air to draw in. The secondaries should be so adjusted that an analysis of a sample of the products of combustion taken well back in the duct immediately below the lowest retort will show on an average from 18 to 19% CO_2 and 1 or 2% O. The injector nozzle opening and air pressure should be so adjusted that an analysis of a sample of the primary mixture taken well back in the space beneath the grate bars of the producer will show an average of from 8 to 12% CO_2 and 8 to 12% O.

The producer gas or CO rising from the fuel of the producer and at a temperature above that required for ignition comes in contact with the highly pre-heated secondary air issuing from the tuyeres below the keys where a partial combustion takes place. This partial combustion is for the purpose of preventing any possible collection of carbon on the producer keys, thus decreasing the opening between the producer and the combustion chamber which sometimes occurs when coal is used and the producer gas formed is very rich. The gas, after passing the small secondary tuyeres and between the keys of the producer arch, comes in contact with the balance

of the secondary air issuing from the large tuyeres above into the combustion chamber. At this point complete combustion starts. The highly heated products of combustion in their passage around the retort and before entering the recuperator give up a certain portion of their heat to the retorts and settings. Entering the spaces immediately below the lowest retorts, the products of combustion are divided, one portion going to the injector and thence beneath the grate bars, and the other portion entering the recuperator, where by contact with the enormous area exposed it again parts with a large portion of the heat it still retains, which heat is transmitted through the thin walls of the recuperator tile to be rapidly absorbed by the secondary air in direct contact. This secondary air rises by its own increase in temperature and volume and finally enters the combustion chamber through the tuyeres at substantially the same temperature as the products of combustion when they enter the recuperator.

Advantages.—The advocates and manufacturers of the Doherty bench claim its advantage over furnaces using H_2O or steam as an endothermic agent, through the fact that clinker is prevented and the fire is not "quenched," as in the case of the agents aforesaid.

If any such advantage or superiority exists, in the opinion of the writer, it depends upon the following reasons:

1. The high temperature of the flue gases permits a large volume to be used and converted in the fire bed into potential gas, as previously explained.

2. That this large volume obtained with low density more thoroughly disseminates through the entire volume of fuel, and its action is therefore more general, or in other words, it does not channel or concentrate its action as does the heavier aqueous vapor or steam, with a consequent formation of "dead spots" adjacent to such channels. This is plausible, by reason of the difference in density between the hot gases and the heavier and more penetrating steam which seeks lines of cleavage rather than diffusion and which is much more concentrated in its action.

To this fact we would attribute the non-production of clinker in the process, that is to siay, it is possible with either CO_2 or H_2O to maintain the fire bed at the temperature below the critical point of fluxing fusible ash, but while this may be done with the use of the hot flue gases and at the same time a reasonable reaction of such gases to CO be obtained, yet if a sufficient amount of H_2O be used to maintain sufficiently low the temperature of the fire, it would be so pitted with "dead spots" due to its channeling as to produce an excessive amount of CO_2 in the resultant gas, or, in producer parlance, the fire would be "killed."

It is also a question whether the temperature requisite for the complete dissociation of steam and its reaction from $H_2O + C$ to $2H + CO$ does not require a higher temperature than the critical point of clinker formation as aforesaid, while it is possible that the reaction $CO_2 + C$ to $2CO$ can occur at a relatively lower temperature, that is to say, below the clinker point, or perhaps over a wider range of temperature.

This fact, of course, depends upon the nature of the fuel used, conditions of radiation, and flame temperature, but it is just possible that they form important elements in the equation.

3. It is a chemical fact that the reaction of CO_2 to CO is constant or what is known as a positive reaction, while the combination of H_2O and C are variable.

4. It is claimed with some justice that while the supply of steam is obtained at

some expense of fuel, labor, and fixed charges, the use of flue gas creates the utilization of an otherwise useless product. Again, the gas obtained from the system described, is more uniform or constant in its value than that made with H_2O. As opposed to these arguments is the fact that the H_2O gas is of higher calorific value.

The chief contentions made by the respective advocates of the CO_2 and H_2O theories are: with the temperature of the several conversions; with the respective specific heats of the two products, and their constant abstraction of sensible heat from the fire at the expense of fuel.

The advocates of the H_2O theory point particularly to the high specific heat of water vapor as compared to CO_2 per unit of weight, but as a matter of fact upon a basis of molecular equivalents, they are about the same, CO_2 being slightly the higher, and it is doubtful whether under practical conditions there is much difference between the two, when the CO_2 plus its attendant nitrogen is compared with the H_2O.

The burden of chemical advantage appears to be against the CO_2 theory, while in its favor are notable results in every-day practice.

As herein suggested from both observation and practice the writer believes that the conditions of a physical nature involved in the question are more prominent than those of a chemical nature, and that the physical elements are more prominent and practical than the chemical considerations involved.

There is a likelihood that in the use of CO_2 in producer regulation, there is a certain prevention of clinker by a " generalization " of combustion (as opposed to concentration or localization of combustion) due to the dilution of the air admitted and the neutral action of said CO_2, in addition to its heat absorbing properties.

If flame temperature is a function of the activity of combination of the elements per unit of space (other conditions being equal) then the converse must hold and flame temperature be lower, and combination be less localized, where one or both elements are diluted, and combustion diffused.

An analogy of this is indicated by the performance of lignites and other low grade coals containing high amounts of neutral or non-combustible matter, which fuels in producer gasification maintain so low a flame temperature as to require but little, and, in extreme cases, no endothermic agent for controlling or absorbing the " plus " heat generated within the producer.

Operation Details.—The following data shows some of the conditions found by the writer in a plant of the type herein described:

Depth of fuel bed, 4 to 5 ft.

Nature of fuel in producer, hot coke withdrawn from the retorts. The coal is known as " Berwin mine run," bituminous, mined in Southwestern Colorado.

Weight of charge in retorts, 333 lbs. in small benches, 400 lbs. in large benches.

Length of time for carbonizing, 4 hours.

Percentage of coke drawn; about 67% of the coal remains as coke.

Bench fuel per ton of coal carbonized, on small benches, 270; on larger benches 250 lbs.

Temperature of flue gases, outlet of recuperator, about 600°.

Temperature of primary air, flue gas mixture under grate bars, or outlet of inductor, varies from a minimum of 200 to 800° (as when a retort cracks and allows coal gas to escape into retort oven.)

As a matter of course the operation of apparatus, such as is herein described, must depend upon the fuel used in the producer, the coal carbonized, the size of charges, the length of carbonization and kindred elments. However, it will also be found that each bench and producer has its individual characteristics, largely due to conditions of radiation, ventilation, and environment, which must be separately and severally learned to facilitate and minimize the individual equation in operation. However, the writer advises a thorough system of draft gauges which will indicate at a glance the draft suction of the stack, pressure of the air through the blower upon each bench, and the suction created by the primary air upon the syphon of the injector.

It may also be of advantage to install these gauges at other points which will reflect conditions of stoppage, of back pressure, which is often due to soot, lampblack, dust, or ashes.

The eye of the operator readily learns the heat of the producer, which is most advantageous to best results, but the minimizing again of errors may be done by recording pyrometers to much advantage.

As in all other classes of producers it has been found, in the experience of the writer, that a dull orange is the most efficient heat color to be maintained, that is to say, the heat should be maintained below the appearance of any white lights, which are invariably the sign of a fusing or clinkering heat. The appearance of white, either as reflected lights or intermingled with the orange shades, are the danger signal alike in producer gas or water gas operation.

CHAPTER XVII

COMBUSTION IN FURNACES

COMBUSTION

It is not the desire of the author to attempt an essay upon the subject of combustion, in the discussion of which we have no empiric premises, the foundations and data which are extant being greatly at variance, and without factors explanatory of its various forms and phases.

It is altogether possible that the author is working from a wrong direction in the principles that he here lays down, but for the benefit of those who may desire to prosecute the subject to a more finished degree, he proposes the following hypotheses, which have been of service to him in the solution of a number of practical problems and which may serve as a working basis for more active and complete analyses.

Heat and Temperature.—To begin with, it is necessary to differentiate between heat and temperature, terms which have unfortunately been often interchangeably used. The distinction between these two is identical with those terms used in electricity, as amperage and voltage, volume and pressure, in which heat corresponds to the former and temperature to the latter.

Assuming these divisions, we will proceed to draw certain other analogies, between the action of heat and temperature, and the known phenomena of light. In this connection we find the law of light wherein the intensity of light increases inversely as a square of the distance from its point of emanation. In the corollary with temperature, this depends upon three things, namely, the amount of heat given off, the time in which it is given off, and the area within which it is given off.

Taking these factors into consideration, we find from a practical standpoint, that flame temperature depends upon the amount of heat envolved in combustion within a unit of area within a unit of time, and we may say that this temperature has (by reason of conduction, radiation, etc.) an evolved heat which increases inversely as the square of the unit within which the combustion takes place.

We also find that, assuming the unit to remain constant, the temperature increases directly with the heat liberated by combustion, and inversely as the square of the radiation.

The above hypothesis accounts for the phenomena resultant upon high pressure and delivery of gas and air in all the ramifications of Bunsen burner work.

We are well acquainted with the analogy of the search-light whose lenses merely tend to parallel the rays of light and prevent diffusion common to all forms of radiant

energy. This is also shown in both air and water jets, acting under pressure, which tend to diffuse in a ratio about inversely as a square root of the initial pressure.

We find therefore that under conditions of pressure this diffusion is retarded and the cross-section or unit space tends to be more constant or protracted, there being a diminution of radiation. In other words, where conditions of high pressure delivery maintain, there is a resultant cohesion or condensing, due to the initial pressure, which tends to retain the combustion within a more confined flame area subtending a decrease of radiation.

Velocity of Flame Propagation.—Again, another feature with which we are not exactly acquainted, comes with the fact that the compression of the gas brings its molecules or atoms into closer juxtaposition, and the transmission of heat evolved is more rapid and complete. This is shown by actual tests, which go to prove that under conditions of high pressure delivery, the same amount of heat is evolved with less fuel, or greater heat with an equal fuel under combustion. We might term this, through lack of a better word, " heat propagation," as the action is analogous to that of flame propagation, which latter is undoubtedly a factor in the radiation activity herein described.

Another manifestation of this heat propagation, or more strictly speaking, propagation of temperature, is seen in the cylinder of the gas engine under high compression. This is possibly the best illustration that we have of the conditions of combustion due to a compressed gas, although, in addition to the " radio-activity " which we have just mentioned, there is in this condition the added value of the fuel, due to the compression of a much larger amount of combustible within a given space, in fact doubling the amount of this combustible at the pressure of each additional atmosphere.

In conditions of daily practice, we will therefore see, that up to a certain point we may increase the flame temperature by increasing the initial pressure. This is caused by the fact, as before mentioned, that within certain limits the compression or contraction of the flame, due to initial pressure, in increased or maintained (within certain limits) at a greater ratio than the diffusion and consequent radiation, or, as it is commonly termed, " ventilation."

Beyond that point, however, the velocity of combustion subtends an increased velocity of radiation or ventilation, which detracts from the gross results of the temperature accrued. Thus we have the phenomena known as " blowing-cold," that is to say, the velocity or initial pressure of the products of combustion is so great as to pass under the flame area when only partially consumed. Here we come upon the time factor of the equation, which under conditions of " over-ventilation " must be taken into consideration.

Theoretically combustion of all sorts has always been expressed by $T_1 - T_2$, that is to say, the highest initial temperature and the lowest terminal temperature, and where the velocity becomes excessive or out of keeping with the other conditions or factors of the equation, the final temperature is either unnecessarily high or else the velocity has been too great to permit of thorough chemical union upon the part of the ingredients. Either of these are generally summarized as " over-ventilation."

Recuperation.—Heat may be either radiant or conducted. The dominant law of heat is the law or equilbrum or the flow from greater to less until both terminals become equalized. This phenomena of equalization of temperature also requires a

time factor, and upon this time factor and the specific heat (better known as the coefficient of heat, inasmuch as it varies at different temperatures and under different conditions of various materials) all processes involving mufflers, recuperators or regenerators, depend.

Here again must occur a balance between an initial velocity, which will apply to the absorbing material and the maximum amount of heat, and the time and space units of contact necessary for the absorption of this heat in working out this equation in exactness, lies the fundamental principle of all regenerative processes.

Where it is possible to recuperate heat, it should invariably be done either in connection with the air blast to the producers or the cool air used in combustion. The resultant economy is very great, and under ordinary industrial conditions, is easily affected, the pre-heating being carried up to a point of 500 or 600° F. in "continuous regenerators." These are usually sections of iron pipe with return bends, but at higher heat, say 900 or 1000° F., brick-lined conduits are preferable. Terracotta pipes are sometimes used, but have a tendency to crack and break.

Great care should be taken to ascertain that the recuperated heat does not come from any active portion of the furnace, but only the waste heat, such as the sensible heat in the products of combustion, the exothermic heat, resultant from the material to the furnace, etc. Otherwise where sensible heat is abstracted from any active portion of the operation, it is doubtful whether there is any economy to be obtained.

Temperature.—The theoretical temperature attainable by the combustion of any fuel may be crystallized in the formula $T = \dfrac{\text{B.T.U.}}{W \times S}$ in which B.T.U. equals the number of B.T.U. generated by the combustion. W equals a weight of gaseous products and S equals the coefficient of heat absorption of the gaseous products, generally known as "specific heat." This equation forms a concept of the propositions already laid down, that is to say, the temperature is dependent upon the conservation of the heat evolved within a given area, and not alone upon the rapidity of combustion, although this may be contributory, and the exponent of the resultant heat evolved.

No better instance can be shown than that already alluded to, of the gas engine, where the flame temperature obtained is undoubtedly identical in the case of city gas of 700 B.T.U. value and producer gas of 100 B.T.U. value.

The unit space within which this combustion occurs, from a standpoint of the net fuel, is very nearly the same, while, weight for weight, the rapidity of combustion is of course many times greater.

Where combustion is slow, radiation under practical conditions is in much greater ratio, and the temperature may thus be indirectly affected to a considerable degree by the rate of combustion; hence in practical operations, the more rapid the rate of combustion, the higher the temperature usually produced, and the more heat evolved.

For instance (Ingalls, "Metallurgy," page 264), "In the operation of a producer the object is merely to burn carbon to carbon monoxide, in which latter the total weight of the products of combustion is only 6.79 lbs." The average specific heat of products of combustion are given in tables, and by substituting them for the terms in the formula the temperature "T" is determined, which is practically 2240

F. In the diagram of flame temperatures curve *A* shows theoretical temperatures which may be obtained under assumed conditions. Practically, however, there are a number of other features which must be taken into consideration, two of which are the furnace walls, which must be maintained at a temperature considerably above atmospheric, with a consequent loss of heat from radiation and conduction, and the other being the sensible heat withdrawn by the ash.

Assuming fuel with an ash content of say 10%, the ash loss, together with the radiation, may be placed at 5.7% of the total heat generated, which figure approximates that of practical tests (see Butterfield, page 87). The combination of these losses reduced to theoretical in curve *A* and more nearly obtain the curve *B* of Chart 1, which approximates the result of practice as aforesaid, always assuming
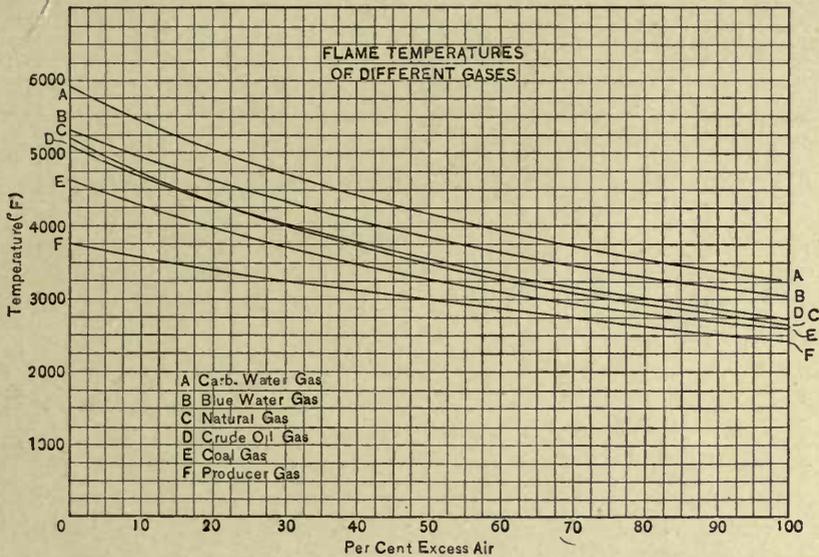
FIG. 189.—Flame Temperatures as influenced by excess Air.

however, that the carbon is burned to CO only, a condition which would be impossible in commercial operation.

In recapitulation, we find that flame temperature is increased by (*a*) the intimacy of the mixture; (*b*) the compactness or density of the fuel in delivery; (*c*) the amount of fuel delivered within a unit space; (*d*) the limitation of the flame area, while conversely flame temperature is reduced by (*a*) increased radiation, as in the case of an increased flame area; (*b*) over-ventilation, as in the case of high velocity or an excess of air.

This latter condition is of course impossible to avoid in all practical conditions, but it must be maintained at the minimum. A table is herewith appended, showing the loss of flame temperature due to the excess of air. In order to support combustion, it is necessary in all practical operations, as a matter of practice, to admit considerably more air than is theoretically necessary, in order to secure proper combustion, the single exception being, in the case of firing powdered fuel, where the intimacy

of the mixture is such that it practically attains approximately theoretical conditions, or about 150 cu.ft. of air per pound of powdered coal fired.

FLAME TEMPERATURES AND EXCESS AIR

Name of Gas.	Analysis (Assumed).									
	CO_2	Ill.	C_6H_6	O	CO	H	CH_4	N	B.T.U.	Sp. Gr.
	%	%	%	%	%	%	%	%	per cu.ft.	Air = 1.0
Carbureted water gas	4.5	13.0	....	0.5	29	32	16	5	650	.60
Coal gas	2.0	5.5	....	0.5	11.5	43.5	35	2	600	.45
Crude oil gas	1.7	4.2	1.6	0.4	6.1	52.4	29.3	4.3	600	1.40
Blue water gas..........	4.0	....	....	....	43.5	48	.5	4	300	.42
Producer gas	6.0	....	....	....	20	12	4	58	150	.85
Natural gas	2	3	....	....	1	....	88.5	5.5	900	.55

Name of Gas.	Flame Temperatures with Air Excess as Specified, Temp. in ° F.					
	Theoretic.	10%	25%	50%	100%	Vols. Air to Burn 1 Vol. Gas, Theoret.
	°	°	°	°	°	
Carbureted water gas	5909	5422	4887	4166	3217	4.85
Coal gas	4615	4285	3846	3296	2581	5.47
Crude oil	5084	4688	4166	3550	2727	5.39
Blue water gas..........	5291	4918	4477	3846	3030	2.24
Producer gas	3750	3571	3333	3000	2420	1.15
Natural gas	5202	4737	4166	3488	2624	8.95

The question of the intimacy of the mixture has not perhaps been discussed at sufficient length. This may be obtained in the highest degree of perfection, first, mechanically, by means of proper mixing chambers, which tend to break up the air and gas rivers, and interpolate them, inter-mixing them as closely as possible, and secondly, thermal conditions, under which head it will be found that gases mixed with each other and with air, are best at a high degree of temperature, due to a lessened vapor tension, the proposition being very nearly analogous to that of metals which will only commingle in a molten condition.

This condition upon the part of air might almost be termed one of fusion, since their mixture is so much more complete at the higher temperatures, and were there no advantage to be obtained from the restoration to the fire of sensible heat in processes of regeneration and recuperation, the process would be justified in itself by the advantage accruing through the intimacy of the mixture obtained.

Practically all burners now used for either natural or artificial gas recognize the necessity for thorough mechanical mixers, and these mixers are arranged with either rotary deflectors, baffles, etc. (of which the Kirkwood is a good example) for the mechanical agitation and commingling of the air and gas or gases.

As a matter of fact, at the present stage of the art, approximation of theoretical temperatures (and here we might again emphasize the fact that "temperature" is the potential and "heat" the volume), is not even close of attainment, which

subject we discussed at greater length under the head of " Furnaces "; but suffice it here to say, that a large portion of the heat necessary to high temperature operation must be recovered in the sensible form and replaced in the fire through means of recuperators or regenerators.

Up to a certain point a lack of recuperation may be overcome by increased pressure, depending somewhat upon the design of the furnace, but when the differ-
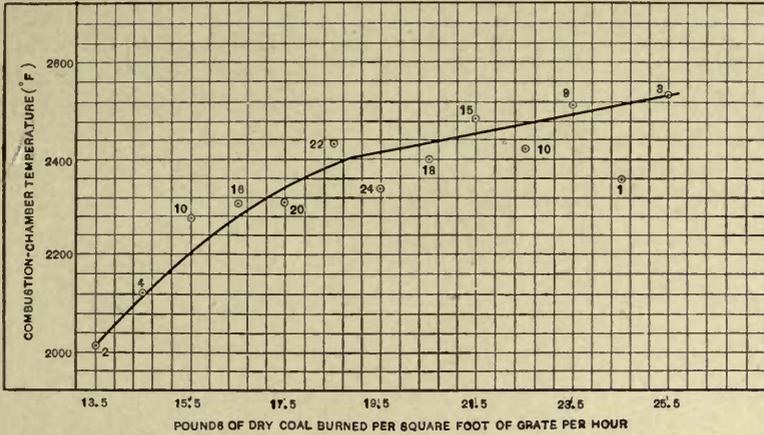
Fig. 190.—Relation of Pounds of Dry Coal Burned per Hour per sq.ft. of Grate Surface to Resulting Combustion Temperature.
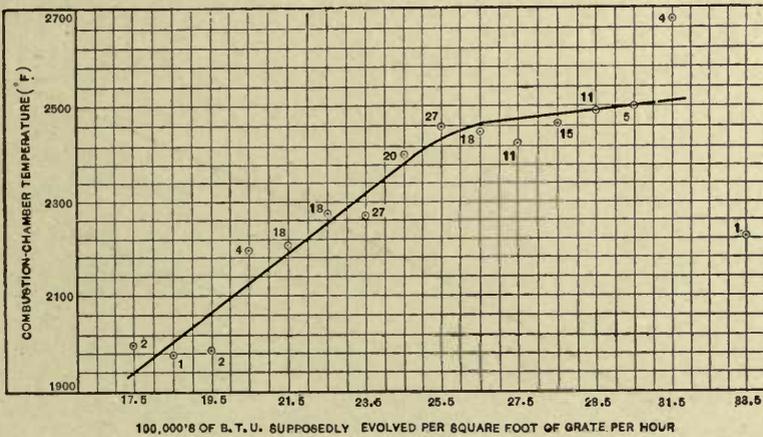
Fig. 191.—Relation of 10,000 B.T.U.'s evolved per sq.ft. of Grate Surface per Hour to Resulting Temperature.

entiation in pressure between initial and terminal pressures of the furnace become so great as to subtend extraordinary velocity or ventilation, the efficiency falls off with great rapidity, and the results are not commensurate. For this type of work 1200 to 1500° F. with anthracite, 1600° with bituminous producer gas, is perhaps the limit.

The principle cause of this falling off in efficiency is the fact that under pressure both gas and air tend to become more dense, and with an increase of vapor-tension, their intimacy of mixture falls off. In analogy, two streams of water eminating from nozzles under high pressure, may be opposed so as to cut each other, when it will be found that there will be practically no intermixture of the water, or loss of identity in the streams, unless indeed these streams cut at a late point where their initial pressure is reduced through friction and the streams are " broomed " or diffused.

It will be observed that while temperature is a function of the rate of combustion in unit area times efficiency (under the latter term is understood radiation, intimacy of mixture, ventilation, etc.), the quantity of heat developed is a function of the fuel. However, as it has been said, under working conditions the amount of heat is frequently dependent indirectly upon temperature, and hence high temperature furnaces, requiring a large product of heat, are usually designed for a high rate of combustion.

It must, however, be borne in mind that primarily volume of heat is dependent upon the nature of the fuel and the actual volume of heat developed from a pound of coal is identical, whether burned in a few moments under forced draft or slowly oxidized through atmospheric exposure.

Combustion.—The rate of combustion is frequently very much over-estimated, which condition is noted in Wm. Kent's experiments, where he cites the fact that a low rate of 10 lbs. of coal per square foot of grate surface per hour in fire-brick furnaces produces so small a radiation that it attains an actual temperature very nearly as high as that obtained by 20 to 40 lbs. of coal per square foot of grate area per hour, the loss in the latter being due of course to the considerable increment of excess air necessary for its combustion.

Even with a gaseous fuel, however, a certain excess of air (above the theoretical) is required for complete combustion, the percentage of air being less in direct proportion to the extent to which the air is pre-heated.

According to H. H. Campbell, with gas at 600° C. and air at 50° C., from 20 to 100% of air in excess, is necessary to prevent the escaping of a considerable quantity of combustible matter unburned, although with air and gas at 1000° C., the escape of unburned combustible gas is reduced to 10% and in some instances 5% in furnaces of satisfactory design.

Again, we find that with dust or powdered fuel, where the intimacy of the mixture is thereby increased and the flame propagation made more rapid, combustion attains very nearly, if not exactly theoretical conditions, and we may allow with the powdered coal about 150 cu.ft. per pound of combustible.

It is of course understood that where an insufficient air supply exists, incomplete combustion and lower temperature must necessarily follow by reason of the fact that a portion of the oxygen passes through the fuel without carbon combination. Moreover, the air supply is usually more or less irregular, even with a nominally steady draft pressure, one reason being that freshly fired coal chokes to some extent the rivers or passages through the fuel bed, or in the grate, creating certain combinations of carbon monoxide, and endothermically chilling the flame.

Wm. Kent obtained temperatures exceeding 650° C. as measured by a Uehling
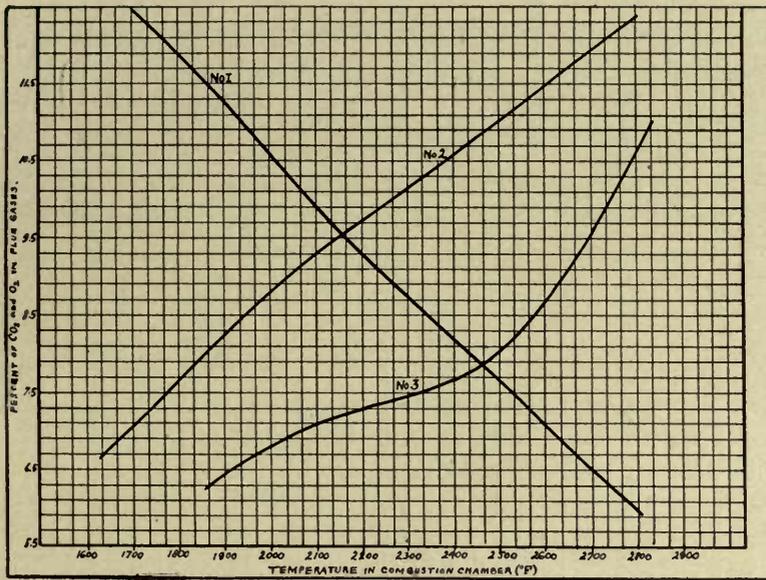
FIG. 192.—Composition of Flue Gas compared with Furnace Temperature.
Curve No.1 $= O_2$; Curve No. 2 $= CO_2$; Curve No. 3 $= CO$.
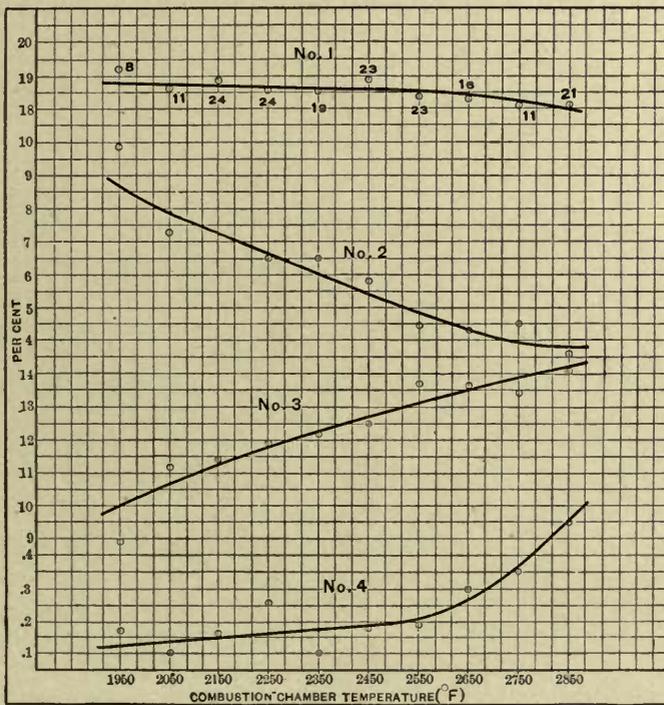
FIG 193.—Composition of Burned Gas in rear of Combustion Chamber at Temperatures Given.
Curve No. 1 $= CO_2$, O_2, and CO; Curve No. 2 $= O_2$; Curve No. 3 $= CO_2$; Curve No. 4 $= CO$. The
samples of gas were taken through water-jacketed sampling tubes.

recording pneumatic pyrometer, with Pittsburg coal containing less than 2% of moisture and having a calorific value of 15,000 B.T.U., in the combustion chamber with fire-brick linings and by constant firing of small quantities of coal at a time.

This approximates very nearly to theoretical temperature due to an air supply of 19 lbs. of air per pound of combustible, which is the figure found in practice to
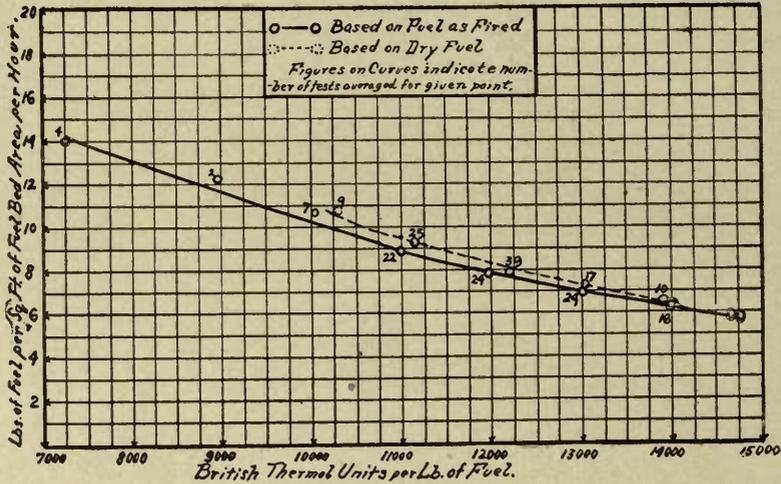
Fig. 194.—Influence of Rate of Combustion and Dryness of Fuel upon Temperature (U. S. Geol. Sur. Report).
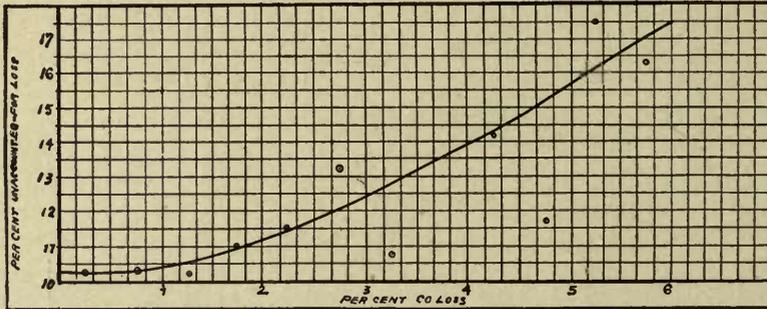
Fig. 195.—Proportion of Losses Due to Imperfect Combustion or Due to CO in Flue Gas.

give the highest efficiency of steam-boiler performance. (See Kent's "Steam Boiler Economy," page 31.)

Ignition.—Every fuel has a certain critical temperature, which is known as its "ignition temperature," to which it must of course be raised before combustion will take place. This naturally reflects another advantage obtained from the pre-heating of the elements of combustion and varies according to their physical properties, chemical compositions, etc. Under the former, density is perhaps the most notable factor. Under the latter it will be noted that fuels which contain the most hydrogen are

usually the easiest to ignite, resinous wood and cannel coal being examples of this fact.

It may be noted, however, that no gas will ignite below a red heat, which fact is true regardless of its content of hydrogen. This is because of its lack of density or rather of the diffusion of its molecules.

Pine wood ignites at 295° C.; ordinary bituminous coal at 325° C.; coke, anthracite, hydrogen, carbon monoxide, etc., require a dull red or cherry heat. (Roberts-Austen, "Introduction to the Study of Metallurgy," page 171).

Where the temperatures of gases are maintained or lowered below ignition point, no combustion of course takes place. This is a principle involved in the " Miners lamps " and numerous safety devices, also the screens in Bunsen burners.

Nitrogen.—Although nitrogen is considered an uninflammable gas, Professor Lewes points out that inasmuch as it forms no less than five compounds with oxygen, it is evident that its lack of combustion is due to an inability, under ordinary circumstances, to produce a sufficiently high temperature to bring about direct combinations.

Compounds of oxygen and nitrogen are found in the atmosphere after thunder storms, and as the result of electric sparks, and it is likely that nitrogen oxides have much to do with certain furnace conditions at high temperatures, which are otherwise unexplainable.

Professor Lewes in his work on "Liquid and Gaseous Fuels" (page 8), points out that oxidization and combustion are identical in their total heat liberation, and differ only in the rate of chemical combination.

Whether a tree decay or be burned, the amount of heat evolved is identical, its generation covering widely different periods. Moreover, the distinguishing demarkation between these combinations is to a great extent that of ignition point, phosphorus forms, igniting and combining with oxygen at a point little above atmospheric temperature; coal at about 500° C., while steel, which is subject to oxidization in the form of rust, has so high an ignition point as to make it, for all practical purposes, uninflamable. In this connection, Prof. Lewes says as follows:

" The spread of ordinary fire and flame is due to the fact that when combustion is started by the ignition point being reached, the combustion raises the temperature generally well above the ignition point of the burning body, so that as one particle burns, it ignites the next, and this action continues until the burning body has entirely combined with oxygen, but if the heat generated be insufficient to raise the body to the ignition point, combustion ceases as soon as the external heat is withdrawn. In the case of a watch spring burning in oxygen gas, the combustion of a piece of German tinder attached to the end of it is sufficient under the exciting influence of the pure oxygen to raise the spring to the point of ignition, and then the temperature developed by the oxidation of the metal in the oxygen is sufficient to continue the combustion until the whole of the spring is burnt away. If, however, instead of allowing the action to go on in the pure oxygen the spring, whilst still vividly burning, is withdrawn from the jar of oxygen into the air, combustion ceases after a few moments, owing to the dilution of the oxygen in the atmosphere by nitrogen lowering the intensity of the combustion, so that the ignition point of the metal is no longer reached."

COMBUSTION OF CARBON DATA

Condition of Bed with Reaction Symbolized.	Parts of C Burned or Oxidized.	Net Total Thermal Effect.	Net Thermal Effect per Unit of Carbon Burned Unit = 1 lb. or 1 kg.
1. Shallow bed and complete combustion, or "oxidation" of C to CO_2 .... Volumes .... I　　I Reaction .... $C + O_2 = CO_2$ Weight .... 12 + 32 = 44	12 lbs. 12 kgs.	DEVELOPING 175766 B.T.U. or 97656 kg.-cal.	DEVELOPING 14648 B.T.U. or 8138 kg.-cal.
2. Deeper bed and conversion or "reduction" of this CO_2 to CO in the producer .... Volumes .... I　　II Reaction .... $CO_2 + C = 2CO$ Weight .... 44 + 12 = 56	12 lbs. 12 kgs.	ABSORBING 68976 B.T.U. or 38328 kg.-cal.	ABSORBING 5748 B.T.U. or 3194 kg.-cal.
3. Direct oxidation of the C to CO; "primary" or incomplete combustion in the producer.................... Volumes .... I　　II Reaction .... $2C + O_2 = 2CO$ Weight .... 24 + 32 = 56	24 lbs. 24 kgs.	DEVELOPING 106400 B.T.U. or 59328 kg.-cal.	DEVELOPING 4450 B.T.U. or 2472 kg.-cal.
4. Combustion of this CO to CO_2 in engine or furnace; "secondary" or completed combustion.................... Volumes .... II　I　II Reaction .... $2CO + O_2 = 2CO_2$ Weight .... 56 + 32 = 88	24 lbs. 2 kgs.4	DEVELOPING 254560 B.T.U. or 136416 kg.-cal	DEVELOPING 10231 B.T.U. or 5684 kg.-cal.

Air for Combustion.—(Ingalls, "Metallurgy"): Theoretically the combustion of 1 lb. of carbon to dioxide requires 11.52 lbs. of air. Practically under the ordinary conditions of chimney draft that quantity is greatly exceeded. Donkin and Kennedy showed in the results of sixteen tests with steam-boiler installations that the air supply ranged from 16.1 to 40.7 lbs. (Walter B. Snow, " The Influence of Mechanical Draft upon the Ultimate Efficiency of Steam Boilers," a lecture delivered before the Engineering Society of Columbia University, December 1, 1898.) The effects of an excess of air upon the combustion of coal are to reduce the temperature produced thereby and increase the relative weight of the products of combustion. Although the initial volume increases with the excess, however, it is to be noted that the relative volume just after passing through the fire remains practically constant because of its lower temperature and consequently greater density. In so far as the temperature is reduced there is a loss of efficiency, since the lower the initial temperature the less rapidly will the gases of combustion transmit their heat, and the final result is that, within practical limits, the temperature of the escaping gases is highest with the greatest excess of air supplied.

In burning 1 lb. of carbon to dioxide there are generated 14,600 B.T.U. The products of combustion comprise 3.667 lbs. of carbon dioxide and 8.853 lbs. of nitrogen, the total weight being 12.52 lbs. Assuming the specific heat of carbon dioxide to be 0.217, and that of nitrogen to be 0.2438, the average specific heat of the gas is 0.2359. According to the formula given in a previous section the theoretical elevation of temperature of the fire above the atmospheric temperature would be 14,600 ÷ 12.52

$\times 0.2359 = 4942.5°$ F. ($272S°$ C.). If the atmospheric temperature were 62° F., the theoretical temperature of the fire would be $4956° + 62° = 5004.5°$. It is probable that the specific heat of gases of combustion at high temperatures is higher than 0.2359, which would have the effect of reducing the temperature. The actual specific heat of combustion of the gases under those conditions has not been determined, but the figure of 0.237 is commonly assumed in temperature calculations. However, because of the excess of air required to effect complete combustion, besides other considerations, it is never possible to attain the theoretical temperature. The effect of different percentages of air supply in reducing the temperature of fire is shown in the subjoined tables which are taken from Kent's treatise on "Steam Boiler Economy" (wherein they are credited to H. T. De Puy, of the Babcock & Wilcox Co.) and other sources:

EFFECT OF AIR EXCESS ON TEMPERATURE

Air excess above 11.52 lbs., %	25	50	75	100	150	200
Air per pound of carbon, lbs	14.40	17.28	20.16	23.04	28.80	34.56
Products of combustion, lbs.	15.40	18.28	21.16	24.04	29.80	35.56
Elevation of temperature of fire, ° F.	3950°	3328°	2875°	2530°	2041°	1711°

CARBON BURNED PARTLY TO CO₂ AND PARTLY TO CO, WITH EXCESS OF AIR

Excess of air, %	50	40	30	20	10	0
Carbon burned to CO_2, %	100	80	60	40	20	0
Carbon burned to CO, %	0	20	40	40	80	100
Products of combustion, lbs.	18.28	15.52	12.99	10.67	8.60	6.76
Elevation of temperature of fire, ° F.	3328°	3375°	3350°	3323°	3139°	2743°

(Heat value of carbon assumed to be 14,600 B.T.U. and specific heat of gases 0.24.)

EFFECT OF AIR EXCESS ON FLUE LOSSES

Temperature of Flue Gases	100° C.	200° C.	300° C.	400° C.	600° C.
Specific heat of waste gases:					
No excess air	0.328	0.336	0.344	0.352	0.367
20% excess	0.327	0.334	0.341	0.348	0.363
40% "	0.324	0.331	0.338	0.345	0.358
60% "	0.322	0.328	0.335	0.341	0.354
80% "	0.320	0.326	0.332	0.338	0.349
100% "	0.318	0.324	0.329	0.334	0.345
Heat lost; per cent of total:	%	%	%	%	%
No excess air	3.8	7.5	11.3	15.5	24.0
20% excess	4.5	8.9	13.4	18.4	28.3
40% "	5.1	10.3	15.4	21.1	32.5
60% "	5.8	11.7	17.5	23.9	36.8
80% "	6.5	13.0	19.5	26.7	41.0
100% "	7.2	14.4	21.6	29.5	45.3

DIRECT COMBUSTION FURNACE. EFFECT OF SURPLUS AIR SUPPLY. (BUTTERFIELD)

1	2	3	4
Volumes of air in excess of ideal requirements for the combustion of carbon to carbonic acid, present in every 100 volumes of air supplied to the furnace.	Volume under normal conditions of chimney gases for the furnace per pound of carbon consumed.	Heat carried by chimney gases leaving the furnace at 975° C.	Ratio of heat carried by chimney gases leaving the furnace at 975° C. to heat furnished by the combustion of the carbon.
	Cubic Feet.	B.T.U.	Per Cent.
0....................	143.5	5940	40.8
1....................	145.0	5995	41.2
2....................	146.4	6050	41.6
3....................	147.9	6100	41.9
4....................	149.5	6160	42.3
5....................	151.0	6215	42.7
7....................	154.3	6330	43.5
10...................	159.4	6515	44.8
12...................	163.1	6645	45.7
15...................	168.8	6855	47.1
20...................	179.4	7235	49.7
25...................	191.3	7665	52.7
30...................	205.0	8155	56.1
35...................	220.8	8725	60.0
40...................	239.2	9385	64.5
45...................	260.9	10170	70.0
50...................	287.0	11110	76.3

DIRECT COMBUSTION FURNACE. EFFECT OF INADEQUATE AIR SUPPLY.

(BUTTERFIELD)

1	2	3	4	5	6
Volumes of air supplied stated in percentages of the volume required to form carbonic acid only from the carbon of the fuel.	Heat developed by the combustion of 1 lb. of carbon with air supply as stated.	Percentage which the values in column 2 represent the heat developed by the combustion of 1 lb. of carbon to carbonic acid only.	Volume under normal conditions of the chimney gases from the furnace per lb. of carbon consumed with air supply as stated.	Heat carried by the chimney gases leaving the furnace at 975° C. (Sensible heat only.)	Percentage which the values in column 5 represent of the heat developed as shown in column 2.
	B.T.U.		Cubic Feet.	B.T.U.	
100.........	14550	100	143.5	5940	40.85
99.........	14345	98.6	142.4	5885	41.04
97.........	13940	95.8	140.1	5773	41.42
95.........	13535	93.1	137.8	5660	41.82
90.........	12525	86.1	132.2	5380	42.94
85.........	11515	79.2	126.5	5095	44.24
80.........	10505	72.2	120.8	4815	45.81
75.........	9500	65.3	115.1	4530	47.71
70.........	8490	58.4	109.4	4250	50.06
60.........	6470	44.5	98.0	3685	56.96
50.........	4450	30.6	86.7	3120	70.12

EFFECT OF EXCESS AIR ON BURNING COAL

Excess Air, Per Cent.	Hard Coal.		Soft Coal.	
	CO₂, Per Cent.	O, Per Cent.	CO₂, Per Cent.	O, Per Cent.
No excess	21.0	0.0	19.1	0.0
10	19.1	1.9	17.3	2.0
20	17.5	3.5	15.8	3.6
30	16.1	4.8	14.5	4.9
40	15.0	6.0	13.5	6.1
50	14.0	6.9	12.6	7.1
60	13.0	7.8	11.7	8.0
70	12.3	8.6	11.0	8.8
80	11.7	9.3	10.4	9.5
90	11.1	9.9	9.9	10.1
100	10.5	10.5	9.4	10.6

Imperfect combustion results when the carbon of a fuel is converted into monoxide CO, instead of into dioxide CO_2; the formation of carbon monoxide may result either from the direct oxidation of carbon to that product by reason of insufficient air supply, or from the reduction of carbon dioxide by another molecule of carbon according to the equation:

$$CO_2 + C = 2CO.$$
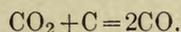
The above reaction takes place when the carbon dioxide produced by the combustion of carbon on the grate is reduced in passing through a bed of red-hot coke by another part of carbon. This is a cooling process, in which 10,150 B.T.U. are absorbed per pound of carbon originally burned to dioxide, wherefore if the reduction occur to the extent that all the dioxide is reduced to monoxide, the heat generated by the combustion of 1 lb. of carbon is $14,600 - 10,150 = 4450$ B.T.U. This reaction and its thermal results are very important considerations in producer work (See Chapter I under Chemical reactions).

Oxidizing and Reducing Flames.—An oxidizing flame is one which acts oxidizingly on the body undergoing heat treatment. This may mean that a very large percentage of oxygen is present, or it may mean that the percentage of oxygen is quite low. In the manufacture of Portland cement, an oxidizing flame is required to thoroughly oxidize all the iron present in the cement to a high stage of oxidation, in order to get bluish-black cement clinker. The percentage of oxygen is, however, quite different in such a flame from that used in the manufacture of steel, by the open hearth process.

A cutting flame is generally used to indicate a flame having intensely oxidizing properties; a very hot flame carrying a high percentage of oxygen is usually a cutting flame. It is used in the steel business to indicate a flame which will cut into a billet of steel rapidly, and waste a great deal of material by rapid oxidation.

A reducing flame is the reverse of an oxidizing flame, and capable of reducing the oxides or other materials which are being heated, from a higher to a lower stage of oxidation, or even to complete reduction to the metallic state, if the materials contain oxides of the metals.

A soaking flame is a neutral or reducing flame having highly radiative properties.

A neutral flame is one which is neither oxidizing or reducing, for the particular material which is being treated.

A voluminous flame, as used in connection with Eldred process, is an expanded or extended flame; one dilated by products of combustion.

In general these are the definitions of the terms mentioned, although in certain special arts there may be a different meaning attached.

Dowson defines a " reducing flame " as " the reducing action a gas has on, or the use of the gas for, deoxidizing the surface of a metal," this being done by reducing the supply of air to the gas below the necessary quota for complete combustion. In this manner a certain amount of free oxygen (enough to complete the combustion of the gas) is withdrawn from the surface of the metal, this " selection " having a reducing action. Thus a plate of bar iron placed in a furnace in contact with an oxidizing flame, the surface will be more or less converted into magnetic iron oxide Fe_3O_4, but if the bar had been coated with rust Fe_2O_3, or with a scale of iron oxide and were put into a furnace heated by the reducing or deoxidizing flame, the gas would attack the iron oxide and its carbon take to itself all or part of the oxygen contained in the latter.

Progressive Combustion Stages.—Mr. W. A. Bone has discussed the matter of combustion in the *Gas World* of April 25th, 1908, of which the following is a digest: In considering the propagation of a flame through an explosive mixture of gases, it is necessary to distinguish between two well-defined conditions. When such a mixture is ignited, the flame travels for a certain limited distance at a fairly uniform slow velocity. This initial stage of the combustion is called " inflammation." After traveling a few feet, however, the flame begins to vibrate, the vibrations become more intense, and then either the flame is extinguished or it goes forward with an exceedingly great and constant velocity, producing the most violent effects. This new condition thus set up is termed " detonation " and the forward movement of the flame, which is sometimes at the rate of a mile a second, is called the "explosive wave."

Opinion has been sharply divided as to the nature of the combustion of a hydrocarbon. During the greater part of the last century the belief prevailed that the hydrogen is much more the combustible of the two elements, and that, consequently, when combustion occurs in a limited supply of oxygen, the hydrogen is preferentially burned. The second theory held that the carbon was burned to carbonic oxide first, and that the excess of carbon divided itself between the carbonic oxide and the hydrogen.

The idea of " preferential combustion," however, seems repugnant to well-established principles, while the direct transformation from, say, ethylene and oxygen to carbonic oxide and water, raises at once serious difficulties. It therefore remained to consider whether the solution of the problem might not be in the assumption of the hydrocarbon and oxygen forming an unstable " oxygenated " molecule, which subsequently rapidly decomposes. This was indeed suggested many years ago by Prof. H. E. Armstrong, but little notice was taken of his suggestion at the time.

Investigations undertaken by Mr. Bone at temperatures from 250 to 400° C. afford conclusive evidence against preferential combustion, whether of carbon or hydrogen. Large quantities of aldehydic intermediate products were isolated, and the balance of evidence was decidedly in favor of the " hydroxylation " theory, with the proviso,

however, that the oxygen is directly active. A scheme is put forward for the slow combustion of ethane, in which the initial oxidation product is probably ethyl alcohol. This oxidizes to the unstable $CH_3CH(OH)_2$, which decomposes into steam and acetaldehyde. This in turn is burned to carbonic oxide, steam and formaldehyde, and finally to steam and oxides of carbon, probably through formic acid and carbonic acid.

As the temperature rises, the intermediate products become more and more unstable, and to an increasing extent decompose into simpler products, which then undergo independent oxidation. Thus ethyl alcohol decomposes into ethylene and steam; acetaldehyde into methane and carbon monoxide, or into carbon, hydrogen, methane and carbon monoxide, according to the temperature; and formaldehyde is resolved into carbon monoxide and hydrogen.

With the extension of the research in regard to conditions existing in hydrocarbon and explosions, it became increasingly evident that the mechanism of combustion is essentially the same above as below the ignition point. It is not meant, of course, that the phenomena observed at low temperatures in slow combustion are exactly reproduced in flames, but rather that the result of the initial molecular encounter between the hydrocarbon and oxygen is probably much the same in the two cases, namely, the formation of an "oxygenated" molecule.

The above theories were illustrated and demonstrated by exploding various mixtures of hydrocarbons and oxygen in glass bulbs, and noting the invisibility of the products of combustion in some cases, and the appearance of free carbon and moisture in the others.

FURNACES

Efficiency.—Under this term, according to Richards, we must distinguish two classes, the first referring to furnaces in which the object is to maintain a certain temperature for a certain time with the minimum consumption of fuel; the second, in which the object is to perform a certain thermal operation with the smallest consumption of fuel. In the first case, one furnace may be compared with another, and thus comparative efficiencies calculated; in the second case real or absolute efficiencies can be also calculated. A few examples will illustrate this difference, which is an essential difference as far as making calculations is concerned.

Specific Efficiency.—Whenever it is desired to melt a metal for the purpose of casting it, a certain definite amount of heat must be imparted to the metal, and the ratio between this efficiently utilized heat and the heating power of the fuel consumed, is the efficiency of the furnace. If the furnace is electric, the theoretical heat value of the electric energy used is the divisor. If, in addition to the heat required to raise the substances to the desired temperature, there is also heat absorbed in chemical reactions, this amount can be added in as usefully applied heat, and the sum of this and the heat in the final products be regarded as the total efficiently applied heat. If a blast furnace takes iron ore and furnishes melted pig iron, the sum of the heat absorbed in the chemical decomposition of the iron oxide and the sensible heat in the melted pig iron is the efficiently applied heat, because it is the necessary theoretical minimum required: all other items are more or less susceptible of reduction, but these are necessary items and, therefore, measure the net efficiency. If a dwelling requires

200 cu.ft. of hot air per minute at 150° F. to keep it at 65° F., while the outside air is at 0° F., the ratio of the heat required to warm the 200 cu.ft. of air from 0° F. to 150° F., to the calorific power of the fuel used per minute, measures the *specific* efficiency of the "heater"; the question of whether this amount of hot air keeps the temperature of the rooms at 65° F. is a question of the *general* efficiency of the construction of the house.

Cases of Generic Efficiency (such are those in which practically all the heat generated eventually leaves the furnace by radiation or conduction, or useless heat in waste gases); this is the case when a certain temperature has to be continuously maintained for a given time, and where the time element is the controlling one, and not any definite amount of thermal work is to be done. Examples are numerous: An annealing furnace, where steel castings, let us say, are to be kept at a red heat for two days, or a brick kiln, where several days' slow burning are required, or a puddling furnace, where the melted iron must be held one to two hours to oxidize its impurities. In all these cases we may say that one furnace keeps its contents at the right heat for the right time with so much fuel, another does the same work with 10 or 25% less fuel, and is, therefore, 10 or 25% more efficient; but we cannot, in the nature of the case, speak of the absolute or specific efficiency of the furnace, because there is no definite term, expressible in calories, to compare with the thermal power of the fuel.

In many cases the two efficiencies are mixed in the same process or operation, and then the calculation of absolute or specific efficiency can be made for that portion of the operation wherein a certain definite amount of thermal work is done. Thus, in an annealing kiln 50 tons of castings may be brought up to annealing heat in 24 hours, starting cold, and the heat absorbed by the castings compared with the calorific power of the coal burnt during this period, is a measure of the real efficiency of this part of the operation. During the rest of the operation, while the castings are simply kept at annealing heat, there can be no calculation of the absolute or specific efficiency of the furnace, because one of the terms necessary for the comparison has disappeared; in that part of the process we can only speak of relative efficiency compared to some other furnace doing a similar operation.

It goes, almost without saying, that we can, of course, apply the conception of efficiency in its relative or general sense to the whole operation or to any part of it.

Hot gas efficiency, according to Wyer, differs from the cold gas efficiency only because account is taken of the sensible heat of the gas as it leaves the producer, as shown by this formula:

Let E_c = cold gas efficiency,
$\quad E_h$ = hot gas efficiency.
$\quad S$ = sensible heat of gas per cubic foot.
$\quad H$ = calorific power of the gas.
$\quad t$ = temperature of atmosphere.
$\quad T$ = temperature of gas as it leaves the producer.
$\quad C_v$ = volumetric specific heat.

$$S = (T - t) \, C_v$$
$$E_h = E_c \times \left(1 + \frac{S}{H}\right).$$

Most modern producers supply hot gas, but it must not be assumed on this account that the real efficiency of these producers is their hot gas efficiency. When the gas is used without passing through a regenerator, the sensible heat is all available, and the real efficiency is the hot gas efficiency; but when the gas is used with a regenerative furnace the case is different, and it seems probable that the sensible heat is almost entirely wasted, the only result being the higher temperature of the chimney gases. If this theory is correct, then, for all producers supplying gas to regenerative furnaces, the only efficiency which need be considered is the cold gas efficiency."

Utilizing Sensible Heat.—For furnace work, as has elsewhere been noted, the gas should be delivered to the combustion chamber at the earliest possible moment, for the following reasons.

1. The saving of sensible heat, otherwise lost through radiation.

2. The condensation of certain condensible hydrocarbons which tend to precipitate upon a cooling of the gas and a changing in the vapor tension; also, the gas should be conducted to a combustion chamber with the fewest possible bends, turns or delays, as it is a law of gas kinetics that any change in either direction or velocity of a gas, tends to precipitate its mechanical ingredients, that is to say, those heavier hydrocarbons which are carried in suspense. These features are necessary of observance in order to obtain the maximum results from the use of producer gas, the efficiency of which, as compared with direct firing, consists chiefly in (a) the ability to direct the combustion at a critical or effective point of the heating operation, (b) the ability to perform complete combustion with very nearly the theoretical amount of air required for the chemical combination.

In explanation of this latter it is well to remark that whereas in direct firing it is necessary to use an excess of air, in some instances amounting to 300% in excess of the theoretical quota, the amount of air necessary to burn C to CO (thereby creating a potential gas) known as " primary air " plus the amount of air necessary to burn the gas CO to CO_2 (known as secondary air) equals the theoretical amount chemically required for combustion, and in practice does not exceed theory by more than 10%.

It will be seen therefore that the difference in the amount of air which must be heated up to the point of theoretical flame temperature in direct firing and gaseous firing, amounts in some instances to 290%, which would reflect a fuel difference of 40 to 50%.

Richards says that: "If the fuel itself or the air which burns it is pre-heated, the sensible heat in either one or in both is simply added to the heat generated by the combustion to give the total amount of heat which must be present as sensible heat in the products of combustion. The effect is exactly the same as if the heat developed by combustion had been increased by the sensible heat in the fuel or air used."

With reference to the use of producer-gas in steel furnaces, Campbell gives the following: " The sensible heat of the gas is regarded as a total loss, since a rise in temperature at the entrance flue of the furnace means a similar and equal rise in temperature for the products of combustion escaping in the stack. It is therefore important to so adjust the calorific work of the producer that the heat developed is utilized in the heart of the fire and the escaping gases are kept as low as possible.

The use of steam will lower the temperature, but it must be remembered that the cooling of the upper part of the fire, by steam from the grate, implies cooling of the zones of decomposition and combustion to the same degree, so that the utilization of the sensible heat of the upper surface of the fuel involves the presence of an increased amount of undecomposed steam in the gases."

Where the producers are used for heating regenerative steel furnaces, he continues, "some engineers advocate—with plausible and, at first sight, conclusive reasons—placing the producer near the furnace, under the impression that thereby they have the sensible heat of the gas. It is true that when the gas is hot, less heating of the gas chambers is required, and hence less checker-work will suffice, but this is a small matter and has no bearing on the fuel economy. Whatever is gained by hot gas at the incoming end, is lost on reversal in the outgoing products of combustion. Moreover, a special system of valves must be used to handle the hot gases; ordinary valves soon warp and leak, and water cooling, is not to be thought of in this case, for this involves chilling the gas, which is manifestly opposed to the intent of the practice in question. With hot gas, the soot and tar will be deposited in the regenerators and this is objectionable. Cool gas is very desirable for the preservation of dampers and valves. Hot gas does not tend to economize energy since the loss of heat in the escaping products of combustion offsets the apparent gain."

The primary function of pre-heated air is to increase the intensity of combustion. At a high temperature the affinity of air for carbon is greater than at atmospheric temperature, and combustion will be very much more vigorous. Pre-heated air should be used in gas-producers whenever it is possible to do so. In producers used for power purposes, the waste heat in the gas-engine exhaust should be used in pre-heating the air.

The writer does not agree with either of these authors. In his opinion the statement by Mr. Campbell should be evidently qualified by the fact, that the sensible heat of the gas is only a loss where there is a certain definite or limited absorption of heat in the operation, as is the case in a steel furnace.

Where, however, in any continuous process, where the degree of heat absorption in the operation is uncertain and may be said to be unlimited, this sensible heat is unquestionably an advantage, and it may be added to the furnace temperature, otherwise obtained under the following conditions. In the opinion of the writer the heat balance under such conditions would be about as follows:

A deduction should be made from the normal heat value of the gas at standard conditions of temperature, such deduction being the difference due to the expansion of the gas between t_1 and t_2. An addition should be made for the actual sensible heat contained in the gas at t_2, and a deduction should be again made for the increased coefficient of heat absorption, otherwise specific temperature of the products of combustion at t_2.

This, however, will leave a considerable net earning in favor of the hot gas. It is of course understood that this is only under conditions of furnace combustion and not for engine purposes, where the cooler and concentrated gas is desired.

In common practice the recuperation is usually limited where the necessary temperature to be secured for either gas or air pre-heat does not exceed 500 to 600°. Above this point regenerators are usually used. Recuperators when attempted at

a higher temperature usually consist of terra-cotta pipes, which are very unsatisfactory.

The burning of producer gas and air should not be attempted unless in operations under a pressure of from one to one and one-half pounds each; otherwise, the flame is too easily extinguished and even a red heat is reached with difficulty.

The intensity of a flame may be very materially affected by the ratio of primary to secondary air (the amounts being inverse). Intensity is created through the total combustion with primary air, while the flame becomes more lambient by decreasing the primary and increasing the secondary.

Size of Tuyeres.—The expansion of air by heat is 0.002036 of its volume for each Fahrenheit degree, or about 1% for each 5° F., conversely, its pressure is increased in that ratio, its volume remaining constant. Therefore, 100 cu.ft. of air at 62° F., when raised to 900° F. expands to 270 cu.ft. under the same pressure.

To admit a given amount of air to a furnace, under a given pressure, the cross-section area of the tuyeres must be 2.7 times as great when the air is blown in at 900° F. as when it is blown in at 62° F.

Thus a tuyere 3 ins. in diameter will admit as many pounds of air at 62° F., under a given pressure, as one 4.9 ins. diameter at 900°, omitting difference in friction. A furnace blown through tuyeres of a given size, with air at 900° F., gets but 37% as much in weight of air as when blown through the same tuyeres at 62° F., the pressure in each case being the same.

Heat Recuperation Furnaces.—The great step in advance which was made in the introduction of the Siemens system of gas firing was not in the producers, but in the scientific and well developed system of recuperating heat from the waste products of combustion. The Siemens system continues in use at the present time in substantially its original form. To a less extent counter-current recuperators are employed, which are also an old invention, the principle dating back to the time of Gaillard & Haillot, Lencauchez, Ponsard, Charneau and Nehse. All these are systems of true heat recuperation, i.e., they recover it from gases which would otherwise waste it, and do not abstract it from the fire-box or combustion chamber of the furnace, although the mere transference of heat in that manner, as exemplified in the well known Boetius furnace, may be highly advantageous.

The terms "regenerative furnaces" and "recuperative furnaces" are commonly employed to designate different types, the former being applied to the Siemens system and the latter to the continuous or counter-current system; it is generally safe to infer that such a distinction is made when the two expressions are used in metallurgical literature, but not always. More exactness is desirable. The terms "heat regeneration" and "regenerative furnaces" are misnomers. Regeneration implies a recreation of heat, which does not take place in such a furnace, the heat wasted from the combustion chamber being simply restored thereto. Recuperation, or recovery, expresses the precise meaning as to what is effected in both types of furnaces. The two systems can be appropriately and exactly designated as the "reversing recuperation" and "continuous recuperation" of heat.

Siemens Regenerative System.—In the Siemens system of heat recuperation the hot products of combustion are made to pass through chambers filled with fire-brick in the form of a checker-work, to which they impart a large portion of their

heat. In the meanwhile the air and gas for combustion enters the furnace through a similar pair of chambers filled with brick checker-work. After a certain time, say 30 minutes, the direction of the gases is reversed by the valves illustrated. The products of combustion are then caused to pass out through the two cooled chambers, while the air and gas enter through the two which have become highly heated, the gas passing through one and the air through the other. The respective chambers for gas and air are sometimes made of the same size, but more commonly are designed
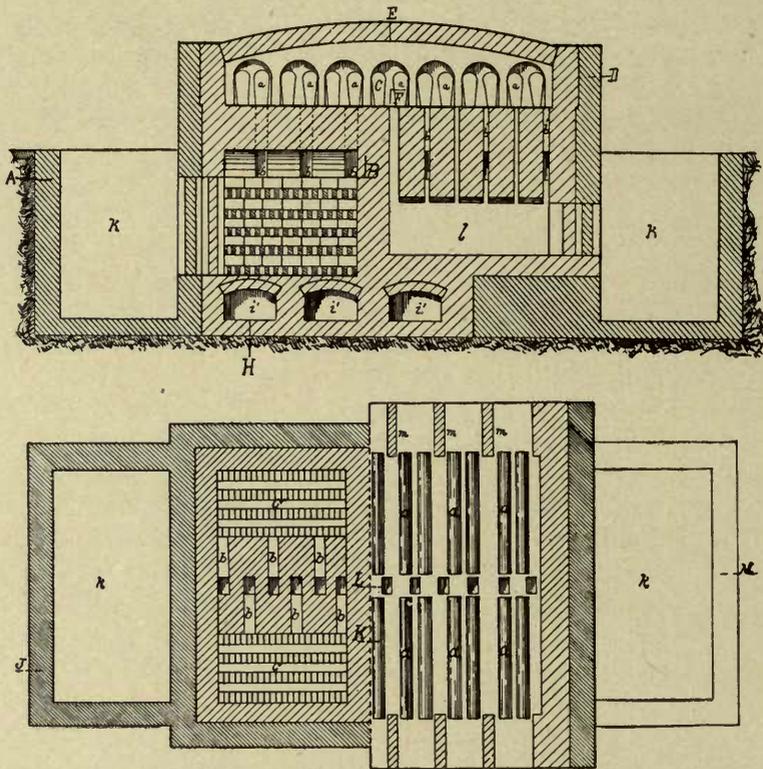
FIG. 196.—Horizontal and Vertical Cross-section of a Siemens Regenerative Furnace as Used at Freiburg.

according to the relative volumes of the gas and air and their heat absorbing capacities.

The extent to which heat may be recuperated by the Siemens system depends upon the temperature of the combustion products discharged into the recuperative chambers, the arrangement and dimensions of the latter, the speed of the gases in passing through them and the length of time between reversals. By giving the chambers a sufficient volume and the hot gases a slight velocity they may be made to issue comparatively cold, while the fresh air and gas may be raised correspondingly to a high degree of temperature. According to Friedrich Siemens, the weight of the brick filling of each pair of regenerators should be theoretically 16 to 17 times the
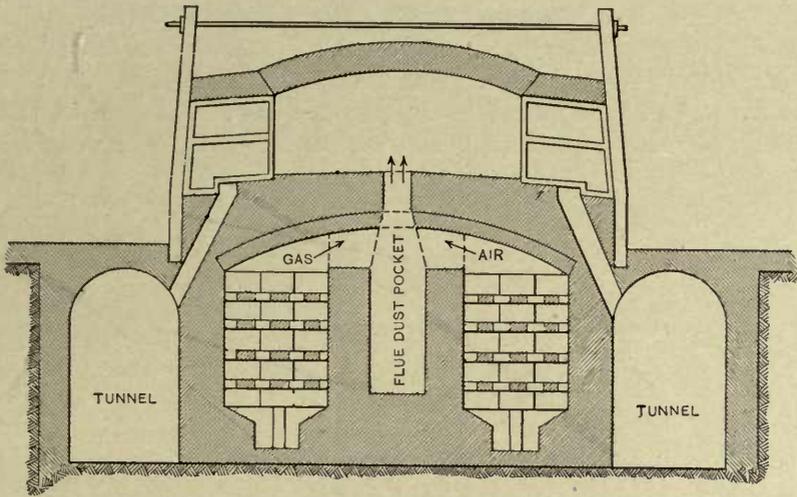
Fɪɢ. 197.—Vertical Cross-section through Entrance Port of Siemens Furnace.
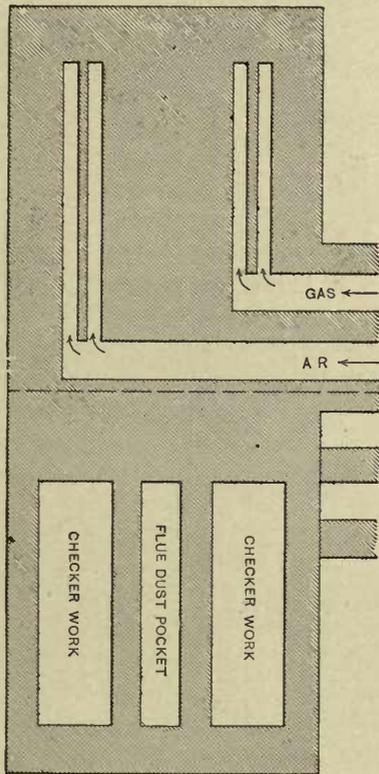
Fɪɢ. 198.—Horizontal Section through Flues under Checkers and through Checker-Brick Chambers.

weight of the coal burned between two reversals in order to take up all the heat of the gases of combustion. Consequently in the combustion of 1000 lbs. of coal per 24 hours, or about 42 lbs. per hour, there should be $17 \times 42 = 714$ lbs. of brick in each pair of regenerators when the gas currents are reversed at intervals of one hour; and about 360 lbs. at half-hour intervals. In practice, however, the whole checker-work is not heated and cooled uniformly, but by far the larger part of its depth is required
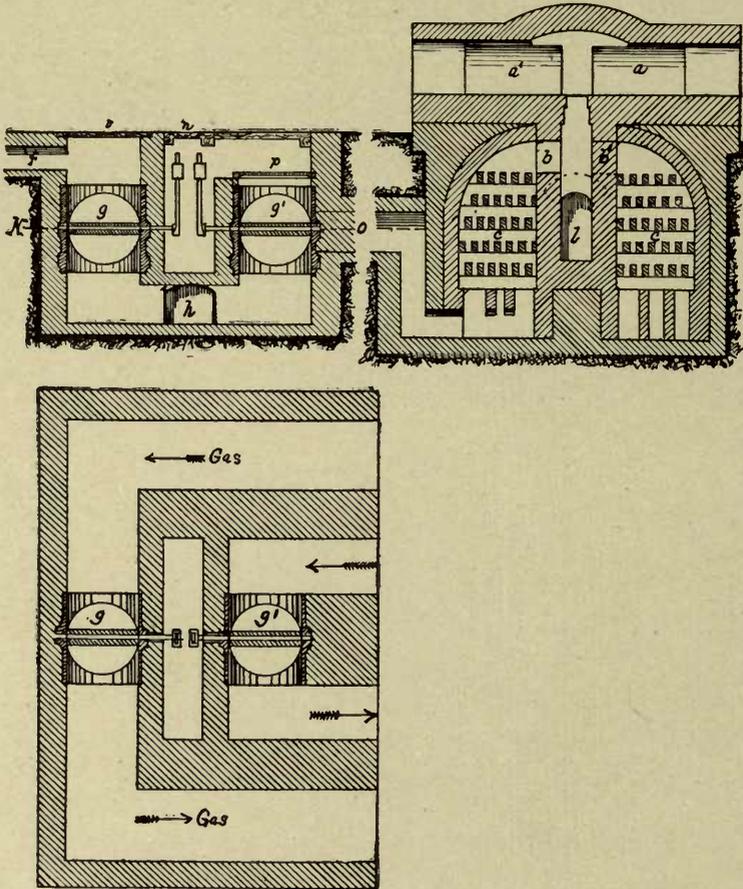
Fig. 199.—Sections of Siemens Furnace showing Flues and Reversing Valves.

to effect the gradual cooling of the products of combustion and only a small portion near the top, perhaps a fourth of the whole mass, is heated uniformly to the full temperature of the flame, the heat of the lower portion decreasing gradually downward nearly to the bottom. Three or four times as much brick-work is therefore required than is equal in heat capacity to the products of combustion.

The size of the chambers is commonly calculated according to the superficial area that is exposed. Siemens considered that each pair of chambers should expose 51 square meters per 1000 kgs. of coal burned per 24 hours, or about 6 sq.ft. per pound per hour. According to Roberts-Austen, in order to insure that the gas shall not

escape to the chimney at a temperature higher than 150° C. there should be **7** to **7.5** sq.ft. of brick surface for every pound of coal burned between reversals in direction. The brick should be arranged in the chambers so as to leave as much space free as full, i.e., they should not occupy more than 50% of the volume of the chambers. The arrangement of the chamber should be such as will compel the gas to travel uniformly through all parts of it, preventing any tendency on its part to take the most direct course, short-circuiting, so to speak, and avoiding dead corners. Siemens considered
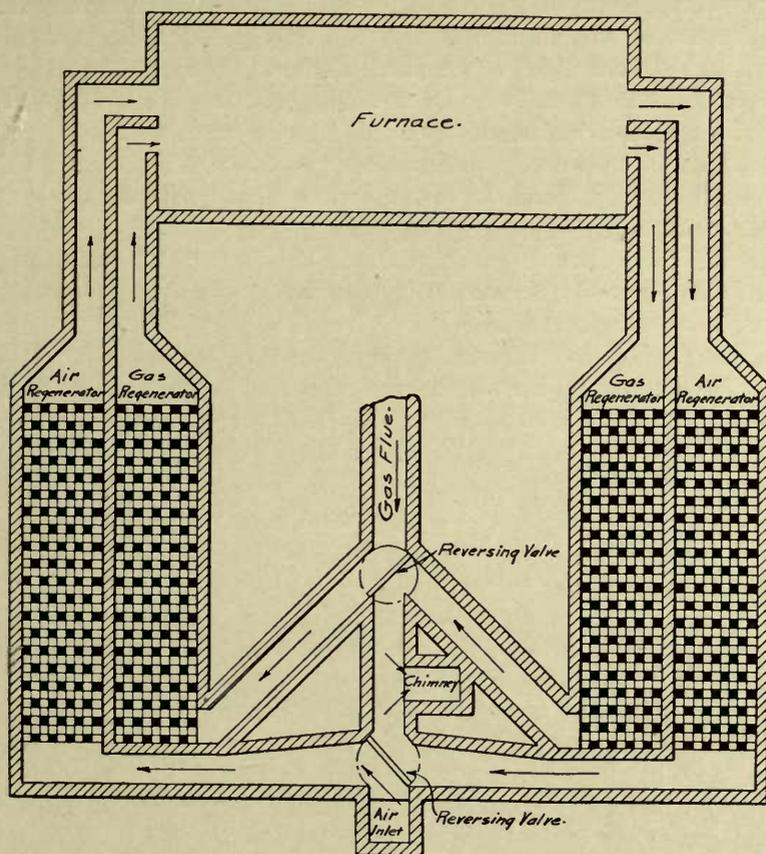
FIG. 200.—Another Arrangement of Reversing Flues and Valves.

that the chambers were best arranged vertically, heating from the top downward. For various reasons it is preferable to put the chambers beneath the hearth of the furnace when that can be done conveniently. The velocity of the gas through the checker-work may be 1 to 2 m. (3.3 to 6.6 ft.) per second. In good practice the escaping products of combustion are cooled down to about 300° C.

Furnace Design.—Under the head of " Furnaces," Ingalls, in his " Metallurgy of Zinc and Cadmium," page 263, says as follows:

" The ultimate analysis of a fuel being known, i.e., its percentage of carbon,

hydrogen, sulphur, nitrogen, etc., the weight and volume of the air required for its combustion, and the weight and volume of the gases that will be produced, can be calculated just as in the case of any chemical reaction and by the same rules. In designing a furnace for metallurgical purposes in which the combustion of fuel is so highly an important matter as it is in the distillation of zinc ore, it is evident that in order to obtain the maximum efficiency the proportions of the furnace, including the grate area, the volume of the laboratory or combustion chamber, and the area of the flues and chimney and the height of the last, should be planned with reference to the volume of the gases that must pass through them, their temperature and other factors. However, this is but rarely done, not merely in the design of zinc-smelting furnaces, but in all other kinds of metallurgical furnaces, and indeed the subject has been as yet studied so imperfectly by metallurgists that much of the data that is required for such calculation is still lacking. The design of metallurgical furnaces in accordance with well known physical laws has not yet been attempted, except in few instances, and naturally little is to be found with respect thereto in existing metallurgical treatises."

The furnace in present day industrial practice is varied in class and in nature of operation. For general purposes they may be divided into open hearth, muffle, crucible, and reverbatory, the function of the first being the direct contact of the contents of the gases in combustion, the second being indirect, the heat being delivered by conduction and convection, the third largely the utilization of convected or radiant heat, and the fourth, the use of heat reflecting surfaces for decreasing the velocity of radiation and reflecting instant heat rays back to a point where they may be reused.

In regard to the surfaces, these may require either alternately high and low temperatures, as in the case of reheating furnaces, or to give temperate temperatures at different conditions of the hearth, as instanced in glass furnaces, or again to give different temperatures in various compartments, an example of which will be found in the Hoffman furnace for bricks, potteries, and ceramic work.

The design of furnaces must take into consideration, first, the nature of the gas, including its calorific value, and that of its explosive mixture, the pressure at which it may be expediently supplied, the elevation above sea-level (exceeding 1000 ft.) the temperature to be attained and maintained, the volume of heat required (a function of the amount of fuel to be gasified), the radiation of the furnace walls, the nature, size, and material of the contents to be heated.

Fuel Required.—No definite rule can be given for the design of these furnaces, their conditions and requirements being so widely varied, but as a "rule of thumb" for estimating or checking and for rough purposes of approximation, the following figures per pound of coal used in common practice of various classes of furnaces are herein tabulated.

    750 lbs. of coal per ton of steel in open earth furnaces.

  1000 to 1500 lbs. of coal per ton of steel in crucible furnaces.

   700 to 1000 lbs. of coal per ton of steel in annealing furnaces for castings.

   200 to   300 lbs. of coal per ton of steel in annealing furnaces for sheets.

   450 lbs. of coal per ton of steel for sheet and pair furnaces.

   200 to   300 lbs. of coal per ton of steel in reheating furnaces.

200 to 250 lbs. of coal per ton of steel in tempering furnaces.

150 lbs. of coal per barrel of clinker in rotary cement kilns.

50 lbs. of coal per barrel in rotary kilns for calcining lime.

One ton per pot per 24 hours in deep eye-glass furnaces, assuming each pot to hold 2000 lbs. of flint gas.

The above figures of course widely vary, the variables in the operation being the efficiency of the furnace, which in turn is dependent upon (a) ventilation, (b) radiation. Under the first efficiency produces a back pressure or blanketing of the flame, while an excess creates only an excess of air through leakage, but an over-rapidity in the velocity of the gases, leaving an insufficient time contact for their deposit of sensible
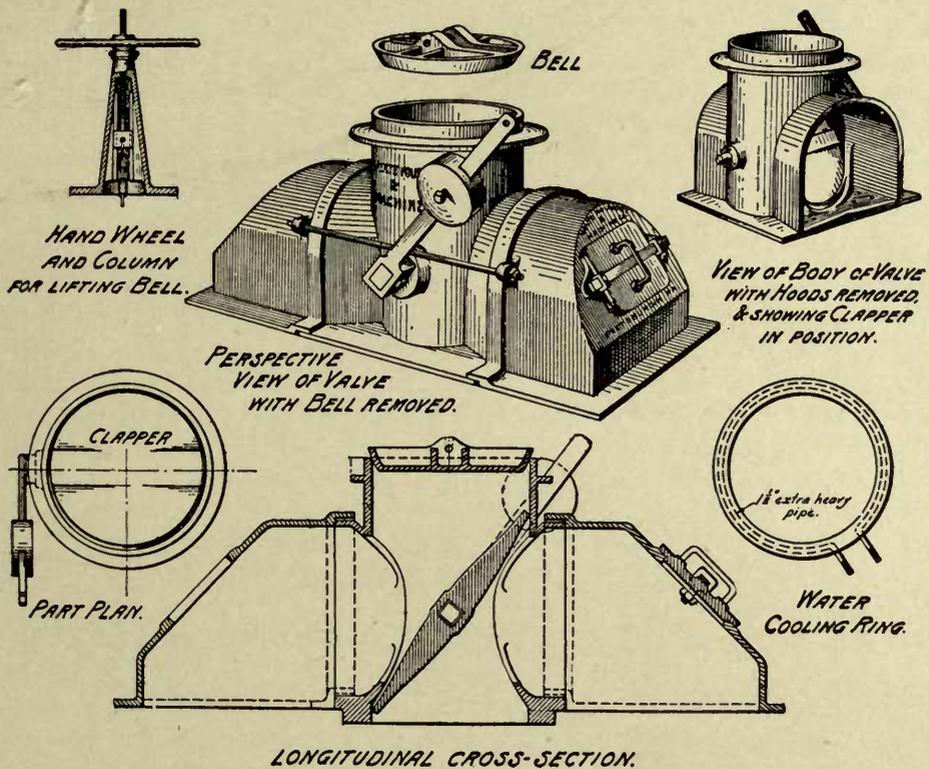
FIG. 201.—Reversing Valve for Siemens Furnace.

heat and expelling the gases at atmosphere at an uneconomical height of temperature. In furnace work, of course, a maximum of efficiency is reflected by the formula $T_1 - T_2$, the first being the highest initial temperature and the last final temperature, under ideal conditions the gases being dsicharged to atmosphere at practically atmospheric temperature. The ideal draft would therefore be the removal of the gases at a rate about equal to the intake of the elements of combustion.

Conditions of radiation will be seen in various forms. For instance, various sizes

of the same type of furnace may be found to vary in efficiency and is often found
that by doubling the sides of a furnace, a considerable increased economy is effected.
This may be laid to two reasons.

First, the larger furnace required the heavier and thicker walls to support a
greater weight and span of roof. This has reduced the radiation by reason of thick-
ness. Again, it must be remembered that the radiating surface does not vary as
the volume of content, this being about proportional to the square and cube respect-
ively of the linear dimensions.

Coal and Gas Firing.—Butterfield notes a range of temperature within a furnace
heated by direct firing of an extreme difference of 400°. This difference under condi-
tions of good design with gas firing, will not exceed 200° C. Euchene found the
maximum temperature of a direct-fired furnace to be 1375° C. the products of com-
bustion leaving the furnace at 975° C., the heat duty reflected by this differential of
temperature or "drop" being approximately 24%. In a regenerative setting the
maximum temperature was 1250° C., the products of combustion escaping the recup-
erator at 1050° C., showing a heat duty of 13.10%.

This would apparently show a thermal advantage upon the part of the direct-
fired furnace, the total heat abstraction being greater upon its part. It however only
indicates a concentration of heat abstraction, such abstraction being unequal and
localized, for Euchene further notes, upon a Siemens alternating recuperative set,
that in traversing the recuperator the temperature fell from 1050° C. at the outlet
of the furnace to 600° at the outlet of the recuperator. Hence the total drop in the
temperature in the furnace, plus the recuperator combined (and which from an
economic standpoint must be taken as a whole), was from 1250 to 600° C., a total
abstraction of 650°, showing a heat duty or thermic efficiency of 43.3%, or a gain in
absolute working economy of 230% (approximately). Even this terminal temperature
is excessive and could be materially reduced by additional heat absorbing and regen-
erative surface, with commensurate economy. Taking these figures, however, not
only does this comparison show an efficiency of more than double that of the direct-
fired furnace, but the abstraction of the heat is more gradual and uniform, the cycle
possessing less irregularities or severe variations.

Igniting the Furnace.—Great care should be taken in lighting any gas furnace
that the light be applied before the gas is turned on, and that the admission of the
gas be very slow and never complete until a small portion is already ignited. This
is best accomplished by throwing into the furnace a small portion of burning waste,
flaming wood or other material, after which the gas should be gradually turned on.

The failure to observe this rule, obvious though it may be, is the cause of nearly
every explosion and the consequent loss of both life and property.

Where gas and air are admitted to the burner or combustion chamber at different
temperatures, they should, unless injected as inductors, be entered with the colder
of the two on top. This is for the reason that on account of the heat convection of
the warmer and gravity of the colder gas, there is a tendency for a better or more
intimate mixture.

Reverberation of Heat.—It is of course a known law that the amount of heat
obtained in any combustion furnace is equal to the total heat evolved by combustion
within unit space, less the radiation and loss by ventilation. In one instance

observed a furnace was equipped with a circular baffle or bridge wall, after the manner of a reverberatory furnace, the flame occurring at about the center of its circle.

Now, not only would a cone or pyrometer placed within this axis be the recipient of the flame as directly impinged upon it, but also the reflected heat returned by the baffle or bridge wall and converged upon it.

In other words, the circular fire-brick baffle or bridge wall acted as a heat reflector, the angle of reflection being equal to the angle of incident, the result obtained was a singular example of heat conservation, whereby not only was the ventilation retarded but a large portion of the retarded heat reflected and returned to the area of usefulness. A diagram showing the above arrangement is herewith appended.

It will be noted that for practical purposes the heat developed in this furnace will be probably one third less than would be indicated by a pyrometer located at the heat axis, the distribution throughout the furnace being necessarily very unequal.
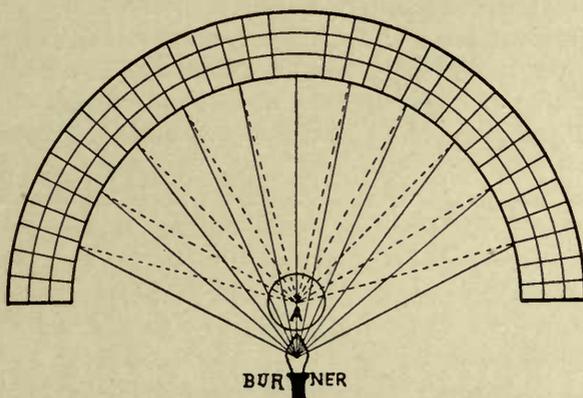
FIG. 202.—Illustrating the Reflection or Reverberation of Heat.

Dehydration of Blast Air.—The possibility or rather the practicability of dehydrating blast air for water gas sets is herewith tentatively suggested as a means for promoting fuel economy, increasing the capacity of the apparatus, and reducing the power, and facilitating the operation of the sets.

Blast-furnace Results.—The conclusion has as its basis the very successful results obtained in blast furnace practice, an example of which is herewith cited as extracted from the report of Joseph H. Hart, Ph.D., upon the Isabella furnace at Aetna, Pa., showing the following significant figures:

The Isabella furnace at Aetna, Pa., produced 350 tons of iron, consumed 2147 lbs. of coke and required 40,000 cu.ft. of air per minute. They installed two ammonia compressors of 225 tons of ice melting capacity, one used as a stand-by and for peaks.

The air was cooled from 80 to 28° F. or reduced 52°. The consequent reduction of moisture averaged from 5.66 grains per cubic foot to 1.75 or an elimination of 3.91 grains per cubic foot.

The results obtained by this was that the quantity of air was reduced to 34,000

cu.ft. per minute, or a saving of 6,000 cu.ft. per minute, a reduction of about 15%, this being due to increased density of the air handled.

The blowers were slowed from 114 to 96 r.p.m., a reduction of 18 r.p.m. The consequent reduction in horsepower being from 2700 to 2013 or 687 h.p. The refrigerating apparatus required about 530 h.p. and there is still a net saving in power of 157 h.p. when operated at maximum capacity.

The moisture contained in air which passes through the furnace was approximately 40 gallons of water per hour, at times being increased to 300 gallons, due to variability in humidity, which is very wide, especially in some locations. About 10 tons of water per day was extracted and the output increased to 450 tons of iron, a gain of 100 tons or about 28%. The coke consumption was reduced from 2147 to 1729 lbs., a saving of 418 lbs. per ton of iron output, or roughly speaking 20%.

Water Gas.—The argument for the use of dehydrated air in connection with water gas sets would be as follows:

First, a reduction of fuel due (a) to reduced blasting period by reason of the denser quality of the air, and resulting high flame temperature subtending a saving in loss by radiation, abstraction of heat by aqueous products of combustion, etc.

The increase of capacity of the sets is manifestly due to the higher flame temperature in the combustion of the fuel in the dryer and denser air; hence shortening of blast period and permitting an increased duty performed by the apparatus during the time unit.

The saving in power would likely occur in the handling of a denser air, and the relief from handling the additional weight of water. It is by analogy that blast furnace figures would show some increment or net economy over and above the power required for the ammonia compressors. In any event the reduction in duty performed by the speed of the fans would at most prove a stand-by for the outlay of power for the compressors.

With regard to facility of operation and general efficiency, it is extremely likely that with the dryer and denser air the blast pressure could be materially reduced, and that there would be a consequent reduction of channeling and chimneys through the fuel bed; hence a lessening of clinkering with a consequent necessity of difficult stoking.

It is also probable that the dry air would involve conditions of more equal heat throughout the entire fuel bed, inasmuch as that under ordinary conditions the strata of fuel in first contact with the humid air is chilled, its heat being abstracted while the succeeding strata are overheated from the lack of this endothermic connection and the combustion of the gases which it forms.

This condition of equal heat throughout the fuel would make a minimum of clinker formation, and a maximum of gas-making efficiency if the fuel is relieved of the "deadening" influence of the aqueous vapor prior to the steam injection.

The above argument seems at least worthy of consideration. It is understood of course, that the efficient operation of such a plant would require work of such size as to maintain a fairly high load factor upon the blast air, that is to say, the lay-out of sets should be such as to produce by their rotation intervals as nearly as possible of constant demand upon the blast. This, although not absolutely indispensible, would tend to the maximum efficiency of the plant proposed.

Cooling Plant.—A tentative lay-out of the foregoing arrangement is herewith illustrated.
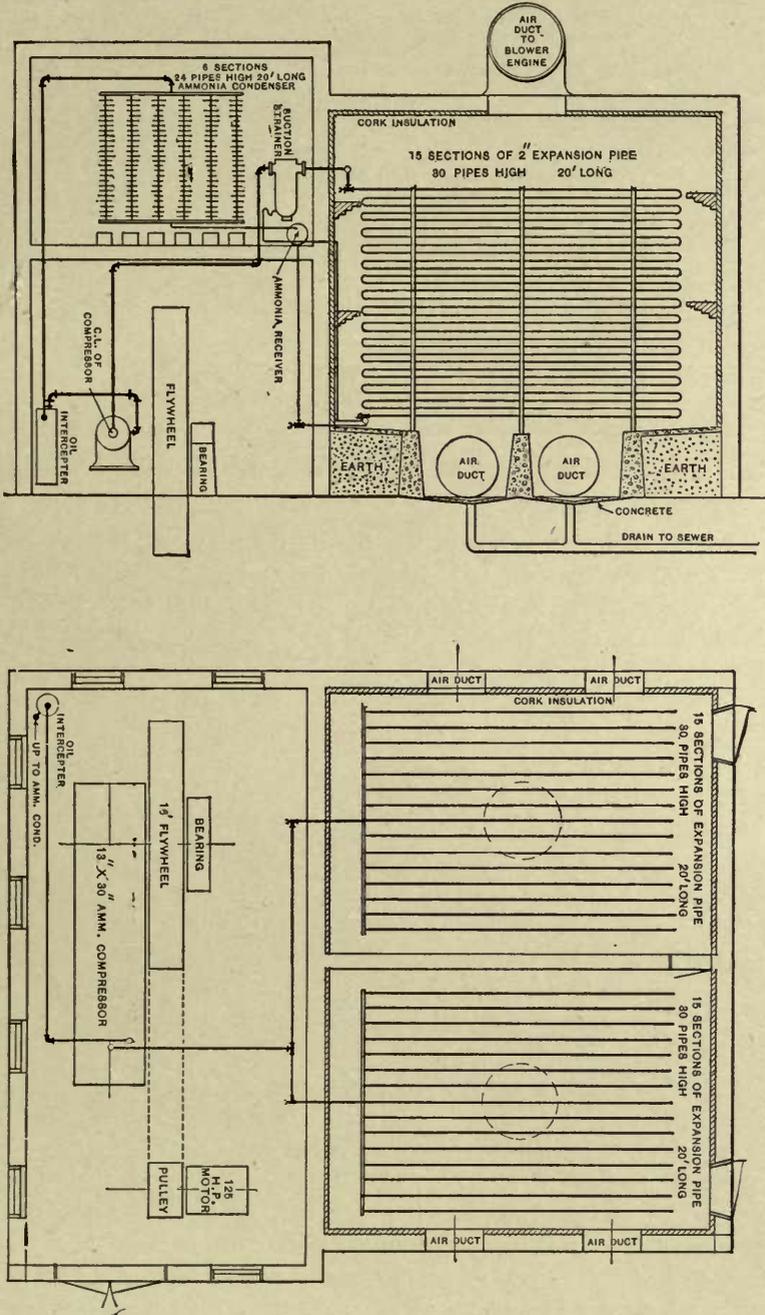
FIG. 203.—Refrigerating Plant for Condensing Moisture in Blast Air.

Testing for Explosive Mixture.—In purging pipes or apparatus from gas for testing, whether all air had been expelled from newly installed gas chambers, it is sometimes desirable to test by means of ignition. In case there is enough gas or air
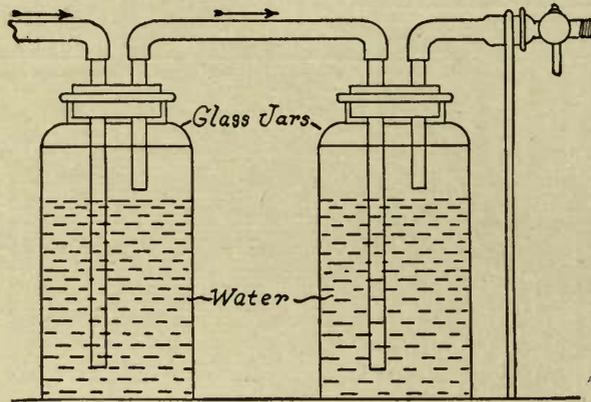
FIG. 204.—Safety Device in Testing Gas when Filling new Holders or Mains.

present to form an explosive mixture, the results may be disastrous. In such cases it is better to connect two dip seals, as shown in Fig. 204, and ignite the burner attached to the fitting on the right hand side. If the mixture is explosive, it will then not strike back further than the jar.

Steel Melting Furnace Practice.—In very high temperature melting operations fairly high per cent of hydrocarbons is necessary, owing to the fact that it gives a more luminous flame, and so intensifies the radiation from the roof of the furnace, hence obtaining a higher reverberation and greater heat concentration.

The flame temperature of the explosive mixture of constituents of the volatile matter of coal possesses, of course, a somewhat higher flame temperature than the corresponding explosive mixture of oxygen and carbon.

The best practice in steel making is 33% volatile matter, and not over 10 or 12% ash. 25% volatile matter would be the lower limit.

Pure slack is inadvisable on account of the choking of the blast, and the necessary high pressure to overcome its resistance.

In the above, mechanical feeding is, of course, presupposed, in order to obtain an equalization of distillation.

Carbonic Acid.—There is always a certain amount of CO_2 formed, even in the best practice; in fact, it is inevitable, and if kept within proper limits does not constitute a net loss of efficiency, especially with very short gas flues, because the energy of the fuel so burned is represented in the sensible heat or temperature of the gas, and results in delivering a hot gas to the furnace, and the flame is made more voluminous and combustion less localized. However, the loss increases rapidly above 4% of CO_2, even when the gas is carried hot in short flues. If *too* hot, the hydrocarbons are broken up and deposit their carbon as soot, or lampblack, and the loss from radiation is material. If an attempt is made to run too cool, by increasing the proportion of steam, the result is equally bad, as a low gas tempera-

ture permits the deposition of tar in the flues, and both the heating value and capacity are largely reduced.

The best result in steel practice is at about 4% CO_2, a gas temperature between 1100 and 1200° F., and flues less than 100 ft. long.

Flues.—It is necessary to provide an ample flue capacity and to carry the full area right up to the furnace ports, which latter may be slightly reduced, or constricted, to give the gas a forward impetus, and concentrate the gas. Generally speaking, the net area of a flue should be not less than one-sixteenth of the area of the interior cross-section of the producers supplying it. Or the carrying capacity of a hot gas flue should be equivalent to 1 sq.ft. of cross-section per 200 lbs. of good coal per hour. Hence, a brick-lined flue 4 ft. diameter inside the lining will carry the gas made from 2500 lbs. of coal per hour (12.5 sq.ft. × 200), and will serve a gas-making area of 200 sq.ft. (12.5 × 16), which corresponds to four 8-ft. producers.

Sulphur.—Over 1% of sulphur usually gives trouble. Below that it is practically harmless; 2% is considered the metallurgical limit. 3% is the operating limit in most furnaces.

A certain percentage of sulphur is residuual in the ash of a producer. Hence the sulphur content permissible is higher in coal than in oil where the total sulphur is burned within the furnace.

The statement concerning the harmless effect of a sulphur element in producer gas does *not* hold good in case of coke oven gas or those gases having higher flame temperature in their explosive mixture. In the case of the oven gas, for instance, one grain of sulphur per cubic foot should be the limit and further purification, say, to 0.5 grains, would be advisable. All sulphur above this must be eliminated, preferably by purification with oxide of iron.

CHAPTER XVIII

HEAT: TEMPERATURE, RADIATION, AND CONDUCTION

TEMPERATURE

Flame Temperature.—The calorific intensity or theoretical flame temperature of a substance, says Dowson, is the temperature to which the products of combustion would be raised, if the initial temperature were 0° C. or 32° F., assuming that the combustion is complete, that no excess of air or oxygen is used, and that all the heat evolved during the combustion of the substance is taken up by the products. The capacity for heat absorption of a gas is termed its specific heat and is therefore a factor in flame temperature calculations.

Specific Heats of Gases.—The specific heat of a gas is greater when the gas is heated under a constant pressure (and therefore allowed to expand) than when it is heated at constant volume.

The difference between the specific heat of a gas at constant pressure and at constant volume is

$$\frac{1.98}{\text{Molecular weight of the gas}} \text{ Centigrade units,}$$

or

$$\frac{3.564}{\text{Molecular weight of the gas}} \text{ Fahrenheit units.}$$

MEAN SPECIFIC HEATS OF GASES AT CONSTANT PRESSURE BETWEEN THE ABSOLUTE
ZERO AND THE TEMPERATURE $t°$ C.

Gas.	Mean Specific Heat[1] (C. Units).		
	a	b	
Carbon monoxide	$0.2326 + 0.0000214$	$\times (t + 273)$	
Hydrogen	$3.2500 + 0.0003000$	$\times (t + 273)$	
Methane	$0.4070 + 0.0000376$	$\times (t + 273)$	
Nitrogen	$0.2320 + 0.0000214$	$\times (t + 273)$	
Oxygen	$0.2036 + 0.0000188$	$\times (t + 273)$	
Carbon dioxide	$0.1481 + 0.0000843$	$\times (t + 273)$	
Water vapor	$0.3619 + 0.00001615$	$\times (t + 273)$	

[1] Based on Le Chatelier's values, "Cours de Chimie Industrielle."

The mean specific heat of a gas between any two temperatures $t_1°$ and $t_2°$ C. is found as follows:

The mean specific heat between absolute zero and $t°$ C.

$$a + b(t + 273),$$

where the values of a and b are taken from the preceding table.

The heat required to raise the temperature of 1 kilo of the gas from the absolute zero to $t_1°$ C. is

$$a(t_1 + 273) + b(t_1 + 273)^2 \text{ calories.}$$

The heat required to raise the temperature of 1 kilo of the gas from the absolute zero to $t_2°$ C. is

$$a(t_2 + 273) + b(t_2 + 273)^2 \text{ calories.}$$

The heat required to raise the temperature of 1 kilo of the gas from $t_1°$ to $t_2°$ C. is the difference between these two quantities, or

$$a(t_2 - t_1) + b(t_2 - t_1)(t_2 + t_1 + 546) \text{ calories.}$$

The mean specific heat between t_1 and t_2 is therefore

$$a + b(t_2 + t_1 + 546).$$

Example.—The mean specific heat of carbon dioxide, at constant pressure, between 0°' and 1000° C. is

$$0.1481 + 0.0000843 \times 1546 = 0.2784.$$

The molecular heat of gas is the quantity of heat required to raise the temperature of 22.32 cubic meters of the gas (or of its molecular weight in kilos) through 1° C.

Flame Temperature.—The resulting flame temperature of the combustion of any substance is found by dividing the number of heat units evolved by the products of combustion multiplied by their respective specific heats. Thus for producer gas:

$$\frac{\text{Heat units evolved per cu.ft.}}{CO_2 \times 0.0265 + H_2O \times 0.0173 + N \times 0.0192} = \text{Temperature.}$$

However, since in practical work there will always be an excess of air, this must be taken into account when calculating the temperature, thus:

$$\frac{\text{Heat units evolved per cu.ft.}}{\text{Air excess} \times 0.0191 + CO_2 \times 0.0265 + H_2O \times 0.0173 + N \times 0.0192} = \text{Temperature.}$$

A definite distinction should at all times be made between theoretical flame temperature and furnace temperature, the former being only relative as far as practical purposes go. In the latter certain distinct conditions arise, which must be carefully differentiated.

For instance, the increased furnace temperature obtained by the use of blast or the admission of either or both elements under pressure, is due to the relative supply of such elements to the ratio of loss of heat by the furnace through radiation and conduction.

Although these losses increase almost directly with temperature, they are relatively slower than the heat generated, and if the combustion be accelerated, it is possible to generate heat within certain limits more rapidly than the consequent loss through raidation and conduction which ensues. Thus it becomes a ratio of the rate of combustion to the rate of radiation, and the acceleration of the former within certain limits, either by the blast of both elements or the blast of one, and the consequent kinetic acceleration of the other, nets a certain increment of temperature in the attendant operation.

Again, where combustion of gases are accelerated by pressure, certain benefits are derived through mass action or molecular agitation, that is to say, in current terms, a more thorough "mix" is obtained.

Also, a certain advantage is gained in the heat balance with both the hot and compressed gas, due to an acceleration of mass action or an increased molecular activity.

In connection with the supply of gas to a furnace under pressure, as has just been referred to, it may be noted from experiments that in a furnace where the elements admitted under atmospheric pressure gave a resultant furnace temperature of about 1600° F., their admission under pressure of one-half a pound increases this furnace temperature to 2000° F., while the increase in pressure of both elements to 2 lbs., gave a corresponding increase of temperature to 2400° F.

One authority notes a temperature as high as 3300 to 3400° F. attained in a furnace where both gas and air were admitted under a pressure of 35 lbs. It is likely that in an instance of this kind (the value of the gas being from 125 to 140 B.T.U. per cu.ft.) that considerable increase in temperature was obtained by the compression or condensation, from the gas, of all entrained moisture, this same condition being observed in illuminating gas where supplied from high pressure transmissions.

It may be noticed at this point that all maximum temperatures must necessarily be obtained at the expense of fuel economy. That is to say, where maximum furnace temperatures are reached, a percentage of CO will be found remaining as a constituent of the products of combustion, or flue gases.

Theoretically of course maximum temperature is to be obtained by the admission of the theoretical quota of air for oxidation, but in practice in the obtaining of complete combustion, an excess of air must be admitted, although this excess is much smaller in case of gases than that necessary for the complete combustion of solid fuel.

The ratio of CO appearing in flue gases (products of combustion) with maximum temperatures has been noted by Professor Breckenridge, and charted in his report

to the United States Geological Survey, the test in this instance being of course in direct firing of bituminous coal.

The maximum temperature, it will therefore be noted, will be obtained under practical working conditions, by the admission of about the theoretical quantity of air, but this theoretical quantity of air will be insufficient for complete combustion. Should this quantity be increased to the necessary excess of air, the combustion will be increased and the temperature (through "over-ventilation") decreased. Axiomatically it may be said that "maximum temperatures may only be obtained at the expense of fuel economy."

This discrepancy is of course reduced to the minimum where the elements are supplied at high temperature, for the reasons already noted.

The sensible heat of a gas adds to the flame for all practical purposes, its actual temperature $(T_1 - T_2)$ above atmospheric and to the effective heat of the furnace $W \times C \times S$, the latter being the coefficient of heat absorption at $T_2°$ and C equalling number of calories per kg. or B.T.U. per pound contained at $T_2°$.

The highest temperature that can theoretically be obtained by burning a gas in air is the temperature that will be reached when no heat is lost in any way, all the heat developed being employed to heat up the products of combustion and the nitrogen accompanying the oxygen drawn from the air for this combustion. These conditions are of course never obtained in practice, but, as it is very hard to measure accurately the losses that occur in practice, the maximum theoretical temperatures are used to furnish a basis for comparisons between different gases, it being assumed that the relations between the temperatures actually obtained will be nearly the same as those existing between the theoretical temperatures, although the absolute temperatures will be very different in the two cases.

This maximum theoretical temperature evidently depends upon the quantity of heat developed by the combustion of a unit weight of gas and upon the quantity of heat required to raise by 1° the temperature of the products resulting from the combustion of this unit weight, and the quotient obtained by dividing the quantity of heat produced by the quantity required to raise the temperature of the products of combustion 1° will give the highest temperature that can be reached by burning the given gas. The quantity of heat produced is given by the calorific value of the gas. The amount of heat required to raise the temperature of the products of combustion 1° can be calculated by multiplying the weight of each product that is produced by its specific heat, the nitrogen mixed with the oxygen in the air and drawn into the flame with it being included. It is therefore necessary to determine what substances are produced by the combustion of the gas and the weight of each of these substances that is obtained from the unit weight of the gases, to multiply the determined weight of each substance by its specific heat, and to add together the numbers obtained by these multiplications, the sum forming the divisor of the fraction.

The maximum temperature that can be produced by burning a gas in air can therefore be determined by dividing the calorific value of the gas per pound by the sum of the numbers obtained, by multiplying the weight of each of the products of combustion produced from one pound of gas by its proper specific heat, the nitrogen mixed in the air with the oxygen required for combustion being considered as one of the products of the combustion.

To illustrate by a simple example, the maximum temperature that can be produced by the combustion of carbonic oxide, CO, may be determined as follows:

One pound of CO requires for its combustion to carbonic acid, CO_2, 0.571 lb. of oxygen, which will have mixed with it in the air $0.571 \times 3.31 = 1.89$ lbs. of nitrogen, N, and the products of the combustion of 1 lb. of CO will therefore be 1.571 lbs. of CO_2 and 1.89 lbs. of N. The calorific value of CO is 4383 B.T.U. per pound, the specific heats of CO_2 and N are respectively 0.217 and 0.244, and the equation of the maximum temperature in degrees Fahrenheit is

$$T = \frac{4383}{1.571 \times 0.217 + 1.89 \times 0.244} = \frac{4383}{0.802} = 5465° \text{ F.}$$

The theoretical temperature depends upon the relation between the quantity of heat developed by the combustion of a unit weight of the gas and the amount of heat required to raise by 1° the temperature of the products resulting from the combustion of this unit weight. This latter amount depends upon the weight of the products and their specific heat or capacity for heat. Therefore a gas which yields a small weight of products of combustion with low specific heats will produce a high flame temperature, even though its heating value is comparatively low.

Hydrogen and hydrocarbon gases containing a large percentage of hydrogen yield upon combustion large weights of aqueous vapor, which has a high specific heat, and consequently, in spite of their high heating value, do not produce as high flame temperatures as do such gases as carbonic oxide, which have a lower heating value, but give smaller weights of products, having a lower specific heat than aqueous vapor.

Since, when the gas is burned in air, weight of the nitrogen mixed with the oxygen in the air is added to that of the products of combustion, the flame temperature is lower when the combustion takes place in air than it is for combustion in oxygen, as is practically illustrated in the oxyhydrogen flame.

Influence of Kind of Gas.—R. Casaubon, in a discussion on the "Temperature of Flames" (*Gas World*, February 22, 1908), says that there is a tendency to assume that the temperature of a flame can be measured by putting a solid body in it, and ascertaining the temperature that this would reach. That this assumption is not justified is shown by the fact that a thermo-couple shows 1600° in a flame, where, nevertheless, a fine platinum wire will melt. But in the experiment cited, the conditions as to consumption of gas, proportion of primary air, etc., are very imperfectly detailed.

In an incandescent mantle in free air the lighting power will rise from 2.3 to 21 carcels as the consumption increases from 1.695 to 6.912 cu.ft. per hour, and the proportion of primary air giving the highest illuminating power in each case rises from 4.20 to 4.93 times the volume of the gas. There are thus two variables, the gas consumption and the proportion of primary air. If, however, we enclose the mantle in a globe with only a small opening at the top for the escape of the products of combustion, the consumption increases from 2.119 to 6.912 cu.ft., the lighting power from 0.67 to 23.9 carcels, but the proportion of primary air only from 5 to 5.03. Thus we have practically but one variable.

This indicates that the velocity of the flame is of importance in determining the temperature attained by a solid body immersed therein, and also of the flame temperature. For instance, water gas has a theoretical combustion temperature

of 2025° C., the volume of the products of combustion being 2.7 times that of the original gas, while coal gas has a theoretical flame temperature 1950° C., with products of combustion of 6.15 volumes. In the case of the coal gas, it is possible that the velocity of the products of combustion may neutralize any advantage obtainable through the higher theoretical velocity of the water gas. While this does not accord with Professor Lewes's experiments, an explanation may be that he used injector burners which are unsuited for coal gas.

Different coal gases give the same temperature of combustion; but the volume of the products of combustion increases nearly with the heating value of the gas. Therefore, for a given consumption of gas, the velocities are nearly in proportion to their heating values. This is in accord with St. Clair Deville's decision that the maximum lighting value is measured by the heating value of the gas. But while this is true for cases in which air is supplied under pressure, it is by no means so when injectors are used. Under ordinary pressures, these fail to bring in a sufficient primary air supply when the heating value of the gas is very high. Hence it may be that a high heating value is useless to anybody except the user of a gas engine. The same injector mantle, and burner, for instance, gave practically identical candles per foot with a coal gas of 628 B.T.U. and a water gas of 478 B.T.U.

High heating powers, as in the case of methane, which requires 9.6 volumes of air, are not of advantage with injector burners unless the pressures are suitably high. Methane alone would require 40 ins. of water, but, of course, methane may be of great value as a means of bringing the heating power up to a required standard, whenever it becomes cheap enough, just as benzol brings up the lighting power.

Melting-points.—Low temperatures may be determined very readily by noting whether any given substance of known ebullition boils when subjected to the given temperature for the required time. The following tables may be useful in this connection.

BOILING-POINTS
ALPHABETICALLY ARRANGED

Substance.	Deg. F.	Substance.	Deg. F.
Acetic acid	245	Iodine	347
Air	311	Lead	1904
Alcohol, grain	173	Linseed oil	600
Alcohol, wood	150	Mercury chloride	572
Ammonia	−37	Mercury	675
Ammonia aqua	140	Naphtha	185
Benzene	176	Nitric acid	248
Bromine	137	Oxygen	−204
Cadmium	1580	Petroleum	316
Carbon disulphide	115	Phosphorus	554
Chlorine	−40	Potassium	1292
Chloroform	140	Sal-ammoniac	257
Coal tar	325	Salt, saturated solution	220
Cyanogen	−6	Sodium	1310
Ether	98	Sulphur	824
Ethylene chloride	184	Sulphuric acid	620
Fusel oil	269	Turpentine oil	315
Gasoline	175	Varnish	600
Glycerine	554	Water	212
Hydrocyanic acid	79	Water in vacuum	100
Hydrofluoric acid	66	Whale oil	630
Hydrogen sulphide	−101	Zinc	1904

BOILING-POINTS AT ATMOSPHERIC PRESSURE

ARRANGED IN THE ORDER OF BOILING-POINTS

Substance.	Deg. F.	Substance.	Deg. F.
Ether, sulphuric	100	Nitric acid	248
Carbon bisulphide	118	Nitrate of soda, saturated	250
Ammonia	140	Carbonate of potash, saturated	275
Chloroform	140	Petroleum	306
Bromine	145	Oil of turpentine	315
Wood spirit	150	Petroleum, rectified	316
Alcohol	173	Coal tar	325
Benzene	176	Acetate of potash, saturated	336
Naphtha	186	Phosphorus	554
Water	212	Sulphur	768
Milk	213	Sulphuric acid	590
Average sea water	213.2	Linseed oil	597
Carbonate of soda, saturated	220.3	Whale oil	630
Acetate of soda, saturated	225.8	Mercury	676
Saturated brine	226	Lead	1500
Nitrate of potash, saturated	240.6	Zinc	1872

MISCELLANEOUS TEMPERATURE DATA

(From Haswell and other sources)

Substance.	Deg. F.	Substance.	Deg. F.
Absolute zero of temperature −273° C. or	−491	Milk freezes	30
Hydrogen under 180 atm. liquifies	−205	Olive oil freezes	36
Nitrous oxide freezes	−150	Vinous fermentation	60–77
Boiling-point of liquid ozone at atmospheric pressure	−119	Acetous fermentation begins	78
Greatest natural cold	−56	Acetification ends	88
Liquid ammonia freezes	−46	Heat of human blood	98
Sulphuric ether freezes	−46	Highest natural temperature in Egypt	117
Sulphuric ether (sp.gr. 1.641) freezes	−45	Gutta-percha softens	145
Nitric acid (sp.gr. 1.424) freezes	−45	Gutta-percha vulcanizes	293
Proof spirit and brandy freezes	−7	Petroleum boils	306
Snow and salt, equal parts	0	Wood, dried, burns	340
Spirits of turpentine freezes	+14	Mercury volatilizes	680
Strong wines freeze	20	Ignition of bodies	750
Human blood freezes	25	Heat of common fire	790
Sea water freezes	28	Combustion of bodies	800
Vinegar freezes	28	Charcoal burns	800

Higher temperatures can be tested by the melting points of other substances as specified in the following tables. Various authorities do not agree upon the exact figure, but substances also vary and the method is more convenient than accurate at any rate.

MELTING-POINTS OF MISCELLANEOUS SUBSTANCES

ARRANGED IN THE ORDER OF MELTING-POINTS

Substance.	Deg. F.	Substance.	Deg. F.
Sulphurus acid	−148	Phosphorus	112
Carbonic acid	−107	Acetic acid	113
Bromine	−9.5	Stearine	109–120
Turpentine	14	Spermaceti	120
Hyponitric acid	16	Margaric acid	131–140
Ice	32	Beeswax, rough	142
Nitroglycerin	45	Beeswax, bleached	154
Pitch or butter	91	Stearic acid	158
Tallow	92	Iodine	225
Lard	95	Sulphur	239

MELTING-POINTS OF FUSIBLE ALLOYS

Lead.	Tin.	Bismuth.	Zinc.	Cadmium.	Mercury.	Authority.	Melting-points, Deg. F.
25	25	50	....	....	250	D'Arcet's	113
25	12.50	50	....	12.50	....	Wood's	149
26	12.78	50	....	10.40	....	Lipowitz'	149
1	1	4	....	1	....	Quoted by Haswell	155
25	12	50	....	13	....	Quoted by Haswell	150–160
19.36	19.97	47.38	....	13.29	....	Guthrie's "Cadmium"	160
2	1	4	....	1	....	Wood's	165
3	2	5	....	....	....	Stereotype writing pencils	199
33.3	....	33.3	33.3	....	....	Quoted by Haswell, less than ...	200
1	1	2	....	....	....	Rose's	200
25	25	50	....	....	....	D'Arcet's	201
1	1	4	....	....	....	Quoted by Kent and Clark	201
5	3	8	....	....	....	Quoted by Kent and Clark	202
....	3	5	....	....	....	Quoted by Kent and Clark......	202
31.25	18.75	50	....	....	....	Newton's......................	202
28.10	24.10	50	....	....	....	Rose's	203
3	5	8	....	....	....	Quoted by Kent...............	208
1	3	5	....	....	....	Quoted by Haswell	210
31	19	50	....	....	....	Newton's, quoted by Haswell, less than	212
3	2	5	....	....	....	Newton's......................	212
2	3	5	....	....	....	Quoted by Haswell	212
1	4	5	....	....	....	Quoted by Kent and Haswell ...	240
1	1	1	....	....	....	Clark	254
1	2	1	....	....	....	Pewter's solder and soap molds ..	?
1	....	1	....	....	....	Quoted by Kent	257
....	1	1	....	....	....	Quoted by Kent and Haswell ...	286
2	2	1	....	....	....	Quoted by Clark	292
4	4	1	....	....	....	Quoted by Clark	320
....	2	1	....	....	....	Quoted by Kent and Haswell ...	336
....	3	1	....	....	....	Quoted by Kent	392
....	1	....	1	....	....	Quoted by Haswell	399

MELTING-POINTS OF FUSIBLE PLUGS. (HASWELL)

Tin.	Lead.		Deg. C.	Deg. F.		Deg. C.	Deg. F.
2	2	Softens at	185	= 365,	melts at	189	= 372
2	6	"	189	= 372,	"	195	= 383
2	7	"	192	= 377½	"	197	= 388
2	8	"	202	= 395½,	"	209	= 408

MELTING-POINTS OF LEAD-TIN ALLOYS. (KENT)

Tin.	Lead.		Deg. C.	Deg. F.
1	25	....	292	= 558
1	10	....	283	= 541
1	5	....	266	= 511
1	3	....	250	= 482
1	2	Cheap solder	227	= 441
1	1	Common solder	188	= 370
1½	1	....	168	= 334
2	1	Fine solder	171	= 340
3	1	....	180	= 356
4	1	....	185	= 365
5	1	....	192	= 378
6	1	....	194	= 381

MELTING-POINTS OF SOLDERS. (KENT)

Description.	Tin.	Lead.	Copper.	Brass.	Nickel.	Melting-points.
Common solder	1	1	. . . . .	. . . . .	. . . . .	188° C., 370° F.
Fine solder	2	1	. . . . .	. . . . .	. . . . .	171° C., 340° F.
Cheap solder	1	2	. . . . .	. . . . .	. . . . .	227° C., 441° F.
Novel's solder for aluminum . .	100	5	. . . . .	. . . . .	. . . . .	280–300° C., 536–572° F.
	100	. . . . .	. . . . .	·5	. . . . .	280–300° C., 536–612° F.
	1000	. . . . .	10–15	. . . . .	. . . . .	350–450° C., 662–842° F.
	1000	. . . . .	. . . . .	. . . . .	10–15	350–450 C., 662–842° F.

For the determination of moderately high temperatures, such as that of hot blast supplied to furnaces, use is often made of metals or alloys of known melting-points, and when two such substances are procurable with melting-points differing only by a few degrees, the temperature of the blast, etc., can be readily kept within that range by regulating the heating apparatus, so that one test piece is liquid and the other solid. By employing a series of test pieces whose melting-points ascend by small and fairly regular increments a tolerably reliable measurement can be made of any temperature within the range of our test pieces. Prinsep's alloys furnish us with fairly good means of reading temperatures between the melting-point of silver and that of platinum.

MELTING-POINTS OF PRINSEP'S ALLOYS

Percentage Composition of Alloy.			Melting-point, Deg. C.	Percentage Composition of Alloy.			Melting-point, Deg. C.
Silver.	Gold.	Platinum.		Silver.	Gold.	Platinum.	
100	. . .	. . .	954	. . .	60	40	1320
80	20	. . .	975	. . .	55	45	1350
60	40	. . .	995	. . .	50	50	1385
40	60	. . .	1020	. . .	45	55	1420
20	80	. . .	1045	. . .	40	60	1460
. . .	100	. . .	1075	. . .	35	65	1495
. . .	95	5	1100	. . .	30	70	1535
. . .	90	10	1130	. . .	25	75	1570
. . .	85	15	1160	. . .	20	80	1610
. . .	80	20	1190	. . .	15	85	1650
. . .	75	25	1220	. . .	10	90	1690
. . .	70	30	1255	. . .	5	95	1730
. . .	65	35	1285	. . .	. . .	100	1775

The values of the higher melting-points are probably within some twenty degrees of the truth. Multiply by 9 and divide by 5 to get Fahrenheit degrees.

MELTING-POINTS OF METALS

Substance.	Deg. F.	Substance.	Deg. F.
Aluminum	1157	Yellow brass	1350
Antimony	810 to 1150	Bronze	1690
Bismuth	476 to 512	Arsenic	365
Copper	1929 to 1996	Cadmium	442
Lead	608 to 618	Lithium	356
Mercury	39	Magnesium	1200
Tin	442 to 451	Potassium	136 to 144
Zinc	680 to 779	Sodium	194 to 208

MELTING-POINTS OF METALS—*Continued*

Substance.	Ceg. F.	Substances.	Deg. F.
Iron, gray	2030 to 2280	Cobalt	2000
Iron, white	1190 to 2075	Nickel	2732
Iron, wrought	2700 to 2912	Manganese	3400
Iron, ferro-silicon	2040 to 2190	Gold, pure	1913 to 2282
Steel, 1.18–1.32. C	2350 to 2450	Gold, standard	2156
Steel, hard	2570	Silver, pure	1773 to 1873
Steel, mild	2687	Platinum	3227
Steel, ferro-manganese	2210 to 2255	Palladium	2732
Steel, ferro-tungsten	2240 to 2280	Rhodium	3650
Steel, ferro-chrom	2180 to 2400	Iridium	3550

MELTING-POINTS

ARRANGED ALPHABETICALLY

Substance.	Deg. F.	Substance.	Deg. F.
Acetic acid	113	Neatsfoot oil	40
Almond oil	15	Nickel	2462
Aluminum	1112	Nitroglycerine	45
Aluminum bronze	1796	Olive oil	36
Antimony	810	Osmium	4892
Arsenic	932	Palladium	2732
Asphaltum	250	Palm oil	104
Beeswax	145	Paraffine	130
Bismuth	516	Phosphorus	111
Bonefat	70	Pitch	91
Brass	1869	Platinum	3227
Bromine	19	Porpoise oil	3
Bronze	1454	Potassium	136
Butterfat	90	Potassium sulphate	1830
Cadmium	608	Rhodium	3432
Carnuba wax	185	Rubidium	101
Castor oil	5	Saltpeter	600
Cerium	1292	Seal oil	37
Chromium	3632	Selenium	422
Coal tar	196	Silicon	2372
Cobalt	2552	Silver	1742
Cocoa butter	90	Sodium	205
Cocoanut oil	75	Spermaceti	120
Cod-liver oil	14	Sperm oil	−13
Copper	1929	Stearic acid	158
Cottonseed oil	54	Stearin	120
Cotton stearine	104	Steel, hard	2570
Croton oil	3	Steel, soft	2675
Ferro-nickel	2660	Strontium	1112
Germanium	1652	Sulphur	237
Glass	1500–2300	Sulphurous acid	−148
Gold	1913	Sunflower oil	1
Ice	32	Tallow	95
Iodine	237	Tellurium	851
Iridium	3632	Thallium	561
Iron, gray	2228	Tin	455
Iron, white	2075	Titanium	4532
Iron, wrought	2900	Tungsten	4712
Lard	95	Turpentine	14
Lead	622	Uranium	4352
Linseed oil	60	Wax	150
Magneisum	932	Whale oil	28
Manganese	2732	Wool fat	105
Mercury	−39	Zinc	784
Molybdenum	3992	Zirconium	2372

Industrial Operation Temperatures.—The following tables have been collected as showing what temperatures should be expected in various kinds of furnaces and operations.

TEMPERATURES IN SOME INDUSTRIAL OPERATIONS

	Deg. C.	Deg. F.
Gold—Standard alloy, pouring into molds	1180	2156
Annealing blanks for coinage, furnace chamber	890	1634
Silver—Standard alloy, pouring into molds	980	1796
Steel—Bessemer Process, six-ton converter:		
Bath of slag	1580	2876
Metal in ladle	1640	2984
'' ingot mold	1580	2876
Ingot in reheating furnace	1200	2192
'' under hammer	1080	1976
Siemens Open-hearth Furnace:		
Producer gas near gas generator	720	1328
'' entering recuperator chamber	400	752
'' leaving recuperator shamber	1200	2192
Air issuing from recuperator chamber	1000	1832
Products of combustion approaching chimney	300	590
End of melting pig charge	1420	2588
Completion of conversion	1500	2732
Pouring steel into ladle { beginning	1580	2876
{ ending	1490	2714
In the molds	1520	2768
Siemens Crucible Furnace:		
Temperature of hearth between crucibles	1600	2912
Blast furnace on gray Bessemer:		
Opening in front of tuyere	1930	3506
Molten metal beginning to tap	1400	2552
'' '' end of tap	1570	2858
Siemens Glass-melting Furnace:		
Temperature of furnace	1400	2552
Melted glass	1310	2390
Annealing bottles	585	1085
Furnace for hard porcelain, end of " baking "	1370	2498
Hoffman red-brick kiln, burning temperature	1100	2012

METAL BATHS FOR TEMPERING. (MOLESWORTH)

	Lead.	Tin.
Turning tools for metals	1.75	1
Wood tools, taps and dies	2.5	1
Hatchets, chipping chisels	4.75	1
Springs	12	1

METALLURGICAL WORKING TEMPERATURES

	Deg. C.	Deg. F.
Blast furnace at tuyeres	2000	3632
Blast furnace tapping	1600	2912
Open hearth furnace during boil	1500	2732
Medium hard steel at tapping	1600	2912
Gas leaving producers	700	1292
Gas leaving regenerators	1200	2192
Air leaving regenerators	1100	2012
Waste gas at stack	300	572
Medium steel ready to roll	1050	1922
Glass pots, working	1050	1922
Glass pots, refining	1325	2417
Tanks for casting glass	1325	2417
Crucible steel furnace	1300	2372
Cement rotary clinkering	1684	3000
Shale drain tile burning	871	1600
Composition earthenware	1015	1860
Fire clay stoneware burning	1610	2922
Fire clay sewer pipe, hottest	1048	1920
Shale sewer pipe, hottest	1016	1862
Fire-clay paving brick, hottest	1048	1920
Shale paving brick, hottest	1000	1800
Under a boiler, hottest	1257	2295
Ingot being rolled	1065	1950
Heating furnace	1150	2120
Limestone burning (approx.)	1000	1832
Distillation of gypsum	....	300

STEEL WORKS TEMPERATURES

	Deg. C.	Deg. F.
Six-ton Converter:		
Bath of slag	1580	2876
Metal in ladle	1640	2984
" ingot mold	1580	2876
Ingot in reheating furnace	1200	2192
" under hammer	1080	1976
Open-hearth Furnace. (Siemens semi-mild steel):		
Fuel gas near generator	720	1328
Fuel gas entering into bottom of regenerator chamber	400	752
Fuel gas issuing from regenerator chamber	1200	2192
Air issuing from regenerator chamber	1000	1832
Chimney Gases.		
Furnace in perfect condition	300	590

STEEL WORKS TEMPERATURES—Continued

	Deg. C.	Deg. F.
Open-hearth Furnace:		
End of the melting of pig charge	1420	2588
Completion of conversion	1500	2732
Molten Steel:		
In the ladle—commencement of casting........	1580	2876
" " —end of casting	1490	2714
In the molds..................................	1520	2768
For very mild (soft) steel the temperatures are higher by 50° C.		
Siemens Crucible or Pot Furnace	1600	2912
Rotary Puddling Furnace........................	1340–1230	2444–2246
Puddled ball—end of operation	1330	2426
Blast Furnace (Gray-Bessemer pig):		
Opening in face of tuyere....................	1930	3506
Molten metal, commencement of fusion	1400	2552
" " end, or prior to tapping	1570	2858
Red-brick Kiln (Hoffmann's):		
Burning temperature	1100	2012
Foundry Irons and Steels:		
Melting heat of white cast iron	1135	2075
" " gray cast iron................	1220	2228
" " mild steel	1475	2687
" " semi-mild steel	1455	2651
" " hard steel	1410	2570
Porcelain Furnace (for hard porcelain):		
Heat at the end of baking	1370	2498
Incandescent Lamps:		
Heat burning normally......................	1800	3272
" when pushed	2100	3812

SUITABLE TEMPERATURES

	Deg. F.
Annealing steel	900–1300
" malleable iron (furnace iron)	1200–1400
" " " (cupola iron).........................	1500–1700
" glass (initial temperature)...........................	950
Working glass..	1200–1475
Melting glass (into a fluid).............................	2200
Hardening tool steel....................................	1200–1400
Case hardening iron and soft steel	1300–1500
Core ovens in foundries	350

SUITABLE TEMPERATURES—*Continued*

	Deg. F.
Drying kilns for wood..	300
Baking white enamel	150
" red and green enamel ⟩bicycle paint............	250
" black enamel	300
Vulcanizing rubber.................................	295
Galvanizing....................................	800
Tinning......................................	500
Burning pottery...................................	2350
" brick..	1800
" fire-brick....................................	2450

CANDY MAKING; BOILING-POINTS FOR SUGAR

Variety of Candy.	Deg. F.	Variety of Candy.	Deg. F.
Smooth	215–220	Hard ball	246–250
Thread	230	Soft crack	290
Blow	232–234	Hard crack	310
Feather.........................	236–238	Hard crack limit	310
Soft ball	240	Caramel	320–400

At 315° sugar begins to part with its sweetness. A little butter added when the sugar begins to boil will prevent boiling over. Add cream of tartar at 240° unless the lower boiling points are wanted without crystallization.

BAKING TEMPERATURES

Substance.	Deg. F.	Substance.	Deg. F.
Bread	400 to 450	Drop cakes	300 to 325
Biscuit.........................	400 to 450	Cookies	275 to 300
Pastry.........................	350 to 400	Angels' food	250 to 300
Eclairs	350 to 400	Wafers.........................	175 to 200
Cream puffs	350 to 400	Kisses	175 to 200
Lady fingers	350 to 375	Macaroons	175 to 200
Layer cakes	300 to 350	Loaf cake	175 to 200

Annealing and Tempering Heats.—This data applies more particularly to steel. The temperatures corresponding to different colors as seen in a furnace are now known quite accurately through the investigations of Maunsel White and F. W. Taylor, together with those of Professor Henry M. Howe. The results of those investigators have entirely discredited the old and generally accepted table of Pouillet, which is still reproduced in most text books and manufacturers' catalogues. The figures of Messrs. White and Taylor and Professor Howe, are as follows:

COLOR SCALE OF HIGH TEMPERATURES

White and Taylor.			Howe.		
Color.	Deg. C.	Deg. F.	Color.	Deg. C.	Deg. F.
Dark red, blood red, low red..........	566	1050	Dull red	550	1022
Dark cherry red	635	1175	Dull red	625	1157
Cherry, full red	746	1375	Full cherry	700	1292
Light cherry, bright cherry, light red ...	843	1550	Light red	850	1562
Orange	899	1650	Full yellow	950	1742
Light orange	941	1725	Full yellow	1000	1832
Yellow.........................	996	1825	Light yellow........	1050	1922
Light Yellow	1079	1975	White.............	1150	2102
White	1205	2200			

COLORS ASSUMED BY INCANDESCENT IRON OR STEEL. (Pouillet)

Deg. C.	Deg. F.	Characteristics and Colors.
261	502	Violet, purple, and dull blue. Between 261° C. and 370° C., it passes to bright blue,
370	680	sea green, and then disappears.
500	932	Commences to be covered with a light coating of oxide, becomes a deal more impressible to the hammer, can be twisted with ease.
525	977	Becomes nascent red.
700	1292	Somber red.
800	1472	Nascent cherry.
900	1657	Cherry.
1000	1832	Bright cherry.
1100	2012	Dull orange.
1200	2192	Bright orange.
1300	2372	White.
1400	2552	Brilliant white; welding heat.
1500	2732	Dazzling white.
1600	2912	

The above colors are observed in the furnace and can best be observed by inserting a 1.5 in. gas pipe to within a yard of the metal and looking through it. Practical furnace men judge temperatures quite closely in this way.

DRAWING THE TEMPER OF TOOLS. (Rose and Kent)

Very pale yellow, 430° F.:
  Scrapers for brass.
  Steel-engraving tools.
  Slight-turning tools.
  Hammer faces.
  Planer tools for steel.
  Ivory-cutting tools.
  Planer tools for iron.
  Paper cutters.
  Wood-engraving tools.
  Bone-cutting tools.
Straw-yellow, 460° F.:
  Milling cutters.
  Wire-drawing dies.
  Boring cutters.
  Leather-cutting dies.
  Screw-cutting dies.
  Inserted saw teeth.
  Taps.
  Rock drills.
  Chasers.
  Punches and dies.
  Penknives.
  Reamers.
  Half-round bits.
Brown yellow, 500° F.:
  Planing and molding cutters.
  Stone-cutting tools.
  Gauges.

Brown yellow, 500° F.:
  Hand-plane irons.
  Twist drills.
  Flat drills for brass.
  Wood-boring cutters.
  Drifts.
  Coppersmith's tools.
Light purple, 530° F.:
  Edging cutters.
  Augers.
  Dental and surgical instruments.
Dark purple, 550° F.:
  Cold chisels for steel.
  Axes.
  Gimlets.
  Cold chisels for cast-iron.
  Saws for bone and ivory.
  Needles.
  Firmer chisels.
  Hack saws.
  Framing chisels.
  Cold chisels for wrought iron.
  Molding and planing cutters.
  Circular saws for metal.
  Screw-drivers.
  Springs.
Dark blue, 570° F.
Pale blue, 610° F.
Blue-green, 630° F.:
  Saws for wood.

Above list is arranged in the order of the color scale as it appears on bright steel when heated in the air.

TEMPER COLORS OF STEEL. (HASWELL)

Deg. C.	Deg. F.		Deg. C.	Deg. F.	
221	430	Faint yellow	304	580	Polish blue.
238	460	Straw color.	316	600	Dark blue.
243	470	Dark straw.	400	752	Bright red in the dark.
277	530	Purple.	474	884	Red hot in twilight.
289	550	Blue.	581	1077	Red, visible by day.
293	560	Full blue.			

Quenching should take place when the above colors appear on the brightened surface of steel.

HEAT RADIATION

Stefan's law is to the effect that the amount of energy radiated is proportional to the difference between the fourth powers of the absolute temperature ($C° + 273$) of the heated body and that of its surroundings. Peclet determined that assuming such surroundings to be at $0°$ C., and the temperature of the heated body at $100°$ C., the following amounts of radiation in c.s.-gram calorie units (i.e. the number of gram calories radiated per square centimeter of surface per $0°$ C.) per $100°$ difference in temperature, to be according to the following table:

Heat Radiating Surface.	C.G.S. Calories per 100° C. Diff.	Heat Radiating Surface.	C.G.S. Calories per 100° C. Diff.
Polished silver	0.00054	Russian sheet iron	0.01410
Silvered paper	0.00177	New cast iron	0.01332
Polished brass	0.00108	Oxidized cast iron	0.01410
Copper	0.00068	Glass	0.01222
Zinc	0.00102	Paper	0.01583
Tin	0.00090	Lampblack	0.01684
Polished sheet iron	0.00189	Building stone	0.01500
Leaded sheet iron	0.00273	Plaster	0.01500
Ordinary sheet iron	0.01164	Wood?	0.01500

Stefan's law covering other ranges of temperature would also use these figures as a basis; or, assuming the heat radiated from $100°$ C. to $0°$ C., as per the table, to represent a difference of 13.8×10^{-3}, then between the temperatures of 273 and 373 the fourth powers of their absolute temperatures, and for any higher numerical difference between the fourth powers and the two absolute temperatures concerned, a corresponding value for the heat radiated could be calculated by interpolation. To save calculation Professor Richards has deduced from Peclet's experiments that the heat radiated for other ranges of radiated temperature are relatively (assuming the figures in the above table to represent unity) as follows:

Deg. C. above 0°.	Multiplier.	Deg. C. above 0°.	Multiplier.
100	1.0	600	26 0
150	2.0	700	35.0
200	3.3	800	45.3
300	7.0	900	57.0
400	12.0	1000	70.0
500	18.3		

Through these calculations one is enabled to determine the heat lost through radiation and to add such loss to the heat transmitted to the air by contact or conduction.

As has been before stated the total heat lost constitutes the sum of these two. That is to say, radiation plus conduction, and which, where the atmosphere is concerned, is assumed to be about equally divided.

The law of heat transfer through conduction or contact will be discussed later, the above referring merely to conduction and radiation.

Taking the temperature of any outer solid surface carefully, and ascertaining the temperature of the surrounding atmosphere or adjacent bodies, should give very nearly the total loss through the above formula, being maintained through both these sources.

Good heat radiators are good absorbers to an equal degree, and reflecting power is the exact inverse of radiating power.

RELATIVE VALUE OF RADIATORS

Substance.	Relative Radiating Value.
Lampblack or soot	100
Cast iron, polished	26
Wrought iron, polished	23
Steel, polished	18
Brass, polished	7
Copper, polished	5
Silver, polished	3

RADIATION RATIOS. (Suplee)

Difference in Temperature, Deg. F.	Ratio.	Difference in Temperature, Deg. F.	Ratio.	Difference in Temperature, Deg. F.	Ratio.
10	1.15	160	1.61	310	2.34
20	1.18	170	1.65	320	2.40
30	1.20	180	1.68	330	2.47
40	1.23	190	1.73	340	2.54
50	1.25	200	1.78	350	2.60
60	1.27	210	1.82	360	2.68
70	1.32	220	1.86	370	2.77
80	1.35	230	1.90	380	2.84
90	1.38	240	1.95	390	2.93
100	1.40	250	2.00	400	3.02
110	1.44	260	2.05	410	3.10
120	1.47	270	2.10	420	3.20
130	1.50	280	2.16	430	3.30
140	1.54	290	2.21	440	3.40
150	1.57	300	2.27	450	3.50

COEFFICIENTS OF RADIATION. (Suplee)

Surface.	B.T.U. per 1° F. per Sq.ft. per Hour.
Silver, polished	0.02657
Copper, polished	0.03270
Tin, polished	0.04395
Tinned iron, polished	0.08585
Iron, sheet, polished	0.0920
Iron, ordinary	0.5662
Glass	0.5948
Cast iron, new	0.6480
Cast iron, rusted	0.6868
Sawdust	0.7215
Sand, fine	0.7400
Water	1.0853
Oil	1.4800

RADIATION LOSS THROUGH WALLS. (Suplee)

LOSS, IN BRITISH THERMAL UNITS, PER SQUARE FOOT PER HOUR FOR 1° F. DIFFERENCE

Thickness in Inches.	Brick.	Stone.	Thickness in Inches.	Brick.	Stone.
4	0.273	0.330	24	0.129	0.255
8	.223	.312	28	.116	.244
12	.188	.295	32	.106	.234
16	.163	.280	36	.097	.224
20	.144	.267	40	.090	.216

CONDUCTION OF HEAT

Conduction of heat follows very nearly the analogy of conduction of electricity, and the conductivity of a substance for one is nearly identical with that of the other.

The unit of heat resistance consists of a cube, 1 cm. square, transmitting 1 gram calorie of heat per second with a drop of temperature potential in transmission of 1° C. For example: If a sheet of copper with a thermal conductivity of 0.92 units, the amount of heat passing per hour through a sheet 1 cm. square by 1 mm. thick with a constant difference of 1° C. between the two sides, would be as follows:

$$0.92 \times \frac{10}{1} \times \frac{10,000}{1} \times 3600 = 331,200,000 \text{ gram calories}$$
$$= 331,000 \text{ kg. cal. (Richard's metallurgical calculations).}$$

The factor 0.92 merely indicates that this is the fraction of unit resistance possessed by copper, hence a sheet one-tenth as thick and ten thousand times the area, would have, during one hour, the heat passing through 1° C., as above.

The standard unit known as the c.g.s.-gram calorie unit, has been tabulated by Professor Richards of Lehigh University, as follows:

HEAT CONDUCTIVITY

Substances.	C.g.s. calorie, per 1° C. Diff.
Ice *	0.00500
Snow	0.00050
Glass (10–15°)	0.00150
Water	0.00120
Quartz sand (18–98°)	0.00060
Carborundum sand (18–98°)	0.00050
Silicate enamel (20–98°) †	0.00040
Fire-brick, dust (20–98°)	0.00028
Retort graphite dust (20–100°) ‡	0.00040
Lime (20–98°) §	0.00029
Magnesia brick, dust (20–100°)	0.00050
Magnesia calcined, Grecian, granular (20–100°)	0.00045
Magnesia calcined, Styrian, granular (20–100°)	0.00034
Magnesia calcined, light, porous (20–100°)	0.00016
Infusorial earth (Kieselguhr) (17–98°)	0.00013
Infusorial earth (0–650°)	0.00038
Clinker, in small grains (0–700°)	0.00110
Coarse ordinary brick dust (0–100°)	0.00039
Chalk (0–100°)	0.00028
Wood ashes (0–100°)	0.00017
Powdered charcoal (0–100°)	0.00022
Powdered coke (0–100°)	0.00044
Gas retort carbon, solid (0–100°)	0.01477
Cement (0–700°)	0.00017
Alumina bricks (0–700°)	0.00204
Magnesia bricks (0–1300°)	0.00620
Fire-bricks (0–1300°)	0.00310
Fire-bricks (0–500°)	0.00140
Marble, white (0°)	0.0017
Pumice	0.0006
Plaster of Paris	0.0013
Felt	0.000087
Paper	0.00040
Cotton	0.000040
Wool	0.000035
Slate	0.00081
Lava	0.00008
Pumice	0.00060
Cork	0.00072
Pine wood	0.00047
Oak wood	0.00060
Rubber	0.00047

* Useful in refrigerating plants, where pipes become coated with ice, as in Gayley's method of drying blast.

† Explains the small conductance of enameled iron ware.

‡ Datum useful where articles are packed in this poorly conducting material.

§ Datum would be highly useful for oxyhydrogen platinum furnaces if it were only known at high temperatures.

Referring to the analogy between heat and electricity, as Prof. Richards suggests, if we call R the thermal specific resistance in c.g.s.-units in the material of a wall or partition having a thickness of D centimeters and an area of S square centimeters, the thermal resistance of the wall or partition will be $\dfrac{R \times d}{S}$, inversely its thermal conductivity will be

$$\frac{S}{R \times d} = \text{coefficient.}$$

Another factor, however, enters into the equation, viz., the surface resistance (or reciprocal conductivity) of the surface or medium surrounding, abutting, or impinging upon its partition and, so to speak, throwing a back pressure upon it.

Suppose for example, two bodies of water of different temperatures separated by a wall. There would be a flow of heat from $+$ to $-$ through the wall, the rapidity of which would be also aided or retarded by the capacity of heat absorption or resistivity of the water upon the minus side, which we may term R_2, the transfer from the water on the plus side to the wall being R_1. Hence, we have water to wall, resistivity of wall, wall to water, or three elements, that is to say, for the entire equation of thermal resistance we would have

$$\frac{R_1}{S} + \frac{R \times d}{8} + \frac{R_2}{S},$$

the thermal conductance being

$$\frac{S}{R_1 + (R \times d) + R_2} = \text{coefficient.}$$

The temperature on the outside of a partition or pipe can be found in several ways, either by laying a flat bulb thermometer made especially for the purpose against it, or to put against it the junction of a thermo-couple, covering the couple with clay or putty. Another way is to take small pieces of metals or alloys possessing known melting points, and observe which alloy melts against the hot metal.

As a matter of course all of the above calculations may be reversed and the temperature on the inside and outside surfaces being known, the heat transmitted may be calculated, or if the temperature of these two surfaces is known and the heat being transmitted is measured the thermal conductivity of the partition may be calculated. Further, if the temperature of two surfaces is known and also its thermal conductivity and also the thermal conductivity of the partition and the temperature of the contingent substances on either side, the thermal resistance of the transfer from either of the contingents to the surface of the partition may be ascertained.

It will be seen from the above that the total heat losses is the sum of several factors, the total of which is much greater than any individual one composing it. For more exact information in this matter the reader is referred to Prof. Joseph W. Richards' published works. The following is an extract from his "Metallurgical Calculations" (McGraw Publishing Co.), p. 178.

Principles of Heat Transfer.—" We have already had to speak of the transfer of heat from fluids to solids, or vice versa, and in one specific case we deduced the value 2222 for the transfer resistivity from hot gases to the surface of iron pipe, meaning thereby that for each degree of temperature difference between the gases and outside of the pipe 0.00045 gram calorie passed per second through each square centimeter of contact surface. A consideration of the transfer of heat through such contact surfaces, from gases or liquids to solids and vice versa, has shown that the transfer resistivity varies with the solid and with the fluid concerned, but much more with the latter than with the former, and is very largely dependent upon the circulation of the fluid, that is, upon the rate at which it is renewed, and therefore upon its velocity. The conductivity or resistivity of such a transfer must, therefore, contain a term which includes the velocity of the fluid. Various tests by physicists have shown the specific conductance (or conductivity of transfer) to vary approximately as the square root of the velocity of the fluid.

" From metal to air or similar gases, the mean velocity of flow being expressed in centimeters per second, and the other units being square centimeters and gram calories, the transfer resistivity is approximately

$$R = \frac{36,000}{2 + \sqrt{v}},$$

and the transfer conductivity of the contact

$$k = 0.000028\,(2 + \sqrt{v}).$$

From hot water to metal the relations are similar, but the conductivity is much better. Experiments show values as follows:

$$k = 0.000028\,(300 + 180\sqrt{v}),$$

$$R = \frac{36,000}{300 + 180\sqrt{v}}.$$

" *Illustration 1.*—In the preceding case of the iron pipe, calculate the difference of temperature of the water in the pipe and the inner surface of the pipe, assuming the water to be passing through at a velocity of 4 cm. per second. Using the above given formula, the heat transfer per 1° difference would be:

$$0.000028\,(300 + 180\sqrt{4}) = 0.0185 \text{ calories,}$$

and the difference to transfer 0.084 calories per second will be

$$\frac{0.084}{0.0185} = 4°.6.$$

The inner surface of the iron pipe will be, therefore, continuously 4°.6 higher than the water, and, therefore, at 14°.6; the outer surface will be continuously 0°.3 higher, or practically at 15°.

" *Illustration 2.*—A steam radiator, surface at about 100° C., caused a current of hot air to rise having a velocity of about 10 cm. per second, which was insufficient to keep the room warm.   An electric fan was set to blow air against the radiator, which it did with a velocity of about 300 cm. per second, and keeping the room comfortably warm.   What were the relative quantities of heat taken from the radiator in the two cases?

The relative thermal conductivities of transfer were

$$2+\sqrt{10}:2+\sqrt{300} \quad \text{or} \quad 5:16,$$

Showing over three times as much heat taken away per unit of time in the second instance.

" This illustration proves the great efficiency which the metallurgist may attain in air cooling of exposed surfaces, by blowing the air against them instead of merely allowing it to be drawn away by its ascensive force."

Conduction through Walls.—The transfer of heat through walls of various materials may be expressed by the following equation:

$$q=\frac{T_1-T_2}{R},$$

where $q=$ B.T.U. transmitted per square foot per hour.
$T_1-T_2=$ Difference in temperature between the two surfaces.
$R=$ Resistance offered by the wall.

R is composed of two elements: the resistance of the material itself, and the resistances of the surfaces of the wall.   The resistance of the material is proportional to the thickness (x) and another quantity (r) depending only on the material.

The following are the values of rX where $X=1$ in. for several materials:

	rX
Copper	0.0018
Aluminum	0.0023
Iron	0.0043
Brick	0.1500

The resistance of one surface is represented by E,

$$E=\frac{0.5}{A(1+B(T_1-T_2))}.$$

A and B depend on the kind of surface and on the nature of the medium resting against it, as given below:

Surface.	A	B
Gas on polished metals	0.90	0.0028
Gas on rough metallic and other surfaces	1.59	0.00
Liquids	8.8	0.058

In boiler work where the material and its surface are constant, the formula

$$q = \frac{(T_1 - T_2)^2}{A},$$

where $A = 160$ to 200, gives very good results.

The great influence of the kind of surfaces and the medium pressing on it, is evident from the following table:

B.T.U. TRANSMITTED PER HOUR PER SQUARE FOOT WHERE THE DIFFERENTIAL TEMPERATURE IS ONE DEGREE FOR EACH INCH OF THICKNESS

Steam to water, copper	1000
" " wrought iron	200
" " cast iron	100
Steam to air, polished copper	0.0327
" " polished tin	0.044
" " polished sheet iron	0.092
" " ordinary sheet iron	0.5662
" " ordinary cast iron	0.648
" " ordinary steam pipe	0.64
Air to air (building walls), marble	25.
" " lime stone	15.
" " red brick	5.
" " fire-brick	12.
" " pine	2.2

Gases and liquids transmit heat very slowly when at rest. This fact, together with numberless repetition of the surface resistance, is probably the cause of the value of some porous substances as heat insulators.

The following table gives the relative quantities of heat transmitted by several heat insulators:

Asbestos	8.17
Slag wool	2.17
Bituminous ashes	3.5
Carbonate of magnesia	2.28

This would seem to indicate that asbestos is really one of the poorest insulators and should be used sparingly and only to hold the other material in place.

However, consensus of opinion seems to be that the asbestos heat insulating lining supplies greater economy than the dead air-space of gas-ranges, although this would probably not be true theoretically. In practice the dead air-space is impossible of realization and the practical loss of radiant heat is greater; moreover, the asbestos-lined oven seems to have its heat more evenly distributed. The following table, compiled by Prof. C. L. Norton, shows the protection afforded by insulating linings:

A steam-pipe heated to 385° F. shows an outside temperature of

$$356° \text{ covered with asbestos-paper } \tfrac{1}{64} \text{ in. thick.}$$
$$329° \quad \text{``} \qquad \qquad \text{``} \qquad \tfrac{1}{32} \quad \text{``}$$
$$302° \quad \text{``} \qquad \qquad \text{``} \qquad \tfrac{1}{16} \quad \text{``}$$
$$266° \quad \text{``} \qquad \qquad \text{``} \qquad \tfrac{1}{8} \quad \text{``}$$

J. C. Bertsch is authority for the statement that the transmission of heat per square foot of surface per minute through a dead air-space 1 in. in thickness is 8 B.T.U., while that of asbestos-paper 1 in. thick is $3\tfrac{1}{2}$ B.T.U. He moreover states that the dead air-space, properly speaking, does not exist in the oven of the modern gas-range, it being impossible to join the metal sheets so closely as to prevent circulation; under these conditions air has little or no value as an insulator. Therefore asbestos-boards $\tfrac{1}{16}$ to $\tfrac{1}{8}$ in. in thickness are the more effective and economical and moreover tend to form a dead air-space with the outside metal sheet.

Heat Absorption by Water.—Siebel notes that the rate of emission of heat from steam pipes in terms of water amounts in round numbers to from 150 to 250 times the rate in air, according as the pipes are in vertical or horizontal positions.

Experiments of the writer go to show an average of 300 times the rate of heat loss by hot water in pipes when surrounded by water as when surrounded by air.

Water Absorption.—G. B. Nicholl experimented with an ordinary surface condenser brass tube $\tfrac{3}{4}$ in. in diameter, No. 18 wire gauge in thickness, encased in a $3\tfrac{3}{4}$ in. iron pipe. Steam of $32\tfrac{1}{2}$ lbs. total pressure per square inch occupied the inter-space while cold water at 58° F. initial temperature was run through the brass tube. Three experiments were made with the tubes in a vertical position, and three in a horizontal position.

Experiments to Determine.	Vertical Postion.			Horizontal.		
	I.	II.	III.	IV.	V.	VI.
Velocity of water through tube in feet per minute	.81	278	390	78	307	415
Steam condensed in lbs. per sq.ft. of surfaces per hour for 1° F. difference in temperature......................	.335	.436	.457	.480	.603	.609
Heat absorbed by the water per sq.ft. per hour per 1° F. difference of temperature in B.T.U..................	346	449	466	479	621	699

HEATING AND EVAPORATING WATER BY STEAM THROUGH METALS

Metal Surface.	Per Square Foot per 1° F. Difference of Temperature.			
	Steam Condensed.		Heat Transmitted.	
	Heating, Pounds.	Evaporating Pounds.	Heating, B.T.U.	Evaporating, B.T.U.
Copper plate	0.248	0.483	276	534
Copper pipe	0.291	1.070	312	1038
Cast-iron boiler	0.077	0.105	82	100

STEAM CONDENSED IN BARE CAST-IRON PIPES IN AIR AND HEAT EMITTED AT ORDINARY TEMPERATURES. (Siebel)

Steam.		Difference or Excess of Temperature of Steam above 62° F.	Steam Condensed per Square Foot per Hour.		Heat Emitted per Square Foot per Hour.	
Total Pressure per Sq.in., Pounds.	Temperature Deg. F.		Total, Pounds.	Per 1° of Difference, Pounds.	Total, B.T.U.	Per 1° F. of Difference, B.T.U.
14.7	212	150	0.29	0.00193	276	1.84
18	222	160	0.346	0.00216	329	2.05
21.5	232	170	0.405	0.00238	284	2.26
26	242	180	0.47	0.00261	446	2.48
31	252	190	0.54	0.00284	513	2.70
36.5	262	200	0.607	0.00303	577	2.89
43	272	210	0.682	0.00325	648	3.08
51	282	220	0.75	0.00345	722	3.28

Heat Absorption by Air.—Concerning the transmission of heat through metal plates from air or other dry gas to water, Siebel says as follows:

The rate of transmission of convected heat is probably from two to five units of heat per hour per square foot of surface per 1° F. of difference of temperature.

In a locomotive fire box where radiant heat co-operated with convected heat the following results have been obtained in generating steam of 80 lbs. pressure per square inch. The temperature of the fire is taken at 2000° F.

	Pounds Water Evaporated per square foot per hour.	B.T.U. Transmitted per square foot per hour per 1° F. Difference of Temperature.
Burning coke 75 lbs. per sq.ft. of grate	25.5	14.5
Burning briquettes 74½ lbs. per sq.ft. of grate . .	35	20

There are in practice little or no differences between iron, copper, and lead in evaporative activity, when the surfaces are dimmed or coated, as under ordinary conditions.

In Motion.—The comparative rate of emission of heat from water tubes in air and in water at rest and in motion has also been investigated. It appears that the rate of emission from water tubes in water was about twenty times the rate in air. Craddock proved it experimentally to be twenty-five times. When the water tube was moved through the air at a speed of 59 ft. per second, it was cooled in one-twelfth of the time occupied in still air. In water moved at a speed of 3 ft. per second, the water in the tube was cooled in half the time.

From some recent observations made in Germany, the following data giving the transmission of heat through metal partitions per hour per square foot and per 1° F. difference between each side, was:

Smoke or air through metal to air . . . .   1.20 to   1.70 B.T.U.
Steam through metal to air . . . .   2.40 to   3.40   " "
Water through metal to air or reverse . . . . . .   2.15 to   3.15   " "
Steam through metal to water   200   to 240   " "
Steam through metal to boiling water 1000   to 1200   " "
Water through metal to water   72   to   96   " "

The heat radiated from a coal or a coke fire is estimated to be about one-half of the whole heat generated. It increases almost as fast as the rate of combustion of the fuel per hour per square foot.

CONVECTION OF HEAT FROM AN EXTERNAL SURFACE

Air . . . . $C = .2849t^{1.233}$
Hydrogen . . . . $C = .9827t^{1.233}$
Carbonic acid . . . . $C = .2759t^{1.233}$
Olefiant gas . . . . $C = .3817t^{1.233}$

$C =$ quantity of heat in B.T.U. conveyed away from a solid body by a gas external to it, per square foot of surface per hour under one atmosphere of pressure.

$t =$ excess temperature of surface in degrees F.

Summary.—From the foregoing experimental data and from other experimental sources it appears that the transference of heat from steam through iron pipes to air increases considerably with the pressure of the steam which may be explained by the greater velocity and force with which the molecules of the steam impinge on the walls of the pipe at the higher pressure and the correspondingly higher temperature combined therewith.

Accordingly the coefficient n or the transfer of heat from steam to air, varies from 1.8 to 3.5 B.T.U. according to pressure per hour for every square foot of pipe surface and for every Fahrenheit degree difference on each side of pipe. For average conditions about three units are frequently adopted. The transfer of heat from steam to water is variously estimated at from 200 to 240 B.T.U. for iron pipe (280 B.T.U. for copper pipe).

The transference of heat or of refrigeration from water to water or to brine and water or the reverse, brine to water, or brine through iron pipe, is about the same, and is generally assumed to amount to 80 B.T.U. per hour in counter-current arrangements or in a Baudelot cooler.

The transference of heat from brine or water through iron pipe to air or the reverse is rated at $2\frac{1}{2}$ B.T.U. in still air, but if the air is moved it may be increased to 4 and 5 B.T.U. per hour and per square foot surface per 1° F. difference.

The transfer of heat from ammonia, such as is circulated in refrigerator coils through such coils to air, is roundly estimated at 10 B.T.U. per hour, and from ammonia to brine and water, as in condenser coils, it may be taken at 30 B.T.U.; in round numbers for 1° F. difference in temperature and per square foot of surface.*

* For further information see Siebel's "Compendium of Mechanical Refrigeration," Nickerson, Collins Co.. Chicago, publishers.

COOLING OF WATER IN PIPES EXPOSED TO AIR. (Siebel)

	Two-inch Wrought-iron Pipes.				Four-inch Cast-iron Pipes.			
Number of Experiment..............	I.	II.	III.	IV.	I.	II.	III.	IV.
Temperature of the atmosphere in degrees F....................	53	53	52.5	52	60	60	60	59
Average difference of temperatures of the water and the air in degrees F....................	103.7	49.4	25.4	14.3	62.3	48.5	33.9	27.3
Total heat emitted per sq.ft. per hour in B.T.U..............	233.7	104.4	46.45	19.7	99.5	69.9	49.5	38.2
Heat emitted per 1° F. difference of temperature, B.T.U.........	2.25	2.11	1.83	1.39	1.59	1.53	1.46	1.4

RADIATION LOSS IN IRON PIPES. (From Suplee)

Mean Temperature of Pipes, Deg. F.	Units of Heat (B.T.U) Emitted, per Square Foot per Hour. Temperature of Air=70° F.				
	By Convection.		By Radiation Alone.	By Convection and Radiation Combined.	
	Air Still.	Air Moving.		Air Still.	Air Moving.
80	5.04	8.40	7.43	12.47	15.83
90	11.84	19.73	15.31	27.15	35.04
100	19.53	32.55	23.47	43.00	56.02
110	27.86	46.43	31.93	57.79	78.36
120	36.66	61.10	40.82	77.48	101.92
130	45.90	76.50	50.00	95.90	126.50
140	55.51	92.52	59.63	115.14	152.15
150	65.45	109.18	69.69	135.14	178.87
160	75.68	126.13	80.19	155.87	206.32
170	86.18	143.30	91.12	177.30	234.42
180	96.93	161.55	102.50	199.43	264.05
190	107.90	179.83	114.45	222.35	294.28
200	119.13	198.55	127.00	246.13	325.55
210	130.49	217.48	139.96	270.49	357.48
220	142.20	237.00	155.27	297.47	392.27
230	153.95	256.58	169.56	323.51	426.14
240	165.90	279.83	184.58	350.48	464.41
250	178.00	296.66	200.18	378.18	496.84
260	189.90	316.50	214.36	404.26	530.86
270	202.70	337.83	233.42	436.12	571.25
280	215.30	358.85	251.21	466.51	610.06
290	228.55	380.91	267.73	496.28	648.64
300	240.85	401.41	279.12	519.97	680.53

COEFFICIENTS FOR THE TRANSMISSION OF HEAT. (Siebel)

Transmission per square foot, in B.T.U. per twenty-four hours, per 1° F. difference of temperature of the air inside and outside (adopted in Germany).

BRICK MASONRY

Thickness of wall	5″	10″	15″	20″	25″	30″	35″	40″
Outside walls	12.00	8.50	6.50	5.25	4.35	3.75	3.25	3.85
Outside walls with air spaces		6.10	5.00	4.25	3.60	3.20	2.85	2.55
Outside walls with stone facing		9.50	7.50	6.00	5.00	4.25	3.70	3.25
Inside walls	11.00	8.00	6.25	5.00	4.25	3.50	3.00	2.50

STONE MASONRY

Thickness of wall	12″	16″	20″	24″	28″	32″	36″	40″	44″	48″
Sandstone	11.0	9.60	8.50	7.65	6.95	6.35	5.99	5.45	5.10	4.75
Limestone	13.0	11.50	10.30	9.35	8.50	7.90	7.25	6.80	6.40	5.95

WOODWORK

	B.T.U.		B.T.U.
Ceiling made of joists	2.5	Single windows	25.5
Solid ceiling with planks	4.0	Single windows with double panes	15.0
Floor of rafters	2.0	Double windows	11.5
Vaulting with planks	3.0	Single skylight	26.5
Solid stone floor	5.0	Double skylight	12.0
Solid stone floor without cellar	7.0	Doors	10.0

Thickness of wall is figured without the air space, the same being 1¼ to 2½ inches.
Sandstone about 5 inches thick, included in the thickness of the wall.
Thickness of glass between usual limits has no influence.

Relative Heat Conductivity.—The following relative coefficients of the internal conduction of heat of some substances are given by Neumann, Forbes, Peclet, Lorenz, etc.

METALS

Aluminum	123–130
Antimony	14–16
Lead (28.5 average)	50–72
Bronze	90–100
Iron (55 average value)	50–72
Steel (22–40 average value)	22–50
Gold	200
Copper (330 average value)	260–396
Brass	72–108
German silver	26–32
Platinum	33
Mercury	6–7
Silver	400
Bismuth	6
Zinc (105 average value)	92–105
Tin (45 average value)	51–55

OTHER SUBSTANCES

Brick masonry	0.69–0.70
Cotton (pressed)	0.01–0.04
Stone masonry	1.3 –2.1
Cement	0.6
Coke, dense	5.0
Coke, powdered	0.16
Oak (along the fiber)	0.21
Ice	0.8
Felt	0.03–0.05
Plaster of Paris	0.33–0.63
Plastered plank	0.4 –0.515
Glass	0.75–0.88
Glass, by Bectz	0.16

Wood ashes	0.06
Charcoal, powdered	0.08
Pumice, loose, for insulation	0.066
Pumice stone for insulation	0.083
Limestone, fine	17–21
Siliceous sinter	0.136
Cork	0.14–0.25
Cork, mass	0.08
Chalk, powdered	0.09
Leroy's mass	0.091
Air (inclosed)	0.02–0.04
Marble, fine	3.48
Marble, coarse	2.78
Marble, by Forbes	0.55
Paper	0.034–0.043
Quartz (sand)	0.27
Sawdust	0.05–0.065
Silk refuse (for insulation)	0.045
Coal	0.11
Pine, along the fiber	0.17
Pine, across the fiber	0.1
Clay (burnt)	0.5–0.7
Wool	0.4

LIQUIDS

Ether	0.15
Alcohol	0.18
Glycerin	0.24
Solution chloride sodium, specific gravity 1.178	0.14
Olive oil	0.49
Water	**0.51**

COEFFICIENTS OF HEAT CONDUCTIVITY PER SQUARE METER PER HOUR DEG. C.

	Calories.
Masonry	1.3 to 3.1
Fire brick	0.7
Air	0.0175 to 0.0205
Cement	0.059
Water	0.44 to 0.56
Iron	40 to 70
Copper	330.00

The conductivity of fire-brick increases with the temperature, that of incandescent brick approximating that of iron.

The Harbison-Walker Refractories Company, of Pittsburg, Pa., have conducted several experiments on heat conduction and find that fire-clay brick is the poorest conductor, followed by silica brick, chrome brick and magnesia brick, the magnesia brick being the best conductor.

If measured by the number of minutes required for the heat of a Bunsen burner to pass along the brick, and melt a ball of wax, the comparison of the different materials is about as follows:

	Minutes.
Fire-clay brick	59
Silica	48
Chrome	34
Magnesia	17

Magnesia brick is such a good conductor of heat that it must be invariably backed up with clay, silica or chrome brick in furnace construction. Magnesia brick should never be laid against the metal shell or metal part, and should not be used without the backing-up necessary to prevent the radiation of heat.

RELATIVE VALUE OF GOOD HEAT CONDUCTORS

Substance.	Relative Conducting Value.
Silver	100
Copper	73.6
Brass	23.1
Iron	1.91
Steel	11.6
Platinum	8.4
Bismuth	1.8
Water	0.147

RELATIVE VALUE OF HEAT INSULATORS

Substance.	Relative Insulating Value.
Silicate cotton or slag wool	100
Hair felt	85.4
Cotton wool	82
Sheep's wool	73.5
Infusorial earth	73.5
Charcoal	71.4
Sawdust	61.3
Gas-works breeze	43.4
Wood, and air-space	35.7

The importance of agitation in connection with heat transference, which has already been alluded to, cannot be too strongly emphasized, for upon it depends the efficiency, in part, of the principles covering the burning of gas under pressure by which the flame temperature is so materially enhanced.

The rotary kiln which is particularly advantageous when the material to be heated tends to "fine" early in the process retarding heat transference through mass action. The efficiency of the powdered fuel producer also lies along these lines.

The principle involved may be seen experimentally in the use of the Parr calorimeter, where the mechanical agitation of the water through the use of the revolving vanes is absolutely necessary to complete the heat transference between the combustion bomb and the surrounding water element from which the thermometer temperatures are taken.

Expansion.—To find the increase in the length of a bar of any material due to an increase of temperature, multiply the number of degrees of increase of temperature by the coefficient for 100° and by the length of the bar, and divide by 100.

LINEAR EXPANSION OF SUBSTANCES BY HEAT

Name of Substance.	Coefficient for 100° F.	Coefficient for 180° F., or 100° C.
Baywood (in the direction of the grain, dry)	0.00026–0.00031	0.00046–0.00057
Brass (cast)	0.00104	0.00188
Brass (wire)	0.00107	0.00193
Brick (fire)	0.0003	0.0005
Cement (Roman)	0.0008	0.0014
Copper	0.0009	0.0017
Deal (in the direction of the grain, dry)	0.00024	0.00044
Glass (English flint)	0.00045	0.00081
Glass (French white lead)	0.00048	0.00087
Gold	0.0008	0.0015
Granite (average)	0.00047	0.00085
Iron (cast)	0.0006	0.0011
Iron (soft forged)	0.0007	0.0012
Iron (wire)	0.0008	0.0014
Lead	0.0016	0.0029
Marble (Carrara)	0.00036–0.0006	0.00065–0.0011
Mercury	0.0033	0.0060
Platinum	0.0005	0.0009
Sandstone	0.0005–0.0007	0.0009–0.0012
Silver	0.0011	0.002
Slate (Wales)	0.0006	0.001
Water (varies considerably with the temperature)	0.0086	0.0155

EXPANSION OF METALS. (Faraday)

The Length of a Bar			The Length of a Bar		
At 32° = 1.	At 212° =	Expansion per Deg. F.	At 32° = 1.	At 212° =	Expansion per Deg. F.
Brass	1.0019062	0.0000106	Wrought iron	1.0012575	0.000007
Copper	1.001745	0.0000097	Tin................	1.002	0.0000111
Cast iron	1.0011112	0.0000062	Zinc	1.002942	0.0000163
Steel	1.0011899	0.0000066			

Almost all bodies expand in equal proportions for each degree between freezing and boiling.

To ascertain the expansion of a body, multiply the dimensions of the body by the number of degrees of increase of temperature and then by the expansion per degree.

Example.—Required the expansion of a steel rail 30 ft. long, with an increase of temperature of 100°.

$$30 \times 100 = 3000; \ 3000 \times 0.0000066 = .0198 \text{ ft.} = \tfrac{1}{4} \text{ in.}$$

LINEAR EXPANSION OF METALS PRODUCED BY RAISING THEIR TEMPERATURE FROM 32° TO 212° F.

Zinc	1 part in 322		Gold	1 part in 682
Lead	" 351		Bismuth	" 719
Tin (pure)	" 403		Iron	" 812
Tin (impure)	" 500		Antimony	" 923
Silver	" 524		Palladium	" 1000
Copper	" 581		Platinum	" 1100
Brass	" 584		Flint glass	" 1248

EXPANSION OF LIQUIDS IN VOLUME

Volume at 32° F. = 1.	Volume at 212° F. =
Water..	1.046
Oil	1.080
Mercury	1.018
Spirits of wine	1.110
Air	1.373–1.375

Non-freezing Solution.—The principal non-freezing solutions are the following: Brine (the objection to which is its tendency to oxidize). Glycerine and water is a mixture much used in France, which will stand fairly low temperature, and which necessitates the use of chemically pure glycerine to prevent the contact of fatty acids, particularly corrosive, especially with rubber.

Wood alcohol, which has a freezing point of 151° F. below zero, and which may be used under ordinary circumstances mixed with water, however, possesses a particularly low boiling point, but is inclined to evaporate.

Another non-freezing solution is calcium chloride, which on ordinary metals has little or no corrosive action, and when dissolved in water makes a colorless and odorless solution as follows:

Calcium chloride to each gallon, lb.	2	2½	3	3½	4	4½	5	5½
Degrees salometer,	18	4	88	95	104	120	124	12
Freezing point, F.	52	80	150	8	17	39	27	27

The calcium chloride is a waste product in the manufacture of salt, and is therefore cheap, and the impurities having been removed should be entirely harmless.

It is also an excellent solution for use in exposed water seals, lutes and boshes.

CHAPTER XIX

HEAT MEASUREMENTS: PYROMETRY AND CALORIMETRY

PYROMETRY

THE application of a pyrometer to the bed of a gas producer is a more less difficult operation, for the following reasons:

The testing instrument must be inserted horizontally, that is to say, from the side of the producer, for should the sound or contact be connected from the top and pass down through the fuel, there would be a tendency to form a draft hole, the draft following along the sides of the sound in a chimney or channel, and thereby causing abnormal combustion and reflecting an undue showing of heat.

Again, when the contact point is made from the side of the producer, it must be remembered that the tendency of all drafts is to follow the walls, and the temperature immediately adjacent to the walls, on this account, together with a certain amount of reverberation, is apt to give an excess or inaccurate result. Great care should be observed in noting that the fire-bed is compact and free from channels.

There are about three zones of importance within the producer; namely, the ash, combustion, and distillation zones, but of these three the combustion zone alone is of particular interest from a pyrometric standpoint, the conditions in the other zones being largely reciprocal.

The use of a pyrometer, especially of the recording type, will be found of great value in the regulation and operation of the apparatus, when empirical results have once been obtained and a standard operation established.

Bristol Pyrometers.—The Bristol electric pyrometers can be applied to pipes, mains, or tanks containing superheated steam, liquids, or gases under pressure. It is of the themo-couple type.

For the application of the electric pyrometer to cases of this character, where there is pressure of either steam, liquids, or gases, a well, provided with a screw, is inserted through the wall of the pipe or tank in which the temperature is to be measured. The illustration shows how the couple is generally applied in a case of this kind by simply inserting it into the well from the outside.

These couples are made in two parts—fire end and extension piece. The two parts are joined together by a separable junction and may be designed of almost any desired length and form to meet the individual requirements. The general construction and simplicity of the couple and leads are shown in the illustration of the fire end in a horizontal and the extension piece in a vertical position with

leads attached and ready to connect with the indicating instrument by means of an ordinary lamp plug.
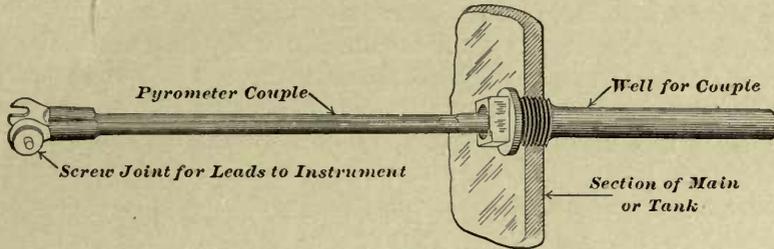
FIG. 205.—Couple of Bristol Electric Pyrometer.

The fire end may be attached to or detached from the extension piece in a few seconds by means of the separable junction, as shown in detail in the following figure.
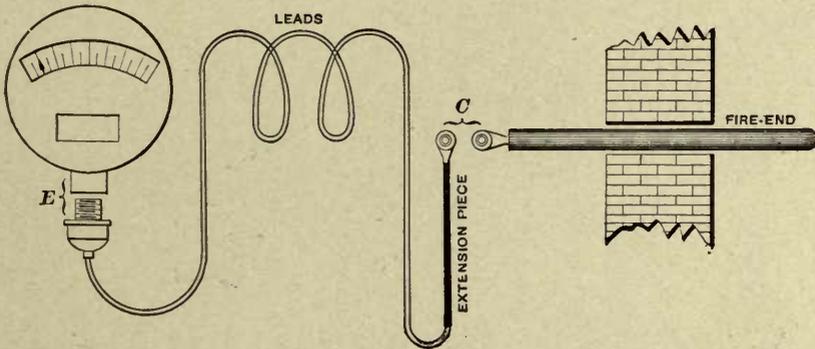
FIG. 206.—Bristol Pyrometer Connections.

This feature is of great practical value and makes it possible to conveniently detach and cheaply renew the fire end when desired. These fire ends are generally made up of two special alloys which will withstand high temperatures and are equipped with fire-proof insulation.

The extension piece is thus a part of the couple itself and the cold end of the couple is where the extension piece terminates and is joined to the lead wires. It is a well-known fact that in using any thermo-couple the cold ends of the elements should be maintained at a constant temperature, or a correction should be made based on the changes of temperature at the cold end. The extension piece provides for carry-

FIG. 207.—Connection C of Fig. 206.

ing the cold ends to a point near the floor where the atmospheric temperature will be practically constant and not influenced by the temperature which is being measured.

In standardizing or calibrating the Bristol pyrometers it is usually assumed that the temperature at the cold end will average 75° F. A great number of experiments have shown that this temperature can usually be secured, but if the cold end temperature is found to vary considerably from that for which the individual pyrometer was standardized, and great refinements of measurements are desired, a very simple correction can be made of the readings of the instrument. In the majority of cases this variation is found to be so slight that it is not necessary to make corrections, but the rule for corrections is as follows when the special alloys are used: Subtract the difference from the reading as indicated by the instrument at that moment.

In most cases the conditions are such that the pyrometers can be standardized for a cold end temperature of 75° F. to the greatest advantage, but they may be standardized for any other average cold end temperature.

Though the sectional couple can usually be applied in such a way as to avoid the necessity for making corrections for the cold end temperature, yet it is sometimes
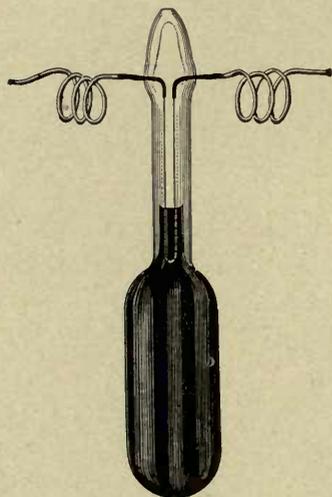
FIG. 208.—Temperature Correction Device.
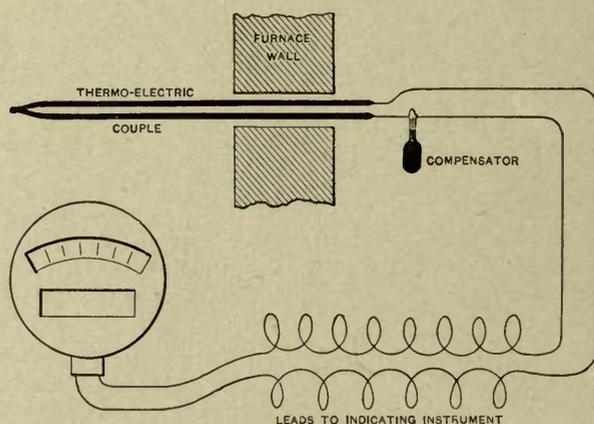
FIG. 209.—Position of Fig. 208 in the Circuit.

extremely desirable to have such corrections made automatically, thus insuring great refinement of measurement. It is possible to accomplish this by the use of the automatic compensators.

The compensator consists of a small glass bulb and capillary tube partially filled with mercury into which a short loop of fine platinum resistance wire dips. Changes in temperature causing expansion or contraction of the mercury have the effect of changing the resistance offered by this loop since the rise and fall of the mercury short circuits more or less of the resistance wire.

The relative position of the compensator is shown connected in the circuit. In actual practice the compensator is attached at the cold end of the couple at the end of the extension piece. The figure shows the compensator attached to the cold end of a straight couple without extension piece. When the temperature at the

cold end rises the mercury expands and thereby cuts down the resistance of the circuit. Thus the change in resistance in the compensator balances the change in electromotive force and the indications on the instrument will remain the same as if no change of atmospheric temperature had occurred.

This thermo-electric couple has been designed to do the work of the expensive platinum platinum-rhodium couple, which is necessary for use in high temperature measurements. By the use of inexpensive alloys for the part of the couple which is not exposed to a temperature above a red heat, a great saving of platinum is possible, as only the active part of the couple is made of the precious metal.
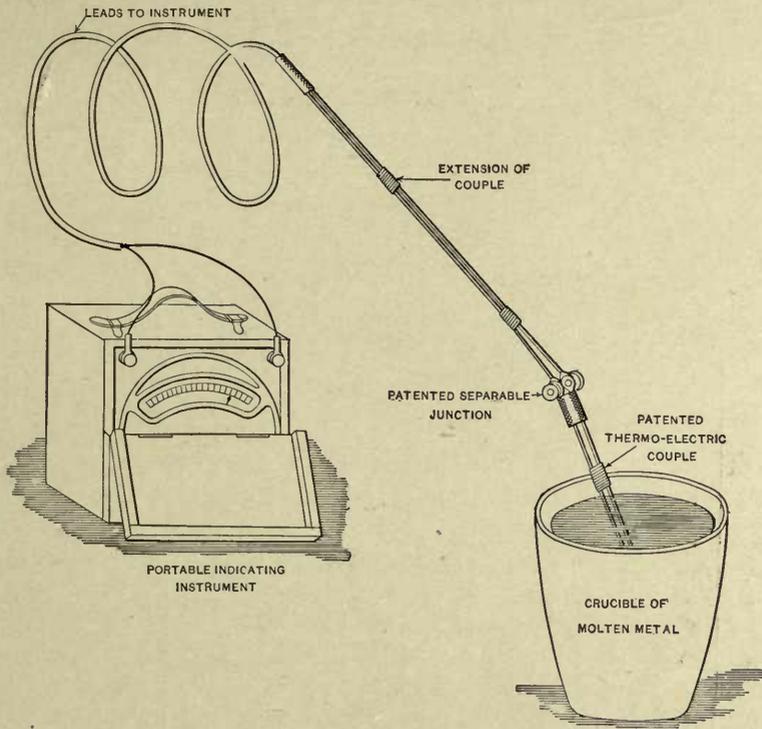
Fig. 210.—Arrangement for Testing Molten Metals.

The thermo-electric junctions B and C are introduced into the circuit where the low-priced alloys and platinum-rhodium elements are connected, but by employing proper alloys the electromotive forces generated are equal and opposed. The resultant electromotive force produced will therefore be the same as if the entire length of the couple was made of the very expensive platinum-rhodium elements.

When the tips of these elements are slightly immersed into molten metal, an electric connection is made and the reading on the instrument will be the same as if the couple had been originally joined.

The general arrangement of the parts forming the complete outfit for this class of temperature measurement is shown in the accompanying diagram, as it would be applied for taking the temperature of a crucible of molten metal just before pouring.

The advantage of this plan is that the tips of the wires forming the elements almost instantaneously assume the temperature of the molten metal and time lag error is eliminated.

This form of couple has been most successfully applied to the measurement of molten metals as cast iron, copper, aluminum, brass, bronze, and other alloys.

When the tip of the couple becomes worn away by continued use, a fresh portion is exposed to the molten metal and the reading will be the same as if the couple had not worn away.
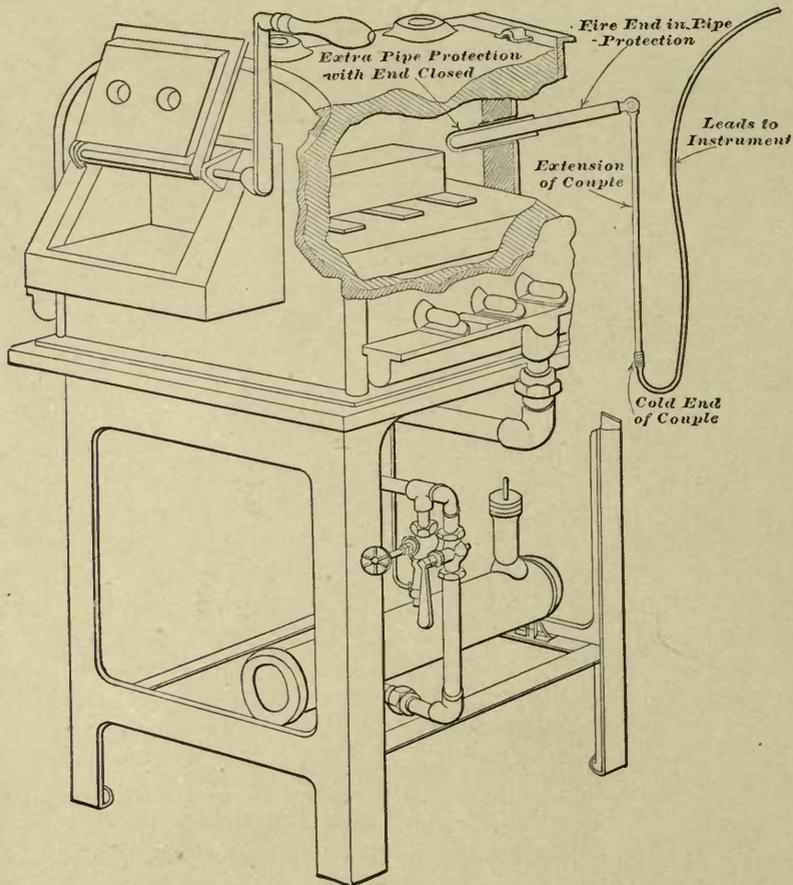
Fig. 211.—Position of Pyrometer in Furnace.

In many instances it is desirable to have means of quickly determining the temperature of the surface of an object. The special feature of the couple for this work consists in having the elements disconnected and reduced to fine points at the ends. When contact is made with the surface of the object whose temperature is to be measured, the fine points of the elements almost instantaneously acquire the temperature of the object, and if it is metallic it will serve to make the electric connection between the elements so that the reading may be taken without delay.

If the object to be measured is a non-conductor of electricity a very thin piece of metal should be placed on the surface before applying the couple.

A special combination of the indicating and recording pyrometers has been designed for cases where it is desirable to have a single couple or fire end actuate both kinds of instruments. It has been found not only possible, but entirely practical, to so arrange the Wm. H. Bristol electric pyrometers, that both the indicating and recording instruments can be connected to and calibrated for the same thermocouple. In order that either instrument may be detached from the other instrument and leads at any time, a special checking system has been devised with switches so that either instrument can be taken out of service without interfering with the other, and either one tested as to its individual accuracy at any time. For cases where the indicating instrument is needed by the operator at his post of duty, and it is also desirable for the superintendent to have definite information regarding the temperatures night and day, this combination unit has been used to great advantage.

The fire end of the pyrometer is applied through an opening in the side of the kiln or flue. The couple itself is generally inclosed in a protecting well of wrought iron pipe with the end closed for temperatures below 2000° F. For temperatures above 2000° special protections of porcelain, graphite or fused quartz are used.

For temperatures that average above a red heat (1000° F.) an extra wrought iron protecting pipe well is recommended for the fire end, as described and illustrated in connection with the oven furnace illustrated below.

The extension piece BD of the thermo-electric couple is joined to the fire end as shown in Fig. 53, when the cold end of the couple D can thus be located at a point where it will not be affected by the variations of temperature in the kiln or flue.

The sectional view of an oven furnace indicates how the fire end of the pyrometer should be applied, using an extra protecting iron pipe with closed end. This extra protecting pipe can be renewed as often as necessary, thus saving the couple and its initial pipe protection from injury when in continuous service. The extra iron pipe wells can be easily, quickly, and cheaply made in an ordinary blacksmith forge.

An extension piece of the couple is shown attached to the fire end, which affords a practical method of keeping the cold end of the couple below and away from the influence of the variations of temperature in the furnace.

As compared with other forms of apparatus for measurement of high temperatures, the thermo-electric pyrometer has many advantages, of which the following according to the makers, are the most important:

They may be employed where the space is extremely small and inaccessible.

The indicating or recording instrument can be located at the most convenient point, at almost any distance from the couple.

They are practically independent of temperature variations intermediate of their hot and cold ends.

They are independent of pressure and rough usage at the point where the temperature is desired to be measured.

They are extremely sensitive to changes of temperature and respond instantaneously, that is, there is no time-lag error.

They are constant in their indications when the couples are properly protected.

They permit the determination of the temperature at many different points by

means of several couples and leads connected to one instrument, provided with suitable switching device.

The important advantages of the low resistance thermo-electric pyrometer system may be summarized as follows:

1. A commercial switchboard or portable dead-beat indicating instrument may be employed instead of the extremely delicate suspension galvanometer required for use with a single platinum-rhodium couple. This advantage is gained by the fact that the thermo-electric couples employed give several times as much electromotive force as the platinum-rhodium couples, which is ample to successfully operate a pivot instrument if of sufficiently low resistance.
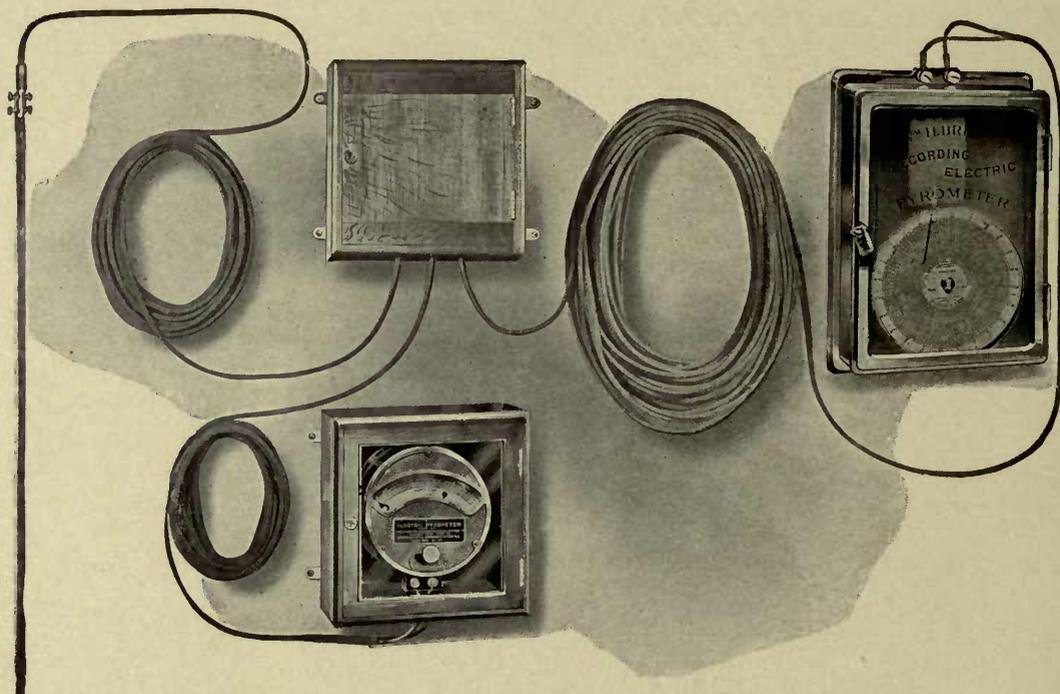
Fig. 212.—Bristol Secondary Electric Pyrometer complete.

2. The low resistance of the special couples makes a high resistance galvanometer unnecessary.

3. The low resistance pivot instruments may be read in vertical or horizontal positions, and do not require any firm foundation or leveling, and may even be read when carried in the hand.

4. It affords a practical method for automatically compensating for the changes of temperature at the cold ends of the couple.

5. It makes it practicable to use the same indicating instrument and the same couple for different total ranges of temperature, by using different binding posts and having several scales drawn, the proper resistances being inserted for each individual total scale.

6. The application of low-priced metals and alloys as a substitute for platinum and rhodium makes it possible to instal a number of couples, and by means of proper switching devices quickly determine the temperatures at the locations of the different couples.   In many instances the first cost of the expensive platinum elements prohibit their use in this way.

7. This system also makes it possible to use the patented compound couple with low-priced metals and alloys as a substitute for a portion of the couple where extremely high temperatures are to be measured requiring the use of platinum platinum-rhodium elements.

8. The low resistance system makes it possible to use a pivot bearing galvanometer arranged to record on the patent smoked chart.

SEGER FIRE-CLAY CONES

The freezing points of cones made of specified mixtures of refractory clays can be used to determine the temperatures of highly heated spaces.   The following tables gives the composition of such cones and the corresponding temperatures at which they fuse at the edges or the points soften and bend over.

TABLE OF MELTING-POINTS OF SEGER CONES

Cone No.	Deg. C.	Degrees F.	Cone No.	Degrees C.	Degrees F.
010	950	1742	14	1410	2570
09	970	1778	15	1430	2606
08	990	1814	16	1450	2642
07	1010	1850	17	1470	2678
06	1030	1886	18	1490	2714
05	1050	1922	19	1510	2750
04	1070	1958	20	1530	2786
03	1090	1994	21	1550	2822
02	1110	2030	22	1570	2858
01	1130	2066	23	1590	2894
1	1150	2102	24	1610	2930
2	1170	2138	25	1630	2966
3	1190	2174	26	1650	3002
4	1210	2210	27	1670	3038
5	1230	2246	28	1690	3074
6	1250	2282	29	1710	3110
7	1270	2318	30	1730	3146
8	1290	2354	31	1750	3182
9	1310	2390	32	1770	3218
10	1330	2426	33	1790	3254
11	1350	2462	34	1810	3290
12	1370	2498	35	1830	3326
13	1390	2534	36	1850	3362

SEGER CONES—(The Stowe-Fuller Co.)

Cone No.	Chemical Formula.	Mixture.	
1	$0.3K_2O$ $\{0.2Fe_2O_3$ $0.7CaO$ $0.3Al_2O_3\}$ $4SiO_2$	Feldspar Marble Quartz Iron oxide	83.55 35.00 66.00 16.00
2	$0.3K_2O$ $\{0.1Fe_2O_3$ $0.7CaO$ $0.4Al_2O_3\}$ $4SiO_2$	Feldspar Marble Quartz Iron oxide Zettlitz kaolin	83.55 35.00 60.00 8.0 12.95
3	$0.3K_2O$ $\{0.05Fe_2O_3$ $0.7CaO$ $0.45Al_2O_3\}$ $4SiO_2$	Feldspar Marble Quartz Iron oxide Zettlitz kaolin	83.55 35.00 57.00 4.00 19.43
4	$0.3K_2O$ $0.7CaO\}$ $0.5Al_2O_3,$ $4SiO_2$	Feldspar Marble Quartz Zettlitz kaolin	83.55 35.00 54.00 25.90
5	$0.3K_2O$ $0.7CaO\}$ $0.5Al_2O_3,$ $5SiO_2$	Feldspar Marble Quartz Zettlitz kaolin	83.55 35.00 84.00 25.90
6	$0.3K_2O$ $0.7CaO\}$ $0.6Al_2O_3,$ $6SiO_2$	Feldspar Marble Quartz Zettlitz kaolin	83.55 35.00 108.0 38.85
7	$0.3K_2O$ $0.7CaO\}$ $0.7Al_2O_3,$ $7SiO_2$	Feldspar Marble Quartz Zettlitz kaolin	83.55 35.00 132.00 51.80
8	$0.3K_2O$ $0.7CaO\}$ $0.8Al_2O_3,$ $8SiO_2$	Feldspar Marble Quartz Zettlitz kaolin	83.55 35.00 156.00 64.75
9	$0.3K_2O$ $0.7CaO\}$ $0.9Al_2O_3,$ $9SiO_2$	Feldspar Marble Quartz Zettlitz kaolin	83.55 35.00 180.00 77.70
10	$0.3K_2O$ $0.7CaO\}$ $1.0Al_2O_3,$ $10SiO_2$	Feldspar Marble Quartz Zettlitz kaolin	83.55 35.00 204.00 90.65
11	$0.3K_2O$ $0.7CaO\}$ $1.2Al_2O_3,$ $12SiO_2$	Feldspar Marble Quartz Zettlitz kaolin	83.55 35.00 252.00 116.55

SEGER CONES—(*Continued*)

Cone No.	Chemical Formula.		Mixture.	
12	$0.3K_2O$ $0.7CaO$	$1.4Al_2O_3$, $14SiO_2$	Feldspar Marble Quartz Zettlitz kaolin	83.65 35.00 300.00 142.45
13	$0.3K_2O$ $0.7CaO$	$1.6Al_2O_3$, $16SiO_2$	Feldspar Marble Quartz Zettlitz kaolin	83.55 35.00 348.00 168.35
14	$0.3K_2O$ $0.7CaO$	$1.8Al_2O_3$, $18SiO$	Feldspar Marble Quartz Zettlitz kaolin	83.55 35.00 396.00 194.25
15	$0.3K_2O$ $0.7CaO$	$2.1Al_2O_3$, $21SiO_2$	Feldspar Marble Quartz Zettlitz kaolin	83.55 35.00 468.00 233.10
16	$0.3K_2O$ $0.7CaO$	$2.4Al_2O_3$, $24SiO_2$	Feldspar Marble Quartz Zettlitz kaolin	83.55 35.00 540.00 271.95
17	$0.3K_2O$ $0.7CaO$	$2.7Al_2O_3$, $27SiO_2$	Feldspar Marble Quartz Zettlitz kaolin	83.55 35.00 612.00 310.80
18	$0.3K_2O$ $0.7CaO$	$3.1Al_2O_3$, $31SiO_2$	Feldspar Marble Quartz Zettlitz kaolin	83.55 35.00 708.00 362.60
19	$0.3K_2O$ $0.7CaO$	$3.5Al_2O_3$, $35SiO_2$	Feldspar Marble Quartz Zettlitz kaolin	83.55 35.00 804.00 414.40
20	$0.3K_2O$ $0.7CaO$	$3.9Al_2O_3$, $39SiO_2$	Feldspar Marble Quartz Zettlitz kaolin	83.55 35.00 900.00 466.20
21	$0.3K_2O$ $0.7CaO$	$4.4Al_2O_3$, $44SiO_2$	Feldspar Marble Quartz Zettlitz kaolin	83.55 35.00 1020.00 530.95
22	$0.3K_2O$ $0.7CaO$	$4.9Al_2O_3$, $49SiO_2$	Feldspar Marble Quartz Zettlitz kaolin	83.55 35.00 1140.00 595.70

SEGER CONES—(*Continued*)

Cone No.	Chemical Formula.	Mixture.	
23	$0.3K_2O$ $0.7CaO$ } $5.4Al_2O_3$, $54SiO_2$	Feldspar Marble Quartz Zettlitz kaolin	83.55 35.00 1260.00 660.45
24	$0.3K_2O$ $0.7CaO$ } $6.0Al_2O_3$, $60SiO_2$	Feldspar Marble Quartz Zettlitz kaolin	83.55 35.00 1404.00 738.15
25	$0.3K_2O$ $0.7CaO$ } $6.6Al_2O_3$, $66SiO_2$	Feldspar Marble Quartz Zettlitz kaolin	83.55 35.00 1548.00 815.85
26	$0.3K_2O$ $0.7CaO$ } $7.2Al_2O_3$, $72SiO_2$	Feldspar Marble Quartz Zettlitz kaolin	83.55 35.00 1692.00 893.55
27	$0.3K_2O$ $0.7CaO$ } $20Al_2O_3$, $200SiO_2$	Feldspar Marble Quartz Zettlitz kaolin	83.55 35.00 4764.00 2551.13
28	Al_2O_3, $10SiO_2$	Quartz Zettlitz kaolin	240.00 129.50
29	Al_2O_3, $8SiO_2$	Quartz Zettlitz kaolin	180.00 129.50
30	Al_2O_3, $6SiO_2$	Quarts Zettlitz kaolin	120.00 129.50
31	Al_2O_3, $5SiO_2$	Quartz Zettlitz kaolin	90.00 129.50
32	Al_2O_3, $4SiO_2$	Quartz Zettlitz kaolin	60.00 129.50
33	Al_2O_3, $3SiO_2$	Quartz Zettlitz kaolin	30.00 129.50
34	Al_2O_3, $2.5SiO_2$	Quartz Zettlitz kaolin	15.00 129.50
35	Al_2O_3, $2SiO_2$	Zettlitz kaolin	
36		Rackonitz shale clay	

The melting of these tetrahedrons determines the temperatures between the melting-point of 90 gold, 10 platinum, (that is, about 1145°) and the highest heat of the porcelain fire. The temperatures which correspond to the melting-points of the cones 21 to 26 are reached in the iron and steel industries. The cones 26 to 36 serve for the determination of the refractoriness of clays.

Heraeus-LeChatelier Pyrometer.—The Heraeus-LeChatelier Pyrometer consists of an element, the one wire of which is of pure platinum and the other wire of the 10% rhodium-platinum alloy, both one millimeter thick, the two wires fused together at one end to a small ball. The free ends of the element are connected to the terminals of a delicate galvanometer, and the current generated in the heating of the ball measured on a suitable scale provided for in the galvanometer, to read in millivolts and degrees Centigrade or Fahrenheit, as desired.

In connecting the wires of the thermo-couple to the galvanometer care should be taken to get the soft or platinum wire to the negative binding post of the galvanometer, and the harder platinum-rhodium wire to the positive side. If this is not done, the needle will swing in the wrong direction. If the galvanometer is placed at some distance from the point at which the temperature is to be measured, copper leads are interposed. These should be of no greater resistance than one ohm, no matter what the distance may be. Below 300 ft. they should be at least No. 12 Brown and Sharpe gauge wire.

Theoretically, the temperature of the junction of the copper leads with the free ends of the thermo-couple should be at the freezing-point. Practically, except for physical research, this matters but little in the reading. Correction may, however, be made by adding to the galvanometer readings one-half the difference from the freezing-point in degrees centigrade, or nine-tenths of the same difference in degrees Fahrenheit. This temperature (of the so-called cold junction) can be measured with the ordinary thermometer, and the rule holds good only up to about 80° Fahrenheit. Hence great care should be taken to keep these junctions out of the direct radiation of heated furnaces.

If, through accidental abrasion or rough treatment, the thermo-couple becomes damaged, it can be returned for repair, and the broken portions allowed for at prevailing scrap rates. The thermo-couple, however, should be properly covered by a protecting medium which will keep it from direct contact with gases and metallic vapors, as well as particles of melted metals, the former ruining the platinum rapidly and the latter alloying at once with the thermo-couple to its destruction. The best medium is the highest grade of porcelain, or melted quartz tubes. For ordinary uses, tubes of the Royal porcelain manufacture are sent with the thermo-couple. When it is desired to make temperature determinations of molten metals, an apparatus provided with a clay or graphite tip is obtainable, which answers every purpose. An inquiry, stating the conditions existing, will bring an estimate of all that is needed for the purpose.

The porcelain tubes made by the Royal Porcelain Works are of such a fine quality that they will easily withstand temperatures up to the melting-point of platinum without deterioration. The hard silica glaze prevents the entrance of gases, and if care is taken to heat them up gradually, and not to expose them to sudden changes, they last very long.

Illustrations are shown herewith of the pyrometer as arranged for the porcelain tube, and when provided with the clay tip.

The galvanometer used in connection with the thermo-couple of the Heraeus-LeChatelier Pyrometer is of the well-known D'Arsonval type. It consists in the main of a permanent magnet and a suspended coil of wire (armature) moving between

its pole pieces. The terminals of the element are connected to this armature, and a current flowing through them turns it to an extent corresponding to the electromotive force involved. The amount of the deflection from the zero mark is indicated
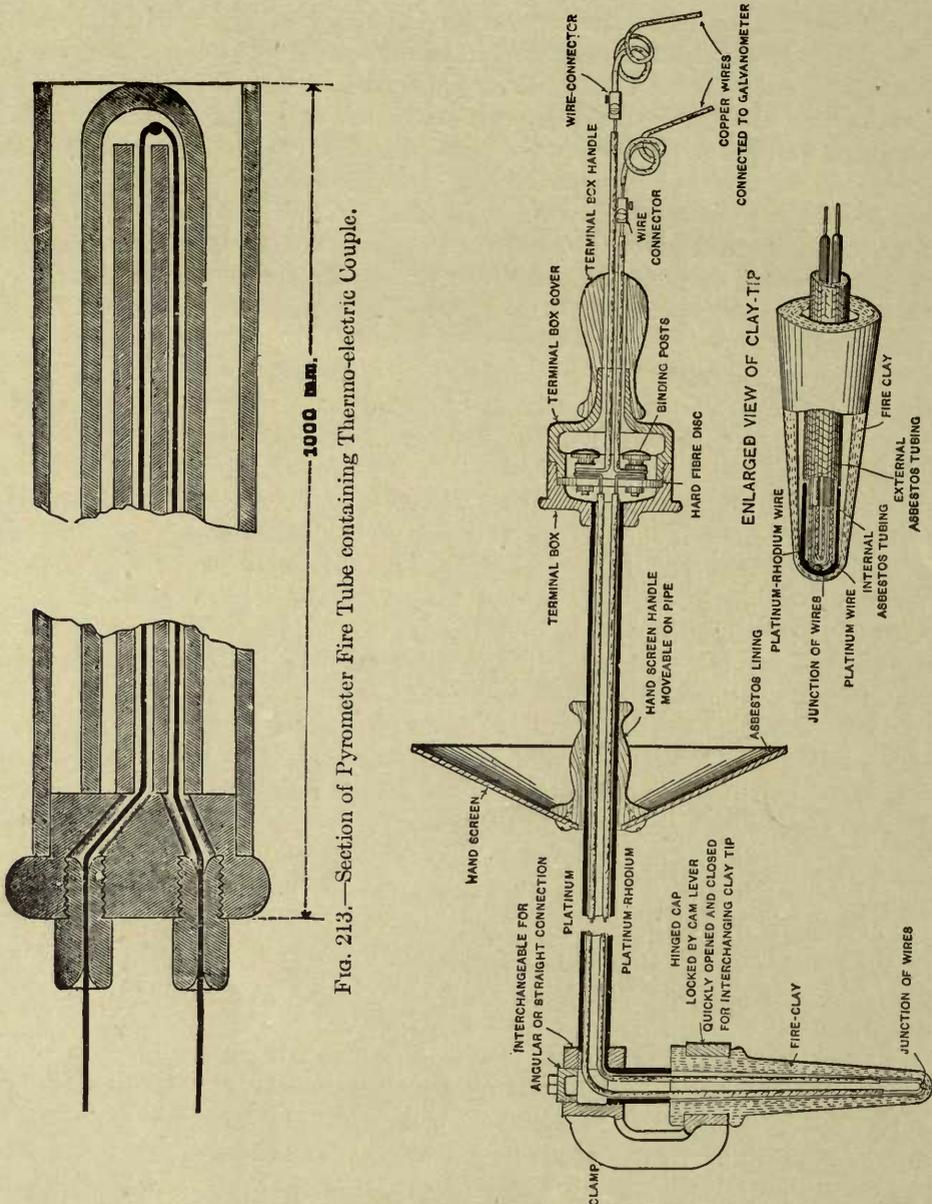
FIG. 213.—Section of Pyrometer Fire Tube containing Thermo-electric Couple.

ENLARGED VIEW OF CLAY-TIP.

FIG. 214.—Complete Heraeus-LeChatelier Pyrometer Outfit.

by a pointer swinging over a divided scale and there read off directly as degrees, Centigrade or Fahrenheit, as may be desired. The delicacy of this instrument requires that it be handled with reasonable care, and if located at some convenient point where it may be free from injury, no difficulty will be experienced. The

galvanometer should rest on a suitable foundation, be kept from jar and vibration, and preferably be inclosed in a tight glass case.

Recording galvanometers are now available for use in connection with industrial plants where it is desired to note the fluctuations of temperature which have a direct bearing on the processes employed. Even for ordinary boiler firing a record which will show up conditions in the boiler-room oftentimes pays very well. In glass works, blast furnaces, and continuous heating or slow cooling of materials, a recording pyrometer outfit will save its first cost very quickly by the improvement it will bring about. The Heraeus-Le Chatelier recording pyrometer can be arranged so that it gives the readings of five different furnaces simultaneously.

Féry Radiation Pyrometers.—Particularly suitable for temperatures from 1500° F. upwards. There is no upper limit, as these pyrometers are capable of measuring the highest temperatures obtainable.
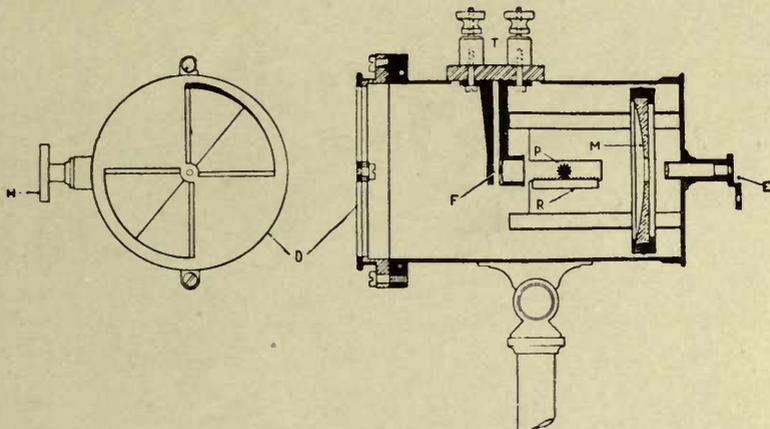
Fig. 215.—Section of Féry Radiation Pyrometer.

No part of the pyrometer has to be inserted in the furnace or other hot body, nor is any portion of the instrument heated to more than 180° F. above the surrounding air temperature. The result is that the life of this type of pyrometer is not shortened by its use in measuring very high temperatures.

Long experience in temperature measurement, over a wide range and under the most varied conditions, has shown the accuracy and value of such instruments and the economies to be effected by their use; at the same time the great practical difficulties to be encountered in many cases, especially where temperatures higher than 2200° F. are to be measured, have shown the need for a convenient and reliable form of radiation pyrometer. As is well known, it is difficult to construct anything of solid material which can be maintained for prolonged periods at a high temperature without suffering some permanent or sub-permanent change in its physical properties, and as we ascend higher in the temperature scale the difficulties increase in a quite disproportionate degree. A further aggravation of the trouble at high temperatures is to be found in the chemical activities of furnace products and furnace gases which in some cases render difficult the adequate protection of the thermo-couple or resistance wire.

With the radiation pyrometer invented by Professor Féry, these difficulties are not encountered, the instrument being of course placed at some distance from the furnace, while no part of it is raised above the air temperature by more than 180° F.
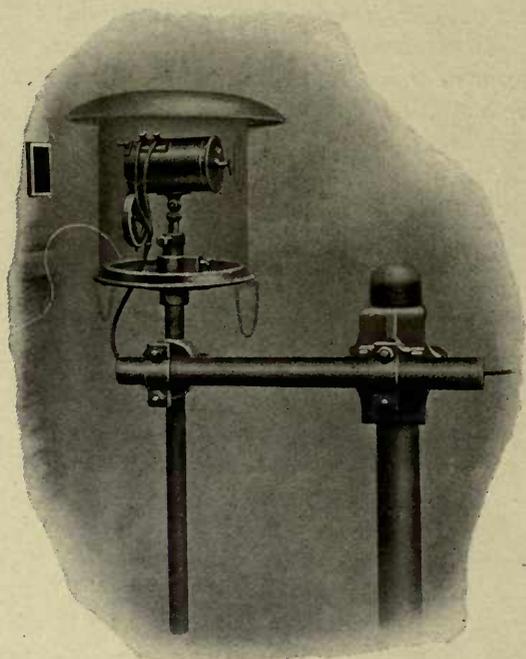
FIG. 216.—Féry Radiation Pyrometer in Protected Case Sighted into Fire-clay Test Hole.
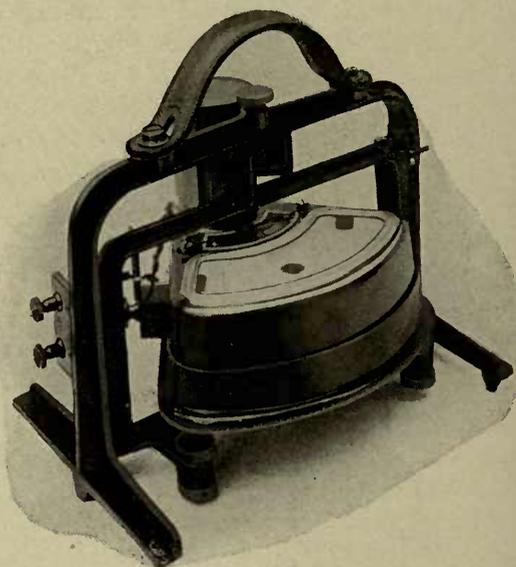
FIG. 217.—Self-leveling Indicator for Féry Pyrometer.
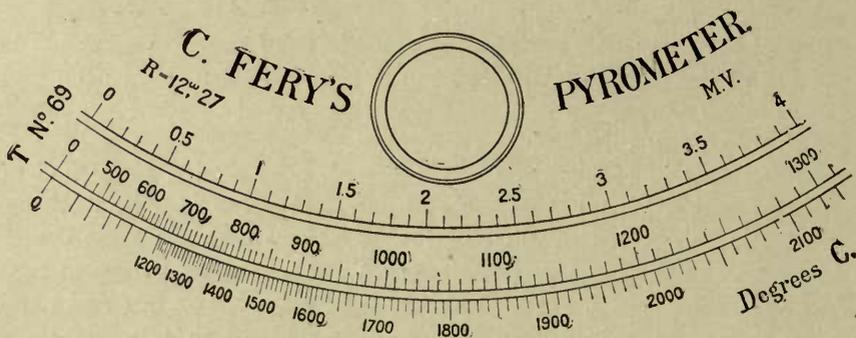
FIG. 218.—Scale of Fig. 218.

The radiation which emanates from a hot body, or which passes out through an observation hole in the wall of a furnace, falls upon a concave mirror and is thus brought to a focus. In this focus is one junction of a thermo-couple, whose temperature is raised by the radiation falling upon it—the hotter the furnace the greater the rise of temperature of the junction.

The arrangement of the instruments is such that they are uninfluenced, within wide limits, by the size of the hot body or observation hole on the one hand, or on the other hand by the distance which separates them from the hot body or furnace.

The absorption of some small amount of radiant heat in passing through the atmosphere cannot of course be strictly without effect, but in practice the error thus arising is not appreciable; it has been found for example that the readings obtained

Fig. 219.—Taking Temperature of a Gas Retort by Féry Pyrometer.

for the temperature of a body of molten steel was precisely the same whether the instrument was set up 3 ft. or 60 ft. away.

The radiation pyrometer is virtually a reflecting telescope having at a point F on its axis one junction of a copper constant thermo-couple.   On this junction the radiant heat of the hot body under examination is focused by the concave mirror M. The two junctions of the thermo-couple are situated quite close together so that they partake equally in any changes of atmospheric temperature, but the " cold " or comparison junction is screened from the radiation focused by the mirror M.   To prevent over-heating the thermo-couple, when the telescope is sighted on a very hot body, a diaphragm D is provided, which can be swung over the mouth of the telescope, thus reducing the effective aperture and consequently the radiant heat falling on the mirror.

To guide the pointing of the telescope an eyepiece E is provided at the rear and through which can be seen a reflected image of the hot body. The focusing is done by means of a milled head H at the side of the telescope and its accuracy verified by observing the reflected image of the hot body.

In the indicating outfit the telescope is mounted on a collapsible tripod. To enable temperature readings to be made the thermo-couple circuit is completed through a short length of flexible cable and an indicator. This indicator is an accurately calibrated millivoltmeter, which is either automatically self-leveling or does not require any leveling.

It is calibrated to read temperature directly upon two scales, one from 1000 to 2400° F., the second from 1800 to 3600° F. Centigrade scales can also be provided. There is a further calibration in millivolts by means of which the sensibility of the indicator can be checked when desired. The whole outfit is arranged to fold up and drop in a box, and is easily carried by one man as it weighs only about 30 lbs.

One of the illustrations shows an example of the Centigrade scale of the indicator supplied with the portable outfit.

The accuracy obtainable with this instrument depends of course to some extent on the observer, but assuming only ordinary care in sighting and reading, the accuracy should be well within 2%, in the neighborhood of say 1800° F.

If the surrounding air temperature does not differ greatly from 64° F. the accuracy might be greatly increased, say to within 1%, while at all times the power of comparison or discrimination is much finer than the absolute accuracy. Reference to the scale will show that at 1000° C. a difference of 5° C. would be easily detected.

In the recording outfit the telescope is generally permanently fixed in position upon a steady support. As it is not usually convenient to have a hole in a furnace wall permanently open, the telescope is then cited into a closed fire-clay tube projecting well into the furnace and of great length compared with its diameter. When the telescope is fixed in a position out-of-doors a weather-proof cover is fitted.

The records are made by a thread recorder which is connected by twin cables to the thermo-couple in the telescope.

The Féry pyrometer calibration is made by direct comparison with certified standards, these standards being referred in turn to those used by the Bureau of Standards, Washington. The indications of the instrument are based upon the Stefan-Boltzmann law, which states that " the radiant energy emitted by a black body is proportional to the fourth power of the absolute temperature of the body," or in other words, if we increase the absolute temperature of any body by 1%, we shall increase the radiant energy it gives out by 4%, hence the great suitability of the instrument to high temperature measurement. If the surface of the hot body is not " black," that is, if it has reflecting power, the radiation from it will be somewhere between that due to its own temperature and that due to the temperature of its surroundings. This is a fundamental condition in the laws of radiation and must be taken into account. The simplest way to meet this condition is to place the hot body in a nearly closed space where its surroundings are at the same temperature as the body itself. In this way the radiation it emits will be the same no matter what kind of a surface the body has. Thus no account of the surface conditions of the hot body need to be taken when the pyrometer is sighted through a relatively small opening in

a furnace or into a closed fire-clay tube which is deeply inserted into a furnace. If, however, the hot body is out in the open and its surface is smooth and has reflecting power, a special factor must be used in making the readings unless the indicator or recorder is ordered calibrated to meet these conditions. For instance, a stream of molten steel has a bright smooth reflecting surface, and unless the calibration has been made for this case, the reading on the indicator scale may be as much as 25% lower than the true temperature. In the case of molten copper the differencce is even greater.

This consideration is fully dealt with in the instructions issued with every pyrometer.

Earnshaw Blue Glass Pyrometer.—This is of the visual type, its principle being the absorption of light or its diminution, through the use of a varying number of
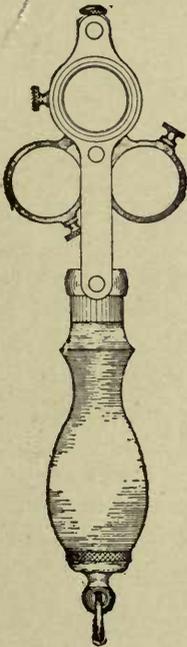
FIG. 220.—End Elevation.   FIG. 221.—Side Elevation.
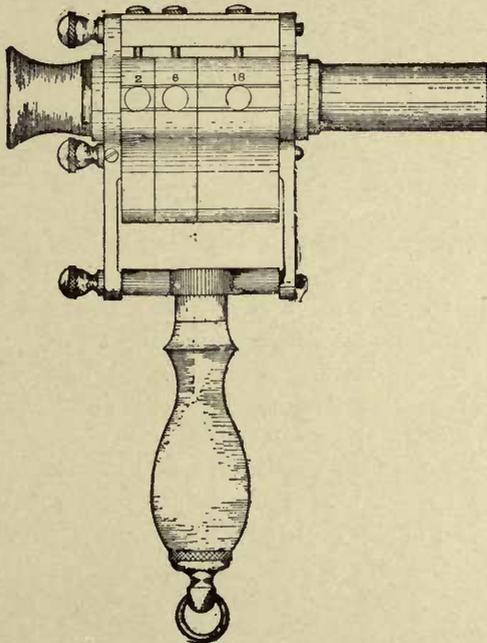
EARNSHAW ABSORPTION PYROMETER.

slides or blue-glass lenses, to create a vanishing point of light, said light of course presumed to vary directly as the intensity of the heat observed.

As the personal equation is very marked in the use of an instrument of this kind, its use would of course be of little service in establishing absolute values, but it will be found of extraordinary usefulness in making comparisons or establishing empiric tests. In other words, it may be used by either engineer or gas-maker with a far greater degree of accuracy than the " naked eye " for checking heats.

Furnace Colors.—Pyrometers are not always at hand and it is often convenient to be able to name the temperature approximately without an instrument. The first perceptible red corresponds roughly to 1000° F.

A dazzling white heat corresponds roughly to 3000° F. The eye is not able to distinguish between heats above 3000° F., so that anything which appears as bright as a gas mantle, or an incandescent filament, or a Nernst glower, when working properly, is at least 3000° F.

In addition the melting-point of zinc is about 780° F.; lead 618° F., and tin 445° F. Alloys of metals often have a much lower melting-point than any of the constituent metals. There are several which will melt in boiling water. See melting-points under the chapter on that data.
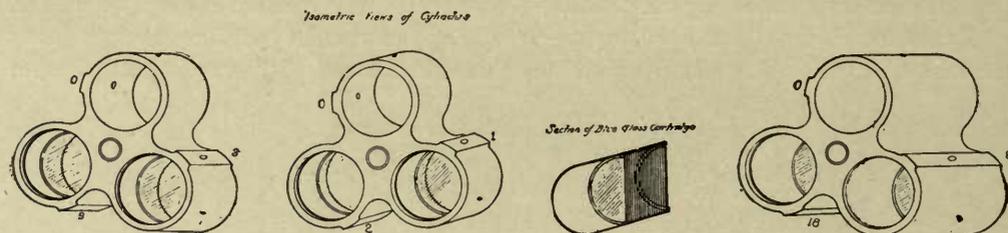
FIG. 222.—Glass Disc Carriers for Fig. 221.

Thermometer Note.—To rejoin a parted mercury column of a low temperature thermometer, the mercury bulb is placed in ice, until the column is no longer visible; the safety reservoir at the top of the capillary tube is then carefully heated over an alcohol lamp, so as to drive down the mercury it may contain. Then slightly heat the large mercury bulb so as to drive the mercury up. This however must be done cautiously, and the heating must cease at once when the mercury is within about $\frac{3}{16}''$ from the top. If forced higher there is danger of bursting the tube.

After following these directions, the column may still be broken, in which case drive the mercury in the upper bulb, and then tap slightly sideways to cut the broken column off. Repeat the tapping sideways as long as may be necessary to rejoin the column and finally cool the large mercury bulb. Never try to shake the mercury down.

CALORIMETRY

The Sargent Gas Calorimeter.—The Sargent gas calorimeter was designed to enable the operator to determine the calorific value as well as the foreign matter in gases, quickly, simply, and accurately.

The section of a calorimeter shows the inlet water having a constant head at the cistern E, the temperature of which is taken at C, envelops the whole instrument and passes through in the direction of the arrows and the rise in temperature is taken by the thermometer at D before any heat is lost by radiation to the air. The combustion of gas takes place in the central flue and the products of combustion pass to the top and down the annular chambers in the direction of the arrows, reaching the temperature of the water before passing out at B, where a damper regulates the velocity and the thermometer gives the temperature of the exhaust products.

The view shows the calorimeter complete as usually furnished, consisting of a

wet test gas meter with thermometer and manometer, a pressure regulator with micrometer adjustment, the calorimeter proper with three thermometers, automatic dumping bucket, hose, batteries, Bunsen burner, beaker etc.

A section of a single unit dust determinator used to ascertain the grains of dust per cubic foot in the gas being tested is also shown. It consists of two light metal disks which clamp the filter paper between gaskets with thumb screws as shown. Gas enters the opening in top disk and spreading out passes through the filter paper, leaving all dust and foreign matter on top of paper. A wire gauze support in bottom disk prevents sagging and tearing of filter paper, should the moisture soften and the accumulated dust tend to rupture it. Filter paper is weighed before and after the test and the grains of dust per cubic foot of gas are readily determined.
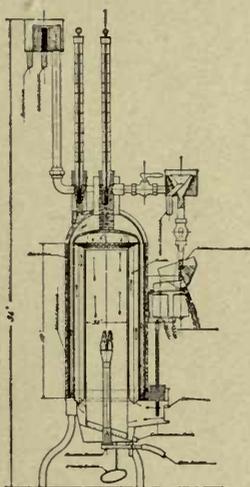
Fig. 223.—Section of Sargent Gas Calorimeter.   Fig. 224.—Sargent Gas Calorimeter Complete.
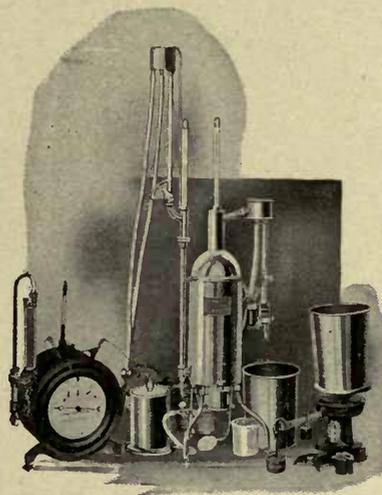
The moisture is determined by cooling the gas in a condenser and passing it through beakers of calcium chloride.

This calorimeter and auxiliaries make a most complete apparatus for the gas engineer, the manufacturer of gas engines and producers, for use in gas works and by-products plants, and for blast furnace gas.

The advantages of the Sargent automatic gas calorimeter are stated as follows: The cold water enters and the warm water discharges at the top, allowing the placing of the thermometers most frequently read, adjacent to each other.

The cold entering water envelops the water whose temperature is rising, thus carrying in any radiated heat.

The Bunsen burner is protected from drafts on all sides of the base but the front, thereby preventing irregular combustion.

The thermometers read in tenth °F., insuring accurate readings and B.T.U. direct, as no transformation from centigrade is necessary.

Outlet water is weighed, thereby eliminating the errors of measuring caused by variation of temperature, the receptacle being out of level or a varying meniscus.

Gas pressure is controlled by micrometer adjustment, insuring a constant flame.

Water is automatically changed from one receptacle to another when $\frac{1}{10}$ of a ft. of gas has passed through the meter, entirely obviating the personal error when this is done by the operator.

By lightening the work of operator he has time to determine and record the B.T.U. for every tenth of a foot burned.

By automatically switching the water from one receptacle to another the determinations are continuous, but each of such short duration that any accidental derangement is immediately discovered.
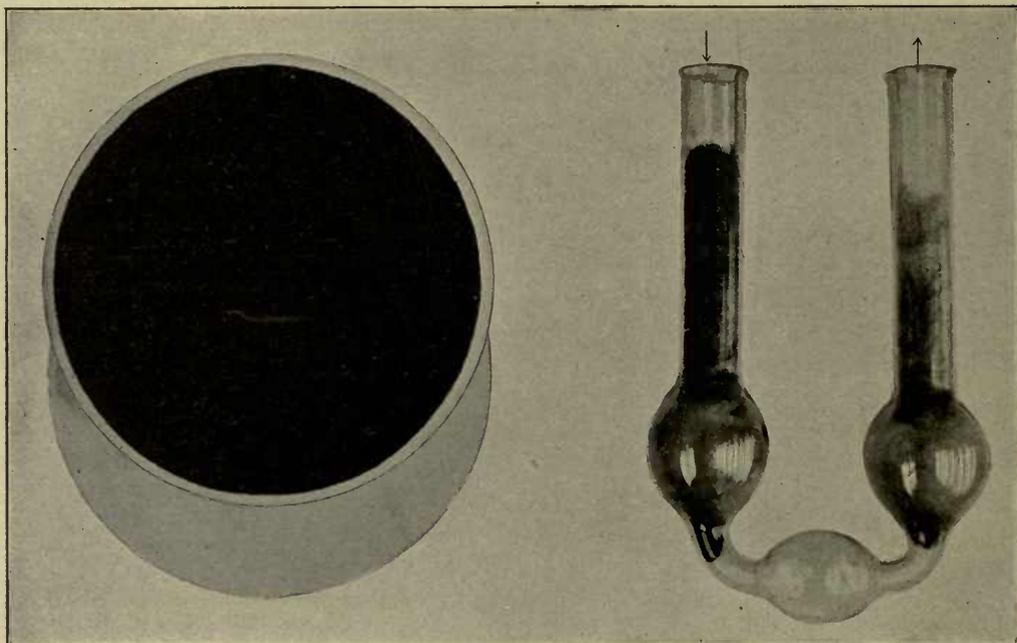
FIG. 225.—Collector for Testing Dusty Gases.

By getting continuous determinations the low calorific value of the gas is ascertained at the same time as the total or high calorific value.

By making continuous determinations of the gas during a test of engine or producer, a complete record is secured, even with a varying gas.

By plotting the curve of B.T.U. in the gas a record of the heat value under varying conditions of load and feed is made.

The dust and moisture in blast furnace gas can be determined at the same time as the calorific value, by passing the gas through a filter and dryer.

The percentage of tar in producer gas per cubic foot can be determined at the same time as the heat value.

The calorimeter complete is well made, well finished, and packed in an apartment chest for transportation.

The Junker Gas Calorimeter.—The increasing use of gas for fuel purposes is making the heat-producing value of relatively greater importance than the candle

power as determined on photometers. Although the heat value of a gas can be estimated by calculation from an analysis, yet the direct determination, in an apparatus designed to burn the gas completely and collect the heat in such a manner as to measure it, is more rapid and direct. Such an apparatus is called a calorimeter, of which the bomb type is the most accurate, but the Junker type the more convenient and most used. The gas first passes through the test-meter provided with a thermometer for taking the temperature of the gas before combustion, a pressure-regulator, to insure constant pressure at the burner, a burner removably attached and adapted to regulate the air supply, as shown by the detail illustration, a calorimeter vessel in which the gas is burned and the heat absorbed by circulating water, an elevated water supply flowing under constant head, and a vessel for measuring the water passing through it. The details of the calorimeter body are
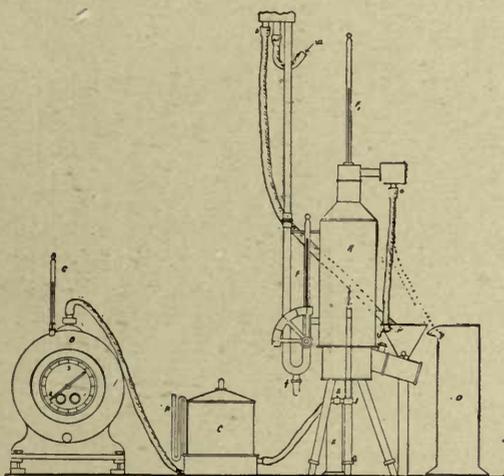
FIG. 226.—General Arrangement of Junker Calorimeter.
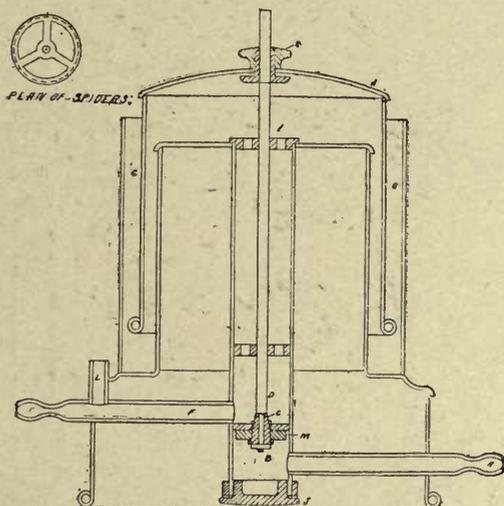
FIG. 227.—Section of Pressure Regulator C.

illustrated, showing how the consumed gases travel up the combustion-chamber and pass down through tubes surrounded by water and out into the air of the room at the lower opening. The heat that enters the apparatus is contained in the form of temperature in the gas, air, and water entering it, and in combustible constituents in the gas; thermometers are therefore necessary to test the temperature of the air of the room, of the gas supplied, and of the water entering the apparatus. The heat escaping from it is contained in the products of combustion (water of condensation and fuel-gas) and the water collected, which requires two more thermometers. The air-jacket prevents radiation of heat, and all essential provisions are made to keep heat from ecaping unrecorded. In construction the apparatus differs slightly according to the ideas of different makers, but the principles of operation remain the same.

The apparatus being set up and properly connected by rubber tubes, water is run into the elevated tank and through the apparatus into the drain at J until the

flow is steady, when the valve can be set with its indicator on the scale so that about 400 cc. of water will flow into the graduate D per minute; there should be a constant but slight overflow through the tube b, which is regulated by a valve on the supply-
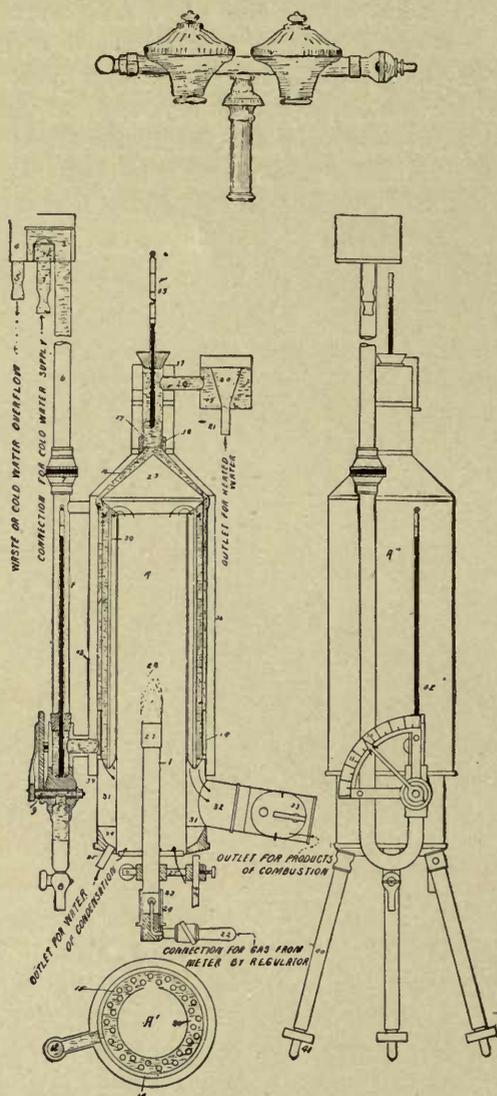
FIG. 228.—Junker Gas Calorimeter in Section and Elevation and Pressure Regulators.
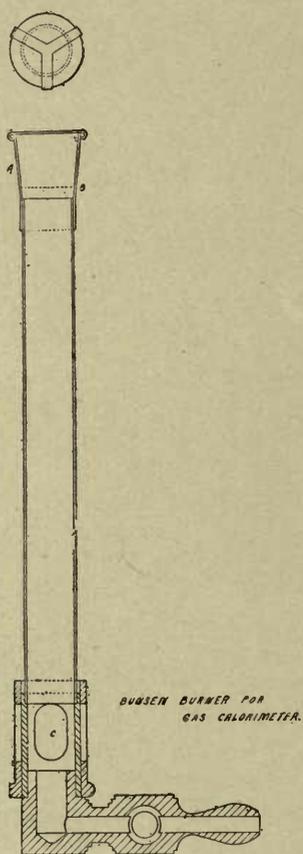
FIG. 229.—Burner of Junker Gas Calorimeter.

tube a. The water level in the wettest meter in the governor and U-tube H are of course looked after and more water added if necessary. Remove the Bunsen burner I, to prevent explosion, turn on the gas, light it, adjust the air shutter, and replace, adjusting the gas supply to keep the difference in temperature between ingoing and outgoing water about 10° C., during which time about 3 liters of water are passing.

The rate of gas flow will be governed by the flame, which should be of proper size to give out about 1200 calories per hour. Variation in the quality of gas therefore will require more consumption for the lean gases and less for rich gases, the latter requiring also a considerable air supply and the lean gases very little, if any, the flue damper being adjusted accordingly.

Having the apparatus in normal operation, a test is begun by taking the temperatures of the air in the room near the calorimeter, the temperature of the gas going through the meter G, and the temperature of the gases of combustion in the flue at J. Then watch the meter-hand until it is at a convenient starting-point, immediately switch the outlet-tube from the drain-funnel to the empty graduate, note the time, temperature of water entering F and leaving F' as quickly as possible to the hundredth part of a degree. A stop-watch is very convenient for this purpose, one that has a second and a minute hand, and reading-glasses on the thermometers facilitate that part of the work. An observation is completed when the water collected reaches a little over 1700 cc. in the graduate, when the readings are taken as at the start, the time being noted when the outlet-tube is removed from the graduate and the meter read. The temperature of inlet and outlet water is observed about every half-minute.

The formula for calculating the calorific value of a gas from these observations, given in metric units, is as follows (see Bates on "Calorimetry," p. 25):

$$C = \frac{1000W(T_{OW} - T_{IW}) + K(T_{IW} - T_G) + K'(T_{EG} - T_{IW})}{G},$$

where C = calories per cubic meter;

G = liters of gas consumed as shown by the meter;

T_{OW} = temperature of outlet water, thermometer F';

T_{IW} = temperature of inlet water, thermometer F;

T_G = temperature of the gas at meter, thermometer G;

T_{EG} = temperature of escaping gases, thermometer J;

W = water collected in graduate D in liters;

K, K' = constants calculated from the specific heats of the average quality of gases by Bates, as follows, in calories:

	K	K'
Natural gas	0.011	3.432
Coal-gas	0.010	2.466
Water-gas	0.009	1.353
Producer-gas	0.0089	0.470

In case the heat value is desired under standard conditions, say of 0° C., where the gas is more dense and the calorific value naturally higher, the value of C is multiplied by $\frac{273 + T_G}{273}$. There is another correction not yet mentioned—the heat carried off by the moisture condensed from the water vapor formed during combustion, which escapes from tube No. 35 shown in the section. When 1 kilogram of hydrogen burns to form 9 kg. of water vapor, at 100° C. (212° F.), it generates 28,732 calories, but if

this vapor is brought to 0° C. the heat given up is 34,462, the difference being due to the latent heat of the steam and in the water formed. As calorimeter results may vary as much as 10% from this cause, it is always well to state whether the calories found are gross or net. The correction is easy, consisting in deducting from the calories found by the formula 0.636 calories per cubic centimeter of water of condensation collected; as less than 1 cc. of water is thus collected per liter of gas, it is generally measured after the series of tests.

Example.—In a 5.5-minute test by Bates in which three readings were made on the gases and twelve on the water, the averages were found to be: $T_G = 25.6°$, $T_{EG} = 20°$, $T_{IW} = 14.739°$, $T_{OW} = 29.76°$, $G = 4.5$ liters, $W = 1.74$ liters. Substituting these values in the formula we get

$$C = \frac{1.740(29.76 - 14.739)1000 \times 0.01(14.739 - 25.6) + 2.466(20 - 14.739)}{4.5}$$
$$= 5820.985 \text{ calories per cubic meter.}$$

Applying now the temperature correction we find that at 0° C. the calorific value will be

$$5820.985 \left(\frac{273 + 25.6}{273} \right) = 6344.8736 \text{ calories.}$$

To reduce this to B.T.U. per cu.ft. multiply by 0.11236, thus:

$$6344.8736 \times 0.11236 = 712.9099 \text{ B.T.U.}$$

Doherty Gas Calorimeter.—The gas under test is completely burned in a Bunsen burner, and the entire quantity of heat liberated by this combustion is transmitted to or absorbed by water which is constantly kept flowing through a boiler, preferably called an absorption-chamber. The temperature of the water before entering and after leaving the absorption-chamber is taken, and the water after leaving the absorption-chamber passes to a tank which contains the gas before it is burned. Thus the water displaces the gas volume for volume. Consequently for each cubic foot of gas burned there passes through the absorption-chamber a cubic foot of water, so that there is a constant ratio between the amount of gas burned and the amount of water passed through the absorption-chamber. As the difference in temperature of the water is taken before and after passing through the absorption-chamber, there is afforded a means for measuring the amount of heat generated by the burning of the gas—that is, the difference in reading of the inlet and outlet thermometers in degrees Fahrenheit, multiplied by the coefficient of thermal capacity of a cubic foot of water, gives the calorific value of a cubic foot of gas in British thermal units. The temperature of the gas under test is brought to that of the room by allowing the gas to remain in a tank until it acquires the room temperature. The waste products of combustion are allowed to escape from the absorption-chamber at a temperature equal to that of the room. Consequently the only heat given to the water passing through the absorption-chamber is the heat due to the combustion of the gas. The

temperature of the waste gases is controlled by varying the amount of exposed cooling-surfaces of the absorption-chamber. Therefore as the gas in the tank is maintained under a constant pressure and the water from the absorption-chamber passes into the tank with a speed equal to that of the gas flowing out and to the Bunsen burner, there is afforded a means for accurately determining the calorific value of the gas without making corrections for difference in temperature of the gas before and after
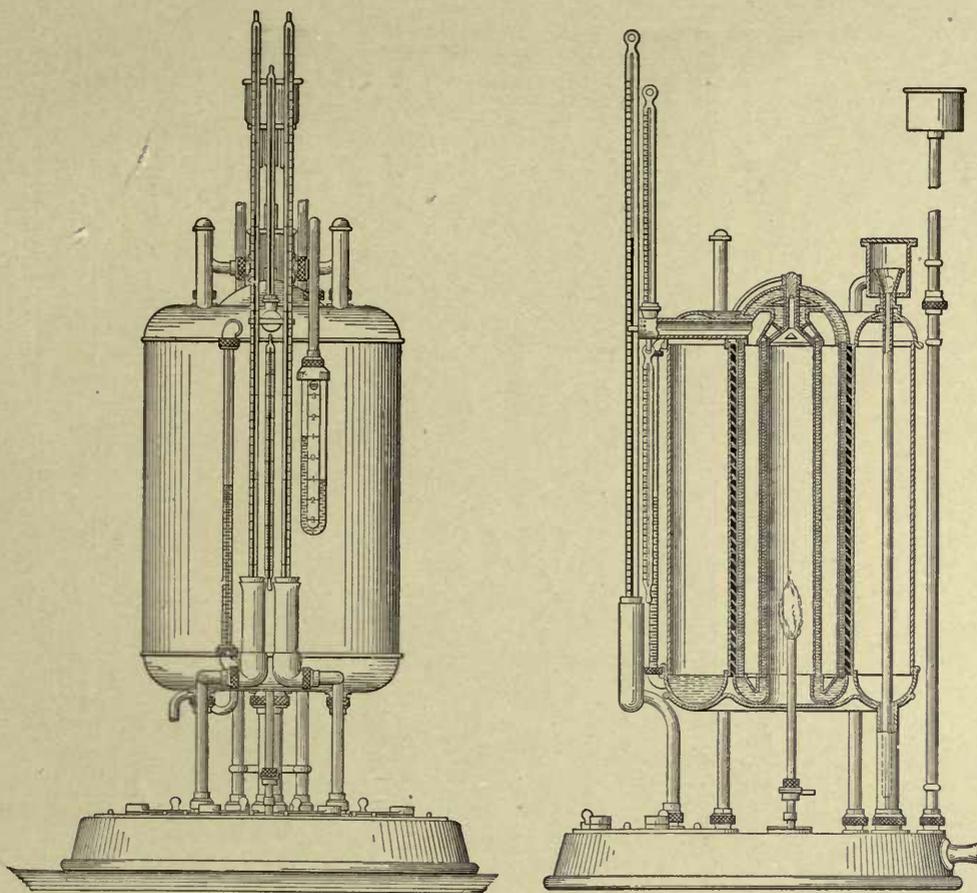
Fig. 230.—The Doherty Gas Calorimeter.

combustion; nor is it necessary to make corrections due to difference in temperature of both the air required to support combustion and the products of combustion. Under the conditions that water is flowing into the tank as fast as the gas is flowing out, and the gas is flowing to the Bunsen burner through a constant orifice and under constant pressure, it is required that water should pass through the absorption-chamber at a constant rate, which reduces to zero any error that might occur due to the absorption-chamber having a high thermal capacity on account of its own mass and the mass of water it contains, provided the temperature of the water at intake remains constant, which is the usual condition in practice.

The Lucke-Junkers Gas Calorimeter.—Dr. Chas. E. Lucke of Columbia University, has converted a Junkers calorimeter into one of the recording or continuous type by the addition of a displacement tank, the air and gas successively displacing one another.
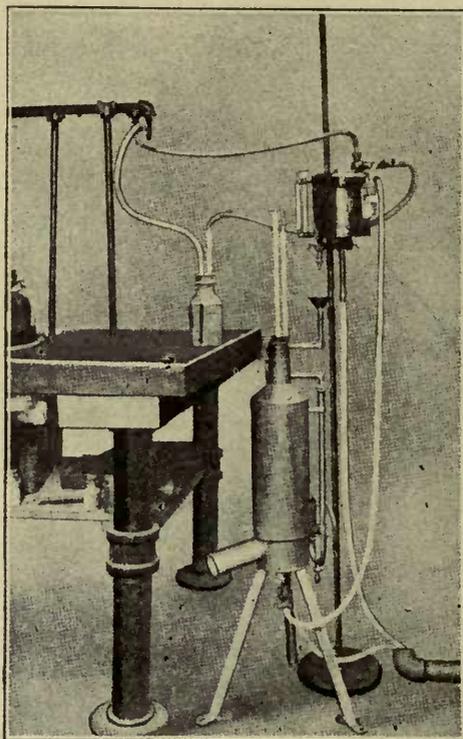
FIG. 231.—The Lucke Continuous Record Gas Calorimeter.

Parr Coal Calorimeter.—The accompanying illustration shows the relative position of parts. The can A is filled with two liters of water. The combustion takes place within the cartridge D. The resulting heat is imparted to the water. The rise in temperature is indicated by the finely graduated thermometer T.

Description.—The facility of operation may be shown by a brief description of the apparatus. In the cartridge is placed a weighted quantity of coal previously ground to pass through a 100 mesh sieve and dried in the usual way at 105–100° C. (220–230° F.). There is also put into the cartridge a chemical compound which is thoroughly mixed with the coal by shaking. The cartridge is then placed in a measured quantity of water in the insulated calorimeter can A as shown. The stirrer is set in motion, operated by a cord about the pulley P. After a constant temperature has been obtained, ignition is effected by means of a short piece of hot wire dropped through the stem of the cartridge. Extraction of the heat is complete in from four to five minutes. The maximuum reading is taken and the rise in temperature, multipled by a simple factor, gives the heat in British thermal units per pound of coal. By a

slight modification of the apparatus ignition may also be effected by an electric fuse, and where a proper current is available, this method is preferred by some users. Electric ignition is effected by means of the fuse wire G connecting the terminals H and I. This wire is of about 34 American gauge and approximately 4 ins. in length. The loop extends about three-fourths of an inch below the terminals and well into the chemical mixture. By making contact with a suitable current of electricity between the outer
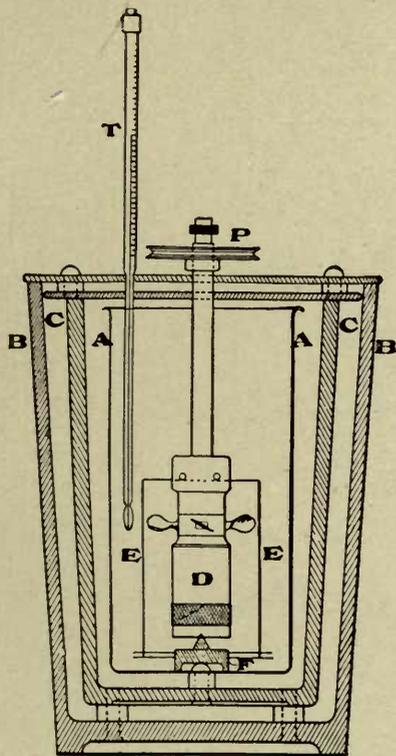
FIG. 232.—Section of Parr Coal
Calorimeter.
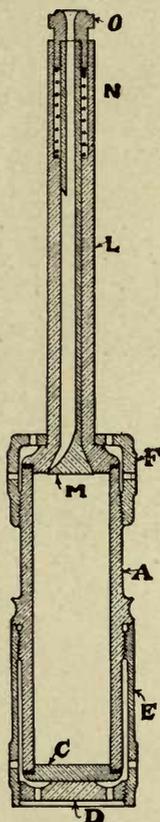
FIG. 233.—Cartridge Ignited
by Hot Wire.
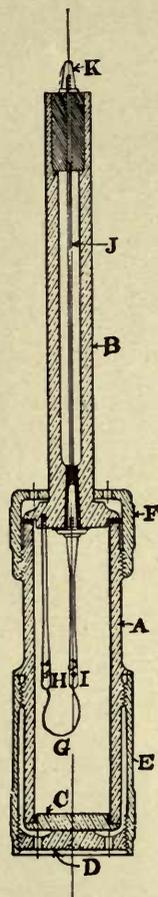
FIG. 234. — Cartridge
Electrically Ignited.

terminal K and the metal of the stem B, the filament of wire G is brought quickly to a red heat, thus igniting the charge. The current required is from 2 to 4 amperes, and is readily obtained by placing in parallel 4 to 8 16-candle power lamps in an ordinary lighting circuit of 110 volts as shown.

Directions.—The calorimeter should be placed on a good firm desk or table. The power needed is exceedingly slight; the smallest possible electric or water motor being ample. Revolve the pulley by means of a loose cord at the rate of about 100 revolutions per minute.

The parts chould be removed from the instrument for filling with water and care observed that no water remains on the outside or is allowed to spill over into the air spaces of the insulating vessels. Exactly two liters of water (preferably distilled) are used and it should have a temperature of about 3° F. below the temperature of the room. That is, approximately three-fourths of the total rise in temperature should occur before the temperature of the room is reached.
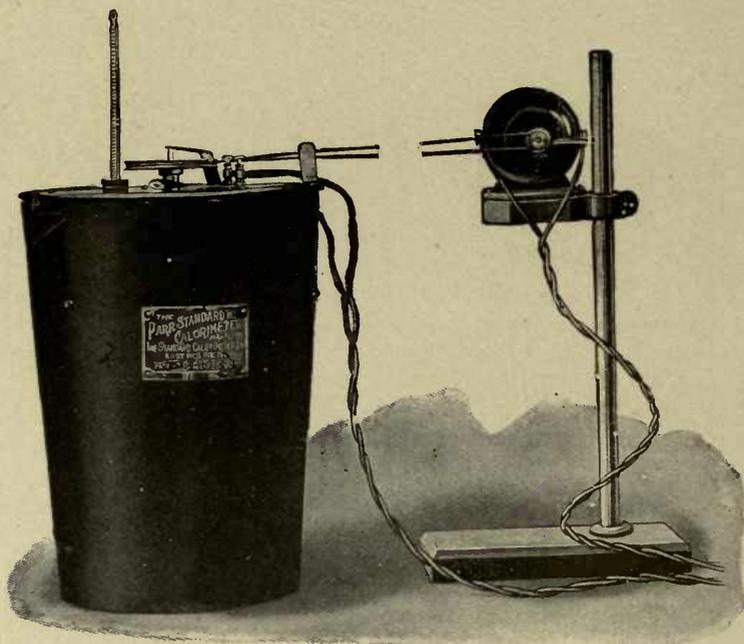
FIG. 235.—Parr Calorimeter, Complete.

The glass jar is for the chemical that should be kept carefully closed and clamped to prevent absorption of moisture from the air. For this reason also, only the contents of one small can of chemical is emptied into the jar at one time. There will also be left room for the measuring cup and handle complete.
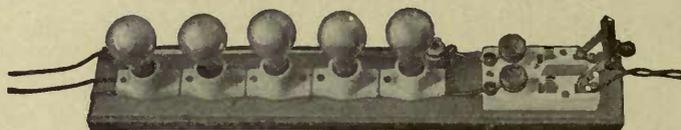
FIG. 236.—Resistance for Electric Circuit.

To prepare the cartridge for filling, dry all the parts perfectly inside and out; see that the inner bottom C with gasket is properly seated, screw on the outer bell E, then with the spanner wrench screw up *firmly* the outer bottom D and place on a sheet of white paper. The coal is prepared by grinding in a mortar and passing through the seive of 100 meshes to the inch. Coals containing over $2\frac{1}{2}$ or 3% of water should have the water removed. In such cases the exact charge of the commercially dry coal is

weighed out and dried for an hour at 105–110° C. (220–230° F.) then transferred to the cartridge.

One of the cartridges represents the new style of bomb with electric method of ignition. A differently devised stem B for ignition by dropping a red hot wire into the charge may also be used if desired.

Operation.—The following procedure is employed for all ordinary bituminous and semi-bituminuos coals, lignites, etc. Exactly one-half gram of coal is taken and dried as above indicated. This is added to the cartridge which has been thoroughly dried and prepared.

Add exactly one-half gram of the " boro-mixture " and finally one full measure of the ordinary chemical (sodium peroxide). Tap the measure against the side of the jar to insure filling completely and expose this material to the air the shortest time possible.

The stem and top B with the terminals HI having a loop of fine wire G extending about an inch below, are put in position and the cap F screwed firmly in place. The loop of fine wire should be long enough to extend into the mixture. Where the spring valve and hot wire method of ignition is used the procedure is not essentially different.

Shake vigorously to thoroughly mix the contents. When the mixing is complete tap the cartridge lightly to settle the contents and to mix all the material from the upper part of the cylinder. Put on the spring clips with vanes. The cartridge is now put in place, the can with water being already in position. Adjust the cover. Insert the thermometer so that the lower end of the bulb will be about midway towards the bottom of the can, place the pulley on the stem and connect with the motor. The cartridge should turn to the right, or as the hands of a watch, thus deflecting the current downward. After about three minutes the first reading of the thermometer may be taken.

Ignition by the electric method is effected by closing the circuit which brings the loop G of fine wire to the red heat, thus igniting the charge. In the hot wire method, ignite with the short piece of soft iron wire which is held or rests on a wire gauze in a Bunsen flame until red hot; drop quickly into the opening at the upper end of the valve, allowing the wire to lodge at the lower end before being admitted. With the pincers the valve is now pressed completely down and released with a quick movement so as to prevent the escape of heated air from the interior.

All the time of course the revolving of the cartridge continues. The combustion should be indicated by a rapid rise of the mercury, which reaches its maximum height after from four to five minutes. Make note of the final temperature and compute thus:

Calculation.—Subtract the correction factor for the heat of the wire and chemical, as indicated on the small bottle of borate mixture. Multiply the remainder by 3117. The product will be the number of B.T.U.'s per pound of coal. (See notes *a* and *b*.)

To dismantle remove the thermometer, pulley, and cover; then take out the can and contents entire, so that the lifting out of the cartridge will not drip water into the dry parts of the instrument. Remove the spring clips and unscrew the ends. It is better to loosen the bottom D, and unscrew the entire bell E for cleaning. The fused mass is easily driven out at the bottom by aid of a short metal rod. The

cartridge and ends are rinsed clean and at once thoroughly dried, when they will be ready for a new test. It is a good plan to place the end with the electric terminals in boiling water for a short time. This facilitates drying and cleans off any chemical from the face that might cause short-circuiting.

For all Anthracite, Cokes, etc., grind and sift the coal as usual. Weigh out exactly one-half gram for the test; drying may be omitted if the water content is below $2\frac{1}{2}$ or 3%. Transfer the sample to the cartridge and add exactly 1 gram of the boro-mixture for anthracites, petroleums, etc., Then add one measure of the ordinary chemical (sodium peroxide). Shake thoroughly and place in the can, assemble and complete the combustion in the usual manner.

Calculation.—The correction factor for the extra chemical and fine wire is marked on the label, but twice the correction should be made where 1 gram is used, excepting that to double this factor would be to count the correction for the wire twice, since its value is included in the correction marked on the label for $\frac{1}{2}$ gram. The wire values alone are as follows:

By electric method . . . . 0.011 deg. F.

By hot wire method . . . . . . 0.022 deg. F.

Hence twice the indicated factor for one half gram, minus twice the wire value, as indicated above would be the correction factor for one gram of the boro-mixture. Subtract this number from the total rise in temperature and compute thus; multiply the remainder by 3117. The product will be the B.T.U. per pound of coal. (See notes *a* and *b*.)

Notes.—(*a*) The factor 3117 is deduced as follows: The water used plus the water equivalent of the water in the metal in the instrument amounts to 2135 grains, In the reaction 73% of the heat is due to combustion of the coal, and 27% is due to heat of combustion of CO_2 and H_2O with the chemical. If now one-half gram of coal causes 2135 grams of water to rise R degrees, and if only 73% of this is due to combustion, then $0.73 \times 2135 \times 2 \times R =$ rise in temperature that would result from combustion of an equal weight (2135 grams of coal: $0.73 \times 2135 \times 2 = 3117$.

(*b*) With the electric method of ignition the fine wire is wrapped firmly, and with good contact around the ends of the terminals, and bent U-shaped so as to extend below about an inch. Do not have too great a length of free wire for the current. Make a preliminary test with the stem free so the action can be seen. The wire should quickly become red hot. The amount of wire burned varies slightly, but ordinarily amounts to about 0.008 gram. If extreme accuracy is desired, the weight of wire consumed most easily determined by measurement, multiplied by the calorific value of iron (1600), and divided by the water equivalent of the apparatus, will give the rise in centigrade degrees due to the combustion of the iron, approximating on the average very closely to 0.011° F. In the other method of starting the combustion, the ignition wire is of soft iron, $2\frac{1}{2}$ mm. in diameter or No 11 gauge and 1 cm. long, it should weigh approximately 0.33 gram. It loses a very little by use. When by oxidation the weight falls very much below 0.3 gram a new wire should be substituted. The correction for the hot wire may be calculated thus;

Taking 0.114 as the specific heat and 1200–1300° F. as the temperature at a red heat, then

$$\frac{1250 \times 0.330 \times 0.114}{2135} = 0.022.$$

Hence the value of the hot wire approximates closely to 0.022° F.

(c) It is imperative that the sodium peroxide be kept securely sealed from contact with the air. The chemical supplied with the apparatus is of a superior grade prepared especially for this work, and is practically free from sodium carbonate.

(d) Do not bring the instrument from a cold room to work at once in a warm room or vice versa. An hour at least should be given for equalization of temperatures. Dry the bomb thoroughly inside before putting away. Dry it before using, if it has stood for some time, as moisture condenses on the inside.

(e) Do not throw a mixture of chemical and unburned coal into water. It may ignite violently. Similarly a drop of water left inside the valve may work into the charge during the shaking and ignite it prematurely.

(f) It is well to test the action of the valve by dropping the wire through on to a sheet of paper a number of times, holding the stem in the hand and dropping the wire as in igniting a charge. It will be noted that the wire is allowed to lodge at the valve, then is released by pressure at the top. Too sudden a pressure and release or a failure to press the valve completely down, may result in catching the wire before it has cleared the valve. In such a case of course the charge would fail of ignition.

(g) The above directions presume the use of a Fahrenheit thermometer. In case a centigrade thermometer is used, the use of the factor 3117 gives the result in kilocalories. To change kilocalories to B.T.U., multiply by 1.8. Also the correction factors as given on the special borate mixtures should be divided by 1.8.

(h) It is to be recommended, especially where room temperatures are not easily controlled, and in all cases where extreme accuracy is desired, that a correction for radiation be introduced. An adaption of Newton's law is well suited to the conditions as follows: Read the fall in temperature for the second, third, and fourth minutes after the maximum has been reached. The average drop per minute represents the correction to be added to each minute preceding the maximum, except for the minute immediately following ignition.

Tap the thermometer lightly to settle the mercury column before each reading.

Total Carbon Apparatus.—The residue from the determination of the heat values has the carbon of the coal combined in the form of sodium carbonate. By adding acid to the dissolved material in a suitable apparatus, and liberating the carbon dioxide gas under conditions which make it available for measurement, we have a ready method for determining the volume of the CO_2. From this reading, in conjunction with the temperature and barometric pressure, we may calculate the weight of the carbon orginally present in the coal. This is a factor not heretofore available except by ultimate analysis.

The fused material is brought into the flask B and dissolved with the washings from the interior of the bomb. By admitting acid from a funnel A, the carbon dioxide is liberated and carried over into a jacketed burette G. In this condition also, the

temperature may be read by means of the thermometer suspended in the water surrounding the burette. The gas thus measured, which may also have a small admixture of air, is conducted over into an absorption bulb P, in which is contained a solution of caustic potash, for absorbing the CO_2. Upon returning the residual gas to the burette G and reading the volume, the diminution indicates the volume of carbon dioxide present at the outset. The apparatus permits of boiling
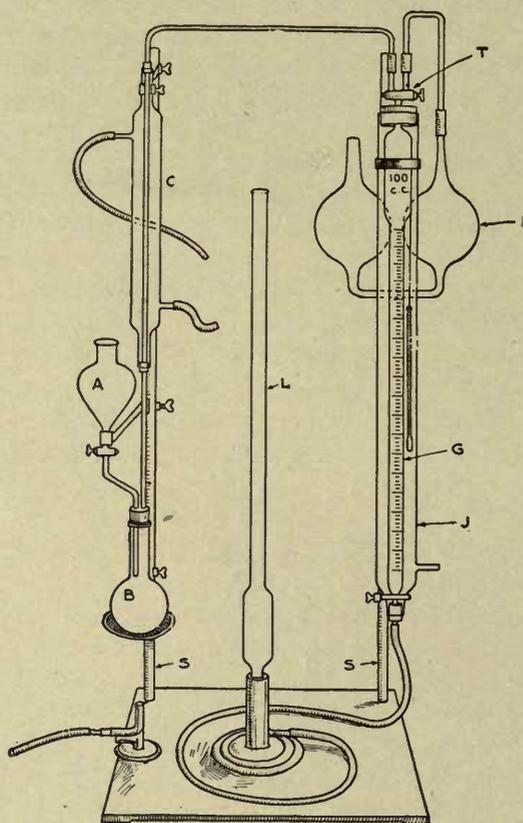
Fig. 237.—Total Carbon Apparatus for Parr Test.
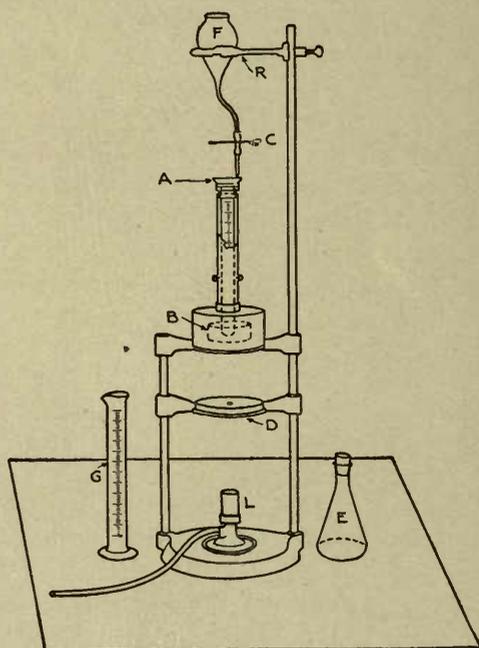
Fig. 238.—Sulphur Determination Apparatus for Parr Test.

the liquid in the flask B in order to expel the dissolved gases and, by means of the condenser, the gas is maintained at a constant temperature.

Moisture—For all practical purposes dry one gram of coal in an open crucible at 220 to 225° F., the amount of distillation will fairly reflect the moisture content. This method is of course only approximately accurate, in connection with the use of analytical balances sensative to milligrams.

Another method is given by A. H. Gill, in his "Engine Room Chemistry," and is as follows: Procure a pair of three-inch watch glasses, the edges of which are ground to fit accurately together, and which are held together by a watch-glass clip. Weigh

out about five grams of the coal from the test tube mentioned above between these glasses using the horn pan balances.

Remove the clip, open the glasses and place them in the oven at 220 to 225° F. (104 to 107° C) for one hour; remove them from the oven, replace the clip, cool under a bell jar and weigh when cold. The loss of weight represents the moisture in the coal and should be expressed in per cent.

Sulphur Photometer.—The fusion of coal, coke, petroleum, etc., by means of sodium peroxide, as carried out in the Parr calorimeter, is made use of for determining sulphur. Upon removal of the fused mass, it is dissolved in water and made slightly acid with pure hydrochloric acid. An aliquot part of this solution is taken and made up to 100 cc. and transferred to an Erlenmeyer flask. To this, at room temperature, is added a large crystal of barium chloride, and at once the flask is shaken vigorously for a short time. The turbid solution is then ready to read in the photometer. The liquid containing the finely divided precipitate of barium sulphate, is poured into the dropping funnel F, and gradually admitted through the pinch-cock C into the graduated tube A. The lens effect at the bottom of the tube is obtained by immersing the same in water, as shown in B. By noting the depth at which the light from the flame disappears a reading is obtained directly, which indicates the percentage of sulphur in the sample under examination. The accuracy of results so obtained is close enough for practical purposes.

CHAPTER XX

PIPES, FLUES, AND CHIMNEYS

CAPACITY OF PIPES

Flow of Gases in Pipes.—The following notes upon Dr. Pole's formula for the flow of gases in pipes have been made by F. S. Cripps and published in the *Journal of Gas Lighting*. Let

Q = discharge of gas in cubic feet per hour;

d = diameter of pipe in inches;

p = pressure of gas in inches of water;

s = specific gravity of gas, air equalling 1;

l = length of pipe in yards.

$$Q = 1350d^2 \sqrt{\frac{Pd}{sl}};$$

$$d = \sqrt{\frac{Q^2 sl}{(1350)^2 p}};$$

$$p = \frac{Q^2 sl}{(1350)^2 d^5};$$

$$l = \frac{(1350)^2 d^5 p}{Q^2 s};$$

$$s = \frac{(1350)^2 d^5 p}{Q^2 l}.$$

From the above it is apparent that, other things being equal,

Q varies directly as $\sqrt{p}$
"   " $\sqrt{d^5}$
"   inversely as $\sqrt{l}$
"   " $\sqrt{s}$
d varies directly as $\sqrt{Q^2}$
"   " $\sqrt{l}$
"   " $\sqrt{s}$
"   inversely as $\sqrt{p}$

p varies directly as Q^2
"   " l
"   " s
"   inversely as d^5
l varies directly as p
"   " d^5
"   inversely as Q^2
"   " s
s varies directly as p
"   " d^5
"   inversely as Q^2
"   " l

A consideration of the foregoing gives rise to the following axioms or rules:

Quantity—Pressure.—Double the quantity requires four times the pressure.

Or, four times the pressure will pass double the quantity.

Half the quantity requires one-fourth the pressure.

Or, one-fourth the pressure is sufficient for half the quantity.

Quantity—Length.—Double the quantity can be discharged through one-fourth the length.

Or, one-fourth the length will allow of double the discharge.

Half the quantity can be discharged through four times the length.

Or, four times the length reduces the discharge one-half.

Quantity—Diameter.—Thirty-two times the quantity requires a pipe four times the diameter.

Or, a pipe four times the diameter will pass thirty-two times as much gas.

A pipe one-fourth the diameter will pass one thirty-second of the quantity.

Or, one thirty-second of the quantity can be passed by a pipe one-fourth the diameter.

Quantity—Specific Gravity.—The specific gravity stands in just the same relation to the volume as the length does (see Axioms 3 and 4).

Pressure—Length.—If the pressure is doubled the length may be doubled.

And, conversely, if the length be doubled the pressure must be doubled.

If the pressure be halved the length may be halved.

And, conversely, if the length be halved the pressure must be halved.

From Axioms 8 and 9 it is evident that—

The pressure required to pass a given quantity of gas varies exactly as the length of the pipe.

Pressure—Specific Gravity.—The pressure required to pass a given quantity of gas also varies exactly as the specific gravity of the gas. Hence if the specific gravity of the gas were doubled, double the pressure would be required.

Pressure—Diameter.—One thirty-second part of the pressure is sufficient if the diameter be doubled; or, in other words, if you double the diameter you require only one thirty-second of the pressure to pass the same quantity of gas.

If you halve the diameter, thirty-two times the pressure is required.

And, conversely, if you increase the pressure thirty-two times, the diameter can be halved.

Length—Diameter.—The length can be increased thirty-two times if the diameter be doubled.

And, conversely, if the diameter be doubled, the length can be increased thirty-two times and pass the same quantity of gas.

If the diameter be halved, the length must be reduced to one thirty-second to pass the same quantity of gas.

And, conversely, if the length be made one thirty-second of the distance, the diameter may be halved.

Specific Gravity—Length.—If the specific gravity be doubled, the length must be halved, and vice versa, to satisfy the equation.

Specific Gravity—Diameter.—The specific gravity follows the same laws as the length does in relation to the diameter.

It must be borne in mind, when using the above rules, that all other conditions remain the same when considering the effect of one factor on another in the different pairs.

The above may be found convenient for rule-of-thumb calculations.

Comparison of Formula.—Mr. Oliphant has checked certain formula on delivering natural gas 100 miles into a gas-holder through 8-inch pipe.

Taking the same conditions and using the several formulæ, we obtain the following results:

Formula.	Calculated Cu.ft. per Hour.
Actual volume delivered.	18,200
Pittsburg	18,380
Cox's	16,000
Oliphant's	16.260
Oliphant's, corrected	17,510
Robinson's	18,730
Unwin's	31,870
Velde's	22,060
Richard's (corrected for 0.6–g gas)	18,708
Hiscox's (corrected for 0.6–g gas)	16,250
Lowe's	26,910

Piping.—The gas-range having 4 top burners and an oven-burner should never be connected to the meter by less than a ¾-in. pipe and this should only be in instances where the run is 50 ft. or under, 1-in. pipe being used for a greater distance. This calculation, based on gas having a specific gravity of 0.7, would show a loss in pressure of about 0.1 in., which, under average conditions should be the maximum loss advisable.

FLOW OF GAS IN CUBIC FEET PER HOUR THROUGH THIN ORIFICES, SUCH AS AIR-MIXERS, FOR GAS-STOVES

Pressure Equivalents.			Diameter of Orifices, Inches.					
Ounces per Square Inch.	Tenths of Inches of Water Head.	Tenths of Inches of Mercury Column.	$\frac{5}{64}$	$\frac{3}{32}$	$\frac{7}{64}$	$\frac{4}{32}$	$\frac{5}{32}$	$\frac{6}{32}$
			Cubic Feet Discharged per Hour.					
....	8	0.59	8.0	12.0	15	20	30	45
....	10	0.74	9.0	13.0	17	23	34	51
....	12	0.89	10.0	15.0	18	25	36	56
0.8	13.6	1.00	10.8	16.0	20	27	40	61
....	14	1.03	11.3	17.0	21	28	42	63
....	16	1.18	11.6	17.5	21	29	43	65
....	18	1.34	12.0	18.0	22	30	44	67
....	20	1.48	12.8	19.0	23	32	46	72
....	25	1.86	13.5	20.4	25	34	50	76
1.6	27	2.00	15.9	21.0	27	38	54	86
1.8	30	2.02	16.4	24.5	31	41	62	92
2.4	41	3	18.0	27.5	34	46	68	105
3.2	54	4	21.6	32.0	41	54	82	122
4.0	68	5	24.0	35.5	46	60	92	135
4.8	81	6	26.4	39.5	51	66	102	148
5.6	65	7	28.4	42.5	54	71	108	160
6.4	109	8	30.0	45.0	57	75	114	169
7.2	122	9	31.0	47.0	61	78	122	176
8.0	137	10	32.4	48.5	64	81	128	182
8.8	150	11	33.0	51.0	68	85	138	191
9.6	163	12	37.2	55.0	71	93	142	209
10.4	177	13	38.8	58.0	74	97	148	218
11.2	190	14	40.4	60.5	77	101	154	227
12.0	204	15	42.0	63.0	80	105	160	236
12.8	218	16	43.0	65.0	82	108	164	243
13.6	231	17	44.0	66.0	84	110	168	247
14.4	245	18	45.6	67.0	87	114	174	255
15.2	258	19	47.0	70.0	90	117	180	263
16.0	274	20	48.0	72.0	92	120	184	270

SIZES OF PIPE REQUIRED FOR CITY GAS

(Allow three-tenths drop in pressure. Add 10 ft. to length of pipe for each elbow)

Cubic Feet Gas per Hour.	Length of Pipe, Feet.	Size of Pipe Required.	Cubic Feet Gas per Hour.	Length of Pipe, Feet.	Size of Pipe Required.
25	0 to 190	$\frac{1}{2}$ inch	200	100 to 300	$1\frac{1}{4}$ inch
25	190 to 500	$\frac{3}{4}$ "	250	0 to 50	1 "
50	0 to 100	$\frac{1}{2}$ "	250	50 to 200	$1\frac{1}{4}$ "
50	100 to 375	$\frac{3}{4}$ "	250	200 to 525	$1\frac{1}{2}$ "
75	0 to 25	$\frac{1}{2}$ "	300	0 to 25	1 "
75	25 to 150	$\frac{3}{4}$ "	300	25 to 100	$1\frac{1}{4}$ "
75	150 to 450	1 "	300	100 to 375	$1\frac{1}{2}$ "
100	0 to 100	$\frac{3}{4}$ "	400	0 to 75	$1\frac{1}{4}$ "
100	100 to 375	1 "	400	75 to 150	$1\frac{1}{2}$ "
150	0 to 25	$\frac{3}{4}$ "	400	150 to 750	2 "
150	25 to 200	1 "	500	0 to 25	$1\frac{1}{4}$ "
150	200 to 600	$1\frac{1}{4}$ "	500	25 to 100	$1\frac{1}{2}$ "
200	0 to 100	1 "	500	100 to 525	2 "

A quick graphical method of finding the diameter of branch pipes leading from mains is to lay off on a straight line the diameter of the main to any scale desired. From its center draw a semi-circle to the ends and erect a perpendicular from the center. Now join the ends of the diameter with the top of this perpendicular and they will equal the diameter of the branch, as shown in the diagram.
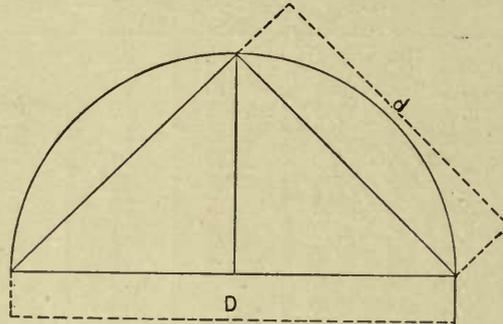
FIG. 239.—Relation of Mains to Branches.

COMPARATIVE CAPACITY OF PIPES OF DIAMETERS GIVEN

Diam., Inches.	1	2	3	4	5	6	7	8	9	10	12	14	16	18	20	24
2	5.7	1														
3	15.6	2.8	1													
4	32	5.7	2.1	1												
5	55.9	9.9	3.6	1.7	1											
6	88.2	15.6	5.7	2.8	1.6	1										
7	130	22.9	8.3	4.1	2.3	1.5	1									
8	181	32	11.7	5.7	3.2	2.1	1.4	1								
9	243	43	15.6	7.6	4.3	2.8	1.9	1.3	1							
10	316	55.9	20.3	9.9	5.7	3.6	2.4	1.7	1.3	1						
11	401	70.9	25.7	12.5	7.2	4.6	3.1	2.2	1.7	1.3						
12	499	88.2	32	15.6	8.9	5.7	3.8	2.8	2.1	1.6	1					
13	609	108	39.1	19	10.9	7.1	4.7	3.4	2.5	1.9	1.2					
14	733	130	47	22.9	13.1	8.3	5.7	4.1	3.0	2.3	1.5	1				
15	787	154	55.9	27.2	15.6	9.9	6.7	4.8	3.6	2.8	1.7	1.2				
16	....	181	65.7	32	18.3	11.7	7.9	5.7	4.2	3.2	2.1	1.4	1			
17	....	211	76.4	37.2	21.3	13.5	9.2	6.6	4.9	3.8	2.4	1.6	1.2			
18	....	243	88.2	43	24.6	15.6	10.6	7.6	5 7	4.3	2.8	1.9	1.3	1		
19	....	278	101	49.1	28.1	17.8	12.1	8.7	6.5	5	3.2	2.1	1.5	1.1		
20	....	316	115	55.9	32	20.3	13.8	9.9	7.4	5.7	3.6	2.4	1.7	1.3	1	
22	....	401	146	70.9	40.6	25.7	17.5	12.5	9.3	7.2	4.6	3.1	2.2	1.7	1.3	
24	....	499	181	88.2	50.5	32	21.8	15.6	11.6	8.9	5.7	3.8	2.8	2.1	1.6	1
26	....	609	221	108	61.7	39.1	26.6	19	14.2	10.9	7.1	4.7	3.4	2.5	1.9	1.2
28	....	733	266	130	74.2	47	32	22.9	17.1	13.1	8.3	5.7	4.1	3	2.3	1.5
30	....	787	316	154	88.2	55.9	38	27.2	20.3	15.6	9.9	6.7	4.8	3.6	2.8	1.7
36	....	....	499	243	130	88.2	60	43	32	24.6	15.6	10.6	7.6	5.7	4.3	2.8
42	....	....	733	357	205	130	88.2	63.2	47	36.2	19	15.6	11.2	8.3	6.4	4.1
48	....	....	....	499	286	181	123	88.2	62.7	50.5	32	21.8	15.6	11.6	8.9	5.7
54	....	....	....	670	383	243	165	118	88.2	67.8	43	29.2	20.9	15.6	12	7.6
60	....	....	....	787	499	316	215	154	115	88.2	55.9	38	27.2	20.3	15.6	9.9

HIGH-PRESSURE GAS DELIVERY—(F. H. OLIPHANT,

$$\text{Cubic feet per hour} = 42a\sqrt{\frac{P-p}{l}}.$$

P and p are gauge pressures at intake and discharge ends of pipe plus 15 lbs.; l is length in yards; a for different sizes of pipe is:

Diameter Inside.	a	Diameter Inside.	a	Diameter Inside.	Diameter Outside.	a
0.25	0.0317	4	34.1	14.25	15	863
0.50	0.1810	5	60	15.25	16	1025
0.75	0.5012	6	96	17.25	18	1410
1.0	1.0000	8	198	19.25	20	1860
				Riveted	or cast-iron	pipes
1.5	2.9300	10	350	20	....	2055
2.0	5.9200	12	556	24	....	3285
2.5	10.3700	16	1160	30	....	5830
3.0	16.5	18	1570	36	....	9330

TRANSMISSION OF GAS OF 0.55 SPECIFIC GRAVITY THROUGH A PIPE WITH 90° BENDS. (NELSON W. PERRY)

Inches, Pressure.	Cubic Feet Delivered.	Velocity of Flow in Cubic Feet per Second.	Increase of Pressure per Bend, Inches.	Total Increased Pressure per 25 Bends, Inches.	Total Initial Pressure, Inches.
1	12,500	4.0	0.0016	0.04	1.04
2	18,000	6.0	0.0034	0.085	2.085
3	23,000	8.0	0.006	0.1495	3.15
4	25,500	8.8	0.0076	0.189	4.189
5	28,000	9.6	0.0086	0.215	5.215
6	32,000	11.0	0.0113	0.28	6.28
7	34,000	12.0	0.0135	0.34	7.34
8	36,000	12.5	0.0147	0.39	8.39
9	38,500	13.0	0.0158	0.4	9.4
10	40,000	14.0	0.0183	0.46	10.46

Friction Loss.—It is a fact not generally appreciated that gaseous friction in pipes depends, under given conditions, upon the difference of the squares of the initial and terminal pressures. Thus the drop in pressure from 500 lbs. down to 400 lbs. would convey the same quantity of air as would be conveyed by the drop in pressure from 300 lbs. down to atmospheric. The insignificant increase in power to compress to 500 lbs. instead of 300 lbs., is perfectly well known, and the net result is that for a slightly greater expenditure for pipe line and for energy of compression, we should have gas delivered at a pressure which would enable it to be used directly in the cylinder of a Diesel engine without further compression, making a great simplification of the engine and giving an enormous capacity of transmission to a pipe line of very moderate size.

PRESSURE AND HORSE-POWER LOST BY FRICTION OF AIR IN PIPES 100 FEET LONG. (STURTEVANT)

Velocity of Air in Feet per Minute	1-inch		2-inch		3-inch		4-inch		5-inch		6-inch		7-inch		8-inch		9-inch		10-inch	
	Loss of Pressure in Ounces per Square Inch	H.P. Lost in Friction	Loss of Pressure in Ounces per Square Inch	H.P. Lost in Friction	Loss of Pressure in Ounces per Square Inch	H.P. Lost in Friction	Loss of Pressure in Ounces per Square Inch	H.P. Lost in Friction	Loss of Pressure in Ounces per Square Inch	H.P. Lost in Friction	Loss of Pressure in Ounces per Square Inch	H.P. Lost in Friction	Loss of Pressure in Ounces per Square Inch	H.P. Lost in Friction	Loss of Pressure in Ounces per Square Inch	H.P. Lost in Friction	Loss of Pressure in Ounces per Square Inch	H.P. Lost in Friction	Loss of Pressure in Ounces per Square Inch	H.P. Lost in Friction
100	0.011	0.0000	0.006	0.0000	0.004	0.0000	0.003	0.0000	0.002	0.0000	0.002	0.0000	0.002	0.0000	0.001	0.0000	0.001	0.0000	0.001	0.0000
200	0.044	0.0000	0.022	0.0000	0.015	0.0000	0.011	0.0001	0.009	0.0001	0.007	0.0001	0.006	0.0001	0.006	0.0001	0.005	0.0001	0.004	0.0001
300	0.100	0.0000	0.050	0.0001	0.033	0.0001	0.025	0.0002	0.020	0.0002	0.017	0.0003	0.014	0.0003	0.012	0.0004	0.011	0.0004	0.010	0.0004
400	0.178	0.0001	0.088	0.0002	0.059	0.0003	0.044	0.0004	0.036	0.0005	0.030	0.0006	0.025	0.0007	0.022	0.0008	0.020	0.0009	0.018	0.0011
500	0.278	0.0002	0.139	0.0004	0.092	0.0006	0.069	0.0008	0.056	0.0010	0.046	0.0012	0.040	0.0014	0.035	0.0017	0.031	0.0019	0.028	0.0021
600	0.400	0.0004	0.200	0.0007	0.133	0.0011	0.100	0.0014	0.080	0.0018	0.067	0.0021	0.057	0.0025	0.050	0.0029	0.044	0.0032	0.040	0.0036
700	0.544	0.0006	0.272	0.0011	0.181	0.0017	0.138	0.0023	0.109	0.0028	0.091	0.0034	0.078	0.0040	0.068	0.0045	0.060	0.0051	0.054	0.0057
800	0.711	0.0008	0.356	0.0017	0.237	0.0025	0.178	0.0034	0.142	0.0042	0.119	0.0051	0.102	0.0059	0.089	0.0067	0.079	0.0076	0.071	0.0085
900	0.900	0.0012	0.450	0.0024	0.300	0.0036	0.225	0.0048	0.180	0.0060	0.150	0.0072	0.129	0.0084	0.112	0.0096	0.100	0.0108	0.090	0.0120
1000	1.111	0.0017	0.556	0.0033	0.370	0.0049	0.278	0.0066	0.222	0.0083	0.185	0.0099	0.159	0.0116	0.139	0.0132	0.123	0.0148	0.111	0.0165
1100	1.344	0.0022	0.672	0.0044	0.448	0.0066	0.338	0.0088	0.269	0.0110	0.224	0.0132	0.192	0.0154	0.168	0.0176	0.149	0.0198	0.134	0.0220
1200	1.600	0.0029	0.800	0.0057	0.533	0.0086	0.400	0.0114	0.320	0.0143	0.267	0.0171	0.229	0.0200	0.200	0.0230	0.178	0.0256	0.160	0.0286
1300	1.878	0.0036	0.939	0.0073	0.626	0.0109	0.469	0.0145	0.376	0.0182	0.313	0.0218	0.268	0.0254	0.235	0.0290	0.209	0.0327	0.188	0.0363
1400	2.178	0.0045	1.089	0.0090	0.726	0.0136	0.544	0.0181	0.436	0.0227	0.363	0.0272	0.311	0.0317	0.282	0.0363	0.242	0.0408	0.218	0.0453
1500	2.500	0.0056	1.250	0.0112	0.833	0.0167	0.625	0.0223	0.500	0.0279	0.417	0.0335	0.357	0.0390	0.312	0.0446	0.278	0.0502	0.250	0.0558
1600	2.844	0.0068	1.422	0.0135	0.948	0.0203	0.711	0.0271	0.569	0.0338	0.474	0.0406	0.406	0.0473	0.356	0.0541	0.316	0.0609	0.284	0.0677
1700	3.211	0.0081	1.605	0.0162	1.070	0.0244	0.803	0.0325	0.642	0.0406	0.535	0.0487	0.459	0.0568	0.401	0.0649	0.357	0.0731	0.321	0.0812
1800	3.600	0.0096	1.800	0.0192	1.200	0.0289	0.900	0.0385	0.720	0.0482	0.600	0.0578	0.514	0.0674	0.450	0.0771	0.400	0.0867	0.360	0.0964
1900	4.011	0.0113	2.006	0.0227	1.337	0.0340	1.003	0.0453	0.802	0.0567	0.669	0.0680	0.573	0.0793	0.501	0.0907	0.446	0.1020	0.401	0.1133
2000	4.444	0.0132	2.222	0.0264	1.481	0.0397	1.111	0.0529	0.889	0.0661	0.741	0.0793	0.635	0.0925	0.556	0.1058	0.493	0.1190	0.444	0.1322
2200	5.378	0.0176	2.689	0.0352	1.793	0.0528	1.344	0.0704	1.076	0.0880	0.896	0.1055	0.768	0.1232	0.672	0.1408	0.597	0.1583	0.538	0.1760
2400	6.400	0.0228	3.200	0.0457	2.133	0.0685	1.600	0.0914	1.280	0.1142	1.067	0.1371	0.914	0.1600	0.800	0.1728	0.711	0.2056	0.640	0.2284
2600	7.511	0.0290	3.756	0.0581	2.504	0.0871	1.877	0.1162	1.502	0.1452	1.252	0.1743	1.073	0.2033	0.939	0.2324	0.835	0.2614	0.751	0.2904
2800	8.711	0.0363	4.356	0.0726	2.904	0.1088	2.178	0.1451	1.742	0.1814	1.452	0.2177	1.244	0.2539	1.089	0.2902	0.968	0.3265	0.871	0.3628
3000	10.000	0.0446	5.000	0.0892	3.333	0.1339	2.500	0.1785	2.000	0.2231	1.667	0.2677	1.429	0.3123	1.250	0.3569	1.111	0.4016	1.000	0.4462
3200	11.378	0.0541	5.689	0.1083	3.792	0.1625	2.844	0.2166	2.276	0.2708	1.896	0.3249	1.625	0.3790	1.422	0.4332	1.263	0.4873	1.138	0.5415
3400	12.844	0.0649	6.422	0.1299	4.281	0.1949	3.211	0.2598	2.569	0.3247	2.141	0.3897	1.835	0.4546	1.606	0.5237	1.427	0.5845	1.284	0.6495
3600	14.400	0.0770	7.200	0.1542	4.800	0.2313	3.600	0.3084	2.880	0.3855	2.400	0.4626	2.057	0.5397	1.800	0.6168	1.600	0.7039	1.440	0.7710
3800	16.044	0.0906	8.022	0.1814	5.349	0.2720	4.011	0.3627	3.209	0.4534	2.674	0.5441	2.292	0.6347	2.006	0.7254	1.783	0.8171	1.604	0.9068
4000	17.778	0.1058	8.889	0.2115	5.926	0.3173	4.444	0.4230	3.556	0.5288	2.963	0.6346	2.540	0.7403	2.222	0.8461	1.975	0.9518	1.778	1.0576
4200			9.800	0.2448	6.533	0.3673	4.900	0.4897	3.920	0.6121	3.267	0.7346	2.800	0.8570	2.450	0.9794	2.178	1.1019	1.960	1.2243
4400			10.705	0.2815	7.137	0.4223	5.353	0.5631	4.283	0.7038	3.569	0.8446	3.059	0.9854	2.676	1.1261	2.379	1.2669	2.141	1.4077
4800			12.800	0.3655	8.533	0.5484	6.400	0.7310	5.120	0.9138	4.267	1.0964	3.657	1.2793	3.200	1.4620	2.844	1.6448	2.560	1.8275
5200			15.022	0.4747	10.013	0.6971	7.511	0.9294	6.008	1.1816	5.007	1.3941	4.292	1.6253	3.756	1.8588	3.339	2.0912	3.004	2.3236
5600			17.422	0.5804	11.613	0.8707	8.711	1.1608	6.969	1.4510	5.807	1.7412	4.978	2.0314	4.356	2.3216	3.872	2.6118	3.484	2.9021
6000			20.000	0.7139	13.333	1.0710	10.000	1.4278	8.000	1.7847	6.667	2.1416	5.714	2.4986	5.000	2.8555	4.444	3.2125	4.000	3.5694

PRESSURE AND HORSE-POWER LOST BY FRICTION OF AIR IN PIPES 100 FEET LONG. (STURTEVANT)—Continued

Velocity of Air in Feet per Minute.	26-inch H.P. Loss in Friction.	26-inch Loss of Pressure in Ounces per Square Inch.	24-inch H.P. Loss in Friction.	24-inch Loss of Pressure in Ounces per Square Inch.	22-inch H.P. Loss in Friction.	22-inch Loss of Pressure in Ounces per Square Inch.	20-inch H.P. Loss in Friction.	20-inch Loss of Pressure in Ounces per Square Inch.	18-inch H.P. Loss in Friction.	18-inch Loss of Pressure in Ounces per Square Inch.	16-inch H.P. Lost in Friction.	16-inch Loss of Pressure in Ounces per Square Inch.	14-inch H.P. Lost in Friction.	14-inch Loss of Pressure in Ounces per Square Inch.	13-inch H.P. Lost in Friction.	13-inch Loss of Pressure in Ounces per Square Inch.	12-inch H.P. Lost in Friction.	12-inch Loss of Pressure in Ounces per Square Inch.	11-inch H.P. Lost in Friction.	11-inch Loss of Pressure in Ounces per Square Inch.
100	0.0000	.000	0.0000	.000	0.0000	.001	0.0000	.001	0.0000	.001	0.0000	.001	0.0000	.001	0.0000	.001	0.0000	.001	0.0000	.001
200	0.0003	.002	0.0003	.002	0.0003	.002	0.0003	.002	0.0002	.002	0.0002	.003	0.0002	.003	0.0002	.003	0.0002	.004	0.0001	.004
300	0.0012	.004	0.0011	.004	0.0010	.005	0.0009	.005	0.0008	.006	0.0007	.006	0.0006	.007	0.0006	.008	0.0005	.008	0.0005	.009
400	0.0027	.007	0.0025	.007	0.0023	.008	0.0021	.009	0.0019	.010	0.0017	.011	0.0015	.013	0.0014	.014	0.0013	.015	0.0012	.016
500	0.0054	.011	0.0050	.012	0.0045	.013	0.0041	.014	0.0037	.016	0.0033	.017	0.0029	.020	0.0027	.021	0.0025	.023	0.0023	.025
600	0.0093	.015	0.0086	.017	0.0079	.018	0.0071	.020	0.0064	.022	0.0057	.025	0.0050	.029	0.0046	.031	0.0043	.033	0.0039	.036
700	0.0147	.021	0.0136	.023	0.0125	.025	0.0113	.027	0.0102	.030	0.0091	.034	0.0079	.039	0.0074	.041	0.0068	.045	0.0062	.049
800	0.0220	.027	0.0203	.029	0.0186	.032	0.0169	.036	0.0152	.040	0.0135	.044	0.0118	.051	0.0109	.055	0.0102	.059	0.0093	.064
900	0.0313	.035	0.0289	.037	0.0265	.041	0.0241	.045	0.0217	.050	0.0193	.056	0.0169	.064	0.0157	.069	0.0145	.075	0.0132	.081
1000	0.0430	.043	0.0397	.046	0.0364	.051	0.0330	.056	0.0297	.062	0.0264	.069	0.0231	.079	0.0215	.085	0.0198	.092	0.0182	.101
1100	0.0572	.052	0.0528	.056	0.0484	.061	0.0440	.067	0.0396	.075	0.0352	.084	0.0308	.096	0.0286	.103	0.0264	.112	0.0242	.122
1200	0.0742	.062	0.0685	.067	0.0628	.073	0.0571	.080	0.0512	.090	0.0457	.100	0.0400	.114	0.0371	.123	0.0343	.133	0.0314	.145
1300	0.0944	.072	0.0873	.078	0.0799	.085	0.0726	.094	0.0654	.104	0.0581	.117	0.0508	.134	0.0472	.144	0.0437	.156	0.0399	.170
1400	0.1179	.084	0.1088	.091	0.0998	.099	0.0907	.109	0.0816	.121	0.0726	.136	0.0635	.156	0.0589	.167	0.0544	.181	0.0499	.198
1500	0.1450	.096	0.1339	.104	0.1227	.114	0.1115	.125	0.1004	.139	0.0892	.156	0.0781	.179	0.0725	.192	0.0669	.208	0.0613	.227
1600	0.1760	.109	0.1624	.119	0.1469	.129	0.1354	.142	0.1218	.158	0.1083	.178	0.0948	.203	0.0880	.219	0.0812	.237	0.0735	.259
1700	0.2110	.124	0.1948	.134	0.1786	.146	0.1624	.161	0.1461	.178	0.1299	.207	0.1137	.229	0.1055	.247	0.0974	.268	0.0893	.292
1800	0.2506	.139	0.2313	.150	0.2120	.164	0.1927	.180	0.1735	.200	0.1542	.225	0.1351	.257	0.1253	.278	0.1156	.300	0.1060	.327
1900	0.2945	.154	0.2720	.167	0.2494	.182	0.2267	.201	0.2040	.223	0.1814	.251	0.1587	.287	0.1472	.308	0.1360	.334	0.1247	.365
2000	0.3437	.171	0.3173	.185	0.2908	.202	0.2644	.222	0.2380	.247	0.2115	.278	0.1851	.317	0.1719	.341	0.1586	.370	0.1454	.404
2200	0.4575	.207	0.4223	.224	0.3871	.244	0.3519	.269	0.3167	.299	0.2815	.336	0.2463	.384	0.2287	.413	0.2111	.448	0.1936	.489
2400	0.5939	.246	0.5483	.267	0.5026	.291	0.4569	.320	0.4112	.356	0.3455	.400	0.3198	.457	0.2970	.492	0.2741	.533	0.2513	.582
2600	0.7552	.289	0.6971	.313	0.6390	.341	0.5809	.376	0.5228	.417	0.4647	.468	0.4066	.537	0.3776	.578	0.3485	.626	0.3195	.683
2800	0.9432	.335	0.8706	.363	0.7981	.396	0.7255	.436	0.6530	.484	0.5804	.544	0.5079	.622	0.4716	.670	0.4353	.726	0.3990	.792
3000	1.1601	.385	1.0708	.417	0.9816	.455	0.8923	.500	0.8031	.556	0.7140	.625	0.6245	.714	0.5800	.769	0.5354	.833	0.4908	.909
3200	1.4079	.438	1.2996	.474	1.1913	.517	1.0830	.569	0.9747	.632	0.8664	.711	0.7581	.813	0.7039	.875	0.6498	.948	0.5956	1.034
3400	1.6882	.494	1.5588	.535	1.4289	.584	1.2990	.642	1.1690	.714	1.0393	.827	0.9093	.917	0.8441	.988	0.7794	1.070	0.7144	1.168
3600	2.0046	.557	1.8504	.600	1.6962	.655	1.5420	.720	1.4078	.800	1.2335	.900	1.0800	1.029	1.0023	1.114	0.9252	1.200	0.8481	1.309
3800	2.3760	.617	2.1742	.669	1.9949	.729	1.8135	.802	1.6342	.891	1.4508	1.003	1.2695	1.146	1.1880	1.234	1.0871	1.337	0.9974	1.459
4000	2.7498	.684	2.5382	.741	2.3467	.808	2.1152	.889	1.9037	.988	1.6922	1.111	1.4807	1.270	1.3749	1.367	1.2691	1.481	1.1734	1.616
4200	3.1832	.754	2.9383	.817	2.7335	.891	2.4486	.980	2.2037	1.089	1.9598	1.225	1.7140	1.400	1.5916	1.508	1.4692	1.633	1.3667	1.782
4400	3.6599	.827	3.3784	.892	3.0969	.973	2.8153	1.071	2.5338	1.189	2.2532	1.344	1.9707	1.537	1.8300	1.655	1.6892	1.784	1.5484	1.946
4800	4.7516	.985	4.3861	1.067	4.0206	1.164	3.6551	1.280	3.2896	1.422	2.9241	1.600	2.5585	1.829	2.3758	1.969	2.1930	2.133	2.0103	2.327
5200	6.0412	1.156	5.5765	1.252	5.1118	1.366	4.6471	1.502	4.1824	1.670	3.7177	1.871	3.2530	2.146	3.0206	2.311	2.7882	2.504	2.5559	2.731
5600	7.5453	1.340	6.9649	1.452	6.3845	1.584	5.8041	1.742	5.2237	1.936	4.6433	2.178	4.0629	2.489	3.7727	2.680	3.4825	2.904	3.1923	3.168
6000	9.2804	1.538	8.5666	1.667	7.8527	1.818	7.1388	2.000	6.4249	2.222	5.7110	2.500	4.9959	2.857	4.6402	3.077	4.2833	3.333	3.9203	3.636

WEIGHT OF ROUND GALVANIZED-IRON PIPE AND ELBOWS OF THE PROPER GAUGES FOR BLAST-PIPE SYSTEMS

Diameter of Pipe, in Inches.	Gauge of Iron.	Weight per Running Foot, in Pounds.	Actual Weight of Full Elbow.	Diameter of Pipe, in Inches.	Gauge of Iron.	Weight per Running Foot, in Pounds.	Actual Weight of Full Elbow.
3	25	0.9	0.6	38	18	23.7	179.8
4	25	1.3	1.1	39	18	24.3	189.4
5	25	1.6	1.6	40	18	24.9	199.2
6	25	1.9	2.3	41	16	31.5	258.4
7	25	2.1	3.0	42	16	32.2	270.7
8	25	2.4	3.9	43	16	32.9	283.3
9	25	2.7	4.9	44	16	33.7	296.2
10	25	3.0	6.0	45	16	34.5	310.3
11	24	3.7	8.2	46	16	35.2	323.8
12	24	4.1	9.8	47	16	35.9	337.6
13	24	4.4	11.4	48	16	36.7	352.6
14	24	4.7	13.2	49	16	37.4	367.0
15	24	5.0	15.1	50	16	38.2	381.6
16	24	5.4	17.1	51	16	39.0	397.6
17	22	6.9	23.5	52	16	39.7	412.8
18	22	7.3	26.3	53	16	40.5	430.5
19	22	7.7	29.3	54	16	41.4	447.5
20	22	8.2	32.8	55	16	42.3	464.8
21	22	8.5	35.9	56	16	43.0	481.3
22	22	8.9	39.3	57	16	43.8	499.2
23	20	11.0	50.7	58	16	44.5	516.2
24	20	11.5	55.1	59	16	45.3	533.6
25	20	12.0	59.9	60	16	46.0	552.5
26	20	12.4	64.3	61	14	57.5	701.5
27	20	12.9	69.9	62	14	58.4	724.2
28	20	13.4	75.2	63	14	59.3	747.2
29	20	13.9	80.6	64	14	60.3	771.8
30	20	14.4	86.3	65	14	61.2	795.6
31	20	14.9	92.4	66	14	62.2	821.4
32	18	20.0	127.4	67	14	63.0	844.2
33	18	20.6	135.8	68	14	64.0	870.4
34	18	21.2	144.2	69	14	65.0	897.0
35	18	21.8	152.7	70	14	66.0	924.0
36	18	22.4	161.5	71	14	67.0	951.4
37	18	23.0	170.5	72	14	67.9	977.5

FACTOR TABLE FOR REDUCING THE WEIGHT OF GALVANIZED-IRON PIPE OF ONE GAUGE TO THAT OF ANOTHER GAUGE

Gauge.	GAUGE AND WEIGHT IN POUNDS PER SQUARE FOOT.																
	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
	4.53	3.91	3.28	2.97	2.66	2.41	2.16	1.90	1.66	1.53	1.41	1.28	1.16	1.03	0.91	0.84	0.78
12	1.00	0.86	0.72	0.66	0.59	0.53	0.48	0.42	0.37	0.34	0.31	0.28	0.26	0.23	0.20	0.19	0.17
13	1.16	1.00	0.84	0.76	0.68	0.62	0.55	0.49	0.43	0.39	0.36	0.33	0.30	0.26	0.23	0.22	0.20
14	1.38	1.19	1.00	0.91	0.81	0.74	0.66	0.58	0.52	0.47	0.43	0.39	0.35	0.32	0.28	0.26	0.24
15	1.53	1.32	1.10	1.00	0.90	0.81	0.73	0.64	0.56	0.52	0.48	0.43	0.39	0.35	0.31	0.28	0.27
16	1.70	1.47	1.23	1.11	1.00	0.91	0.81	0.71	0.62	0.58	0.53	0.48	0.44	0.39	0.34	0.32	0.29
17	1.88	1.62	1.36	1.23	1.10	1.00	0.90	0.79	0.69	0.63	0.59	0.53	0.48	0.43	0.38	0.35	0.32
18	2.10	1.81	1.52	1.38	1.23	1.12	1.00	0.88	0.77	0.71	0.65	0.59	0.54	0.48	0.42	0.39	0.36
19	2.38	2.06	1.73	1.56	1.40	1.27	1.14	1.00	0.87	0.81	0.74	0.67	0.61	0.54	0.48	0.44	0.41
20	2.72	2.36	1.98	1.79	1.60	1.45	1.30	1.16	1.00	0.92	0.85	0.77	0.70	0.62	0.55	0.51	0.47
21	2.96	2.56	2.14	1.94	1.74	1.57	1.41	1.24	1.09	1.00	0.92	0.84	0.76	0.67	0.59	0.55	0.51
22	3.21	2.77	2.32	2.10	1.89	1.71	1.53	1.35	1.18	1.08	1.00	0.91	0.82	0.73	0.65	0.60	0.55
23	3.54	3.07	2.56	2.32	2.08	1.88	1.69	1.49	1.30	1.20	1.10	1.00	0.91	0.81	0.71	0.66	0.61
24	3.90	3.37	2.82	2.56	2.29	2.08	1.86	1.61	1.43	1.32	1.22	1.10	1.00	0.89	0.78	0.72	0.67
25	4.40	3.79	3.18	2.88	2.58	2.34	2.10	1.86	1.61	1.49	1.37	1.24	1.12	1.00	0.88	0.82	0.76
26	4.98	4.30	3.60	3.26	2.92	2.65	2.37	2.10	1.82	1.68	1.55	1.41	1.27	1.13	1.00	0.92	0.86
27	5.40	4.66	3.90	3.54	3.17	2.87	2.57	2.28	1.96	1.82	1.68	1.52	1.38	1.23	1.08	1.00	0.93
28	5.81	5.01	4.20	3.80	3.41	3.09	2.77	2.45	2.13	1.96	1.81	1.64	1.49	1.32	1.17	1.08	1.00

In the preceding table the weights as given include the weight of rivets and solder, and due allowance has been made for laps and trimmings. The elbows have the internal radius equal to the diameter of the pipe. Rectangular pipes are usually made of the same gauge as round pipes of equivalent area.

The table above serves for the estimation of weights of pipe of other gauges than those given in the preceding table. Thus, suppose it is desired to find the weight of 28-in. pipe made of No. 16 gauge. From the preceding table, pipe of this size made of No. 20 gauge weighs 13.4 lbs. per running foot. By the table above, the figure found at the junction of the column headed 16 and the line designated 20 is 1.60; therefore, the weight per foot of No. 16 gauge is 13.4 × 1.60 = 21.44 lbs.

Capacity of Flues.—It is necessary to provide large flue capacity and to carry the full area right up to the furnace ports, which latter may be slightly reduced to give the gas a forward impetus. Generally speaking, the net area of a flue should not be less than one-sixteenth of the area of the gas-making surface in the producers supplying it. Or it may be stated thus: The carrying capacity of a hot gas flue is equivalent to 200 lbs. of coal per hour per square foot of section. Thus a brick-lined flue 4 ft. diameter inside the lining will carry the gas made from 2500 lbs. of coal per hour (12½ sq.ft. × 200), and will serve a gas-making area of 200 sq.ft. (12½ × 16), which corresponds to four 8-ft. producers.

In addition to proper size, it is necessary to provide proper facilities for occasional cleaning out. The accumulation of soot is not very rapid unless the producers are over-driven, and it can be easily burned out by shutting off the steam from the producers, opening a few cleaning doors, and allowing the air to sweep through the hot flue. The soot takes fire and burns away. If time is short, the process can be hastened by using a by-pass connection to the stack, so as to get its draft right on the flue without passing through the furnace; and it can be hastened, if necessary, by hoeing through the cleaning doors and using a steam jet to loosen the soot from the walls of the flue.

Natural Gas Measurement.—The Chapin-Fulton Manufacturing Company contributes the following information on the measurement of the volume or output of natural gas wells and pipes:

To measure the volume or output in cubic feet per hour of a gas well or of any orifice discharging gas into the atmosphere, an instrument called the Pitot Tube Gauge, named from Pitot, its inventor, is used. This instrument is remarkable for its simplicity and accuracy of results, and its principle is that the instrument gives the velocity of the current at the point of its application, which velocity, multiplied by the sectional area of the stream, gives the volume of the flow. The simplest form of the instrument is a small tube bent at right angles, the open end of which is inserted in the well mouth at right angles to the flow, and to the opposite end of which is attached a pressure gauge. For convenience the connection may be made with a piece of flexible hose. For wells of light volume, a U-water or mercury gauge is used, and if the wells have a strong flow and show a pressure running into pounds, an accurate steam gauge must be used. The open end of the small pipe should be held just below the top of the pipe or flush with it, and at one-fourth of the diameter from the outer edge.

The formula from which the following tables were worked out was first applied to flowing gases by Prof. S. W. Robinson, of the Ohio State University, in which the specific gravity of the gas is taken at 0.6.

The number of cubic feet per hour that will pass out of a circular opening one inch in diameter at pressure measured by a column of water or mercury, or by a spring gauge, is given in the following tables. The third table contains multipliers for sizes of pipe less and greater than one inch.

For any specific gravity other than 0.6, multiply the result obtained by

$$\sqrt{\frac{0.6}{\text{Specific gravity gas}}}.$$

For temperature of flowing gas when observed above 60° F. deduct 1% for each 5°, and add a like amount for temperature less than 60° F. In obtaining the approximate flow of a gas well, these corrections are usually neglected.

Example 1. Suppose it is required to find the cubic feet output per day of a gas well or an orifice discharging from a two-inch opening, the gauge in the Pitot tube showing a water pressure of 5 inches. In Table I, opposite this figure we find 3500 cubic feet, which is the volume discharged by a one-inch opening, but as two-

inch pipe was the size on which the test was made this amount must be multiplied by the multiplier in the third table for two-inch pipe, which is 4. Then we have 3500×4×24 hours = 336,000 cu.ft., the daily flow.

Example 2. Suppose it is required to find the output per day of a gas well or orifice discharging from a three-inch opening, the gauge showing a pressure of 30 pounds. Opposite this figure in Table II we find 37,945. Using the multiplier for three-inch pipe in Table III, which is 9, we have 37,945×9×24 = 8,196,120 cu.ft. daily output of well.

TABLE I—LOW-PRESSURE DISCHARGE

DISCHARGE OF GAS OF 0.6 SPECIFIC GRAVITY FROM 1-INCH OPENING, CORRESPONDING TO WATER PRESSURE IN INCHES

Pressure in Inches.	Cubic Feet per Hour.	Pressure in Inches.	Cubic Feet per Hour.	Pressure in Inches.	Cubic Feet per Hour.	Pressure in Inches.	Cubic Feet per Hour.
0.10	495	0.90	1485	3.50	2928	10.00	4950
0.20	714	1.00	1555	4.00	3130	11.00	5215
0.30	857	1.25	1738	4.50	3321	12.00	5422
0.40	980	1.50	1915	5.00	3500	13.85	5800
0.50	1106	1.75	2070	6.00	3834	20.77	7110
0.60	1213	2.00	2214	7.00	4140	27.70	8200
0.70	1310	2.50	2475	8.00	4428		
0.80	1401	3.00	2712	9.00	4694		

TABLE II—HIGH-PRESSURE DISCHARGE

DISCHARGE OF GAS OF 0.6 SPECIFIC GRAVITY FROM 1-INCH OPENING, CORRESPONDING TO PRESSURE OF MERCURY COLUMN AND OF GAUGE PRESSURE

Mercury Pressure in Inches.	Pounds Gauge Pressure per Square Inch.	Cubic Feet per Hour.	Mercury Pressure in Inches.	Pounds Gauge Pressure per Square Inch.	Cubic Feet per Hour.	Pounds Gauge Pressure per Square Inch.	Cubic Feet per Hour.
0.10	0.05	1,835	5.59	2.75	13,375	14.00	28,495
0.20	0.10	2,590	6.10	3.00	14,175	15.00	29,295
0.30	0.15	3,170	6.61	3.25	14,755	16.00	30,045
0.40	0.20	3,655	7.11	3.50	15,320	17.00	30,755
0.50	0.25	4,095	7.62	3.75	15,850	18.00	31,415
0.60	0.30	4,490	8.13	4.00	16,370	20.00	32,730
0.70	0.35	4,850	8.64	4.25	16,875	22.00	33,470
0.80	0.40	5,180	9.15	4.50	17,360	25.00	35,620
0.90	0.45	5,495	9.65	4.75	17,845	30.00	37,945
1.02	0.50	5,790	10.16	5.00	18,330	35.00	40,040
1.52	0.75	7,095	12.20	6.00	19,835	40.00	41,945
2.03	1.00	8,195	....	7.00	21,555	45.00	43,605
2.54	1.25	9,165	....	8.00	22,600	50.00	45,080
3.05	1.50	10,030	....	9.00	23,735	60.00	47,380
3.56	1.75	10,830	....	10.00	24,815	75.00	50,975
4.07	2.00	11.550	....	11.00	25,915	90.00	54,350
4.57	2.25	12,275	....	12.00	26,775	100.00	55,705
5.08	2.50	12,950	....	13.00	27,695	110.00	57,055

TABLE III—MULTIPLIERS FOR PIPE OF OTHER DIAMETERS THAN ONE INCH

Diameter in Inches.	Multiplier.	Diameter in Inches.	Multiplier.	Diameter in Inches.	Multiplier.	Diameter in Inches.	Multiplier.	Diameter in Inches.	Multiplier.
$\frac{1}{16}$	0.0038	1	1.00	4	16.00	6	36.00	8	64.00
$\frac{1}{8}$	0.0156	$1\frac{1}{2}$	2.25	$4\frac{1}{4}$	18.00	$6\frac{1}{4}$	39.00	$8\frac{1}{4}$	68.00
$\frac{1}{4}$	0.0625	2	4.00	5	25.00	$6\frac{5}{8}$	43.90	9	81.00
$\frac{1}{2}$	0.2500	$2\frac{1}{2}$	6.25	$5\frac{3}{16}$	26.90	7	49.00	10	100.00
$\frac{3}{4}$	0.5625	3	9.00	$5\frac{5}{8}$	31.60	$7\frac{1}{4}$	52.50		

High Pressures.—A standard cubic foot of gas is a cubic foot measured under a compression equal to the atmospheric pressure, which we will call for convenience 15 lbs. Now suppose gas is passing through a meter at a gauge pressure of 15 lbs., then each cubic foot will have a value of 2. The gas is then under a compression of two atmospheres, one atmosphere (15 lbs.) within the pipe, counterbalanced by the external pressure of the atmosphere, and therefore not indicated on the gauge, and one atmosphere (15 lbs.) indicated, and as the volume of gas is increased once for every atmosphere, we have

$$\frac{15+15}{15} = 2.$$

That is, a cubic foot of gas measured at a gauge pressure of 15 lbs. is the equivalent of 2 standard feet. It must be remembered that gas will not flow from a pipe until its internal pressure is equal to the atmospheric pressure. If it were less, the atmosphere would flow into the pipe, hence we must always assume that we start with one atmosphere (15 lbs.) before the gauge begins to indicate. Then to obtain a multiplier for gas measured at any number of lbs., we would have the formula

$$\frac{p+h}{h} = M, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

in which p is the gauge pressure in lbs.

h is the atmospheric pressure (assumed 15 lbs).

M is the multiplier required.

But the atmospheric pressure is a little less than 15 lbs, and for the elevations generally of present natural gas fields, it is usually taken at 14.4 lbs., and substituting this value in formula (1), we have

$$\frac{15+14.4}{14.4} = 2.0416,$$

which is the multiplier for gas measured at 15 lbs. gauge pressure, and sold on the atmospheric basis.

Again, since gas is usually sold at standard pressure of ounces to the square inch, we must add this pressure to the divisor in formula (1).

We then have formula

$$\frac{p+h}{h+.25}=M,\ \ \cdots\cdots\cdots\cdots\quad(2)$$

in which M is the multiplier required.

p is the guage pressure in lbs.

h is the atmospheric pressure of 14.4 lbs.

0.25 is 4-ounce pressure reduced to lbs.

For Example.—Suppose it is required to find the multiplier for gas measured at 30 lbs. gauge pressure, and sold at the standard pressure of 4 ounces. Then substituting the known quantities in formula (2) we have

$$\frac{30+14.4}{14.4+.25}=\frac{44.4}{14.65}=3.0307,$$

the required multiplier. Hence, if the meter had registered 1,000,000 cu.ft. the correct number of feet at 4-ounce pressure would be 1,000,000×3.0307=3,030,700 cubic feet.

If it be desired to sell gas on any other basis than a 4-ounce pressure, then we have formula

$$\frac{p+h}{h+n}=M,\ \ \cdots\cdots\cdots\cdots\quad(3)$$

in which p is the gauge pressure in lbs.

h is the atmospheric pressure in lbs.

n is the agreed pressure or basis of measurement in lbs.

M is the multiplier required.

Example.—Suppose it is required to sell gas at one lb. to the square inch as the standard of measurement, and the gauge pressure of the meter is 25 lbs. Substituting known values in formula (3) we have

$$\frac{25+14.4}{14.4+1}=\frac{39.4}{15.4}=2.5584,$$

the required multiplier. If 1,000,000 cu.ft. has been registered by the meter, then 1,000,000×2.5584=2,558,400, the correct amount at a standard pressure of·1 lb.

In like manner a multiplier may be obtained for any standard, delivered at any gauge pressure.

For convenience we append a table of multipliers to be used for guage pressures greater than 4 ounces per square inch, in which the standard is 4 ounces, but from the foregoing formula multipliers may be readily figured to suit any conditions of measurement.

In this table decimals are carried out to four figures; any further extensions would not change the result more than 100 cubic feet in 1,000,000.

Gauge Pressure, Pounds per Sq.In.	Multiplier or Density.	Gauge Pressure, Pounds per Sq.In.	Multiplier or Density.	Gauge Pressure, Pounds per Sq.In.	Multiplier or Density.	Gauge Pressure, Pounds per Sq.In.	Multiplier or Density.	Gauge Pressure, Pounds per Sq.In.	Multiplier or Density.
0	0.9829	24½	2.6553	49½	4.3617	74½	6.0682	99½	7.7747
¼	1.0000	25	2.6894	50	4.3959	75	6.1023	100	7.8088
½	1.0170	25½	2.7235	50½	4.4300	75½	6.1365	100½	7.8430
1	1.0511	26	2.7577	51	4.4642	76	6.1706	101	7.8771
1½	1.0853	26½	2.7918	51½	4.4983	76½	6.2047	101½	7.9112
2	1.1194	27	2.8259	52	4.5324	77	6.2389	102	7.9453
2½	1.1535	27½	2.8600	52½	4.5665	77½	6.2730	102½	7.9795
3	1.1877	28	2.8942	53	4.6007	78	6.3071	103	8.0136
3½	1.2218	28½	2.9283	53½	4.6348	78½	6.3413	103½	8.0477
4	1.2559	29	2.9624	54	4.6689	79	6.3754	104	8.0819
4½	1.2901	29½	2.9966	54½	4.7031	79½	6.4095	105	8.1501
5	1.3242	30	3.0307	55	4.7372	80	6.4436	106	8.2184
5½	1.3583	30½	3.0648	55½	4.7713	80½	6.4778	107	8.2866
6	1.3924	31	3.0990	56	4.8055	81	6.5119	108	8.3549
6½	1.4266	31½	3.1331	56½	4.8396	81½	6.5460	109	8.4232
7	1.4607	32	3.1672	57	4.8737	82	6.5802	110	8.4914
7½	1.4948	32½	3.2013	57½	4.9079	82½	6.6143	111	8.5597
8	1.5290	33	3.2355	58	4.9420	83	6.6484	112	8.6279
8½	1.5631	33½	3.2696	58½	4.9761	83½	6.6825	113	8.6962
9	1.5972	34	3.3037	59	5.0102	84	6.7167	114	8.7645
9½	1.6314	34½	3.3379	59½	5.0444	84½	6.7508	115	8.8327
10	1.6655	35	3.3720	60	5.0785	85	6.7849	116	8.9010
10½	1.6996	35½	3.4061	60½	5.1126	85½	6.8191	117	8.9692
11	1.7338	36	3.4403	61	5.1468	86	6.8532	118	9.0375
11½	1.7679	36½	3.4744	61½	5.1809	86½	6.8873	119	9.1058
12	1.8020	37	3.5085	62	5.2150	87	6.9215	120	9.1740
12½	1.8361	37½	3.5426	62½	5.2491	87½	6.9556	121	9.2423
13	1.8703	38	3.5768	63	5.2833	88	6.9897	122	9.3105
13½	1.9044	38½	3.6109	63½	5.3174	88½	7.0238	123	9.3788
14	1.9385	39	3.6450	64	5.3515	89	7.0580	124	9.4471
14½	1.9727	39½	3.6792	64½	5.3856	89½	7.0921	125	9.5153
15	2.0068	40	3.7133	65	5.4198	90	7.1262	126	9.5836
15½	2.0409	40½	3.7474	65½	5.4539	90½	7.1604	127	9.6518
16	2.0751	41	3.7816	66	5.4880	91	7.1945	128	9.7201
16½	2.1092	41½	3.8157	66½	5.5221	91½	7.2286	129	9.7884
17	2.1433	42	3.8498	67	5.5563	92	7.2628	130	9.8566
17½	2.1774	42½	3.8839	67½	5.5904	92½	7.2969	131	9.9249
18	2.2116	43	3.9181	68	5.6245	93	7.3310	132	9.9931
18½	2.2457	43½	3.9522	68½	5.6587	93½	7.3651	133	10.0614
19	2.2798	44	3.9863	69	5.6928	94	7.3993	134	10.1296
19½	2.3140	44½	4.0205	69½	5.7269	94½	7.4334	135	10.1979
20	2.3481	45	4.0546	70	5.7610	95	7.4675	136	10.2662
20½	2.3822	45½	4.0887	70½	5.7952	95½	7.5017	137	10.3344
21	2.4164	46	4.1228	71	5.8293	96	7.5358	138	10.4027
21½	2.4505	46½	4.1570	71½	5.8634	96½	7.5699	139	10.4709
22	2.4846	47	4.1911	72	5.8976	97	7.6041	140	10.5392
22½	2.5187	47½	4.2252	72½	5.9317	97½	7.6382	141	10.6075
23	2.5529	48	4.2592	73	5.9658	98	7.6723	142	10.6757
23½	2.5870	48½	4.2935	73½	6.0000	98½	7.7064		
24	2.6212	49	4.3276	74	6.0341	99	7.7406		

CHIMNEYS

The chimneys of furnaces should be so designed as to relieve the furnace of the products of combustion as rapidly as formed and maintain thereby an equilibration of pressure therein. This service must lie between two extremes, both of which tend to evil results, and may be termed insufficient and over-ventilation.

From the first, the accumulation of inert gases in the furnace form a back pressure or damper upon combustion, and retard the reliability of combustion and the efficiency of the furnace.

Upon the second, or over-ventilation, the tendency is either to draw in an excess of air through any apertures, fissures, or cracks which may exist, and thereby reduce the temperature of the furnace, or it may carry the products of combustion away from the flame with such rapidity that there is not sufficient time contact between these products and the contents of the furnace, the mufflers, or reverberators, with the result that their sensible heat is not absorbed and escapes unused into the atmosphere.

The net loss of this latter is of course less in the case of recuperators or regenerators where it is possible to recover a portion of this heat, but naturally the efficiency of such apparatus in the cycle is lower than the direct contact of the hot gases to the object to be heated.

The rate of flow of the products of combustion varies and it is usually a function of temperature where natural gas is used. In small house chimneys it is frequently as low as 3 to 4 ft. per second. In that of boiler chimneys from 6 to 15 ft. per second, while in furnace chimneys as high as from 10 to 20 ft. per second. The temperature of the first will probably lie between 100 to 200° C. (200° to 350° F.), the second-class between 100 to 300° C. (200 to 550° F.), and in the last between 300 to 1000° C. (550 to 1800° F.).

There are many more or less intricate formula for calculating the size and height of chimneys, but as a practical consideration it must be borne in mind that the pull or suction of a chimney is purely a matter of equilibrium between the weight of a column of hot gases and the weight of an equal column of air at atmospheric temperature. If the volume of the one, multiplied by its specific gravity at its average temperature, giving its weight, be subtracted from that of the other at atmospheric temperature, the difference will represent the amount of pressure or pull exerted over the area or cross-section of the chimney. This will represent the total head from which, for practical purposes, must be subtracted the velocity head and the friction head, the remainder equaling the net or available head.

The formula given by Richards in his metallurgical calculations for the head of gases in the chimney due to their heated condition in terms of external air, is in English units.

$$h_0 = H \left[\frac{1 - D + \frac{1}{491}[(t-32) - D(t'-32)]}{\left[1 + \frac{1}{491}(t'-32)\right]\left[1 + \frac{1}{491}(t-32)\right]} \right];$$

h_0 = total head of air in ft., at 32° F.

H = height of chimney in ft.

t = temperature in chimney.

t' = temperature of air outside.

D = specific gravity of chimney gas, air = 1.

Friction head may be said to be a function of the roughness of the walls and has been empirically determined to be about $\frac{1}{40}H$. It can be expressed in the formula

$$h \text{ (friction)} = 1.9 \frac{H}{d} K,$$

where K is 0.05 for a smooth interior, to 0.12 for a rough one, the average being 0.08, and d the diameter or side of square section.

The above equations are given merely to show the basis for calculation in ascertaining ventilation. For all practical purposes, tables are sufficiently accurate for purposes of practice, and they may be checked by calculating along the lines above indicated.

About 150 ft. represents the practical maximum height of chimneys; for greater capacity, chimneys in multiple should be used.

Chimney Draft.—The influence of temperature upon chimney draft is given by Sturtevant, who says that the changes in the temperature, either of the external atmosphere or the gases within the chimney, have a most marked influence upon the draft, is very clearly shown in the table below, in which the draft, as indicated in inches of water, is given for a chimney 100 feet high, with various internal and external temperatures. For any other height of chimney than 100 feet, the height of the water column is directly proportional to that of the chimney. Hence doubling the height doubles the draft. This is not to be confused with the fact that the velocity which the draft has power to create and the corresponding volume of air moved vary as the square root of the height. This table clearly indicates the necessity of high chimney temperatures for ample draft, and readily accounts for the stronger draft which exists in cold weather because of the greater temperature difference.

The ordinary form of draught-gauge, consisting of a U-tube containing water, lacks sensitiveness when used for measuring small quantities of draught. The Barrus draft-gauge multiplies the indication of the ordinary U tube as many times as may be desired. This instrument consists of a tube, usually made of half-inch glass, which is surmounted by two glass chambers having a diameter of about $2\frac{1}{2}$ ins., being arranged in the manner shown in Fig. 62. It is placed in a wooden case provided with a cover, the outside dimensions being $6\frac{1}{2} \times 20$ in.; this is screwed to the wall in

HEIGHT OF WATER COLUMN DUE TO UNBALANCED PRESSURES IN CHIMNEY
100 FEET HIGH

Tempera-ture in Chimney.	TEMPERATURE OF EXTERNAL AIR.										
	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°
200°	0.453	0.419	0.384	0.353	0.321	0.292	0.263	0.234	0.209	0.182	0.157
220	0.488	0.453	0.419	0.388	0.355	0.326	0.298	0.269	0.244	0.217	0.192
240	0.520	0.488	0.451	0.421	0.388	0.359	0.330	0.301	0.276	0.250	0.225
260	0.555	0.528	0.484	0.453	0.420	0.392	0.363	0.334	0.309	0.282	0.257
280	0.584	0.549	0.515	0.482	0.451	0.422	0.394	0.365	0.340	0.313	0.288
300	0.611	0.576	0.541	0.511	0.478	0.449	0.420	0.392	0.367	0.340	0.315
320	0.637	0.603	0.568	0.538	0.505	0.476	0.447	0.419	0.394	0.367	0.342
340	0.662	0.638	0.593	0.563	0.530	0.501	0.472	0.443	0.419	0.392	0.367
360	0.687	0.653	0.618	0.588	0.555	0.526	0.497	0.468	0.444	0.417	0.392
380	0.710	0.676	0.641	0.611	0.578	0.549	0.520	0.492	0.467	0.440	0.415
400	0.732	0.697	0.662	0.632	0.598	0.570	0.541	0.513	0.488	0.461	0.436
420	0.753	0.718	0.684	0.653	0.620	0.591	0.563	0.534	0.509	0.482	0.457
440	0.774	0.739	0.705	0.674	0.641	0.612	0.584	0.555	0.530	0.503	0.478
460	0.793	0.758	0.724	0.694	0.660	0.632	0.603	0.574	0.549	0.522	0.497
480	0.810	0.776	0.741	0.710	0.678	0.649	0.620	0.591	0.566	0.540	0.515
500	0.829	0.791	0.760	0.730	0.697	0.669	0.639	0.610	0.586	0.559	0.534

an upright position. Two different liquids, which will not mix and which are of different color, are used for filling the instrument, one occupying the portion A, B, and the other, which is the heavier of the two, the portion B, C, D. When the right-hand tube is connected to the flue, the suction produced by the draught draws the line of demarcation B downward, and the amount of motion is proportional to the difference in the areas of the two chambers and of the U-tube, modified somewhat by the difference in the specific gravity of the liquids. By referring to the scale on the side the amount of motion is measured. This scale is movable, and can be adjusted to the zero-point by loosening the thumb-screws. The liquids generally employed are alcohol colored red and a certain grade of petroleum oil. A multiplication varying from 8 to 10 times is obtained in the instrument shown; in other words, with one-quarter inch draft, the movement of the line of demarcation is from 2 in. to $2\frac{1}{2}$ in., the exact amount of multiplication being determined by calibration referred to a standard instrument.
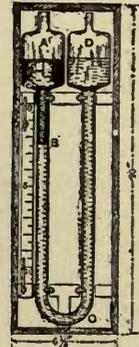
Fig. 240.—Barrus Draft Gage.

Weight of Chimney Gas.—Prof. Junkers in an article upon the "Removal of Flue Gases from Gas Fires," in the *Journal of Gas Lighting* (Apr. 14th, 1908), discusses chimneys at length, an excerpt of his remarks being herewith given:

"In order that the combustion products may be carried away at the proper speed, a certain amount of energy derived from the ascensional force of the gases is required to overcome the resistance in the flue. This force depends upon the height of the flue and the specific gravity of the products. It is shown that, at any given

temperature, the removal of the water vapor increased the specific gravity of the gases and diminishes their ascensional force, and that an excess of air prevents condensation, and is, accordingly, advantageous both in maintaining the ascensional force and in preserving the inner surface of chimneys from injury by condensation."

The gravity of the waste products depends also upon their temperature. It must be understood, however, that this is the mean temperature, since a reduction in the temperature of the gases at the inlet of a flue, brought about by the introduction of some air there, does not necessarily involve a reduction of the mean temperature of the gases within the flue.

From a properly designed flue the gases escape at a temperature still exceeding that of the surrounding atmosphere. If the chimney, however, removes so much heat from the gases that they fall almost to the temperature of the air before leaving the top, water may be condensed so that the residual gas becomes heavier than air, and the draft of the flue is damped. It may happen during a very hot day after cold weather that the walls of the flue are cooler than the air, when a definite down-draft may be established.

If a domestic heating apparatus, consisting of stove and chimney, is so erected that both the top and bottom of the chimney are equally exposed to the wind, no practical interference with the chimney is likely to result; but if one end of the flue is more exposed than the other, as usually obtains in houses, the effect may be either an increase or decrease in the draft, according to the suction or pressure exerted by the wind at the outlet of the chimney and in the apartment. The conditions are always alterable by opening or closing windows in the room, according to the direction of the wind.

Smoke.—Smoke, whether produced from gaseous or direct firing, is usually the product of (a) relative low temperature of fuel bed, or (b) excess depth of fuel bed. As a matter of fact visible smoke is usually tarry vapor or hydrocarbons from the distillation zone which have been distilled at a temperature lower than their point of ignition. These vapors of course entrain lamp black and dust which are carried upward with them by the gases of combustion. The smoke derived from combustion of producer gas is rarely of an objectionable nature, but is occasionally apparent for the reasons aforementioned.

In discussing the subject of smoke in his work on " Liquid and Gaseous Fuels " (p. 17), Professor Lewes says as follows:

" Of the three gaseous products of combustion steam alone plays an important part in the formation of smoke, whilst the other important constituents are tar vapor, minute particles of unburned carbon, and ash, drawn upwards by the draft created by the fire.

" The popular idea held by many is that smoke consists mainly, if not entirely, of particles of carbon rendered slightly adhesive by tarry matters, and that it is in fact like the soot found deposited in the chimney. But a microscopic examination of smoke reveals a far more interesting condition of things. A very beautiful experiment, first made by Mr. Frederick Hovenden, is to show that if one takes the smoke from a cigar or cigarette, and blows it into a little glass chamber highly illuminated from below by focusing upon it the beam from an electric lantern or limelight, and examines it under a microscope, it presents a most remarkable and wonderful appearance. Such

smoke contains no particle of free carbon, but appears to consist of an immense number of little round particles in the wildest condition of commotion and movement, each particle rushing about and never coming in contact with its neighbor. Indeed, it presents as beautiful a picture as one could imagine of the molecular movement with which theorists have endowed matter. On still further examination these little particles prove to be tiny vesicles, the skins of which are formed of condensed vapor and liquids from the burning substances which give rise to them. These vesicles, being filled with gases, are excessively light, and float in the atmosphere until brought forcibly in contact with some surface, which causes them to burst and deposit the liquid film, so setting the contents free.

" Whether this cloud of floating vesicles be derived from a cigarette, a coal fire, or other source, if they are collected in such a way as by friction to cause the tiny vessels to burst, one obtains a liquid which comes under the generic heading of " tar," this tar being a highly complex mixture of many different organic liquids formed by the action of heat on the constituents of the burning matter, whilst the gases which escape from the interior of the vesicles on the rupture of the skin consist of nitrogen, carbon dioxide, carbon monoxide, hydrogen, trace of oxygen, and such hydrocarbons as methane.

"The smoke, however, from the combustion of oil or coal, when burned with an insufficient air supply, forms a heavy black cloud, the deepening of density and color being due to the presence in it of minute particles of unconsumed carbon, which have been deposited by premature cooling or during secondary chemical actions taking place in the flame of the burning material.

"The domestic grate using bituminous coal is the chief cause of the smoke curse, which pollutes our town atmospheres.

"The idea that smoke means a large waste of fuel is erroneous, and, in point of fact, the carbon wasted as soot is extremely small, and varies in smoke with the state of the fuel which is fed on to the fire. Under the ordinary conditions, experienced in any ordinary fire grate, in which the fire has just been made up with bituminous coal, the heavy smoke escaping will contain on an average $1\frac{1}{2}\%$ of the total weight of fuel consumed, and as the temperature of the mass gradually increase, this falls to less than $\frac{1}{2}\%$, whilst when the fire is burning clear, no smoke at all is given off. In the same way that we have a rapid fall in the carbons given off as soot, so we also find a fall in the hydrocarbons liberated as tar vapor, whilst the gases evolved as products of combustion vary in the same way with the condition of the fire. When the coal is first put on the fire imperfect combustion in its mass takes place, and the gases passing up the flue under these conditions will closely approximate to the following analysis:

Carbon dioxide	0.70
Methane	0.36
Hydrogen	0.29
Carbon monoxide	0.01
Oxygen	19.85
Nitrogen	79.79

showing that the combustion, owing to the cooled surface at the top of the fire and excessive dilution with inert nitrogen, is very incomplete. Gradually, however, as the

temperature rises, less and less combustible matter escapes, whilst as soon as the fire begins to burn clear, the products of combustion are practically simply carbon dioxide and water vapor."

Dr. Lewes also gives his analysis of the smoky elements of the atmosphere which have been precipitated on the roofs of some orchid houses at Chelsea by rain or snow, which is as follows:

Carbon 39.00%
Hydrocarbons 12.30%
Organic bases 1.20%
Sulphuric acid 4.33%
Ammonia 1.37%
Metallic iron and magnetic oxide 2.63%
Other mineral matter, chiefly silica and ferric oxide 31.24%
Water not determined.

CHAPTER XXI

MATERIALS: FIRE CLAY, MASONRY, WEIGHTS, AND ROPE

FIRE CLAYS

E. P. Page and W. J. Rees, make the following comments in an article upon the valuation of "Fire Clays" in the *Gas World*, Feb. 22d, 1908, a digest of which is as follows:

A clay cannot be considered refractory which is not equal in fire-resisting properties to Cone 26, in the Seger series (about 1650° C.). The rule adopted by the German Association of Fire-brick Manufacturers, is: " The limits of refractoriness is to be considered as exceeded when the material, or one of its constituents, uniformly distributed in fragments, begins to melt or separate by liquidation; not only the surface of the piece tested, but also the face of the fracture must be taken into consideration when judging."

Chemical analysis is of value as indicating the presence or absence of deleterious substances. A large portion of fluxing impurities, such as iron oxides, lime, titanium, alkalies, etc., will naturally seriously affect the value of a clay. The usual method of using the ultimate analysis is to consider only the ratio of total fluxes to silica; but Richter, Bischof, and Seger showed, years ago, that this was unsatisfactory, as it left the alumina contents of the clay entirely out of consideration. The primary ratio to be taken into consideration is that of silica to alumina, and it is the ratio of total fluxes to this ratio which is important. The exact state of the presence of the silica in the clay is also very important. If this is in a fine amorphous state it may be lead to fluxing, while, if in comparatively coarse particles, it renders the clay more refractory.

A mineralogical analysis by treatment with sulphuric acid and caustic soda to remove the clay, and treating the residue for the determination of alumina, iron, and alkalies, is useful, and gives good practical information, indicating, to some extent, the probable behavior of clays at high temperatures as to fusibility.

In a mechanical analysis, the clay is first broken down by boiling, and a microscopical examination of the coarser particles is made. To obtain definite information and measurement of the grains recourse must be had to elutriation.

The specific gravity and porosity are useful in determining the structure of the manufactured article, the porosity test being generally considered the most useful. At the present time the porosity is expressed either as the percentage of water absorbed by a given weight of dry brick, or else—and more rationally—as the volume of pore

space to that of the brick. The term " specific gravity " is also used ambiguously as being either the gravity of the clay or as that of the whole piece.

The old method of testing refractoriness by mixing pure quartz sand with clay to be tested and determining the proportion of sand necessary to cause the test piece to run to a liquid at same temperature as a standard clay, was not satisfactory. Bischof used standard clays as a means of comparison, and Seger adopted mixtures of silica, alumina, etc., forming the mixtures into " cones." The most modern, and, it is claimed, the most accurate, method, is to expose the clay to the high temperatures of the electric furnace. Inasmuch, however, as furnace gases, dust, and time factor enter into the question, a comparison with standard mixtures of comparative purity for the same length of time and at the same furnace temperature is of greater value than the limit of refractoriness in so many degrees.

Fire-Brick Testing.—The temperature of resistance of fire bricks in producers is not high, rarely exceeding 2000° or a maximum of 2500. This does not require a highly recalcitrant brick and the ordinary No. 3 grade is what is usually used.

Brick should be well shaped, clean cut, in order to make tight joints, which is the principal requisite, and should be sufficiently hard to resist erosion by clinkering.

The tests to apply to fire-brick to determine its quality, according to the trustees of the gas educational class, are as follows:

The qualities desired in fire-brick are: infusibility, strength, regularity of shape, uniformity of composition, and facility of cutting; and the tests to be applied to a fire-brick should be such as to determine to what extent it possesses these qualities.

The degree of infusibility can be determined, to a certain extent, by an analysis of the material of which the brick is composed. If this analysis shows the presence of about 60% of silica, less than 6% of sesqui-oxide of iron and not more than 2 to 3% as a total of lime, magnesia, and the hydrates of potassium and sodium, the brick probably possesses a high degree of infusibility. If the analysis shows more than 6% of sesqui-oxide of iron or 2 to 3% of the lime, magnesia, etc., the brick should be rejected. But exposure of the brick to the action of heat under the conditions to which it will be subjected when used furnishes the best test for infusibility. In coal gas works the test can be made by placing the brick in the combustion chamber of a regenerative bench. If, when the brick is removed after being exposed for a week or ten days to the heat of the combustion chamber, the edges and corners are found to be sharp, and the surfaces show no signs of incipient fusion, the brick may be passed as a first-class quality, as far as infusibility is concerned. In water-gas plants the space at the bottom of the super-heater, in which the secondary combustion occurs, furnishes a good place for the test.

If the material of which the brick is made is well compressed during manufacture, and the brick is hard burned there is no question as to its strength when cold. The degree to which compression has been carried is indicated by the weight of the brick, and a fire-brick of the regulation size, 9 in. $\times 4\frac{1}{2}$ in. $\times 2\frac{1}{2}$ in., should weigh from $7\frac{1}{4}$ to $7\frac{1}{2}$ lbs. A well burnt brick usually shows a reddish tinge. A well compressed and well burnt brick will give a ringing sound when struck with a hammer. It is especially important that the bricks that are to be used for lining the furnaces of retort benches, or for lining water gas generators, should be hard, since they are subjected to a great deal of abrasion from the fuel and the clinkering bars,

so that for this work hardness and strength are of more importance than infusibility. In the combustion chamber, on the contrary, infusibility is the most important quality, since the material used there is not exposed to any wear and tear except that arising from the effect of the heat. It may thus frequently happen that the same brick is not suitable for use both in the furnace and the combustion chamber. An examination of the exterior of the brick is all that is necessary to determine whether it possesses regularity of shape.

Uniformity of composition can be tested by breaking the brick and examining the surface of the fracture. This should present a compact and uniform appearance, though not necessarily a close and fine texture. In fact some authorities consider a coarse texture to be preferable. Uniformity of composition is also indicated by the giving out of a clear ringing sound when the brick is struck a sharp blow with the hammer.

Facility of cutting is important only as reducing the cost of labor and the amount of waste during the operation of laying the brick, and while desirable, if it can be secured without sacrificing the more important qualities, it cannot be considered an equivalent for any one of them.

Shapes.—Fire-brick are made in standard shapes for almost any construction met with in practice. The regular fire-brick is $9 \times 4\frac{1}{2} \times 2\frac{1}{2}$ ins. and is called "9 straight." They are made $1\frac{1}{4}$ ins. thick instead of $2\frac{1}{2}$ ins. and are called "split brick." Half as wide, $2\frac{1}{4}$ ins. instead of $4\frac{1}{2}$ ins., are called "soap brick."

To make arches and circles, tapering brick are made. "Key brick" taper from $4\frac{1}{2}$ ins. at one end to 4 ins. or smaller at the other. "Arch brick" taper from $2\frac{1}{2}$ ins. at one edge to 2 ins. or smaller at the other. "Wedge brick" taper from $2\frac{1}{2}$ ins. at one end to 2 ins. or smaller at the other. Besides these enumerated, there are several other standard shapes of less importance. The taper brick lay circles of a definite diameter. Circles of larger diameter can be laid by inserting straight brick at regular intervals.

Fire-Brick Joints.—The joints in furnace construction should be as close as possible. The brick should rest on each other, the fire-clay should only close the crack remaining.

The following is an analysis of several heat-resisting materials:

	Fire Clay.	Asbestos.	Magnesia Brick.
Silica	50%	41.5%	1%
Alumina	35%	2.0%	..
Water	15%	13.5%	..
Magnesia	....	43.0%	95%
Iron oxide	....	....	4%

From this it is evident that the fire-resisting qualities are not dependent on any one constituent.

The water in the asbestos is partially driven out at a temperature below red heat, which leaves the asbestos so brittle that it may be reduced to a powder between the thumb and finger.

Notes.—Concerning fire-brick, the Stoe-Fuller Company of Cleveland, O., say as follows:

A standard fire-brick (straight) weighs 7 lbs.

A standard silica brick weighs 6.2 lbs.

A standard magnesia brick weighs 9 lbs.

A standard chrome brick weighs 10 lbs.

A silica brick expands about $\frac{1}{8}$ in. per ft., when heated to 2500°.
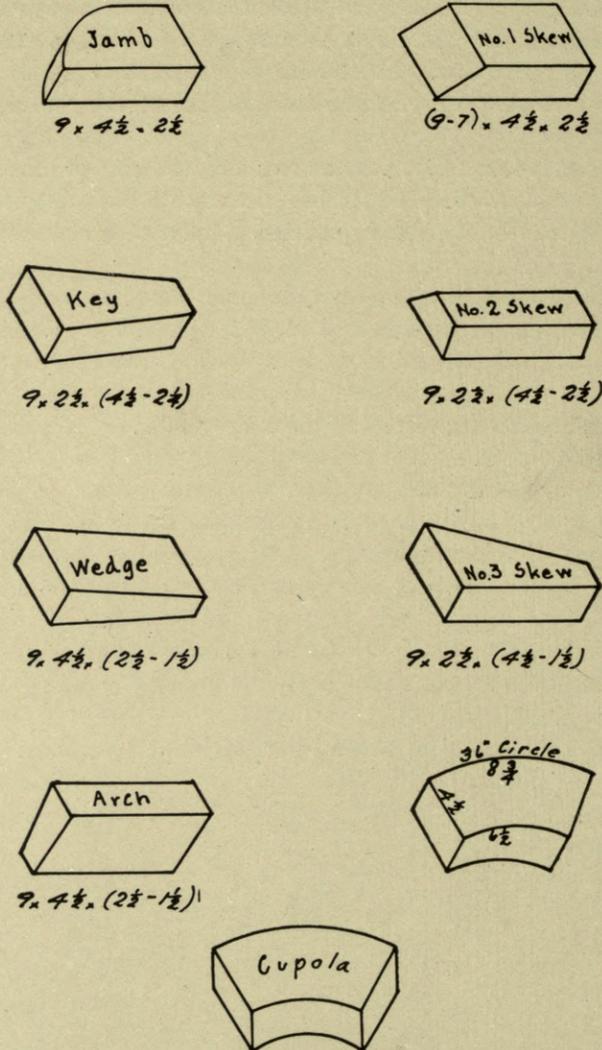
Fig. 241.—Fire-brick Shapes.

Clay brick expand or shrink, dependent upon the proportion of silica to alumina contained in the brick; but most fire-clay brick contain alumina sufficient to show some shrinkage.

One cubic foot of wall requires 17 9-in. bricks; one cubic yard requires 460.   Where keys, wedges, and other " shapes " are used, add 10% in estimating the number required.

In ordering linings customers should send a sketch showing outline of space to be occupied by brick-work, or inside lines with thickness of walls desired, if possible.

Those ordering for cupolas and stacks should be careful to designate in order both inside and outside diameters with height.

Silica brick, when necessary, should be laid in silica cement and with the smallest joint possible.

To secure the best results, fire-brick should be laid in the same clay from which they are manufactured.

One ton of ground clay should be sufficient to lay 3000 ordinary bricks.

Ground fire-brick or old cupola blocks mixed with fire-clay make the best cupola daub known.

Be careful of furnace stays.   Silica brick expand.   Fire-clay brick shrink.

Cool your furnaces slowly.

Cold air after extreme heat is the hardest test on good fire-brick.

The minimum carload of brick or clay is 40,000 lbs.

Clay for shipment by boat must be sacked or barreled.

MASONRY CONSTRUCTION

Foundations.—The stone used in making concrete, according to Baker, should be clean and of such a size as to pass in any direction through a 2½ in. ring.   The sand should be clean, sharp, and coarse.   A coarser sand than that used for making mortar for brick can be employed to advantage for concrete.   The proportions of the ingredients depend upon the strength required and upon the average size of the pieces of stone and of the grains of sand used, but, under ordinary conditions, the following proportions make a good concrete: 1 part of Portland cement, 2 parts of sand, 5 parts of broken stone.

Broken slag or coarse gravel, if entirely free from loam, may be substituted for the broken stone, and even when the latter is used, one or two parts of gravel may be added to the mixture as given above without decreasing the strength of the concrete.

For mixing the concrete a platform of plank about 10×16 ft. should be laid.   If the cement and sand are to be mixed wet, before being put on the stone, a mortar box should be placed at one end of this platform.   Measuring boxes to measure the sand and broken stone should be provided.   These are made with four sides only, being open both at the top and bottom.   They may be either of one-barrel capacity, or the one for the sand may be of two-barrel capacity and that for the stone of five-barrel capacity, if the mixture is to be as above, 1 to 2 to 5, and should be provided with handles so that they can be easily lifted and set to one side after the material has been measured.

The sand and cement should be measured in the mortar box and the stone measured and placed on the platform at the foot of the box in a layer about 6 to 8 ins. thick. The sand and cement are mixed, the stone is wet and the mortar spread in an even layer

on top of it.　The whole mass is then turned over a sufficient number of times to cause the stone and mortar to be thoroughly mixed together.　During this operation care should be taken to really turn the mass instead of merely shoveling it from one place to another. If properly handled two or three turnings should be sufficient to produce thorough mixture.

Sometimes the cement and sand are mixed and spread on the wet stone in a dry state, the whole mass then being turned over once to mix the stone and cement.　Water is then added while the mass is being turned a second time, and the turning continued until the mixture is completed.　When this method is followed there is no need of a mortar box, the cement sand being mixed on the platform.

In either case it is important not to use too much water, since wet concrete can not be compacted by ramming.　The proper quantity of water to be used should be determined by experimenting with the first two or three batches made, and the same amount should thereafter be used for each batch unless the temperature and humidity of the atmosphere change decidedly, in which case the amount of water will have to be varied to suit the changed conditions.

When thoroughly mixed the concrete should be put in barrows, carried to the excavation, dumped quietly into place and then rammed until the moisture appears on the surface.　In no case should it be thrown into place with shovels, or dropped from any height, since the result of such treatment is to separate the stone and mortar and prevent the formation of a solid block of concrete.

In preparing the excavation the earth at the bottom should not be disturbed, and should it be loosened it must be rammed until firm.　Where soft or yielding earth or sand occurs, the bottom should be planked and the concrete laid on this planking. The concrete should be laid in layers of not less than 5 ins. or more than 9 ins.　When joined to old work this should be carefully cleaned, wetted and dusted with dry cement.

Mortar.—A paste of good hydraulic cement hardens simultaneously and uniformly throughout the mass, and its strength is impaired by an addition of sand.　The relative quantities of sand and cement depend somewhat upon the condition of the ingredients when measured.　For ordinary use it is customary to add as much sand as is possible without making the mortar porous.　The proportions may vary from one part of cement and two parts of sand to one part of the former and four of the latter.

The proportion of sand and cement are generally measured by volumes.　In actual work the cement is usually divided in barrels, and consequently the most convenient unit for the cement is the commercial barrel, while it is most convenient to measure sand loose.

When the mortar is required in small quantities, as for use in ordinary masonry, it is mixed about as follows: about half the sand to be used in a batch of mortar is spread evenly over the bed of the mortar box; and then the dry cement is spread evenly over the sand; and finally the remainder of the sand is spread on top.　The sand and cement is then mixed with a hoe, or by turning and re-turning with a shovel.　It is very important that the sand and cement be thoroughly mixed.

The dry mixture is then shoveled to one end of the box, and the water is poured into the other end.　An excess of water is better than a deficiency, particularly when a very energetic cement is used, as the capacity of this substance for solidifying water is great.　The sand and cement are then drawn down with a hoe, small quantities

at a time, and mixed with the water until enough has been added to make a good stiff mortar. This should be vigorously worked with a hoe for several minutes to insure a complete mixture. The mortar should then leave the hoe clean when drawn out of it, and very little should stick to the steel.

Hydraulic cements set better and attain a greater strength under water than in the open air; in the latter, owing to the evaporation of the water, the water is liable to dry instead of setting. This difference is very marked in hot dry weather. If cement mortar is to be exposed to the air, it should be shielded from the direct rays of the sun, and kept moist by sprinkling or otherwise.

Grout is a thin or liquid mortar of lime or cement. The interior of a wall is sometimes laid up dry, and the grout, which is poured on top of the wall is expected to find its way downwards and fill up all voids, thus making a solid mass of the wall.

Grout should never be used when it can be avoided. If made thin, the water only slowly dries out of the wall; and if made thick, the grout fills only the upper portion of the wall. To get the greatest strength, the mortar should have only enough water to make a stiff paste—the less water the better. If the mortar is stiff, the brick or stone should be dampened before laying; else the brick will absorb the water from the mortar before it can be set, and thus destroy the adhesion of the mortar. (Baker's "Treatise on Masonry Construction.")

Cement mortar should be used in all thick walls, in all masonry subject to vibration, and in masonry exposed to water or moisture. It should be used, therefore, in the foundations of buildings and machinery, and in holder tank walls. Unlike lime mortar, good cement mortar increases in strength with age even under water or exposed to moisture—exposure to which will disintegrate lime mortar rapidly.

When cement is cheap it is a question whether it could not be substituted for lime in the mortar for even ordinary masonry. Its cost for such purpose when great strength is not required may be reduced without serious loss of strength by the addition to the mortar of from 20 to 25% of lime paste.

Laying Brick.—Baker's "Treatise on Masonry Construction" gives the following instructions: "Brick should not be merely laid, but every one should be rubbed and pressed down in such a manner as to force the mortar into the pores of the bricks and produce the maximum adhesion; with a quick setting cement this is still more important than with lime mortar. For the best work it is specified that the brick should be laid with a 'shove joint;' that is, that the brick should first be laid so as to project over the one below, and be pressed into the mortar, and then be shoved into its final position. Since bricks have great avidity for water, it is best to dampen them before laying. If the mortar is stiff and the brick dry, the latter absorb the water so rapidly that the mortar does not set properly and will crumble in the fingers when dry. Neglect in this particular is the cause of most of the failures of brick work. . . . Wetting the brick before laying will also remove the dust from the surface, which otherwise would prevent perfect adhesion."

Brick Tank Wall.—There is among constructors a difference of opinion as to how the bricks should be put into the wall. The following is from a man who has had considerable experience in tank work, and whose tanks have been tight:

"The bricklayer should put only enough mortar on the wall to embed one brick, place the brick in the mortar, then give it a sliding motion in two directions to

fill the joints on one end and on one side, and to expel the air from under the brick. The mortar should then be cut of the top and returned to the board. It is impossible to accurately describe how to push brick; the only way is to get a brick mason that can and will do this kind of work, and have him instruct each mason that is taken on the job, how the work is to be done."

An advocate of grouting, who has been perfectly successful in tank work, writes as follows: "The thickness of joint being decided upon, the outside and inside circle should be laid up five courses, making a trough for filling in. Spread thick mortar in the bottom of this trough and lay the brick in this mortar, care being taken that the brick shall be put down in such a manner as to drive all the air out as they fall into place. This makes a full joint under the brick. Then grout with mortar to be thrown over the tops of these bricks from a bucket in the same manner as coke is quenched, the mason using his trowel to fill in any joints that are not filled by spreading the mortar in this way. On this layer of bricks spread another layer of stiff mortar and lay another course of brick, grouting in these as in the former case. Care should be taken to arrange headers and stretchers, so that there will be a good bond.

"By pursuing this method, a fair mason can lay from 1800 to 2200 bricks per day; 2100 to 2200 bricks were laid per day, per mason, under my supervision. The brick for the inside and outside circle should be wetted with a hose. The brick for filling in should be throughly wetted, and I would advise having a number of tubs placed at intervals on the scaffold, and the brick thoroughly soaked with water in these tubs before being put in the wall; in fact, the brick should be taken from these tubs and placed in the wall without giving them time to dry."

There can be no doubt that entirely satisfactory tanks have been built by each method. It is probably equally true that a mason can lay from 200 to 400 more bricks a day by adopting the second or grouting method. It is also probably true that more close supervision is required to obtain good work with the grouting system.

Baker's "Treatise on Masonry Construction," page 37, contains the following paragraph:

Requisites for Good Brick.—1. "A good brick should have plane faces, parallel sides, and sharp edges and angles. 2. It should be of fine, compact, uniform texture; should be quite hard and should give a clear ringing sound when struck a sharp blow. 3. It should not absorb more than one-tenth of its weight of water. 4. Its specific gravity should be two or more. 5. The crushing strength of half brick when ground flat and pressed between thick metal plates, should be at least 7000 lbs. per square inch."

Regularity of shape can be determined by inspection of the brick, as can also, to a certain extent, compactness and uniformity of texture. The absorptive power, which effects the durability of the brick, especially as regards its resistance to frost, can be determined by weighing the brick after it has been kept exposed in a room under ordinary atmospheric conditions for a week and then again after it has been immersed in water for from 40 to 48 hours, and allowed to dry until all the water on the surface has evaporated, the difference between the first weight and the second one being the weight of water absorbed. The smaller the amount of water so absorbed the greater will be the durabiility of the brick.

In determining the crushing strength of the brick different methods are followed.

Sometimes half brick are tested and sometimes whole ones. In some cases the surfaces to be subjected to the pressure are ground accurately to planes parallel to each other, while in other cases the surfaces are leveled up by putting on a thin coat of plaster of paris, and in still others the bricks are put into a testing machine in the rough state. The best practice is to either grind the faces or to level them up by the use of plaster of paris, so that the pressure is applied equally all over the surface. These crushing tests are usually made in a hydraulic press provided with cast iron pressing surfaces which are self adjusting.

The test for transverse strength is about the most valuable that can be given to brick to determine its practical value. It is made by supporting the brick on two supports with thin edges placed the required distance apart, and then loading it in the center with a load which is applied by a beam with a thin edge bearing on the brick, the load required to break the brick being carefully determined. The modulus of rupture as determined by this test should be at least 1000 lbs. per square inch.

Brick-Work Measurement.—Brick-work is generally measured by 1000 bricks laid in the wall. In consequence of variations in size of bricks, no rule for volume of laid brick can be exact; the following scale is, however, a fair average.

<div style="text-align:center">

7 bricks to a superficial square foot of 4-in. wall = 40 lbs.
14 " " " 9-in. wall = 94 "
21 " " " 13-in. wall = 121 "
28 " " " 18-in. wall = 168 "
35 " " " 22-in. wall = 210 "

</div>

Corners are not measured twice as in stone work. Openings over 2 feet square are deducted. Arches are counted from the spring. Fancy work is counted $1\frac{1}{2}$ bricks for one. Pillars are measured on their face only.

A cubic yard of mortar requires 1 cubic yard of sand and 9 bushels of lime, and will fill 30 hods.

One thousand bricks, closely stacked, occupy about 56 cubic feet.

One thousand old bricks, cleaned and loosely stacked occupy about 72 cubic feet.

One superficial foot of gauged arches requires 10 bricks.

Stock bricks commonly measure $8\frac{3}{4}$ ins. × $4\frac{1}{4}$ ins. × $2\frac{3}{4}$ ins., and weigh from 5 to 6 lbs. each.

Paving bricks should measure 9 ins. × $4\frac{1}{2}$ ins. × $1\frac{3}{4}$ ins., and weigh about $4\frac{1}{2}$ lbs. each.

One yard of paving requires 36 stock bricks, of above dimensions, laid flat, or 52 on edge; and 35 paving bricks laid flat, or 82 on edge.

In brick masonry about 20 bricks are calculated per cubic foot of the larger size, such as prevails in the Western and Middle States, and about 22 bricks of the smaller size, which is chiefly used in the East. Of the former about 7 bricks are allowed for each square foot superficial area of the wall (one-half brick thick) and of the latter 7.5 bricks.

Stone-Work.—Stone walls are measured by the perch ($24\frac{3}{4}$ cu.ft.). Openings less than 3 ft. wide are counted solid; over 3 ft. deducted, but 18 ins. are added to

the running measure for each jamb built. Arches are counted solid from their spring. Corners of buildings are measured twice. Pillars less than 3 ft. are counted on three sides as lineal, multiplied by fourth side and depth.

It is customary to measure all foundation and dimension stone by the cubic foot. Water tables and base courses by lineal feet. All sills and lintels or ashlar, by superficial feet, and no wall less than 18 ins. thick.

The greatest safe load per superficial foot on

Granite piers...........................=40 tons
Limestone piers........................=25 "
Sandstone piers........................=15 "
Brick-work in cement...................= 3 "
Rubble masonry.........................= 2 "
Lime concrete foundations..............= 2½ "

According to Siebel brick walls will safely withstand a load of from 5 to 6 tons per sq.ft. according to quality; rubble walls in courses from 6 to 12 tons; dimension stones (sand or limestone) 12 to 18 tons, and granite from 18 to 36 tons. Concrete walls from 6 to 8 tons per sq.ft.; hollow tiles about 5 tons per sq.ft. actual bearing surface.

The height of brick or stone piers should not exceed 12 times their least thickness at base.

" Brick-work is not as strong as ashlar masonry, but costs less, while it is stronger and costs more than ordinary rubble." (Baker's "Masonry Consstruction.")

The best grades of stone have greater compressive strength and durability than brick and are better for massive work, such as heavy abutments and piers for bridges and large foundations. In comparatively thin walls, however, a better bond can be obtained with brick than with stone, and in such work the use of stone has been entirely abandoned in favor of brick except when the stone is employed for the purpose of ornament. In the class of buildings needed about gas works brick masonry is given the preference to stone masonry, for the reasons stated in the quotation given above, except in places where good stone can be obtained either on or very close to the site of the works.

Cement.—Rosendale or Utica cement, also called natural cement, is made from limestones composed of carbonate of lime, carbonate of magnesia and clay. The limestone is burned in a kiln and then ground to a fine powder. " Any magnesian limestone containing as high as 60% of carbonate of magnesia, may be presumed to be capable of yielding hydraulic cement of greater or less value, if properly burned, no matter whether clay be present or not."

Cement should be tested for fineness, liability to cracking and tensile strength.

1. Fineness. From 90 to 95% of the cement should pass though a sieve of 250 meshes to the inch. Other qualities being equal, the finer a cement is ground the greater is its value.

2. Checking or cracking. The test for checking or cracking is an important one, and though simple, should never be omitted. It is as follows: "Make two cakes of neat cement 2 or 3 ins. in diameter, about ½ in. thick, with thin edges. Note the time

in minutes that these cakes, when mixed with the water to the consistency of a stiff plastic mortar, take to set hard enough to stand the wire test recommended by Gen. Gillmore, $\frac{1}{12}$-in. diameter wire if loaded with $\frac{1}{4}$ lb. and $\frac{1}{24}$-in. when loaded with 1 lb. One of these cakes when hard enough should be put in water and examined from day to day to see if it becomes contorted or if cracks show themselves at the edges, such contortions or cracks indicating that the cement is unfit for use at that time. In some cases the tendency to crack, if caused by the presence of too much unslaked lime, will disappear with age. The remaining cake should be kept in the air and its color observed, which, for a good cement, should be uniform throughout (yellowish blotches indicating a poor quality), the natural cements being light or dark according to the character of the rock of which they are made. The color of the cements when left in the air indicates the quality much better than when they are put in water.

3. Tensile strength. The tests should be applied to the cement as offered for sale. The following table gives the average range of tensile strength per square inch which some good cements have attained:

AVERAGE TENSILE STRENGTH IN POUNDS PER SQUARE INCH

Age of Mortar when Tested.	Rosendale Cement.	
Neat Cement.	Min.	Max.
1 day—1 hour (or until set) in air, the remainder of the time in water	40	80
1 week—1 day in air, the remainder of time in water	60	100
4 weeks—1 day in air, the remainder of time in water	100	150
1 year—1 day in air, the remainder of time in water	300	400
One Part Cement and One Part Sand.		
1 week—1 day in air, the remainder of time in water	30	50
4 weeks—1 day in air, the remainder of time in water	50	80
1 year—1 day in air, the remainder of time in water	200	300

" If satisfactory results are obtained with a full dose of sand, the trials need go no further. If not the coarser particles should be excluded by using a No. 100 sieve, in order to determine approximately the grade the cement would take if ground fine, for fineness is always attainable, while inherent merit may not be.

" Weight. For any particular cement the weight varies with the degree of heat in burning, the degree of fineness in grinding, and the density of packing. Other things being the same, the harder burned varieties are the heavier. The finer a cement is ground the more bulky it becomes, and consequently the less it weighs. Hence, the light weight may be caused by laudable fine grinding or by objectionable under-burning.

" The weight per unit of volume is usually determined by sifting the cement into a measure as lightly as possible, and striking the top level with a straight edge. In careful work the height of fall is specified. The weight per cubic foot is neither exactly constant nor can it be determined precisely, and for the practical purpose of the user is of very little service in determining the value of a cement. However, it is often specified as one of the requirements to be fulfilled.

" The weight of Rosendale cement, determined by sifting the cement with a fall of three feet into a box having a capacity of one-tenth of a cubic foot, is 49 to 56 lbs. per cubic foot. The difference in weight for any particular kind is mainly due to a difference in fineness.

"Ulster County Rosendale cement weighs 300 lbs. per barrel net; Akron, Milwaukee, Utica, and Louisville Rosendales weigh 265 lbs. per barrel net. (See Baker, "Masonry Construction.")

Concrete Walls.—Concrete walls for houses are built of 1 of cement to 6 or 7 of broken stone, shingle, gravel, or slag. The substance mixed with the cement must be free from loam, fine sand, clay, or dirt of any kind. To prevent the cement from adhering to the planks of the mold, apply freely to them with a brush, soap boiled to the consistency of paint.

WEIGHTS

WEIGHT PER CUBIC FOOT OF MATERIALS

Names of Substances.	Average Weight, Pounds.
Anthracite, solid, of Pennsylvania	93
Anthracite, broken, loose	54
Anthracite, broken, moderately shaken	58
Anthracite, heaped bushel, loose	(80)
Ash, American white, dry	38
Asphaltum	87
Brass (Copper and Zinc), cast	504
Brass, rolled	524
Brick, best pressed	150
Brick, common hard	125
Brick, soft inferior	100
Brick-work, ordinary	112
Brick-work, pressed brick	140
Cement, hydraulic, ground, loose, American, Rosendale	56
Cement, hydraulic, ground, loose, American, Louisville	50
Cement, hydraulic, ground, loose, English, Portland	90
Cherry, dry	42
Chestnut, dry	41
Coal, bituminous, solid	84
Coal, bituminous, broken, loose	49
Coal, bituminous, heaped bushel, loose	(74)
Coke, loose, of good coal	27
Coke, loose, heaped bushel	(38)
Copper, cast	542
Copper, rolled	548
Earth, common loam, dry, loose	76
Earth, common loam, dry, moderately rammed	95
Earth, as a soft flowing mud	108
Ebony, dry	76
Elm, dry	35
Flint	162
Glass, common window	157
Gneiss, common	168

WEIGHT PER CUBIC FOOT OF MATERIALS—*Continued*

Names of Substances.	Average Weight, Pounds.
Gold, cast, pure, or 24 carat	1204
Gold, pure, hammered	1217
Granite	170
Gravel, about the same as sand, which see.	
Hemlock, dry	25
Hickory, dry	53
Hornblende, black	203
Ice	58.7
Iron, cast	450
Iron, wrought, purest	485
Iron, wrought, average	480
Ivory	114
Lead	711
Lignumvitae, dry	83
Lime, quick, ground, loose, or in small lumps	53
Lime, quick, ground, loose, thoroughly shaken	75
Lime, quick, ground, loose, per struck bushel	66
Limestones and marbles	168
Limestones and marbles, loose, in irregular fragments	96
Mahogany, Spanish, dry	53
Mahogany, Honduras, dry	35
Maple, dry	49
Masonry, of granite or limestone, well dressed	165
Masonry, of mortar rubble	154
Masonry, dry (well scabbled)	138
Masonry, sandstone, well dressed	144
Mercury, at 32° F.	849
Mica	183
Mortar, hardened	103
Mud, dry, close	80–110
Mud, wet, fluid, maximum	120
Oak, live, dry	59
Oak, white, dry	52
Oak, other kinds	32–45
Petroleum	55
Pine, white, dry	25
Pine, yellow, northern	34
Pine, yellow, southern	45
Platinum	1342
Quartz, common, pure	165
Rosin	69
Salt, coarse	45
Salt, fine for table use	49
Sand, well shaken	99–117

WEIGHT PER CUBIC FOOT OF MATERIALS—*Continued*

Names of Substances.	Average Weight, Pounds.
Sand, perfectly wet	120–140
Sandstones, fit for building	151
Shales, red or black	162
Silver	655
Slate	175
Snow, freshly fallen	5–12
Snow, moistened and compacted by rain	15–50
Steel	490
Sulphur	125
Water, pure rain, or distilled at 60° F	62⅓

Green timbers usually weigh from one-fifth to one-half more than dry.

WEIGHTS OF FUEL AND MORTAR MATERIALS

Anthracite, broken, 1 cu.ft	54 lbs.
Coke, broken, 1 cu.ft	31.5 "
Bituminous, broken, 1 cu.ft	49 "
Charcoal, broken, cu.ft	18.5 "
1 ton anthracite (loose)	40–43 cu.ft.
1 ton coke (2240 lbs.)	70.9 "
1 ton bituminous coal	43–48 "
1 ton charcoal (2240 lbs).	123 "
Cement, Rosendale, 1 bu.	70 lbs.
Cement, Louisville, 1 bu	62 "
Cement, Portland, 1 bu	96 "
Lime (loose), 1 bu	70 "
Lime (shaken), 1 bu	80 "
Sand (avg.) 98 lbs. per cu.ft., 1 bu	122.5 pounds.

Sand, 18.29 bu. = 1 ton; 1.181 tons = 1 cu.yd.

SHEET IRON WEIGHTS

Weight of a Square Foot Rolled to Partridge Gauge.—Where accuracy is required, take thickness in thousandths of an inch, or weight per foot:

Number of Gauge.	Weight per Foot.	Number of Gauge.	Weight of per Foot.	Number of Gauge.	Weight per Foot.	Number of Gauge.	Weight per Foot.
1	11.25	9	6.25	$16 = \frac{1}{16}$	2.5	24	1
2	10.625	10	5.625	17	2.1875	25	0.9
$3 = \frac{1}{4}$	10	$11 = \frac{1}{8}$	5	18	1.875	26	0.8
4	9.375	12	4.375	19	1.7188	27	0.72
5	8.75	13	3.75	20	1.5625	28	0.64
6	8.125	14	3.125	21	1.4063	29	0.56
7	7.5	15	2.8125	$22 = \frac{1}{32}$	1.25	30	0.5
8	6.875			23	1.12		

PLATE-IRON WEIGHTS

WEIGHT PER SQUARE FOOT

Thickness in Inches.	Weight, Pounds.	Thickness in Inches.	Weight, Pounds.
$\frac{1}{32}=0.03125$	1.25	$\frac{5}{16}=0.3125$	12.58
$\frac{1}{16}=0.0625$	2.519	$\frac{3}{8}=0.375$	15.10
$\frac{3}{32}=0.0937$	3.788	$\frac{7}{16}=0.4375$	17.65
$\frac{1}{8}=0.125$	5.054	$\frac{1}{2}=0.5$	20.20
$\frac{5}{32}=0.1562$	6.305	$\frac{9}{16}=0.5625$	22.76
$\frac{3}{16}=0.1875$	7.578	$\frac{5}{8}=0.625$	25.16
$\frac{7}{32}=0.2187$	8.19	$\frac{3}{4}=0.75$	30.20
$\frac{1}{4}=0.25$	10.09	$\frac{7}{8}=0.875$	35.30
$\frac{9}{32}=0.2812$	11.38	$1=1$	40.40

To ascertain the weight of plate iron for rectangular sheets:

Rule.—Multiply the product of length by breadth in inches, by one of the following decimals, according to thickness, and the product will be the weight required.

$\frac{3}{16}$ thick $\times 0.0526$		$\frac{9}{16}$ thick $\times 0.158$	
$\frac{1}{4}$ " $\times 0.07$		$\frac{5}{8}$ " $\times 0.1748$	
$\frac{5}{16}$ " $\times 0.0874$		$\frac{3}{4}$ " $\times 0.2096$	
$\frac{3}{8}$ " $\times 0.1048$		$\frac{7}{8}$ " $\times 0.245$	
$\frac{7}{16}$ " $\times 0.1226$		1 " $\times 0.28$	
$\frac{1}{2}$ " $\times 0.14$			

WEIGHT OF CIRCULAR BOILER HEADS

Diameter in Inches.	THICKNESS OF IRON, INCHES.						
	$\frac{3}{16}$ Pound.	$\frac{1}{4}$ Pound.	$\frac{5}{16}$ Pound.	$\frac{3}{8}$ Pound.	$\frac{7}{16}$ Pound.	$\frac{1}{2}$ Pound.	$\frac{9}{16}$ Pound.
16	11	14	18	21	25	28	32
18	13	18	22	27	31	36	40
20	17	22	27	33	38	44	50
22	20	27	33	40	47	54	60
24	24	32	40	47	55	64	71
26	28	37	46	56	64	75	84
28	32	43	53	65	75	86	97
30	37	50	62	74	87	100	112
32	42	56	70	84	99	112	127
34	48	64	79	96	111	128	143
36	54	71	89	108	125	142	161
38	60	79	99	120	139	158	179
40	66	88	110	132	154	176	198
42	73	97	121	146	170	194	220
44	80	107	133	160	187	214	240
46	88	117	145	176	204	234	262
48	95	127	158	190	222	254	286
50	103	138	172	206	241	276	310
52	112	149	186	224	260	298	335
54	121	160	200	242	281	320	362
56	130	172	214	260	302	344	389
58	139	185	231	278	324	370	417
60	149	198	247	298	336	396	446

GAS PRODUCERS

WEIGHT OF TANK RIVETS—NUMBER TO THE POUND

Length.	⅛-inch Diameter.		3/16-inch Diameter.		¼-inch Diameter.		5/16-inch Diameter.		⅜-inch Diameter.		7/16-inch Diam.	
	Flat and Round Heads.	Counter-sunk.	Flat and Round Heads.	Counter-sunk.	Flat and Round Heads.	Counter-sunk.	Flat and Round Heads.	Counter-sunk.	Flat and Round Heads.	Counter-sunk.	Flat Heads.	Counter-sunk.
⅜	204	280	165	230	103	155	67	89	....	....	....	....
7/16	190	250	153	200	92	128	58	78	35	....	....	....
½	175	222	135	172	81	108	50	69	31	45	....	....
⅝	160	200	118	148	71	93	44	60	27	39	....	....
¾	144	180	103	129	63	80	39	53	24	34	17	22
⅞	135	165	92	114	56	70	35	47	22	30	15	19
1	126	150	84	102	50	62	32	42	20	27	14	17½
1⅛	116	140	77	93	46	56	30	37	19	24	13	16
1¼	108	130	72	85	43	51	28	34	18	22	12	15
1⅜	100	120	67	78	40	47	29	31	17	21	11½	14½
1½	93	112	62	72	37	44	24	29	16	20	11	14
1⅝	87	104	58	67	34	41	22	27	15	19	10½	13½
1¾	81	96	54	62	32	38	21	25	14	18	10	12¾
1⅞	....	....	51	58	30	36	20	24	13	17	9½	11½
2	....	....	48	54	29	34	19	23	12	16	9	11
2¼	....	....	43	49	27	32	17	21	11	15	8¼	10½
2½	....	....	39	45	24	29	16	20	10	14	7¾	9¾
2¾	....	....	35	40	22	26	14	17	9	12	7¼	9
3	....	....	31	36	20	24	13	16	8	11	6¾	8½
3½	....	....	....	....	18	21	11	14	7	10	6	7½
4	....	....	....	....	16	20	10	13	6	9	5	6½

NUMBER CONE HEAD RIVETS IN 100 POUNDS

Lengths	⅜-inch.	7/16-inch.	½-inch.	9/16-inch.	⅝-inch.	11/16-inch.	¾-inch.	⅞-inch.
¾	1965	1429	1092	944	665	....	....	....
⅞	1848	1335	1027	846	597	....	....	....
1	1692	1222	940	763	538	450	....	....
1⅛	1512	1092	840	727	512	415	....	....
1¼	1437	1036	797	691	487	389	356	228
1⅜	1368	988	760	653	460	370	329	211
1½	1300	949	730	624	440	357	280	180
1⅝	1260	924	711	596	420	340	271	174
1¾	1200	900	693	553	390	325	262	169
1⅞	1156	840	648	532	375	312	257	165
2	1100	789	608	511	360	297	243	156
2⅛	1031	744	575	502	354	289	237	152
2¼	999	721	555	491	347	280	232	149
2½	945	682	525	475	335	260	220	141
2¾	900	650	500	443	312	242	208	133
3	828	598	460	411	290	224	197	127
3¼	779	562	433	379	267	212	180	115
3½	743	536	413	352	248	201	169	108
3¾	715	513	395	341	241	192	160	102
4	....	....	....	326	230	184	158	99
4¼	....	....	....	312	220	177	150	96
4½	....	....	....	298	210	171	146	94
4¾	....	....	....	284	200	166	138	89
5	....	....	....	270	190	164	135	87

WEIGHT OF CORRUGATED IRON ROOFING

British Wire Gauge.	Pounds per Square of 100 Square Feet, Plain or Painted.	British Wire Gauge.	Pounds per Square of 100 Square Feet, Plain or Painted.
No. 28	97 lbs.	No. 20	185 lbs.
" 26	105 "	" 18	270 "
" 24	128 "	" 16	340 "
" 22	150 "		

Galvanized iron weighs from 5 to 15% heavier than plain, according to the number B.W.G. For a good durable roof, lighter than No. 22 is not recommended. Corrugated iron is usually made in sheets from 6 to 8 ft. long, and from 2 to 3 ft. wide.

The sheets when used for roofing should overlap about 6 ins. in girth, and be double-riveted at the joints. One-third of the net width may be allowed approximately for lappage and corrugations. From $2\frac{1}{2}$ to $3\frac{1}{2}$ lbs. of rivets will be required for a square.

DECREASE OF STRENGTH OF WROUGHT IRON AT HIGH TEMPERATURES

(Experiments by W. Johnson and Benj. Reeves, Com. Franklin Inst., 1839.)

Temperature.		Decrease Per Cent of Maximum Tenacity.	Temperature.		Decrease Per Cent of Maximum Tenacity.
Centigrade.	Fahrenheit.		Centigrade.	Fahrenheit.	
271°	520°	0.0738	500°	932°	0.3324
313	....	0.0899	554	....	0.4478
332	630	0.1047	599	....	0.5514
350	....	0.1155	624	1154	0.6
389	732	0.1491	669	....	0.6622
440	....	0.2010	708	1306	0.7001

ROPE

Strength of Manila and Hemp Rope.—A well known authority says: "The strength of rope is very irregular, much depending on the quality of the fiber used and the solidity in which the rope is put together. For instance, $3\frac{1}{4}$-in. circumference soft-laid rope will not measure over 3 ins. circumference hard-laid.

"Our tests of the various makes of rope from the manila fiber show about the following average maximum strength:

3-in. circumference soft-laid . . . . 7300 lbs.
3-in. circumference medium-laid . . . . 8000 lbs.
3-in. circumference hard-laid . . . . 9000 lbs.

"We find it is a safe rule, up to 5-in. circumference, to multiply the square of the circumference by 8 and the product will be the number of net 100 lbs. required to break the rope.

" From the tests we have from the U. S. Government Cordage Works, of the breaking strength of tarred Russia and American hemp cordage, we would say that the above rule will apply to tarred cordage as well as to manila.

" Where blocks and falls are used it is a safe rule to put rope in use at one-eighth its breaking strain; and that in two double-blocks of suitable size. Say for instance, it is desirable to raise regularly 1000 lbs.: Two double 8-in. blocks reeved with 3-in. circumference manila rope should be used.

" For direct pulls on a single rope, say up to 5-in. circumference, we find it safe where in constant use to put it at work at only one-twentieth its breaking strain. For instance, on a hoisting machine in a warehouse where hoists of 1000 to 1500 lbs. are made (the latter occasionally), we place for the hook rope 5-in. circumference manila rope. This gives durability, and allows for wear and tear.

" Of course wear and tear and the want of proper care must be allowed for as rope grows old. The best rope made will be quickly destroyed by allowing it to become wet and then putting it in a damp cellar or room where there is no circulation of air."

AVERAGE LENGTH PER COIL AND WEIGHT PER 100 FATHOMS

	Manila and Sisal Rope.			Tarred Cordage.	
Diameter in Inches.	Circumference in Inches.	Length of Coil in Feet.	Pounds per 100 Fathoms.	Length in Feet.	Pounds per 100 Fathoms.
$\frac{1}{4}$ or 6 thread	$\frac{3}{4}$	1300	12	840	18
$\frac{5}{16}$ or 9 "	$\frac{15}{16}$	1300	17	840	29
$\frac{3}{8}$ or 12 "	$1\frac{1}{8}$	1200	·23	840	40
15 "	....	1200	31	840	47
18 "	....	1100	45	840	58
21 "	....	1100	50	840	68
$\frac{1}{2}$	$1\frac{1}{2}$	990	52	960	64
$\frac{9}{16}$	$1\frac{3}{4}$	990	70	960	79
$\frac{5}{8}$	2	990	83	960	94
$\frac{3}{4}$	$2\frac{1}{4}$	990	105	960	130
$\frac{7}{8}$	$2\frac{1}{2}$	990	125	960	140
$\frac{15}{16}$	$2\frac{3}{4}$	990	155	960	170
1	3	990	175	960	207
$1\frac{1}{16}$	$3\frac{1}{4}$	990	205	960	238
$1\frac{3}{16}$	$3\frac{1}{2}$	990	255	960	272
$1\frac{1}{4}$	$3\frac{3}{4}$	990	280	960	300
$1\frac{5}{16}$	4	960	310	960	332
$1\frac{3}{8}$	$4\frac{1}{4}$	960	355	960	376
$1\frac{1}{2}$	$4\frac{1}{2}$	960	410	960	440
$1\frac{5}{8}$	$4\frac{3}{4}$	960	450	960	505
$1\frac{11}{16}$	5	960	500	960	573
$1\frac{3}{4}$	$5\frac{1}{4}$	960	550	960	610
$1\frac{7}{8}$	$5\frac{1}{2}$	960	610	960	654
$1\frac{15}{16}$	$5\frac{3}{4}$	960	690	960	797
2	6	960	750	960	900
$2\frac{3}{16}$	$6\frac{1}{2}$	960	845	960	1057
$2\frac{1}{3}$	7	960	1000	960	1163
$2\frac{1}{2}$	$7\frac{1}{2}$	960	1100	960	1356
$2\frac{5}{8}$	8	960	1270	960	1613
3	9	960	1595	960	2013

USEFUL TABLES

CIRCUMFERENCES AND AREAS OF CIRCLES

Diam.	Circum.	Area.	Diam.	Circum.	Area.	Diam.	Circum.	Area.
1/16	0.1963	0.00307	8	25.132	50.265	55	172.788	2375.83
1/8	0.3927	0.01227	9	28.274	63.617	56	175.929	2463.01
3/16	0.5890	0.02761	10	31.416	78.540	57	179.071	2551.76
1/4	0.7854	0.04909	11	34.558	95.033	58	182.212	2642.08
5/16	0.9817	0.07670	12	37.699	113.097	59	185.354	2733.97
3/8	1.1781	0.1104	13	40.840	132.732	60	188.496	2827.43
7/16	1.3744	0.1503	14	43.982	153.938	61	191.637	2922.47
1/2	1.5708	0.1963	15	47.124	176.715	62	194.779	3019.07
9/16	1.7771	0.2485	16	50.265	201.062	63	197.920	3117.25
5/8	1.9635	0.3068	17	53.407	226.980	64	201.062	3216.99
11/16	2.1598	0.3712	18	56.548	254.469	65	204.204	3318.31
3/4	2.3562	0.4418	19	59.690	283.529	66	207.345	3421.19
13/16	2.5525	0.5185	20	62.832	314.160	67	210.487	3522.66
7/8	2.7489	0.6013	21	65.973	346.361	68	213.628	3631.68
15/16	2.9452	0.6903	22	69.115	380.133	69	216.770	3739.28
1	3.1416	0.7854	23	72.256	415.476	70	219.912	3848.45
1 1/16	3.3379	0.8866	24	75.398	452.390	71	223.053	3969.19
1 1/8	3.5343	0.9940	25	78.540	490.875	72	226.195	4071.50
1 3/16	3.7306	1.1075	26	81.681	530.930	73	229.336	4185.39
1 1/4	3.9270	1.2271	27	84.823	572.556	74	232.478	4300.84
1 5/16	4.1233	1.3530	28	87.964	615.753	75	235.620	4417.86
1 3/8	4.3197	1.4848	29	91.106	660.521	76	238.761	4536.46
1 7/16	4.5160	1.6229	30	94.248	706.860	77	241.903	4656.63
1 1/2	4.7124	1.7671	31	97.389	754.769	78	245.044	4778.36
1 5/8	5.1051	2.0739	32	100.531	804.249	79	248.186	4901.68
1 3/4	5.4978	2.4052	33	103.672	855.30	80	251.328	5026.55
1 7/8	5.8905	2.7611	34	106.814	907.92	81	254.469	5153.00
2	6.2832	3.1416	35	109.956	962.11	82	257.611	5281.02
2 1/8	6.6759	3.5465	36	113.097	1017.88	83	260.752	5410.61
2 1/4	7.0686	3.9760	37	116.239	1075.21	84	263.894	5541.77
2 3/8	7.4613	4.4302	38	119.380	1134.11	85	267.035	5674.51
2 1/2	7.8540	4.9087	39	122.522	1194.59	86	270.177	5808.80
2 3/4	8.6394	5.9395	40	125.664	1256.64	87	273.319	5944.68
3	9.4248	7.0686	41	128.805	1320.25	88	276.460	6082.12
3 1/4	10.210	8.2957	42	131.947	1385.44	89	279.602	6221.14
3 1/2	10.995	9.6211	43	135.088	1452.20	90	282.744	6361.73
3 3/4	11.781	11.044	44	138.230	1520.53	91	285.885	6503.88
4	12.566	12.566	45	141.372	1590.43	92	289.027	6647.61
4 1/4	13.351	14.186	46	144.513	1661.90	93	292.168	6792.91
4 1/2	14.137	15.904	47	147.655	1734.94	94	295.310	6939.78
4 3/4	14.922	17.720	48	150.796	1809.56	95	298.452	7088.22
5	15.708	19.635	49	153.938	1885.74	96	301.593	7238.23
5 1/4	16.493	21.647	50	157.080	1963.50	97	304.734	7389.81
5 1/2	17.278	23.758	51	160.221	2042.82	98	307.876	7542.96
5 3/4	18.064	25.967	52	163.363	2123.72	99	311.018	7697.69
6	18.849	28.274	53	166.504	2206.18	100	314.159	7853.98
7	21.991	38.484	54	169.646	2290.22			

PROPERTIES OF THE CIRCLE

Circumference = diameter × 3.1416 or $3\frac{1}{7}$.
Diameter × .8862 = side of equal square.
Diameter × .7071 =   "   inscribed square.
Diameter × .7854 = area of circle.
Length of arc of circle = No. of degrees × .017453
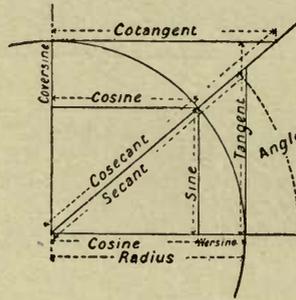
FIG. 242.—Circular Functions.

CONVERSION TABLES

MEASURES OF DISTANCE

Inches.		Feet.		Yards.	Miles.	Centimeters.	Meters.
1	=	0.083	=	0.02778	=0.0000158=	2.539998 =	0.02539998
12	=	1	=	0.33333	=0.0001894=	30.47997 =	0.3047997
36	=	3	=	1	=0.000568 =	91.43992 =	0.9143992
63360	=	5280	=	1760	=1	=160934.259	=1609.34259
0.39370	=	0.03281	=	0.01094	=0.000006 =	1	= 0.01
39.37011	=	3.28084	=	1.09361	=0.000621 =	100	= 1

MEASURES OF SURFACE.

Sq. Inches.		Sq. Feet.		Sq. Centimeters.	Sq. Meters.
1	=	0.00694	=	6.451589	=0.000645
144	=	1	=	929.03	=0.093
0.155	=	0.00108	=	1	=0.0001
1550.006	=	10.76393	=	10000	=1

1 acre = 4840 sq. yards = 43560 sq.ft. = a square, the side of which is 208.71 ft.

MEASURES OF VOLUME

Cu. In.		Cu. Feet.		R. S. Gallons.		Liters.	Cu. Meters.
1	=	0.0005788	=	0.00433	=	0.016387	=0.000016
1728	=	1	=	7.4805	=	28.31677	=0.028317
231	=	0.1337	=	1	=	3.78544	=0.003785
61.0239	=	0.03531	=	0.2642	=	1.	=0.001
61023.90	=	35.31476	=	264.2	=	1000.	=1.

1 bushel, U. S. Standard = 2150.42 cu.ins.   =   1.2445 cu.ft.
1 bushel, British   = 2218.19 cu.ins.   =   1.2837 cu.ft.
1 cu.meter   = 1000 liters   = 1,000,000   cu.cm.
1 Imperial gallon   =   1.20032 U. S. gallons =   277.274 cu.ins.

MEASURES OF WEIGHT

Grains.	Ounces.	Pounds.	Grams.	Kilograms.
1	= 0.00229	= 0.000143 =	0.0647989	= 0.000065
437.5	= 1.	= 0.0625 =	28.34953	= 0.02835
7000	= 16.	= 1. =	453.59243	= 0.45359
15.43236	= 0.03527	= 0.002205 =	1.	= 0.001
15432.35639	= 35.274	= 2.20462 =	1000.	= 1.

MEASURES OF HEAT ENERGY

Calorie. (1° C. and 1 kg.)		B.T.U. (1° F. and 1 lb.)		Pound Calorie (1° C. and 1 lb.)
1.	=	3.968	=	2.2046
0.252	=	1.	=	0.5556
0.4536	=	1.8	=	1.

Calories per Cu. Meter.		B.T.U. per Cu. Foot.
1.	=	0.11236
8.898	=	1.

Calories per Kilogram.		B.T.U. per Pound.
1.	=	1.800
0.5556	=	1.

TEMPERATURES

Degrees Fahrenheit = $\frac{9}{5}$ degrees Centigrade + 32, or F.° = 1.8 C.° + 32.

Degrees Centigrade = $\frac{5}{9}$ (degrees Fahrenheit − 32).

Degrees absolute temperature, T. = C.° + 273.

"   "   "   T. = F.° + 491.

Absolute zero = −273° on Centigrade scale.

"   " = −491° on Fahrenheit scale.

Mercury remains liquid to −39° C., and thermometers with compressed N above the column of mercury may be used for as high temperatures as 400 to 500° C.

HEAT UNITS

A French calorie = 1 kilogram of H_2O heated 1° C. at or near 4° C.

A British thermal unit (B.T.U.) = 1 lb. of H_2O heated 1° F. at or near 39° F.

A pound-calorie unit = 1 lb. of H_2O heated 1° C. at or near 4° C.

1 French calorie = 3.968 B.T.U. = 2.2046 pound-calories.

1 British thermal unit = .252 French calorie = .555 pound = calorie.

1 pound-calorie = 1.8 B.T.U. = .45 French calorie.

1 B.T.U. = 778 ft.-lbs. = Joule's mechanical equivalent of heat.

1 h.p.   = 33,000 ft.-lbs. per minute

= $\frac{33000}{778}$ = 42.42 B.T.U. per minute

= 42.42 × 60 = 2545 B.T.U. per hour.

The British Board of Trade unit is not a unit of heat, but of electrical measurement and

= 1 killowatt hour

= 1000 watts = $\frac{1000}{746}$ = 1.34 h.p. per hour.

MEASURES OF PRESSURE

Lbs. per Sq.in.		Kg. per Sq.cm.		Inches of Water (62°) Column.		Inches of Mercury (62°) Column.
1.	=	0.070308	=	27.71	=	2.0416
14.22	=	1.	=	394.1	=	29.03
0.0361	=	0.0025	=	1.	=	0.0736
0.49	=	0.0344	=	13.98	=	1.

TO CHANGE BRITISH THERMAL UNITS (B.T.U.) TO CALORIES OR CALORIES TO BRITISH THERMAL UNITS—(BATES)

Thermal Units.—$1°$ C. $=\frac{9}{5}°$ F. or $1.8°$ F.; $1°$ F. $=\frac{5}{9}°$ or $0.556°$ C.; 1 kilogram $=2.2046$ lbs; 1 lb $=0.4536$ kilogram; 1 calorie $=1$ kilogram (2.2046 pounds) of water raised through $1°$ C. $(1.8°$ F.$)=2.2046\times1.8=3.968$ B.T.U., since 1 British thermal unit is 1 pound (0.4536 kilogram) of water raised through $1°$ F. $(0.556°$ C.$)$, and similarly $0.4536\times0.556=0.252$ calorie, consequently

To convert calories into British thermal units, multiply by the constant 3.968, and

To convert British thermal units into calories, multiply by the constant 0.252

British thermal units are generally given per cubic foot or per pound, and calories per cubic meter (or liter $=.001$ cubic meter) or per kilogram.

1 cubic meter $=35.314$ cubic feet;

1 cubic foot $=0.02832$ cubic meter, consequently

To convert calories per cubic meter into British thermal units per cubic foot, multiply the calories by 3.968, giving British thermal units per cubic meter, and divide the product by 35.314, when the quotient will be the number of British thermal units per cubic foot.

To convert calories per kilogram into British thermal units per pound, multiply the calories by 3.968, giving British thermal units per kilogram, and divide the product by 2.2046 when the quotient will be the number of British thermal units per pound.

Since $3.968\div2.2046=1.8$ (approximately), the calories per kilogram may be multiplied by the constant 1.8, giving the number of British thermal units per pound directly as in the previous case.

To convert British thermal units per cubic foot into calories per cubic meter, multiply the British thermal units by 0.252, giving calories per cubic foot, and divide the product by 0.02832, when the quotient will be the number of calories per cubic meter directly similarly;

To convert British thermal units per pound into calories per kilogram, multiply the British thermal units by 0.252, giving calories per pound, and divide the product by 0.4536, when the quotient will be the number of calories per kilogram.

Since $0.252\div0.4536=0.4536=0.556$ (approximately), the British thermal units per pound may be multiplied by the constant 0.556, giving the equivalent number of calories directly.

Another unit often employed in connection with the quantative measurement of heat by scientific writers is the thermal unit, which may be defined as the quantity of heat required to raise one pound of pure water one degree centigrade at or about $4°$ C.

MEASURES OF ENERGY

B.T.U. (1° F. and 1 lb.)		Foot-pounds.		Kg.-meters.		Horse-power Hours.	Kilowatt Hours.
1	=	778.	=	107.6	=	0.000393	= 0.000293
0.001285	=	1.	=	0.1383	=	0.0000005	= 0.00000083
0.0093	–	7.233	=	1.	=	0.00000365	= 0.00000272
2545	=	1980000.	=	273740.	=	1.	= 0.746
3412	=	2654200.	=	367000.	=	1.34	= 1.

1 Horsepower = 17 lbs. of water raised from 62° to 212° F. = 2.64 lbs. of water evaporated from and at 212° F. = 0.175 lb. carbon oxidized with perfect efficiency.

COMPOUND MEASURES OF QUANTITY

Grains per 100 cu.ft.		Grams per 100 cu.m.
1	=	2.29
0.437	=	1.

1000 cu.ft. weigh, lbs.		One cu.m. weighs, kilograms.
1	=	0.016
62.428	=	1

BAROMETRIC READINGS IN MILLIMETERS AND INCHES

Mil'meters	Inches.	Millimeters.	Inches.	Millimeters.	Inches.	Millimeters.	Inches.
700	27.56	723	28.47	746	29.37	769	30.28
701	.60	724	.50	747	.41	770	.32
702	.64	725	.54	748	.45	771	.36
703	.68	726	.58	749	.49	772	.39
704	.72	727	.63	750	.53	773	.43
705	.76	728	.66	751	.57	774	.47
706	.80	729	.70	752	.61	775	.51
707	.84	730	.74	753	.65	776	.55
708	.88	731	.78	754	.69	777	.59
709	.91	732	.82	755	.73	778	.63
710	.95	733	.86	756	.76	779	.67
711	.99	734	.90	757	.80	780	.71
712	28.03	735	.94	758	.84	781	.75
713	.07	736	.98	759	.88	782	.79
714	.11	737	29.02	760	.92	783	.83
715	.15	738	.06	761	.96	784	.87
716	.19	739	.10	762	30.00	785	.91
717	.23	740	.13	763	.04	786	.94
718	.27	741	.17	764	.08	787	.98
719	.31	742	.21	765	.12	788	31.02
720	.35	743	.25	766	.16	789	.06
721	.39	744	.29	767	.20		
722	.43	745	.33	768	.24		

THERMOMETRIC DEGREES
Centigrade and Fahrenheit

Degrees C.	Degrees F.	Degrees C.	Degrees F.	Degrees C.	Degrees F.	Degrees C.	Degrees F.	Degrees C.	Degrees F.
−40	−40	18.3	65	55	131	95	203	200	392
−34.4	−30	20	68	57.2	135	96.1	205	204.4	400
−30	−22	21.1	70	60	140	98.9	210	260	500
−28.9	−20	23.9	75	62.8	145	100	212	300	572
−23.3	−10	25	77	65	149	104.4	220	400	752
−20	− 4	26.7	80	65.6	150	110	230	500	932
−17.8	0	29.4	85	68.3	155	115.6	240	600	1112
−12.2	10	30	86	70	158	120	248	700	1292
−10	14	32.2	90	71.1	160	121.1	250	800	1472
− 6.7	20	35	95	73.9	165	126.7	260	900	1652
− 1.1	30	37.8	100	75	167	130	266	1000	1832
0	32	40	104	76.7	170	132.2	270	1100	2012
1.7	35	40.6	105	79.4	175	137.8	280	1200	2192
4.4	40	43.3	110	80	176	140	284	1300	2372
5	41	45	113	82.2	180	143.3	290	1400	2552
7.2	45	46.1	115	85	185	148.9	300	1500	2732
10	50	48.9	120	87.8	190	150	302	1600	2912
12.8	55	50	122	90	194	162.8	325		
15	59	51.7	125	90.6	195	175	347		
15.6	60	54.4	130	93.3	200	176.7	350		

THE EQUIVALENT OF OUNCES PER SQUARE INCH PRESSURE IN INCHES OF WATER AND OF MERCURY

Ounces.	Inches of Water.	Inches of Mercury.	Ounces.	Inches of Water.	Inches of Mercury.
1	1.7	0.125	9	15.5	1.125
2	3.4	0.250	10	17.2	1.250
3	5.2	0.375	11	19.0	1.375
4	6.9	0.500	12	20.8	1.500
5	8.6	0.625	13	22.5	1.625
6	10.3	0.750	14	24.2	1.750
7	12.0	0.875	15	26.0	1.875
8	13.8	1.000	16	27.7	2.000

These conversion tables are often useful in natural-gas distribution:

HEIGHT OF WATER COLUMN IN INCHES CORRESPONDING TO VARIOUS PRESSURES, IN OUNCES PER SQUARE INCH

Pressure in Ounces per Square Inch.	Decimal Parts of an Ounce.									
	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0	....	0.17	0.35	0.52	0.69	0.87	1.04	1.21	1.38	1.56
1	1.73	1.90	2.08	2.25	2.42	2.60	2.77	2.94	3.11	3.29
2	3.46	3.63	3.81	3.98	4.15	4.33	4.50	4.67	4.84	5.01
3	5.19	5.36	5.54	5.71	5.88	6.06	6.23	6.40	6.57	6.75
4	6.92	7.09	7.27	7.44	7.61	7.79	7.96	8.13	8.30	8.48
5	8.65	8.82	9.00	9.17	9.34	9.52	9.69	9.86	10.03	10.21
6	10.38	10.55	10.73	10.90	11.07	11.26	11.43	11.60	11.77	11.95
7	12.11	12.28	12.46	12.63	12.80	12.97	13.15	13.32	13.49	13.67
8	13.84	14.01	14.19	14.36	14.53	14.71	14.88	15.05	15.22	15.40
9	15.57	15.74	15.92	16.09	16.26	16.45	16.62	16.79	16.96	17.14

BEAUMÉ HYDROMETER DEGREES AND SPECIFIC GRAVITIES FOR LIQUIDS LIGHTER THAN WATER

TEMPERATURE 60° F. = 15.6° C.

Degrees Beaumé.	Specific Gravity, Water = 1.000.	Weight, Pound per Gallon.	Degrees Beaumé.	Specific Gravity, Water = 1.000.	Weight, Pound per Gallon.
10	1.000	8.3328	26	0.901	7.50
11	0.993	8.27	27	0.896	7.46
12	0.986	8.22	28	0.890	7.42
13	0.980	8.17	29	0.885	7.37
14	0.973	8.11	30	0.880	7.33
15	0.967	8.06	31	0.874	7.28
16	0.960	8.00	32	0.869	7.24
17	0.954	7.95	33	0.864	7.20
18	0.948	7.90	34	0.859	7.15
19	0.942	7.85	35	0.854	7.11
20	0.936	7.80	36	0.849	7.07
21	0.930	7.75	37	0.844	7.03
22	0.924	7.70	38	0.839	6.99
23	0.918	7.65	39	0.834	6.95
24	0.913	7.60	40	0.830	6.91
25	0.907	7.56			

BEAUMÉ HYDROMETER DEGREES AND SPECIFIC GRAVITIES FOR LIQUIDS HEAVIER THAN WATER

TEMPERATURE 60° F. = 15.6° C.

Degrees Beaumé.	Specific Gravity, Water = 1.000.	Weight, Pounds per Gallon.	Degrees Beaumé.	Specific Gravity, Water = 1.000.	Weight, Pounds per Gallon.
0	1.000	8.3328	15	1.109	9.24
1	1.007	8.39	16	1.118	9.31
2	1.013	8.45	17	1.126	9.38
3	1.020	8.50	18	1.134	9.45
4	1.027	8.56	19	1.143	9.52
5	1.034	8.61	20	1.152	9.59
6	1.041	8.67	21	1.160	9.67
7	1.048	8.73	22	1.169	9.74
8	1.056	8.80	23	1.178	9.82
9	1.063	8.86	24	1.188	9.90
10	1.070	8.92	25	1.197	9.97
11	1.078	8.98	30	1.246	10.38
12	1.086	9.05	35	1.299	10.82
13	1.094	9.11	40	1.357	11.31
14	1.101	9.17			

SPECIFIC GRAVITY AND WEIGHT OF SOLID SUBSTANCES AT 60° F.

Name.	Specific Gravity.	Pounds per Cu.ft.	Pounds per Cu.in.
Aluminum	2.67	166	0.0963
Anthracite, solid	1.50	93	....
Anthracite, broken	....	58	....
Asphaltum	1.39	87	....
Brass	8.40	524	0.3031
Brick, common, hard	2.00	125	....
Cement, loose	1.25	78	....
Charcoal	....	18	....
Cherry, dry	0.67	42	....
Clay, dry	1.92–2.4	120–150	....
Coal, bituminous, solid	1.35	84	....
Coal, bituminous, broken	....	50	....
Coke, loose	....	30	....
Concrete	1.92–2.24	120–140	....
Copper	8.85	552	0.3195
Earth	1.15–1.76	72–110	....
Glass	2.50–2.75	156–172	....
Gold	19.26	1201	0.6949
Granite	2.56–2.72	160–170	....
Gravel	1.60–1.92	100–120	....
Ice	0.92	57.5	....
Iron, cast	7.22	450	0.2604
Iron, wrought	7.70	480	0.2779
Lead	11.38	710	0.4106
Lime, quick, in bulk	0.80–0.88	50–55	....
Limestone, solid	2.72	170	....
Limestone, broken	2.00	125	....
Manganese	8.00	499	0.2887
Magnesia, carbonate	2.40	150	....
Mahogany	0.81	51	....
Maple, dry	0.68	42	....
Marble	2.88	180	....
Masonry, stone, dry	2.24–2.56	140–160	....
Masonry, brick, dry	1.79	112	....
Mercury, 32° F.	13.62	849.3	0.4915
Mercury, 60° F.	13.58	846.8	0.4900
Mercury, 212° F.	13.38	834.4	0.4828
Nickel	8.80	548.7	0.3175
Oak	0.74–1.11	46–69	....
Oxide, purifying sponge	....	30–50	....
Pine	0.45–0.61	28–38	....
Platinum	21.50	1347	0.7758
Sand	1.44–1.76	90–110	....
Sandstone	2.24–2.4	140–150	....
Silver	10.50	655	0.3790
Slate	2.88	180	....
Snow, freshly fallen	0.19	12	....
Steel	7.85	489.6	0.2834
Sulphur	2.00	125	....
Tile	1.76–1.92	110–120	....
Tin	7.35	458.3	0.2652
Walnut, dry	0.58	36	....
Wax	0.98	60	....
Zinc	7.00	436.5	0.2526

SPECIFIC GRAVITY AND WEIGHT OF GASES AND VAPORS AT 32° F.=0° C. AND 760 MM.=29.92 INS. BAROMETER

Name.	Symbol.	Specific Gravity.		1000 Cu.ft. Weigh, Lbs.	1 Cu. Meter Weighs, Kgs.
		Air=1.	Hydrogen=1		
Air..............................	....	1.00	14.438	80.757	1.2936
Hydrogen.......................	H_2	0.06926	1.00	5.594	0.0896
Oxygen.........................	O_2	1.105	15.96	89.246	1.4292
Nitrogen........................	N_2	0.970	14.01	78.322	1.2546
Carbon monoxide.................	CO	0.967	13.96	78.072	1.2506
Carbonic acid....................	CO_2	1.520	21.95	122.683	1.9652
Methane (marsh gas).............	CH_4	0.553	7.98	44.642	0.7151
Ethane..........................	C_2H_6	1.037	14.97	83.691	1.3406
Butane..........................	C_4H_{10}	2.004	28.94	161.788	2.5916
Ethylene (olefiant gas)...........	C_2H_4	0.967	13.97	78.097	1.2510
Propylene.......................	C_4H_6	1.451	20.95	117.146	1.8765
Acetylene (ethine)...............	C_2H_2	0.898	12.97	72.510	1.1615
Ammonia........................	NH_3	0.589	8.50	47.545	0.7616
Chlorine........................	Cl_2	2.450	35.37	197.734	3.1674
Hydrochloric acid................	HCl	1.259	18.18	101.664	1.6285
Sulphuretted hydrogen...........	H_2S	1.177	16.99	94.984	1.5215
Nitrous oxide....................	N_2O	1.523	21.99	122.953	1.9692
Nitric oxide.....................	NO	1.038	14.99	83.772	1.3419
Cyanogen.......................	C_2N_2	1.799	25.99	145.239	2.3265
Coal gas........................	about 0.42	6.06	33.92	0.543
Water gas, blue..................	" 0.52	7.51	41.99	0.673
Water gas, carbureted............	" 0.62	8.96	50.07	0.801
Water gas, crude oil (Pacific coast)....	" 0.40	5.78	32.30	0.517
Oil gas, Pintsch..................	" 0.75	10.83	60.57	0.970
Natural gas.....................	" 0.57	8.23	46.03	0.737
Producer gas....................	" 0.85	12.27	70.64	1.100
Flue gas........................	" 1.05	15.16	81.16	1.358

If 1000 cu.ft. of gas weigh 1 lb., 1 cu.m. weighs 0.016 kilogram.
If 1 cu.m. of gas weighs 1 kilogram, 1000 cu.ft. weigh 62.428 lbs.

SPECIFIC GRAVITY OF WATER AT VARIOUS TEMPERATURES

Temperature in Degrees.		Specific Grav., Water at 4° C.=1.	1 Cubic Foot Weighs, Lbs.	Temperature in Degrees.		Specific Grav. Water at 4° C.=1.	1 Cubic Foot Weighs, Lbs.
Celsius.	Fahr.			Celsius.	Fahr.		
0	32	0.999874	62.42	55	131	0.98579	61.54
4	39.2	1.000000	62.42	60	140	0.98331	61.37
10	50	0.999736	62.41	65	149	0.98067	61.20
15	59	0.999143	62.37	70	158	0.97790	61.02
20	68	0.998252	62.32	75	167	0.97495	60.83
25	77	0.997098	62.26	80	176	0.97191	60.64
30	86	0.995705	62.17	85	185	0.96876	60.44
35	95	0.994098	62.08	90	194	0.96550	60.22
40	104	0.99233	61.97	95	203	0.96212	60.00
45	113	0.99035	61.85	100	212	0.96863	59.76
50	122	0.98813	61.70				

SPECIFIC GRAVITY AND WEIGHT OF FLUIDS AT 60° F.

Name.	Specific Gravity.	Pounds per Gallon.
Alcohol, pure	0.794	6.6
Alcohol, 95%	0.816	6.8
Alcohol, 50%	0.934	7.8
Ammonia, aqua, 29.01%	0.898	7.5
Ammoniacal gas liquor 4 "ounce" (weak)	1.005–1.01	8.3–8.4
Ammoniacal gas liquor 60 "ounce" (concentrated)	1.12–1.19	9.3–9–9
Bromine	2.97	24.7
Carbon disulphide	1.26	10.5
Ether, sulphuric	0.72	6.0
Muriatic acid	1.20	10.0
Nitric acid	1.217	10.2
Oil, linseed	0.94	7.8
Oil, petroleum	0.80	6.7
Oil, turpentine	0.87	7.3
Sulphuric acid	1.849	15.4
Tar	1.01–1.20	8.4–10.0
Vinegar	1.08	9.0
Water, pure	1.00	8.3
Water, sea	1.03	8.6

One cubic foot of pure water at 60° F. weighs 62.36 lbs.
One gallon of pure water at 60° weighs 8.3328 lbs.

COSTS FOR ERECTION

Suction-gas producer plants:
    Anthracite or bituminous coal.................... 100 to 350 H.P. $1.70 to $2.50
    Lignite fuel ....   10 per cent less
Pressure producer plants, with holder:
    Anthracite or bituminous coal or lignite.............. 350 H.P. $3.00 to $4.00
    Anthracite or bituminous coal or lignite.............. 350 to 1000 H.P. $2.50 to $3.00
Gas engines, costs for erection per ton................................... $12.00 to $13.00

APPENDIX

OIL FUEL PRODUCER GAS

THE manufacture of producer gas from oil may be divided into three heads: the first is where the majority of the fuel is converted into CO_2, and subsequently reacted into CO; the second being the combustion of the fuel in an insufficient atmosphere, the products of the combustion being carbonated or "carbureted" in their passage through the vapors of distillation; the third may be called a distillation process in which a portion of the oil, usually the residual (generally including the asphaltum or paraffin base) is used as a basic fuel, supplying the necessary heat for distillation or vaporization of the volatile matter.

Jones Oil-Gas Set.—The first method, consisting of oil-gas sets of the "Lowe system" or preferably the "Jones improved" type, designed by E. C. Jones of San Francisco (the pioneer of oil-gas development), constitutes a most satisfactory apparatus. With this type of machine the process of manufacture becomes more a matter of manipulation of the apparatus than of any specified change or adaption of the design. In this instance the apparatus is operated continuously instead of intermittently. The basic gas is formed by the nearly complete combustion of oil in the presence of steam and almost enough air for complete combustion within the generator. The products are recarbureted, the secondary reaction occurring in the checker work or archers of the subsequent apparatus.

TYPICAL ANALYSIS OF OIL PRODUCER GAS MANUFACTURED IN THE JONES APPARATUS

Component.	Per Cent.
CO_2	4
CNH_2N	2 or less
O_2	1
CO	10
H_2	5
CH_4	8
N_2	70

Calorific value................160 B.T.U. per cu.ft.

By proper manipulation, the hydrogen in this case may be maintained very low, not exceeding 4 or 5%, or, under operating conditions, probably 12% as a low limit when using the more viscous oil, and hence requiring an increment of steam.
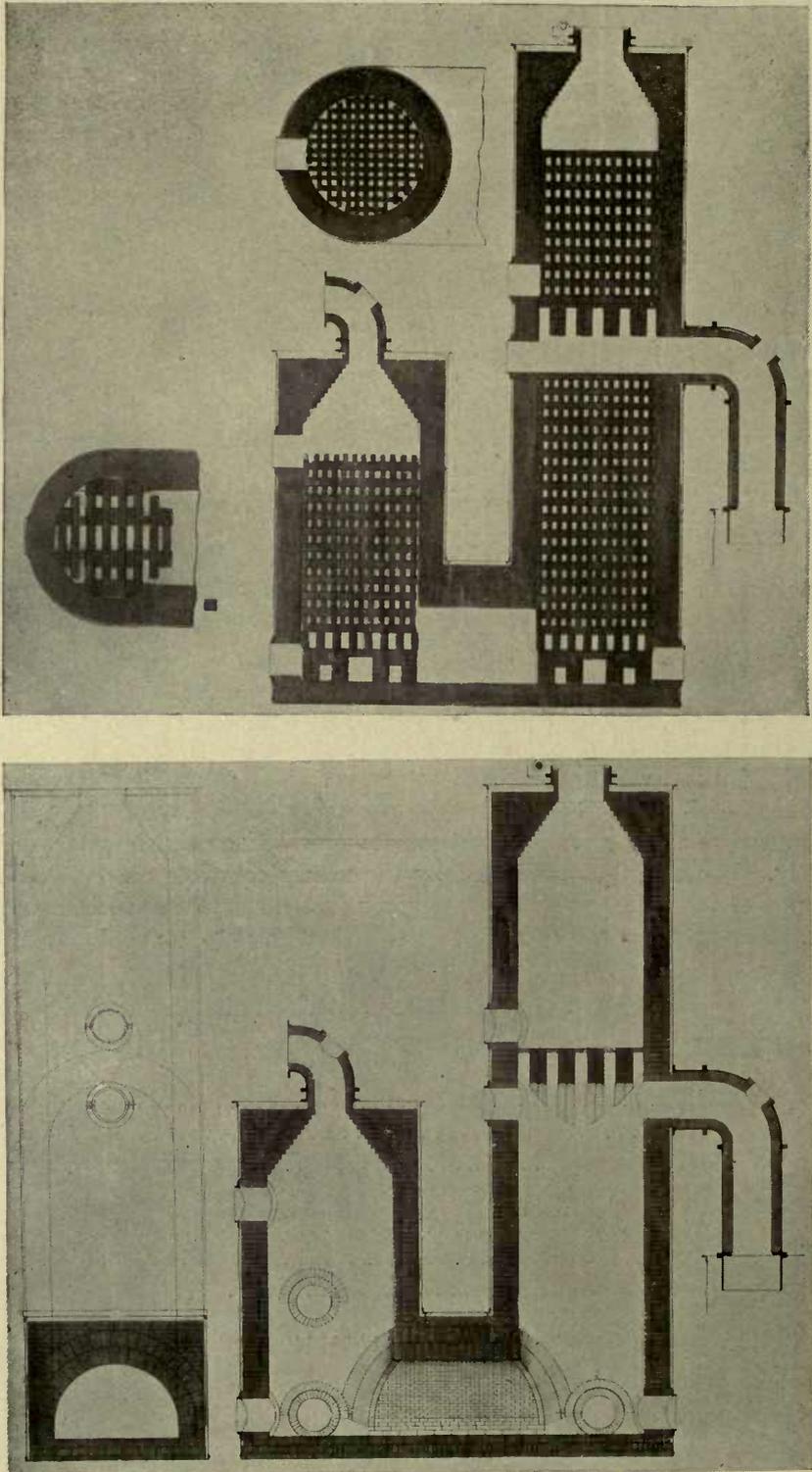
FIG. 243.—Jones Oil-Gas Producer Set, with and without Checker Brick Filling.

The enormous capacity of these machines, their sympathetic regulation and high efficiency, render them of particular advantage in the manufacture of large quantities of gas for large units, say engines above the 1000 H.P. type.

Nix-Frost Producer.—Of the second classification, the Nix-Frost type manufactured by the Western Gas Engine Company of Los Angeles, is probably the most representative. This apparatus is extremely similar in its operation to the powdered
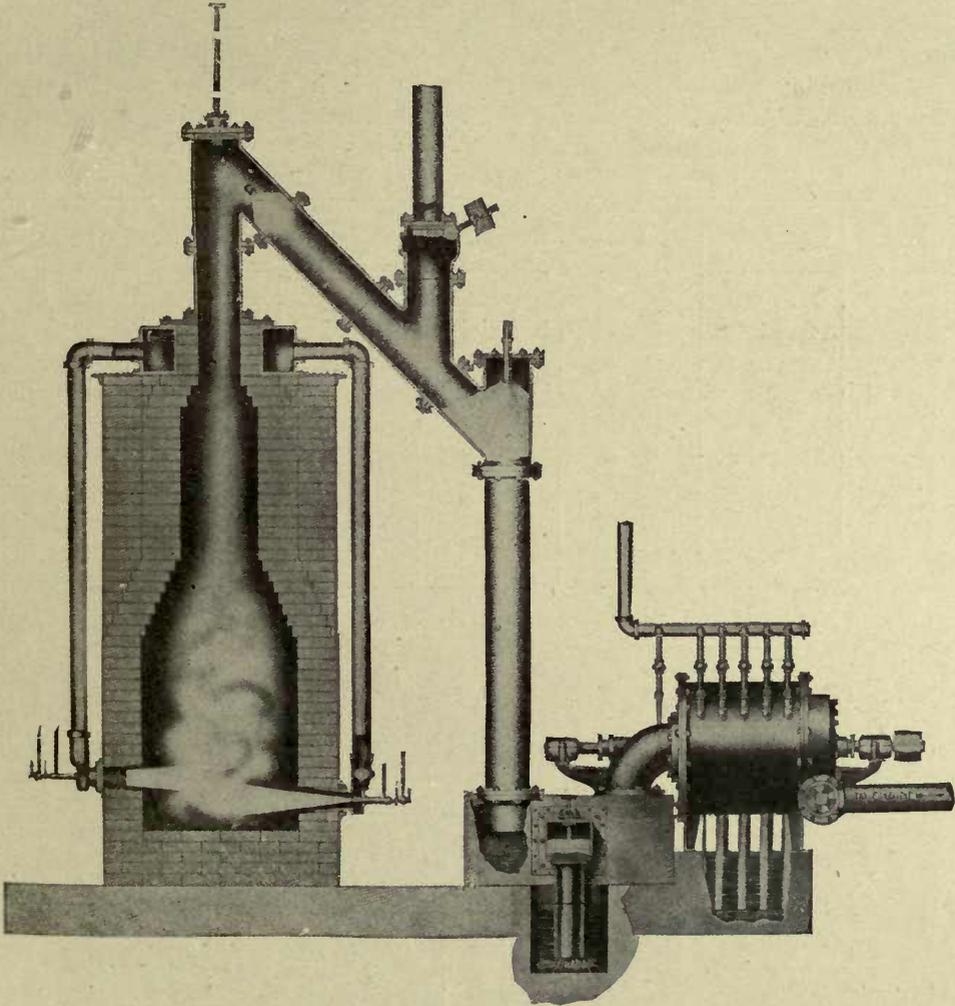
FIG. 244.—The Nix-Frost Crude-Oil Suction Gas Producer.

fuel producer and may be said to be analogous with the single substitution of liquid for powdered fuel. The data herewith appended contains some of the distinctive features of the operation in connection with the 300 H.P. set.

Two or more Tate-Jones burners are set radially at about 90°.

An air pressure of 40 to 90 lbs. is employed, depending upon viscosity of the oil.

The auxiliaries, consisting of an air blower, pump, exhauster, and tar washer, in an

average plant consume about 10% total power decreasing with large size plants (500 H.P.); the auxiliaries are estimated to consume about 35 H.P.

The capacity of the 15 ft.×5 ft. generator, with net diameter of 3 ft. reduced at the arch to 18 ins., is rated at 300 H.P.

With an exhauster a suction of approximately 8 ins. of water is constantly maintained upon the generator. This is supposed to prevent or minimize the formation of coke and lampblack.

The economy guaranteed is 1 b.h.p.h. per 1⅛ pounds of oil (18,500 B.T.U. per lb.).

The following tests of the oil-producer gas made in the Nix-Frost system are by Prof. William F. Durant of Leland-Stanford University.

TEST OF ENGINE AND QUALITY OF OIL

Time.	Elapsed Time, Minutes.	R.p.m.	Brake H.P.	Rate of Oil per Hour.	H.P. Hours.	Actual Oil.
1:15						
2:00	45	197.33	111.3	105.3	83.48	79
3:00	60	192.70	108.7	108.0	108.70	108
4:00	60	195.00	110.0	109.0	110.00	109
4:00						
5:30	30	195.50	110.3	106.0	55.15	53
6:00	60	193.60	109.2	109.0	109.20	109
7:00	60	198.70	112.1	109.0	112.10	109
7:35						
8:35	60	196.40	110.8	107.5	110.80	107.5
9:35	60	*183.10	103.3	112.5	103.30	112.5
10:20	45	*186.30	105.2	110.7	78.90	75.5

	H.P. Hours.	Actual Oil.
Totals	871.63	862.5
Average for 8 hours	108.95	107.81
Oil per horse-power hour	. . . . . .	0.99 lb.
Omitting the last two hours, the results are:		
Totals	661.83	646.5
Average for six hours	110.31	107.75
Oil per horse-power hour	. . . . . .	0.977 lb.
Gravity of oil	. . . . . .	19° Bé.

* One sparker on engine was occasionally missing fire.

ANALYSES AND CALCULATED HEATING VALUE OF GAS

Time.	12:20 P.M.	2:00 P.M.	4:00 P.M.	6:00 P.M.	8:00 P.M.	Average.
Carbon dioxide . . . . CO_2	3.8	3.8	3.7	3.6	4.1	3.80
Oxygen . . . . O_2	3.6	3.7	4.3	3.7	3.4	3.74
Illuminants . . . . C_nH_{2n}	4.6	3.0	2.6	4.5	2.5	3.44
Carbon monoxide . . . . . CO	11.0	11.5	10.8	11.4	11.7	11.28
Hydrogen . . . . H_2	3.8	5.4	7.0	5.0	6.60	5.56
Methane . . . . CH_4	6.9	6.0	4.8	6.0	6.0	5.94
Nitrogen . . . . N_2	66.3	66.6	66.8	65.8	65.7	66.24
Calculated B.T.U.	*202.0	173.0	156.7	196.4	169.5	179.53

* Before starting engine.

The Amet-Ensign Producer.—The last classification is typified in the Amet-Ensign apparatus, manufactured by the Western American Gas Engine Company of Phoenix, Arizona. This apparatus is exceedingly compact. The 100 H.P. machines occupy a floor space of only 2 ft × 3 ft. It consists of a small rectangular brick-
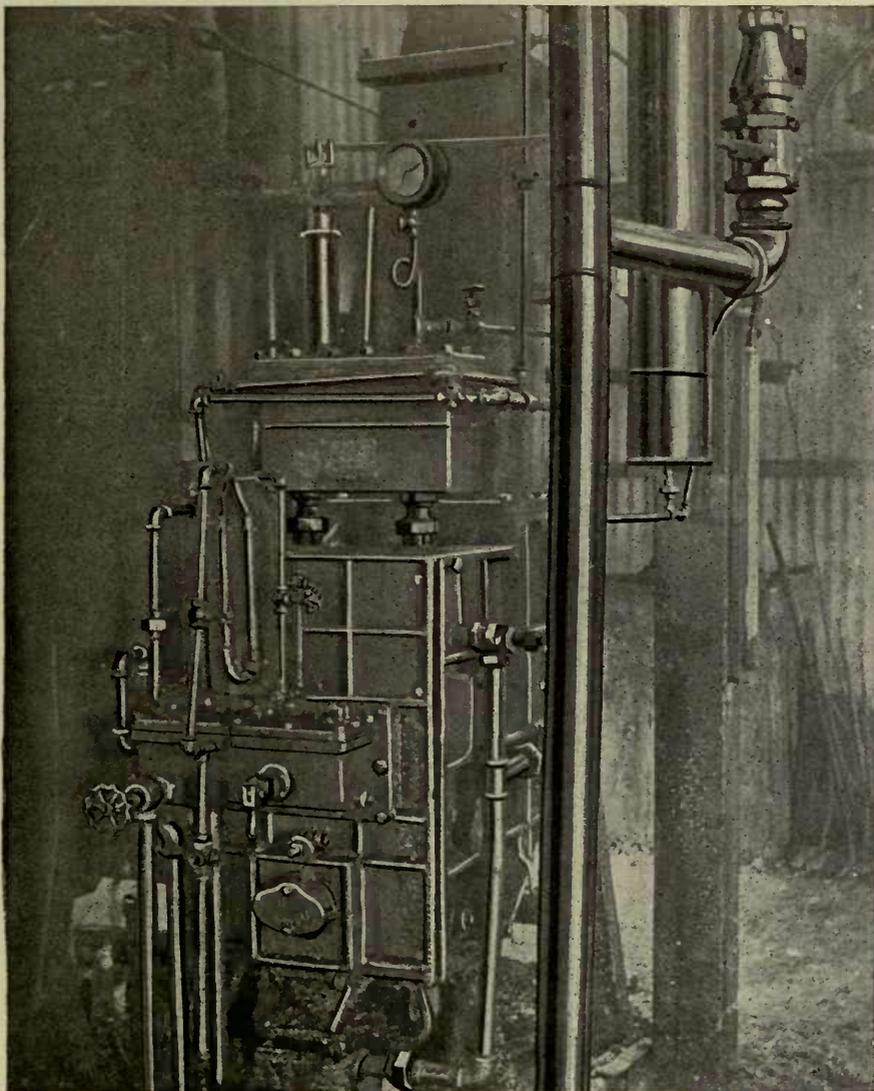
Fig. 245.—Amet-Ensign Oil-Gas Producer.

lined retort about 30 in. square × 4 ft long with 7 in. fire-brick linings. This retort is equipped with an apron or shelf pointing downward at an angle of about 45° from the wall and extending about a foot in length into the interior of the chamber.

Over this apron or shelf the total oil supply of the producer is dripped. The

volatile portion of the oil being evaporated during its passage over this hot plate, and the residuals, usually consisting of tar, asphalt, or paraffin, dropping from the edge encounter an air blast entering the bottom of the retort where they are consumed, the result of this combustion supplying the heat for vaporizing the oil in its
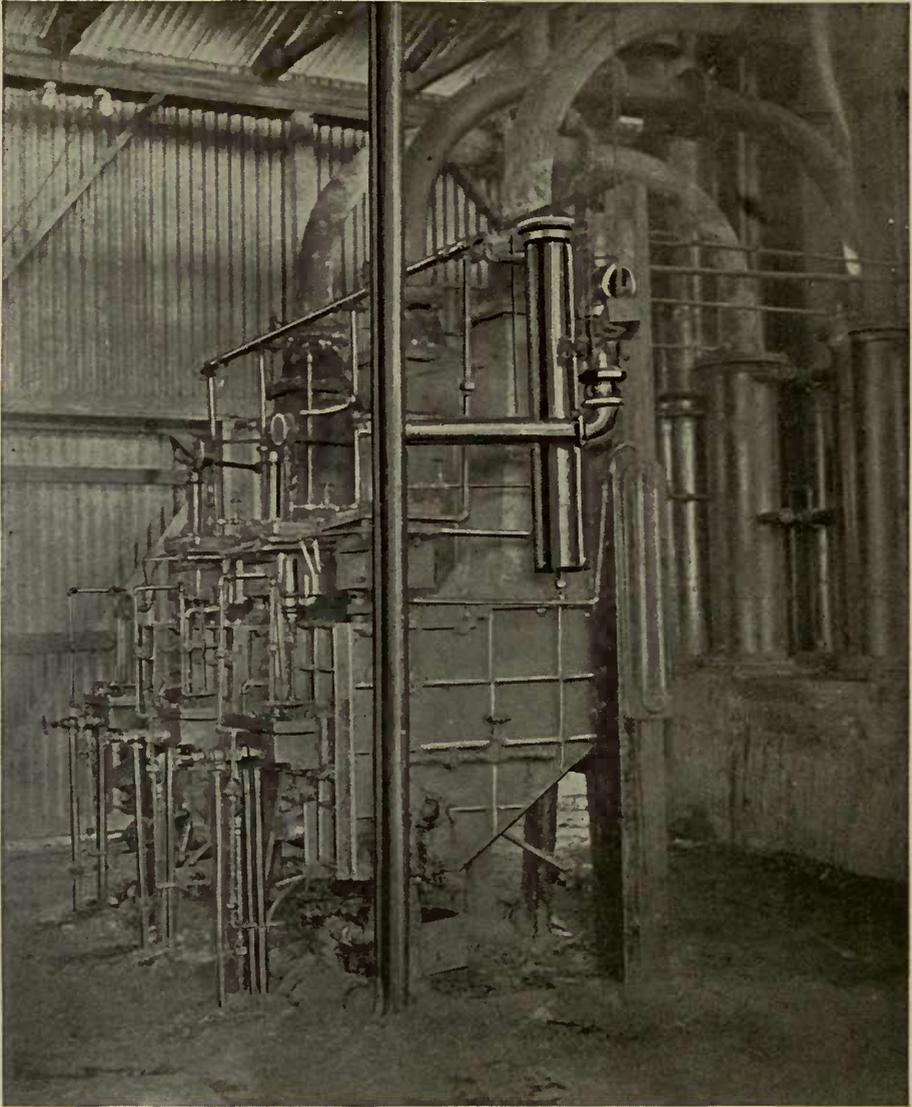
FIG. 246.—Battery of Amet-Ensign Producer.

passage over the apron. The products of this combustion are presumed to be recarbureted when combined with the oily vapors resulting from the earlier distillation.

The attached data indicates some of the operating conditions of the Amet-Ensign retort of the 100 H.P. size.

This oil producer has the following peculiarities:

The economy is 9 b.h.p.h. per gallon of oil. In commercial service they guarantee 7 h.p. per gallon oil (18,500 B.T.U. per lb.).

The thermal efficiency claimed by the maker is 58 to 62%.

As to the nature of the gas, a wide range is possible by the method of operation, varying from 101 to 210 B.T.U. per cu.ft.; maximum hydrogen, 3%; 180 B.T.U. guaranteed by makers, also 450 cu.ft. per 1 gallon of oil.

The auxiliaries are the oil pump and blower, the percentage of total power used by auxiliaries being 2.5%. A centrifugal gas washer has also been used to advantage, consuming probably 2.5 to 5% additional.
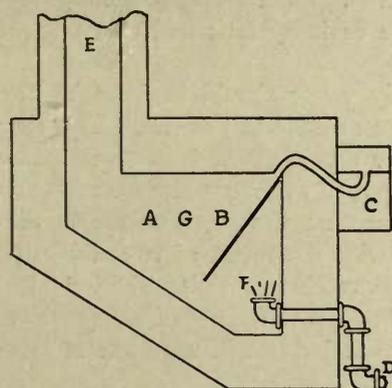
A = Retort.

B = Apron or distillation plate.

C = Oil reservoir.

D = Air blast

E = Take-off or stack.

F = Combustion area (where oil residue is burned by air blast.)

G = Distillation area (where volatile is distilled on apron or plate.)

Fig. 247.—Section of Amet-Ensign Producer, showing Oil-vaporizing Plate.

The maximum air blast is 19 in. of water to 6 oz.; sufficient air pressure is maintained upon the oil to balance the pressure of the blast and compensate for any internal pressure of the retort.

Shut-downs or intermission of 6 to 8 or 24 hours (depending upon nature of load, oil, or load factor) are required; to withdraw coke requires 5 to 15 minutes.

Every 20 to 30 minutes it is necessary to burn out stack of soot and lampblack; this requires $1\frac{1}{2}$ to $2\frac{1}{2}$ minutes.

A tank or gasholder for 100 H.P. at the U. S. Reservation service plant has a capacity of 2500 cu.ft.

The fuel is crude oil, Bakersville district, of which 1 gal. weighs 7.7 lbs.; this oil has 18,500 B.T.U. per lb. oil, and 42 gals. equal 1 bbl.

TYPICAL ANALYSIS OF GAS MADE IN THE AMET-ENSIGN OIL GAS PRODUCER

CO_2	4.5	B.T.U. per cu.ft.	171.85
CO	7.4	Claimed thermal efficiency	39 to 63%
O_2	0.4	Operating ditto	55%
CH_4	12.		
H	3.1		
N_2	71.9		
	100.0		

Gasifying Oil.—There can be little question but that the most efficient method of gasifying oil is that which breaks up the oil in sequence of fractional distillations, the process being very similar to that used in the refining of oil. Such an arrangement should distil the lighter hydrocarbons and illuminants at a relatively low temperature without "crocking," cracking, or over-cooking, and prevents the dissociation of these lighter hydrocarbons into lampblack or coke.

The heat in such process being gradually increased throughout the progress of the process, each fraction should be vaporized at its critical temperature; that is to say, the heat most appropriate to that particular fraction, the ascending temperature being progressively maintained until the volatile matter is completely driven off and the residue brought to the point of volatilization. Such an arrangement prevents a waste from either extreme quantities of tar or lampblack and seems to be the natural order of the process.

It should be borne in mind that the oil or oily vapor should be brought into direct contact with any iron or other metal substance as little as possible. This may be, for a number of reasons, probably, because of the coefficient of heat transference of metals as compared with, say, fire-brick, and also possibly because of their reflecting or refracting qualities. At any rate it would appear that the metal seems to concentrate the heat upon the oil globule or monecule with the result of vaporizing the hydrogen content too rapidly and leaving the carbon residue precipitated in solid or semi-solid form. This is known as "frying the oil," and is the cause of many serious difficulties in operation, principally through stoppage and waste in the form of tarry compounds, lampblack, coke or naphthaline.

Oil.—The oil produced in the United States, while practically all composed of about 85% of carbon and 15% hydrogen, may be classified under two distinct heads, namely: those possessing a paraffin base, which geographically include the principal oils of Texas, Oklahoma and the Southern States, and those possessing an asphalt base, which are limited in the main to California. Although similar in their ultimaate analysis, the combinations of sulphur and carbon appear in various groups and in a large diversity of compounds. Oils in even adjacent wells will show marked differences in these analyses as well as in the extraneous matter which they may entrain, or their sulphur content.

The followinn typical analysis will sufficiently illustrate samples collected from various localities:

DISTILLATION TESTS OF VARIOUS OILS

(Specific gravity of oil at 60° F., 31.50° Bé. Fractions 10% by volume.)

	KANSAS OIL.	INDIANA OIL.
First fraction	95° C. to 200° C.	60° C. to 175° C.
Second fraction	200° C. to 285° C.	175° C. to 256° C.
Third fraction	285° C. to 320° C.	256° C. to 294° C.
Fourth fraction	320° C. to 330° C.	294° C. to 315° C.
Fifth fraction	330° C. to 345° C.	315° C. to 330° C.
Sixth fraction	345° C. to 360° C.	330° C. to 337° C.
Seventh fraction	. . . .	337° C. to 340° C.
Eighth fraction.	. . . .	340° C. to 360° C.
Coke (per cent by weight)	77%	1.00%

The tenth fraction of the Kansas oil is thick and on cooling turns to a vaseline-like mass.

BEAUMONT, TEXAS, OIL

(Color, dark red; specific gravity, 0.9336 or 20° Bé.; water, trace.)

Fraction.	Temperature of Distance, Deg. F.	Per Cent by Volume.	Per Cent by Weight.	Specific Gravity Direct Baumé.		Color of Fraction.	Résumé.
				Sp. Gr.	Deg. B.		
1	200°	Water oil	Water oil	....	....	....	Water 212° F., trace.
2	200–250°	Water oil 0.6	Water oil	....	....	....	Napthas, 200–302° F., 15%
3	250–300°	0.9	1.79	0.8385	37.0	Apple green. . .	
4	300–350°	0.5	....	....	....		
5	350–400°	2.6	2.37	0.8533	34.1	Canary	Burning oil 302–572° F.,
6	400–450°	5.7	5.30	0.8681	31.1		39.7%
7	450–500°	7.9	7.45	0.8803	29.0	Chrome yellow	
8	500–550°	12.9	12.32	0.8912	27.1	Spruce	
9	550–600°	20.2	19.55	0.9039	24.9	....	Paraffin oils 572 to
10	600–650°	33.4	32.44	0.9067	24.4	Terra-cotta. . .	730° F., 56.3%
11	650–700°	8.8	8.79	0.9325	21.0	Bronze green. .	By weight 4.02%
12	700–730°	4.0	4.06	0.9473	17.8	Dk. bronze gr'n	
Coke	....	....	....	....	....	....	
Total	....	97.5	98.09	....	....		

CALIFORNIA OILS

Oil Used by Los Angeles Gas and Electric Co.

From Whittier-Fullerton Wells of the Union Oil Co.

Gravity at 60° F . . . . 20° Bé.
Calorific value . . . . 18,500 B.T.U. per lb.
Sulphur 0.85%
Water . . . . None to 1%
Flash point (open cup) . . . . 100° F.

Distillation Products.

Up to 350° F. . . . . 6% of 45° Bé. distillate
From 350 to 500° F . . . . 24% of 35°   "
From 500 to 650° F . . . . 20% of 26°   "
From 650 to asphalt . . . . 30% of 22°   "
From asphalt " D " . . . . 20%   "

The California oils, are usually heavy in gravity, some in commercial service running as low as 11° Bé. These of course require pre-heating prior to admission to a burner.

GLOSSARY

Absolute Temperature.—The temperature of a substance reckoned from that temperature —461° below the zero on the Fahrenheit scale and 273° below the zero on the centigrade scale—at which all heat is supposedly absent.

Avogadro's Law.—The temperature and pressure being the same, the number of molecules in a unit volume of all true gases is the same for all gases. Therefore every gas molecule occupies the same space.

Baffle.—A term applied to partitions designed to change the course of moving gases in the combustion chamber or among the boiler tubes.

Base Values.—A term used to designate the abscissa value of any point on a curve—that is, the horizontal distance of that point from the left side of the chart.

Black Body—A term used to designate a hollow body whose walls are all at the same temperature. If an extremely small hole were made in such a body, heat would be radiated through the hole in proportion to the difference of the fourth powers of the absolute temperatures of the black body and the surrounding objects.

British Thermal Unit.—That quantity of heat which is required to raise the temperature of 1 lb. of pure water through 1° F. at or near 39.1° F., the temperature of maximum density of water. The abbreviation B.T.U. is used in this volume.

Caking Coal.—A term applied to coal which fuses together when burning—a coal that is not free burning.

Carbon.—Available hydrogen ratio. The total carbon content of coal divided by the available hydrogen.

Catalyzer.—A substance whose presence, among the substances participating in a chemical reaction, hastens or retards the speed of the reaction, although the nature and total amount of catalyzer present is always the same at the end as at the beginning of the reaction, so far as can be detected.

Cellulose.—A substance represented chemically by the expression $C_6H_{10}O_5$. It is the basis of wood structure, excluding a slight amount of mineral ash in the cell walls.

Clinker.—A term used herein to designate the more or less molten or fusible portions of ash (including some carbon) drawn from the grate and ash pit.

CO.—Abbreviation for carbon monoxide.

CO_2.—Abbreviation for carbon dioxide.

Combustible.—A loose expression and misnomer for the phrase " coal free from moisture and ash," sometimes called " pure coal." The pounds of " combustible " used in every steam test have been computed in two ways, as follows:

1. Obtained by subtracting from the total pounds of dry coal fired the pounds of ash and combustible drawn out of the ash pit and through the fire doors in cleaning the fire.

2. The weight of the coal fired is corrected for moisture and ash as given by the proximate analysis, thereby giving the pounds of " combustible " fired. From this amount is subtracted the pounds of " combustible " lost in the refuse, giving the total pounds of " combustible " actually ascending from the grate during the test.

Combustible Zone.—In this zone the air and steam meet the carbon, the oxygen uniting with the incandescent C to form CO_2, while the steam is superheated and possibly begins to decompose.

Conduction.—The process of transferring heat by direct contact—as when heat travels along a rod, or from a hot stove lid to a flat iron resting on it.

Convection.— The addition to, or removal from, a body of heat, by gases or liquids circulating in direct contact with the body; as the removal of heat from a steam radiator by the circulation of air.

Decomposition Zone.—This is where CO is generated, the steam decomposed into H, and the CO_2 reduced to CO. A large amount of heat will be absorbed in this zone to compensate for the carbonization of CO_2 and the decomposition of the steam. In order that the reactions may take place, the temperature must be kept above 1800° F.

Distillation, Destructive.—Destructive distillation is the process of heating a substance beyond the point of decomposition without the access of air. The object may be the dry residue, the condensed distillate, or the gases evolved. The residue will always be carbon.

Distillation, Fractional.—This is the separating of different constituents from a composite substance. It is made possible by the fact that different substances pass into vapors at different temperatures.

Distillation Zone.—This occupies the upper part of the fire. The addition of fresh fuel always lowers the temperature, but the heat from the lower zones distils the volatile constituents of the fresh fuel. The nature of the hydrocarbons will depend upon the temperature. If the temperature is kept high, the hydrocarbons will be easily broken up, and the hydrogen liberated. This means a large yield of permanent gases and very little tar or soot. If the temperature is kept low, the hydrocarbons will be easily condensed and the amount of tar and soot will be greatly increased. For the complete distillation of the coal, a long exposure to a high temperature is necessary on account of its tendency to coke into large masses which are broken up with difficulty.

Dissociation.—The state of separation of the molecules of a substance into two or more parts. A term used herein to denote effects due to high temperatures.

Dry Chimney Gases.—In all calculations in this glossary this term includes CO_2, O_2, CO, and N_2 gases.

Furnace Efficiency, or per cent of completeness of combustion, denoted by E_3, is the ratio of the heat actually evolved in the furnace to the potential heat of the combustible ascending from the grate.

Empirical Formula.—A formula expressing the actual relations between two or more variables and constants, but not founded on known laws. Cf. " Rational formula."

Endothermic.—An adjective describing a chemical reaction which can take place only by absorbing heat from the surroundings or by reducing the temperature of the reacting matter. The opposite of exothermic.

Exothermic.—An adjective describing a chemical reaction which evolves heat. The opposite of endotheric.

Firing, Direct.—By direct firing is meant burning coal or other solid fuel in a fire-box close to the working chamber and in a layer so thin that enough free atmospheric oxygen passes through some of the wider crevices between the lumps of fuel, both to burn the carbonic oxide generated, by the incomplete combustion of the fuel, by the limited quantity of air which passes through other and narrower crevices, and also to burn the hydrocarbons, if

any, distilled from the fuel. Thus both the combustible gas and the air for burning it escape simultaneously and side by side from the surface of the fuel, the flame beginning at the very surface of the fuel.

Firing, Gas.—By gas-firing is meant chiefly burning the fuel in a layer so thick that all of the oxygen of the air which passes through it combines with the fuel, and that nearly all of it forms carbonic oxide with the carbon of the fuel; so that from the surface of the fuel escapes a stream of combustible gas, chiefly the carbonic oxide thus formed, and hydrocarbons from the distillation of the fuel, diluted with atmospheric nitrogen. The stream of gas is in turn burnt by air specially admitted for this purpose. In short, in direct-firing the fuel bed is so thin that it delivers flame direct from its surface; in gas-firing it is so thick that it delivers there a stream simply of c mbustible gas. This is the essential distinction.

Fixed Carbon.—A term applied to that portion of the carbon in a coal left after the "volatilization" process of the proximate analysis. It is obtained by subtracting from 100 the percentages of ash, moisture, and volatile matter.

Free-Burning Coal.—A term applied to coal which when thrown in the fire burns without the separate pieces of coal fusing together. A non-caking coal.

"Free" Moisture.—Moisture which is driven off from coal when subjected to a tempertaure of 105° C. (221° F.) for one hour.

Gram Molecule.—An amount of a substance in grams, numerically equal to the molecular weight of the substance. For instance, a gram molecule of water is 18 grams, the molecular weight of water being 18 (2 of hydrogen and 16 of oxygen).

Hydrocarbon Gases (Hydrocarbons).—Gases which are distilled from coal when it is heated. They are high in heating value, approximately $1\frac{1}{2}$ times as high in B.T.U. per lb. as pure carbon. They usually occur in three forms, expressed by the formulas: C_nH_n, C_nH_{2n}, and C_nH_{2n+2}.

Ignition Temperature.—The ignition temperature of a substance is that temperature to which it must be raised in the presence of oxygen to cause the two to unite by combustion. This temperature is rather indefinite, as extremely slow union begins far below the point of rapid union. For any one substance there are generally two temperatures, within perhaps 200° F. of each other, at the lower of which the rate of combustion is inappreciable and at the higher of which it is almost infinite.

Kinetic Theory of Gases.—This theory postulates that gases consist of immense numbers of individual molecules moving among each other with enormous velocities. The sum of the molecular impacts against the sides of a containing vessel constitutes the pressure of a gas. Raising the temperature of a gas inceases the molecular speed, and consequently the force of impact.

Mass Action, Law of.—The speed of a chemical reaction is proportional to the product of the weights of reacting substances present, in unit volume, the weight of each substance being expressed in gram-molecules.

O_2.—Abbreviation for oxygen (one gaseous molecule made up of 2 atoms of O).

Orsat Apparatus.—An instrument for determining the percentages of carbon dioxide, oxygen, and carbon monoxide by absorbing them successively in certain solutions. (See text-books on gas analysis).

Potential Heat.—A term applied to the heat in coal as determined by a calorimeter.

Probability Curve.—The graphic plotting of certain mathematical equations expressing the likelihood of a quantity being more or less different from what it " ought " to be.

Proximate Analysis of Coal.—An empirical method of determining the percentage of " free " moisture, of " volatile matter," of " fixed carbon " and of ash in coal. The method of determination varies somewhat with different chemists.

Pyrometer.—An instrument for measuring high temperatures.

Radiation.—The process of transferring heat through space from one body to another without the aid of tangible substance; for example, the transfer of heat from the sun to the earth.

Rational Formula.—A formula deduced from fundamental laws, as of physics.

Refuse.—Clinker, ash, and unconsumed coal taken from the ash pit and pulled out of the furnace when cleaning fire.

Seger Cones.—Small pyramids made of various chemicals variously mixed. The temperatures of softening of the different cones are fairly well known. Several of them are put into a furnace in a row, each having a melting point intermediate between its neighbors. By watching the curling over of the tips one can form a fairly correct estimate of the average temperature.

Stefan and Boltzmann's Law.—The amount of energy radiated by a black-body surface to another body is proportional to the difference of the fourth powers of their absolute temperatures.

Straight-line Function.—A value changing directly or inversely with a variable, so that if simultaneous values are plotted on co-ordinate paper, the points would lie in a straight line.

Temperature Gradient.—Any continuous change of temperature in a body actively conducting heat.

Ultimate Analysis of Coal.—A chemical analysis so made as to give, in percentages, the amounts of carbon, hydrogen, oxygen, nitrogen, and ash in a dry coal. The sulphur is separately determined.

Unaccounted-for Loss.—That percentage of the potential heat of a combustible which remains after deducting all the known expenditures of heat.

Velocity.—A term loosely applied to the speed of a chemical reaction, for example, combustion. It is proportional at any instant to the rate of formation of new substance by the reaction.

Volatile Matter from Proximate Analysis.—Or volatile combustible matter," as it is often incorrectly termed, is the mixture of gases, together with some particles of carbon, driven off when a sample of finely ground coal is heated in a closed vessel. This is an arbitrary determination, dependent on the operator, and the conditions under which it is made. A committee from the American Chemical Society has suggested a method of volatilization which is generally followed. This method gives fairly concordant results when the same operator, using the same apparatus, makes duplicate determinations on the same sample of coal.

Volatile Carbon.—A name given to that part of the carbon in coal which is expelled in the process of volatilization by the " standard method " of proximate analysis. It exists in the " volatile matter " resulting from distillation, largely in combination with hydrogen as gaseous hydrocarbons.

Water of Composition.—A fictitious value determined by uniting the total oxygen in dry coal with such a part of the hydrogen as would be required to form water.

INDEX.

D. VAN NOSTRAND COMPANY'S

LIST OF BOOKS

ON

PRODUCER GAS

AND

Gas, Gasoline and Oil

ENGINES

ALLEN, HORACE. How to Design a Gas Engine. With full working drawings for a 7 B. H. P. gas engine. 20 illustrations. 4to. cloth. 40 pp. Manchester, 1907. *net*, **$1.00**

——Modern Power Gas Producer Practice and Applications. A practical treatise dealing with the gasification of various classes of fuels by the pressure and suction systems of producer. 136 illustrations. 12mo. cloth. 334 pp. London, 1908. *net*, **$2.50**

——Gas and Oil Engines. A treatise on the design, construction and working of internal combustion engines. 240 illustrations. 8vo. cloth. 548 pp. Manchester, 1907. *net*, **$4.50**

ASKLING, C. W., and ROESLER, E. Internal Combustion Engines and Gas Producers. 178 illustrations. 6 x 9. cloth. 305 pp. London, 1912. *net*, **$4.50**

AUDEL'S Gas Engine Manual. A practical treatise on the theory and management of gas, gasolene, and oil engines. 156 illustrations. 8vo. cloth. 465 pp. New York, 1908. **$2.00**

BOTTONE, S. R. Magnetos for Automobilists: How Made and How Used. A handbook of practical instruction in the manufacture and adaptation of the magneto to the needs of the motorist. *Second Edition, enlarged.* 52 illustrations. 12mo. cloth. 118 pp. London, 1909. *net*, **$1.00**

BREWER, R. W. A. Motor Car Construction. A practical manual, with notes on wind resistance and body design, for the use of engineers, students and motor car owners. 78 illustrations. 12mo. cloth. 247 pp. London, 1912.   **net, $2.00**

BUTLER, EDWARD. Carburettors, Vaporizers, and Distributing Valves Used in Internal Combustion Engines. 100 illustrations. 8vo. cloth. 187 pp. London, 1909.   **$2.00**

CARPENTER, R. C., and DIEDERICHS, H. Internal Combustion Engines; Their Theory, Construction, and Operation. *Third edition, corrected.* Illustrated. 8vo. cloth. 611 pp. New York, 1912.   **net, $5.00**

CONTENTS: Introduction, Definitions, and Classification, Indicated and Brake Horse-Power. Thermodynamics of the Gas Engine. Theoretical Comparison of Various Types of Internal Combustion Engines. Various Events of the Constant-Volume and Constant-Pressure Cycle as Modified by Practical Conditions. The Temperature Entrophy Diagram Applied to the Gas Engine. Combustion. Gas Engine Fuels, the Solid Fuels, Gas Producers. Liquid Fuels: Carbureters and Vaporizers. The Gas Fuels. The Fuel Mixture—Explosibility, Pressure, and Temperature. History of the Gas Engine. Modern Types of Internal Combustion Engines. Gas Engine Auxiliaries: Ignition, Mufflers, and Starting Apparatus. Regulation of Internal Combustion Engines. The Estimation of Power of Gas Engines. Methods of Testing Internal Combustion Engines. The Performance of Gas Engines and Gas Producers. Cost of Installation and of Operation.

CHALKLEY, A. P. Diesel Engines for Land and Marine Work. With an introductory chapter by Dr. Rudolph Diesel. Illustrated. 6 x 9. cloth. 237 pp. London, 1912.   **net, $3.00**

CONTENTS: General Theory of Heat Engines, with Special Reference to Diesel Engines. Action and Working of the Diesel Engine. Installing and Running Diesel Engines. Testing Diesel Engines. Diesel Engines for Marine Work. Construction of the Diesel Marine Engine. The future of the Diesel Engine. Appendix.

CLARK, A. G. Textbook on Motor Car Engineering. Vol. 1. Construction. 213 illustrations. 6x9, cloth. 440 pp. London, 1911. **net, $3.00**

CLARK, CARL H. Marine Gas Engines; Their Construction and Management. 102 illustrations. 5¾ x 8. cloth. 115 pp. New York, 1911.   **net, $1.50**

CONTENTS: Types of Engines. Two-Cycle Engines. Four-Cycle Engines. Vaporizers and Carbureters Ignition Devices. Ignition Wiring. Lubrication. Multiple-Cylinder Engines. Reversing Mechanisms. Propellers. Installation. Operation and Care of Engines. Power of Engines. Selecting an Engine.

CLERK, DUGALD. The Gas, Petrol, and Oil Engine. Vol. I. Thermodynamics of the Gas, Petrol and Oil Engine together with Historical Sketch. *New and Revised Edition.* 121 illustrations. 5 plates. 8vo. cloth. 380 pp. New York 1909. **net, $4.00**

CLERK, DUGALD. The Theory of the Gas Engine. *Third Edition.* With additional matter edited by F. F. Idell. Illustrated. 16mo. boards. 180 pp. (Van Nostrand's Science Series, No. 62.) New York, 1903. **.50**

Dictionary. Illustrated Technical Dictionary. In six languages—English, German, French, Russian, Italian and Spanish. Edited according to the Deinhardt and Schlomann method by Alfred Schlomann. Vol. IV. Internal Combustion Engines. Compiled by Karl Schikore. 1,000 illustrations. Numerous formulas. 16mo. cloth, 628 pp. New York, 1908. **net, $3.00**

DONKIN, B. Textbook on Gas and Oil Engines. *Fourth Edition, revised and enlarged.* 165 illustrations. 8vo. cloth. 568 pp. London, 1905. **net, $7.50**

DOWSON, J., and LARTER, A. T. Producer Gas. *Second Edition.* Illustrated. 8vo. cloth. 320 pp. London, 1907. **net, $3.00**

GARRATT, H. A. Heat Engines. 174 illustrations and folding plates. 5¼ x 7½. cloth. 345 pp. London, 1912. **net, $1.70**

GOLDINGHAM, A. H. The Gas Engine in Principle and Practice. Including comparison of the two-cycle and four-cycle types of Internal-Combustion Engines. With description of various designs; together with notes on suction and pressure type gas producers, crude oil vaporizers, etc. 105 illustrations. 6¼ x 9¼. cloth. 195 pp. New York, 1912. **net, $1.50**

—— **Design and Construction of Oil Engines.** With directions for erecting, testing, installing, running and repairing. *Third Edition, revised and partly rewritten.* Illustrated. 12mo. cloth. 280 pp. N. Y., 1910. **$2.50**

GROVER, F. Modern Gas and Oil Engines. An exhaustive treatise. *Fifth Edition.* Illustrated. 12mo. cloth. 372 pp. London, 1909. **net, $2.00**

GÜLDNER, H. The Design and Construction of Internal Combustion Engines. Translated and revised, with additions on American Engines, by H. Diederichs. A handbook for designers and builders of gas and oil engines. 728 illustrations. 36 folding plates. 4to. cloth. 690 pp. New York, 1910. **net, $10.00**

CONTENTS: VARIOUS METHODS OF OPERATING GAS ENGINES AND THE GAS ENGINE CYCLES. General Considerations. The Various Cycles of Operation. Critical

Examination of the Various Cyclic Events. THE DESIGN AND CONSTRUCTION OF INTERNAL COMBUSTION ENGINES. Fundamental Considerations. Determination of Principal Dimensions. General Engine Parts. Special Parts for Gas and Oil Engines. Auxiliaries. CONSTRUCTION, ERECTION AND TESTS OF MODERN INTERNAL COMBUSTION ENGINES. Stationary Engines. Portable and Self-Propelled Engines. THE GAS ENGINE FUELS AND COMBUSTION IN GAS ENGINES. Fuel Gases. Liquid Fuels. Fuel Mixtures. Combustion in Gas Engines. APPENDIX. Synopsis of Thermodynamics. Fundamental Principles of Thermochemistry. Some Details from Practice.

HELDT, P. M.   The Gasoline Automobile; Its Design and Construction. Volume I.—The Gasoline Motor. 314 illustrations. 5½ x 9. cloth. 500 pp. New York, 1911. **net, $4.00**

HISCOX, G. D. Gas, Gasolene, and Oil Engines. *Eighteenth Edition, entirely rewritten.* 412 illustrations. 8vo. cloth. 485 pp. N. Y., 1910. **net, $2.50**

HOGLE, W. M. Internal Combustion Engines. A reference book for designers, operators, engineers and students. 106 illustrations. 12mo. cloth. 250 pp. New York, 1909. **net, $3.00**

HUTTON, F. R. The Gas Engine. A treatise on the internal combustion engine, using gas, gasolene, kerosene, alcohol or other hydrocarbon as a source of energy. *Third Edition, revised.* Illustrated. 8vo. cloth. 562 pp. New York, 1908. **$5.00**

JONES, FORREST R. The Gas Engine. 142 illustrations. 8vo. cloth. 447 pp. New York, 1909. *New Edition.* **$4.00**

—— **Electric Ignition for Combustion Motors.** 294 illustrations. 6¼ x 9½. cloth. 450 pp. New York, 1912. **net, $4.00**

JUNGE, F. E. Gas Power. A study of the evolution of gas power, the design and construction of large gas engines in Europe, the application of gas power to various industries, and the rational utilization of low grade fuels. Illustrated. 8vo. cloth. 548 pp. N. Y., 1908. **net, $5.00**

KENNEDY, RANKIN. Modern Engines and Power Generators. A practical work on prime movers and the transmission of power. Fully illustrated. 4to. cloth. London, 1907. Six volumes. **$15.00**

Single volumes. **$3.00**

CONTENTS: The Prime Mover: Its Sources of Energy, Heat, Electricity. The Working Substance in Heat Engines: Air, Steam, Water. The Engines—Turbines: Air, Water, Steam, Gas. Reciprocating Engines: Single Acting, Double Acting, Compound, Triple, and Quadruple; Horizontal, Vertical. Engines, Rotary. Important Parts of Engines: Valves and Expansion Gear, Governors, Condensers,

Pumps, Air and Water, Bearings and Rod Ends, Lubricators. Generators—Steam Boilers: Cylindrical, Tubular, Flash, Water Tube, Economizers, Superheaters, Feed Pumps, Injectors, Ejectors, Water Supply and Coolers, Care of and Mechanical Stokers. Gas Generators—Coal Gas and Blast Furnace Gases: Water Gas, Mond Gas, Dowson Gas. Oil Fuels: Heavy Oils, Light Oils. Spirit, Gasoline, Benzoline, Naphtha, and Alcohol. Electric Engines—Dynamos: Batteries, Generators, Motors. Prime Movers Special, as made by Leading Engineers—For Mills, Factories, Works, etc., on Land—Turbines, Steam, Water and Air. Reciprocating, Steam, Water, and Air. For Marine Propulsion, Steam, Electric, Water, and Air. For Motor Cars: Steam, Oil, Electric. For Railways and Street Railways. Power Transmission and Transmitting Gearing, Belts, Ropes, Wheels, Compressed Air, Hydraulic Pressure, Electricity.

LATTA, NISBET. Handbook of American Gas Engineering Practice. With numerous diagrams and figures. 8vo. cloth. 460 pp. New York, 1907. **net, $4.50**

CONTENTS: Water Gas Manufacture: The Generator. The Carburetter. The Superheater. Wash-Box and Tar. Scrubbers. Condensers. Purifiers. Exhausters. Station Meters. Holders. Details of Works Operation. Gas Distributors: Naphthalene. Mains. Services. Consumers' Meters. Pressure. House Piping. Appliances. General Technical Data: Properties of Gases. Steam. Mathematical Tables. Conversion Factors. Pipe and Miscellaneous Data.

—— **American Producer Gas Practice and Industrial Gas Engineering.** A new and original work. 246 illustrations. Large 8vo. cloth. 550 pp. New York, 1910. **net, $6.00**

CONTENTS: Producer Operation: Cleaning the Gas. Works Details. Producer Types: Down Draft Producers. Down Draft Apparatus. The Wood System. The Tait System. Operation of Tait Producer. Loomis-Pettibone System. Westinghouse Double Zone. Westinghouse Bituminous Gas Producer. The Morgan Producer. The Herrick Producer. Smith Lignite Producer. Lignite Suction Producer. Wood-Fuel Suction Producer. Powder Fuel Producer. Marconet Powdered Fuel Producer. Moving Gases. Solid Fuels. Physical Properties of Gases. Chemical Properties of Gases. Gas Analysis. Gas Power. Gas Engines. Industrial Gas Applications. Furnaces and Kilns. Burning Lime and Cement. Preheating Air. Doherty Combustion Economizer. Combustion in Furnaces. Heat. Temperature. Radiation and Conduction. Heat Measurement: Pyrometry and Calorimetry. Pipes, Flues and Chimneys. Materials: Miscellaneous Data. Useful Tables. Oil Fuel Producer Gas. Glossary.

LEVIN, A. M. The Modern Gas Engine and the Gas Producer. 181 illustrations. 8vo. cloth. 500 pp. New York, 1910. **net, $4.00**

LEWES, V. B. Liquid and Gaseous Fuels and the Part They Play in Modern Power Production. Illustrated. 8vo. cloth. 334 pp. (Van Nostrand's Westminster Series.) New York, 1907. **net, $2.00**

LIECKFELD, G. Oil Motors; **Their Development, Construction and Management.** A handbook for engineers, owners, attendants and all interested in engines using liquid fuel. 306 illustrations. 8vo. cloth. 287 pp. London and Philadelphia, 1908.   **$4.50**

LUCKE, C. E. Gas Engine Design. Second edition. 145 illustrations. 8vo. cloth. 254 pp. New York, 1912.   **net, $3.00**

> The work is divided into three parts. The first, treating of power, efficiency, and economy, gives the material necessary for deciding on the necessary piston displacement for any specified output for any kind of gas, and enables the designer to approximately predict economy. The second part contains the data and method for determining the stresses in the parts and the number and arrangement of cylinders necessary for balance or turning effort to meet the specifications. The last is entirely concerned with the dimensions of the parts to resist the stresses, both by theoretic analysis and by empirical formulæ, showing between what limits every principal dimension should lie.

MARKS, L. S., and WYER, S. S. Gas and Oil Engines and Gas Producers. Illustrated. 8vo. cloth. 137 pp. Chicago, 1908.   **$1.00**

MARSHALL, W. J., and SANKEY, H. RIALL, CAPT. Gas Engines. 127 illustrations. 6 x 8½. cloth. 293 pp. New York, 1911. **net, $2.00** CONTENTS: Theory of the Gas Engine. The Otto Cycle. The Two-Stroke Cycle. Water-Cooling of the Gas-Engine Parts. Ignition. Operating Gas Engines. The Arrangement of a Gas Engine Installation. The Testing of Gas Engines. Governing. Gas and Gas Producers.

MATHOT, R. E. The Construction and Working of Internal Combustion Engines. Translated from the French by W. A. Tookey. A practical treatise on methods of construction; with calculations for the use of engineers, manufacturers and users, and a critical study of present-day types. Illustrated. 6¼ x 9½. cloth. 576 pp. London, 1910. **net, $6.00**

—— **Gas Engines and Producer Gas Plants.** Translated from the French by W. B. Kaempffert. Illustrated. 8vo. cloth. 314 pp. New York, 1906.   **$2.50**

MEHRTENS, A. C. Gas Engine Theory and Design. Illustrated. 12mo. cloth. 261 pp. New York, 1909.   **$2.50**

MOSS, S. A. Elements of Gas Engine Design. Illustrated. 16mo. boards. 197 pp. (Van Nostrand's Science Series, No. 121.) N. Y., 1906.   **.50**

O'CONNOR, HENRY. Petrol Air-Gas. A practical handbook on the installation and working of air-gas lighting systems for country houses. Illustrated. 12mo. cloth. 75 pp. London, 1909.   **net, .75**

PARSELL, H. V. A., and WEED, A. J.   **Gas Engine Construction.** *Third Edition, revised and enlarged.* 145 illustrations. 8vo. cloth. 300 pp. New York, 1906.   **$2.50**

POOLE, CECIL P.   **The Gas Engine.** Illustrated. 8vo. cloth. 103 pp. New York, 1909.   **net, $1.00**

POPPLEWELL, W. C.   **An Elementary Treatise on Heat and Heat Engines.** Illustrated. 12mo. cloth. 382 pp. Manchester, 1897.   **$2.50**

Questions and Answers from "The Gas Engine Magazine." Illustrated. 16mo. cloth. 280 pp. Cincinnati, O., 1907.   **$1.00**

RATHBUN, J. B.   **Gas Engine Troubles and Installation.** Illustrated. 5¼ x 8. cloth. 450 pp. Chicago, 1911.   **$1.00**

ROBERTS, E. W.   **The Gas Engine Handbook.** A manual of useful information for the designer and engineer. *Sixth Edition, revised and enlarged.* Illustrated. 32mo. leather. Cincinnati, O., 1903.   **$1.50**

—— **Gas Engines and Their Troubles.** With additional chapters on Design, Construction and Propulsion of Launches. Illustrated. 12mo. cloth. 151 pp. New York, 1905.   **$1.50**

ROBSON, P. W.   **Power Gas Producers; Their Design and Application.** 105 illustrations. 8vo. cloth. 254 pp. London, 1908.   **net, $3.00**

RUSSELL, T. H.   **Ignition, Timing and Valve Setting.** Illustrated. 5¼ x 8. cloth. 240 pp. Chicago, 1912.   **$1.00**

SEXTON, A. H.   **Producer Gas.** A sketch of the properties, manufacture and uses of gaseous fuels. Illustrated. 8vo. cloth. 228 pp. Manchester, 1905.   **net, $4.00**

SHARP, ARCHIBALD.   **Balancing of Engines; Steam, Gas and Petrol.** An elementary textbook, using principally graphic methods. Illustrated. 8vo. cloth. 223 pp. London, 1909.   **net, $1.75**

SIMMANCE, J. F.   **Calorimetry of Producer and Illuminating Gases.** With special reference to future legislation. 16mo. cloth. 30 pp. London.   **$1.00**

SMITH, C. ALFRED.   **Suction Gas Plants.** 55 illustrations. 12mo. cloth. 205 pp. London, 1909.   **net, $2.00**

SOREL, ERNEST.   **Carbureting and Combustion in Alcohol Engines.** Translated from the French by S. M. Woodward and J. Preston. Illustrated. 12mo. cloth. 269 pp. New York, 1907.   **$3.00**

STODOLA, A. Steam Turbines. With an appendix on *Gas Turbines and the Future of Heat Engines.* Authorized translation from the German by Louis C. Lowenstein. *Second Edition.* 243 illustrations. 8vo. cloth. 488 pp. New York, 1906.   **net, $5.00**

SUPLEE, H. H. The Gas Turbine. Progress in the design and construction of turbines operated by gases of combustion. 93 illustrations. 6 x 9. cloth. 270 pp. Philadelphia, 1910.   **net, $3.00**

TOOKEY, W. A. The Gas Engine Manual. A practical handbook of gas engine construction and management. Fully illustrated. 8vo. cloth. 186 pp. London, 1908.   **$1.50**

WADSWORTH, C., Jr. Primary Battery Ignition. A simple, practical pocket guide on the construction, operation, maintenance and testing of primary batteries for automobile, motorboat and stationary engine ignition service. Illustrated. 5 x 7. boards. 78 pp. New York, 1912.   **net, .50**

CONTENTS: Definitions and Principles of Operation. Electrolyte. Electrode. Battery Terminals. Path of Current. Potential. Electromotive Force. Amalgamation. Polarization. Details of Construction. Voltage of Cell. Resistance, Electrical Units. Ohm's Law. Output of Batteries. Setting Up and Removing Batteries. Open and Closed Circuit Batteries. Dry Cells. Construction, Output, Life and Capacity, Care. Battery connections. Battery Connectors. "Screw-top" Cell Connections. "Combination" Battery Holders. Testing. Use of Ammeter. Testing with Buzzer. Current Required to Produce Spark. Various Battery Troubles and Remedies.

WIMPERIS, H. E. The Internal Combustion Engine. Being a text-book on gas, oil and petrol engines for the use of students and engineers. 114 illustrations. 8vo. cloth. 339 pp. London, 1908.   **net, $3.00**

WYER, S. S. A Treatise on Producer Gas and Gas Producers. *Second Edition.* 8vo. cloth. 310 pp. New York, 1907.   **net, $4.00**

—— **Catechism on Producer Gas.** Illustrated. 12mo. cloth. 46 pp. New York, 1906.   **net, $1.00**


Any Book in this List will be sent Postpaid to Any Address in the World on Receipt of Price, by

D. VAN NOSTRAND COMPANY

Publishers and Booksellers

25 PARK PLACE   NEW YORK