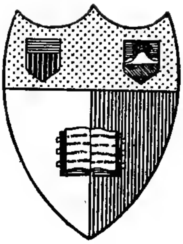

THE PRACTICE OF LUBRICATION

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LUBRICATION

AN ENGINEERING TREATISE
ON
THE ORIGIN, NATURE AND TESTING OF LUBRICANTS,
THEIR SELECTION, APPLICATION AND USE

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TO ALL THOSE WHO STRIVE TO
ADVANCE THE SCIENCE OF LUBRICATION,
RAISE THE STANDARDS OF LUBRICANTS,
AND IMPROVE THE METHODS OF THEIR
APPLICATION AND USE

THIS BOOK IS DEDICATED

PREFACE

Lubrication has for many years received only scant attention and existing standards of lubrication still leave considerable room for improvement. Very few firms employ qualified chemists to assist them in maintaining a reasonable standard of efficiency; and such a thing as technical service embodying a highly trained staff of lubricating engineers was unheard of until recent years and is still considered an expensive luxury by most firms.

A development is, however, gradually taking place in the right direction. Both oil suppliers and oil users are beginning to realize that lubrication can no longer be left to guess work; that to send salesmen out with a set of samples and a price list, but without the necessary technical knowledge or backing, is to court failure; that entertaining customers or obtaining business simply through friendship between salesman and buyer is not sufficient, because friendship does not add to the lubricating value of the oil, nor does it always help to select the right oil or use it in the right way.

Lubrication is rapidly becoming a science. Some oil firms have appreciated the value of the assistance of a staff of qualified lubricating engineers, who should be able to inspect a plant, to report intelligently on the lubrication conditions of all engines and machinery, to point out and estimate the value of possible improvements in regard to savings in power or lubricants, to investigate complaints, etc. These men should have a thorough knowledge of their firms' products, so that they can recommend the correct grades for any kind of machinery, even without knowing anything about the lubricants actually in use.

Obtaining samples for analysis and "matching" them at a lower price per gallon is unfortunately still the standard of procedure of most oil firms, and should be discouraged by the consumer in favor of a more efficient lubrication service, which places the supply of lubricants on a sound engineering basis.

Large consumers of lubricants will find it worth their while to ask oil suppliers to demonstrate the value of their lubricants;

and they will soon find that it is of far greater importance than is generally realized that the lubricating systems of the engines or machinery be as perfect as possible, that the correct grades of lubricant be selected, that the lubricants be stored and distributed in the best manner, used in the right way and in the right amount, and that the waste oil, if any, be collected, purified and used again.

Oil firms who intend to develop a technical organization must not make the mistake of thinking that they can engage any kind of engineers. A high standard of general engineering knowledge is essential, besides considerable tact in dealing with consumers.

Furthermore, an engineer, however excellent his general knowledge, does not become a lubricating engineer the moment he is engaged by an oil firm. He will have to study the available literature, but must not expect to develop his experience by sitting in the office. He should study closely lubrication of machinery under actual working conditions to the minutest details, and thus he will in time accumulate the right kind of special knowledge and develop the right instinct to enable him to render first-class service, and to add his effort, be it great or small, to the advancement of the science of lubrication.

The lubricating engineer needs good assistance from the chemical laboratory in analysing oils, deposits, etc. On the other hand, chemists should not be expected nor should they be allowed to make recommendations, except in consultation with an engineer, who is able to investigate and judge the importance of the mechanical and operating conditions of the plant, which is essential in order to interpret correctly the value of the laboratory's findings.

The oil manufacturer, through lubricating engineers, must watch constantly the results obtained under working conditions by the various standard grades of lubricants, and he will in this way accumulate knowledge as to the value and range of service of each particular grade; he will also find out possible weaknesses and the engineering staff in conjunction with his chemical staff will be able to point the way to remedy.

Oil firms who have developed an efficient technical staff will always have a great advantage over other firms who are less well equipped. Their salesmen having the benefit of technical assistance will easily command greater sales than their competitors. Even if their products are no better, they will yet be able to render to their customers better service, because they know how to select the correct grades, and can indicate to the consumer how the maximum value of these grades can be obtained. Such service always brings credit and goodwill to the oil supplier, and demonstrates to the consumer that lubrication service comprises a great deal more than is indicated by the price per gallon.

The Chief Engineer or Master Mechanic of a works cannot be expected to know everything there is to know about lubrication; it is no discredit to him if he gains a few points by discussing the lubrication of his plant with lubricating engineers who have made a life study of the subject.

The author hopes that oil firms who have no engineering staff will see the necessity of developing a technical service, sufficient for their needs in keeping with modern sales methods, which are directed towards selling lubrication, rather than lubricants, or selling experience and knowledge rather than selling oils on a price per gallon basis.

The subject of lubrication is intimately connected with the mechanical and operating conditions of engines or machinery. The author has therefore endeavored to present for each type of engine or class of machinery the "technical background," without which it is futile to attempt to focus the lubricating problems, as seen by the engineer or the chemist, and without which it is impossible to determine the character of the oils required to give the best service.

The author is well aware of the magnitude of such a task and the many shortcomings of the present work, but he ventures to hope that the way in which he has dealt with the problems and endeavoured to convey his experience may prove of some value in stimulating others to take a deeper interest in lubrication matters, and in helping them to get a clearer view of possible problems or difficulties, and their solution.

Mechanical and electrical engineers in charge of plant, and *lubricating engineers* as well as *general consulting engineers* will, the author hopes find some food for thought; they may not always agree with the theories and views put forward, which are often novel or even contrary to traditional opinions; but in that case the author would urge them to try out his recommendations, which are based on many years of practical experience in many parts of the world; they will then be able to draw their own conclusions, and constructive criticism will always be welcomed by the author and gratefully received.

Engine builders, it is hoped, will find information which will prove useful to them in equipping their engines and machinery with correctly designed lubricating systems and appliances and in giving their customers sound advice or instructions with reference to the grades of lubricants required and the best manner of using them.

Oil chemists and manufacturers, and chemists employed by oil consumers will, it is hoped, find the book helpful in pointing out the conditions under which lubricants have to work for particular types of machinery, and the influences, such as oxidation, emulsification, etc., to which they are subjected during use. The author has endeavored to focus the problems and describe the mechanical conditions in such a manner as to assist chemists in deciding which are the physical and chemical tests of greatest importance in each particular case.

References are given throughout the text to special sources of information, but the author wishes particularly to record his indebtedness to *Mr. L. Archbutt* for analyses of graphites; to *Mr. J. Hamilton Gibson* for photographs of stream lines in connection with Michell's thrust blocks; to *Mr. I. L. Langton* for information regarding dielectric strength of transformer oils; to "*The Engineer*" for permission to make use of some articles by the author on "Lubrication of modern turbines;" to *Mr. E. W. Johnston* for information regarding the use of Aquadag in steam engines; to the *Vacuum Oil Company of New York* for raising no objection to the author making use of several technical papers, which he prepared during the time he was associated with that Company as Chief Engineer in London; to the *Controller of His Majesty's Stationery Office* for permission to make use of Bulletin No. 2 on "Cutting Lubricants and Cooling Liquids," and Bulletin No. 4 on "Solid Lubricants," both of which have been published by the Department of Scientific and Industrial Research, and the material for which was prepared by the author; and to *Mr. W. A. E. Woodman* for valuable assistance in preparing many of the drawings.

T. C. THOMSEN.

LONDON, ENG.,
August, 1920.

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THE
PRACTICE OF LUBRICATION

CHAPTER I

MINERAL LUBRICATING OILS

PETROLEUM CRUDE

Oil Wells.—Petroleum crudes are secreted by nature and are found in many countries all over the world.

Occasionally, petroleum crude is found lying on the surface of water in pools, but usually it is found at various depths in the earth, from a few hundred feet up to as much as five thousand feet. To bring the crude to the surface a hole is drilled, varying in diameter from a few inches up to 18 inches according to the depth.

Wells may be drilled by the percussion system or by the rotary system, the latter being mostly used for drilling through soft ground. By the *percussion* system a chisel-shaped heavy steel "bit" is suspended from a cable or a long chain of poles. It is lifted and dropped alternately by means of a steam engine situated on the surface, the steel bit in this way hammering through the earth or rock and deepening the bore hole. By the *rotary* system the drill is attached to the lower end of a length of tubes and is rotated by a steam engine or electric motor situated on the surface. In order to remove from the bore hole sand and fragments of rock a stream of water is continuously pumped through this long tube, and on rising through the hole it carries away the sand and fragments.

When a certain depth has been reached, steel piping called "casing" of slightly less diameter than the hole (from 4 inches to 18 inches in diameter) is driven into the ground. The hole is then continued with a slightly smaller diameter as far as possible, when again a smaller diameter "casing" is inserted, so that the deeper the hole the smaller is the diameter at the bottom. Speaking generally, the oil should be reached with not less than a four-inch diameter casing.

It is usual to find confined with the oil a large amount of gas under great pressure, which may be as high as 800 lb. per square inch. Due to this pressure the oil when first reached is forced up the bore hole and rises many feet in the air; such a well is called a "gusher."

Some gushers have produced enormous quantities of crude oil, for example the "Potrero No. 4" well drilled in 1910 by the Mexican Eagle Oil Company. This well was capable of giving about 120,000 barrels of crude oil daily but has now turned into salt water.

Another well, "Dos Bocas," drilled in 1908 by the same Company was probably the largest oil well the world has ever seen; unfortunately it could not be controlled, and drained the field. The gas and oil pressure was so enormous that the heavy casing, 2,000 feet deep, was hurled bodily into the air. This well has probably been the most spectacular well in the world. It burned for 40 days with a flame mounting to 1,800 feet, and newspapers could be read seven miles away by its light. After some months the enormous flow of oil ceased, the original eight-inch hole developed into a huge crater many acres in extent, and a daily volume of several million of barrels of salt water is flowing from it at the present day.

When the gas pressure is sufficiently reduced in an old well, it is no longer a "flowing well" but becomes a "pumping well," and the output is reduced to a small fraction of its former value.

Production of Petroleum Crude.—Table No. 1 shows the world's production of petroleum crude oil in metric tons.

The United States, Russia and Mexico are the three great oil-producing countries.

United States.—The production is still increasing in the United States, but will probably not increase much longer; many of the old American fields (Pennsylvania, etc.) are becoming exhausted; the new fields discovered in California and Oklahoma have, however, made up for the decreased production in the older fields.

Russia.—There are still large possibilities of increased production, but the development of the oil industry is handicapped by the political conditions.

Mexico.—The Mexican oil industry has developed rapidly since 1908. The potential resources are enormous, being probably as great as or even greater than the resources of the United States.

Origin of Petroleum Crude.—There are three theories held concerning the origin of crude oils, but no one is universally accepted.

1. *Inorganic Theory.*—According to this theory, petroleum is produced deep down in the crust of the earth by the action of high temperature and pressure on the minerals found there;

TABLE 1.—WORLD'S PRODUCTION OF PETROLEUM CRUDE OIL IN METRIC TONS

	1915	1916	1917	1918
United States.......	38,583,063	37,864,031	43,953,560	47,715,580
Russia..............	9,385,000	9,045,700	8,980,790	9,515,510
Mexico.............	4,846,471	6,742,480	8,264,260	5,500,000
Roumania...........	1,673,145	1,432,296	300,000	1,260,000
Galicia..............	578,388	878,670	780,000	786,000
Dutch East Indies...	1,710,000	1,820,247	1,700,000	1,800,000
British East Indies..	1,093,667	1,097,143	1,100,000	1,060,000
Japan...............	415,785	399,624	400,000	315,000
Persia..............	400,000	600,000	800,000	900,000
Peru................	331,633	340,000	340,000	340,000
Argentine...........	91,000	130,000	207,000	200,000
United Kingdom....	300,000	300,000	300,000	300,000
Germany...........	140,000	130,000	140,000	140,000
Egypt..............	33,600	54,800	134,500	333,000
Trinidad............	155,000	160,000	220,000	291,100
Canada.............	28,729	26,416	25,100	40,000
Italy...............	5,500	5,500	5,500	5,500
Other countries, approximately.........	40,000	40,000	40,000	40,000
Total...........	59,810,981	61,066,907	67,690,710	68,541,690

1 Metric Ton = 2,204 lb. = 1,000 kilograms.

carbon and hydrogen are supposed to have combined and formed the hydrocarbons which are the chief constituents of petroleum crude. Only a minority of geologists favor this theory.

2. *Vegetation Theory.*—According to this theory, vegetable matter has been covered by a layer of impervious material; the air thus being excluded, rotting was prevented, and slow decay during hundreds of thousands of years transformed the vegetable matter into petroleum crude oil and petroleum gas. Several geologists favor this theory.

3. *Marine Animal Theory.*—According to this theory, dead fishes or tiny marine animals with chalk shells were covered over by a layer of impervious material and gradually transformed into crude oil and gas. Most geologists favor this theory.

Whichever theory is correct, it seems certain that the world's stocks of petroleum crude are practically complete and are being rapidly consumed.

Composition and Character of Petroleum Crude.—When the crude comes to the surface it often contains water (frequently salt water) and dirt, which are separated out in large collecting and settling reservoirs.

The crude is rarely transparent; the color is usually dark brown or black.

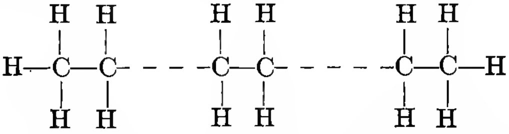
Petroleum crude consists chiefly of carbon (C) and hydrogen (H) in the form of hydrocarbons. Besides carbon and hydrogen, there is usually also a certain amount of oxygen, nitrogen and sulphur present.

The percentages of the various chemical constituents vary within limits as indicated in the following table:

Carbon	81.00	to	88.0	per cent.
Hydrogen	10.00	to	14.0	per cent.
Oxygen	0.01	to	1.2	per cent.
Nitrogen	0.002	to	1.7	per cent.
Sulphur	0.01	to	5.0	per cent.

Hydrocarbons:

Paraffins (Cn.H2n+2).—The molecules of these hydrocarbons are bound together in the form of chains, and are members of the large family of hydrocarbons known as open-chain hydrocarbons, thus:



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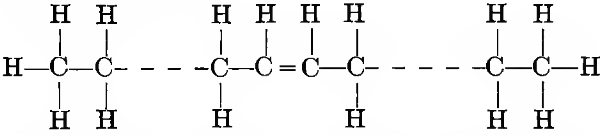
As all the carbon atoms are fully engaged, each carbon atom being tetravalent and attached to four other atoms, the paraffins are called saturated hydrocarbons.

Olefines (Cn.H2n).—The olefines are also open-chain hydrocarbons, but their molecules have two atoms of hydrogen less than the paraffins, thus:



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They are called unsaturated, because they are capable of absorbing hydrogen, oxygen, sulphur, etc., to a value equivalent to two atoms of hydrogen per molecule.

Napthenes (Cn.H2n).—Naphthenes are closed-chain hydrocarbons; they have the same chemical formula as the olefines, but the atoms are not arranged in the form of open chains, but more in the nature of rings or closed chains, in such a manner as to fully saturate all the carbon atoms.

Naphthenes being saturated hydrocarbons are consequently more stable than the olefines.

C_nH_{2n-2}, C_nH_{2n-4}, etc. Most *hydrocarbons of the formulæ* C_nH_{2n-2}, C_nH_{2n-4}, etc., are more or less unsaturated, and the more so the less hydrogen they contain.

Hydrocarbons having from 1 to about 15 carbon atoms per molecule represent the light products of petroleum crude, viz. petroleum gas, gasolenes, kerosenes, and light transformer and spindle oils.

Most lubricating oils are mixtures of hydrocarbons possessing more than 15 carbon atoms per molecule; the greater the number of carbon atoms, the greater is the viscosity of the oil. Comparing two hydrocarbons having the same number of carbon atoms, the one containing the least hydrogen is the more viscous of the two, but its viscosity is less stable, *i.e.*, it changes more rapidly with changes in temperature.

Most petroleum crudes are very complicated in character, and it is difficult to classify them; they contain hydrocarbons of practically all types, but the proportions vary considerably according to the origin of the petroleum.

Petroleum crudes are, however, referred to as Paraffin Base Crudes, Asphaltic Base Crudes, Russian Crudes, and Mixed Base Crudes.

Paraffin base crudes are so called because they contain paraffin hydrocarbons (C_nH_{2n+2}). There are only a few lubricating oils of low viscosity which are actually paraffin hydrocarbons, as paraffins from $C_{17}H_{36}$ and upward represent the hydrocarbons present in paraffin waxes. The heavy viscosity lubricating oils which are found in paraffin base crudes are largely composed of olefines and naphthenes (C_nH_{2n}) and acetylenes (C_nH_{2n-2}). As paraffin base crudes always contain a certain amount of paraffin wax, usually about 2 per cent. lubricating oils made from such crudes have high setting points.

The most important supplies of paraffin base crudes come from Pennsylvania and Ohio in the United States. They are fairly fluid, rich in gasolenes and kerosenes, usually contain only a little asphalt, sulphur, oxygen or nitrogen, and have a low specific gravity.

Asphaltic base crudes are so called because they contain a large amount of asphalt; they usually contain certain small percentages of sulphur, oxygen and nitrogen. The crudes from California, Mexico, Texas, and South America belong to this class.

They are very viscous, black in color, rich in lubricating oils, fuel oils and asphalt, and have a high specific gravity; they often contain complex sulphur compounds, which are difficult to extract.

The lubricating oils produced from non-paraffinic asphaltic base crudes have low setting points and possess a wide range of viscosity, ranging from quite thin oils to exceedingly viscous oils.

The hydrocarbons in asphaltic base crudes are lower in hydrogen than the paraffins, although paraffins are often present, particularly in some Mexican crudes. For example, *California crudes* contain olefines (CnH2n), asphaltic hydrocarbons (CnH2n–4) and also some benzenes (CnH2−6). *Texas crudes* are rich in asphaltic hydrocarbons.

Russian crudes are in a class by themselves, consisting chiefly of naphthenes (CnH2n); they also contain a small percentage of acetylene hydrocarbons (CnH2n−2).

Russian crudes contain little or no paraffin wax; hence produce lubricating oils with low setting points.

Mixed base crudes are crudes of a character intermediary between paraffin base crudes and asphaltic base crudes, containing both paraffin wax and asphalt.

DISTILLATION AND REFINING

Petroleum crude is a mixture of many hydrocarbons, all having different boiling points.

The crude is gradually. heated in cylindrical stills and the hydrocarbons distil over as their boiling points are reached; the vapors escape through a dome at the top of the still, pass a coil of pipes immersed in cold water, become liquefied and run through an inspection box with glass windows in the "tail" house, whence the various "fractions" are directed into their respective collecting tanks. The specific gravity and color form a sufficient guide for the attendant to enable him to judge when to "cut" the various fractions.

The distillation may be carried out by the intermittent system or the continuous system.

By the *Intermittent System* batches of oil are treated in separate cylindrical stills, the crude stills being as much as 45 feet long and 12 feet in diameter, holding about 1000 barrels of crude. The distillation may be carried to a finish in the crude stills, as in the Tower vertical still, or the crude may only be freed from the lighter fractions (gasolenes and kerosenes), and the residue, known as tar, transferred to other stills (tar stills), holding about 250 barrels each, in which the final distillation takes place.

By the *Continuous System* the crude oil passes slowly but continuously through a row of stills, perhaps ten in number, all connected together. The stills are placed at lower and lower levels, so that the crude flows by gravity from the first to the last still, passing through all the stills one after the other. Each still is heated to a higher temperature than the previous one, so that a definite distillate is being taken out from each still, and the character of the distillates can be varied at will by regulating the temperatures of the various stills and the rapidity of the flow of crude. This system is largely used in Russia and is rapidly gaining favor in America and Mexico.

Cracking.—The crude itself or certain distillates are cracked when it is desired to produce a maximum amount of light fractions. When hydrocarbons are suddenly heated to a temperature above their boiling points and not given time to distil in the ordinary way, they decompose into simpler hydrocarbons which possess lower boiling points; this process is called "cracking."

When crude oil (after gasolenes and kerosenes have been removed) is slowly heated for a prolonged period, the oil falls back from the cooled top of the stills into the hot liquid, and in this way a large portion of kerosene is produced from the heavier fractions of the crude. This process is, however, slow, and experience has shown that quicker and more effective results can be obtained in special cracking stills, heated to a high temperature, into which the kerosene, gas oil, or other heavy oil is sprayed. The effect of cracking on the lubricating oils is that viscous oils are decomposed into low-viscosity oils. In certain cracking processes the oil is cracked under a pressure of several atmospheres, which further increases the yield of lower boiling point fractions. These improved cracking stills are responsible for the large increase in production of cracked motor spirits and kerosenes which has taken place during recent years to meet the increased demand for motor spirits.

With every cracking process a certain amount of unsaturated hydrocarbons is formed, but most of the undesirable ones may be removed by treatment with sulphuric acid or by filtration through Fuller's earth or like material.

Steam Distillation.—When it is desired to produce a maximum amount of lubricating oils and to minimize cracking, the stills in addition to being heated by fire externally are heated internally by live superheated steam, introduced directly into the body of the oil near the bottom of the stills, so as to mix well with the oil and also to prevent overheating of the still bottom. To increase further the yield of lubricating oils and to prevent overheating, the oils may be distilled under a partial vacuum, as the vacuum causes the various fractions to distil over at lower temperatures.

When the distillation is assisted by the application of steam with or without vacuum, a lower percentage of unsaturated hydrocarbons is formed than when distilling without steam, and less acid or treatment is therefore required when refining the distillates.

Redistillation.—Usually the crude is split into only a few fractions, which may be further separated into a greater number of fractions by redistillation. For example, crude gasolene is redistilled by steam distillation into light and heavy gasolene, and the residue may be used as first-grade turpentine substitute or kerosene stock. Crude kerosene is similarly redistilled into the particular grades of kerosene desired, and if the crude kerosene contains too light fractions, these may be utilized as a second-grade turpentine substitute, whereas too heavy fractions are mixed with the gas oil distillates. Lubricating oil distillates are also redistilled, by fire and live steam distillation with or without vacuum, and separated into heavier and lighter lubricating oils.

PETROLEUM PRODUCTS

When the light fractions, viz. gasolenes (distilling over up to 150°C.) and kerosenes (distilling over between 150°C. and 300°C.) have been distilled off, the next distillate is a high flash burning oil called 300 fire test oil, mineral colza, mineral sperm, or mineral seal; but if the quality of this distillate is not such as to produce a satisfactory burning oil, the distillate is called solar oil or gas oil, and is used for making oil gas or carburetted water gas, or as a high class fuel oil for semi-Diesel or Diesel oil engines. Also, when mixed with heavy black residual oils (asphaltic or non-asphaltic) it is used as fuel oil in Diesel engines, or in furnaces using liquid fuel.

The *lubricating oil* fraction or fractions (from which spindle oils, engine and machinery oils are manufactured) now distil over and if the crude contains wax the distillate containing wax is chilled to about 20–25°F., and in the wax filter press the oils are squeezed out and the wax left in the press. Lubricating oils made from a paraffin base crude, therefore, have setting points of about 20–25°F. unless they are specially treated to remove more of the wax; they may also be blended with other oils having very low setting points so as to produce oils with low setting points.

The *wax* when removed from the press contains as much as 50 per cent. of oil which is removed by "sweating," viz. slow prolonged heating of the wax. The melting points of the sweated wax range from 100°F. to 130°F.; it is melted, crystallized in molds, and sold as white paraffin wax used chiefly for making candles, also for preserving fruit and jellies, for polishing floors, etc.

The pressed lubricating oils are redistilled into heavier and lighter oils and either *treated by sulphuric acid* or filtered through *Fuller's earth* or *bone black* (animal charcoal) in order to remove unstable hydrocarbons or other undesirable elements, and to lighten the color.

Sunbleaching, exposing the oil in shallow troughs, has the effect of forming a heavy sludge of the unstable elements, which sinks to the bottom and the oil becomes lighter in color. After exposure for some time the oil commences to darken, and the sunbleaching process should then be stopped, as otherwise the oil is injured.

After the oil has been treated with acid in vertical, lead-lined agitators it is washed with water, neutralized with an alkali, washed again with water to remove the alkali, and finally blown with hot air to remove the last traces of moisture; it should then be bright and transparent, and be free from acid or alkali.

When filtered through Fuller's earth or animal charcoal the first few gallons of oil which come out are colorless, but as the filtering material becomes saturated with the absorbed impurities and coloring matter the color of the oil gradually darkens. Each grade of oil is filtered to be within the standard color limits for that particular grade.

Dark Cylinder Stock.—When the distillates containing the light and heavy lubricating oils have passed off there remains in the still a very heavy viscous dark oil used principally for internal lubrication of steam engine cylinders and valves. If it contains too much asphalt it cannot be used as a cylinder oil, but may be mixed with light viscosity lubricating oils to produce dark lubricating oils.

Filtered cylinder stock is produced from dark cylinder stock by filtration; the color becomes green, amber; the heavy gravity tarry matter is removed, the viscosity is reduced 15 per cent. to 25 per cent. and the specific gravity is likewise reduced, but the setting point is increased.

Petroleum jelly (mineral jelly, petrolatum) is an amorphous wax produced by slow cooling of dark cylinder stock diluted with gasolene; the petroleum jelly separates out and is afterwards refined (decolorized) by hot filtration. Petroleum jelly is used in the manufacture of cordite (an addition of 2 per cent. of jelly makes the cordite less brittle), as an anti-rust grease, for ointments (veterinary purposes), etc., etc. Vaseline is the proprietary name given to a certain high grade petroleum jelly.

Cold Test Cylinder Stock.—By distilling off the gasolene from the liquid portion a *low cold test cylinder stock* is produced, which may be further refined by filtration. *Cylinder stocks* are almost exclusively produced from paraffin base crudes. When a paraffin base crude is cracked during distillation and it is not desired to produce cylinder stock, the cracking of the heavy distillates produces carbon, so that as much as 5 per cent. of the crude may remain in the still in the form of *petroleum coke,* which is used for smelting furnaces, for electric arc carbons, or as refinery fuel, according to its quality.

When asphaltic base crudes are distilled, cylinder stock can rarely be produced; the residue consists of asphaltic matter. Heavy liquid asphaltic residues are used as *road spraying material* in place of coal tar, and are also used in the manufacture of various *liquid fuels.*

Petroleum pitch or bitumen has found a most important use, chiefly in the making of wearing surfaces for modern roads; also for roofing felts, bituminous paints, etc. It is also used in the making of hot neck greases for steel works rolling mills.

When the liquid bitumen in the stills is "blown" with air, it oxidizes into blown asphalt, which has a rubbery nature and finds an important use as rubber substitute, for roofing felt, etc.

SHALE OIL

Oil shale is a dark grey or black mineral yielding about 23 gallons of crude shale oil per ton of shale. By distillation is produced crude naphtha, green oil, and coke. The crude naphtha is redistilled and yields mainly motor spirit. The green oil yields paraffin wax, kerosene, fuel oil, gas oil, and lubricating oils.

The lubricating oils are of very low vicosity and are chiefly used as batching oils (for softening the fibres of flax, jute, etc., during their process of manufacture into yarns); they contain a large percentage of unsaturated hydrocarbons (olefines). The setting point is about 32°F. When used as lubricants they are rarely used alone but are usually mixed with 5 per cent. to 15 per cent. of fixed oil (sperm, whale or lard) to increase their oiliness; they can then be used for lubricating light, quick running spindles and machinery, but are inclined to gum on account of the presence of highly unsaturated hydrocarbons.

CLASSIFICATION OF LUBRICATING OILS

Dark Cylinder Oils.—Dark cylinder oils are the undistilled dark residues left in the stills (by steam distillation chiefly of non-asphaltic crude), freed from solid impurities but not filtered. They are chiefly used for lubrication of steam engine cylinders and valves, either alone or mixed with from 3 per cent. to 10 per cent. of acidless tallow oil. The ordinary characteristics are as follows:

Flash point open	From 500°F. to 620°F.
Specific gravity	From 0.900 to 0.916
Saybolt viscosity at 212°F.	135 sec. to 250 sec.
Color, in reflected light	Dark brown or dark green to black
Color in transmittent light	Dark brown to black
Setting point	35°F. to 60°F.

Filtered Cylinder Oils.—Filtered cylinder oils are made from dark cylinder oils by filtration. They represent the highest quality oils used for internal lubrication of steam engines; they are used either alone or mixed with from 3 per cent. to 12 per cent. of acidless tallow oil. They are also largely used for mixing with lower viscosity oils to produce heavy viscosity oils for internal combustion engines, or *heavy viscosity* engine and machinery oils, air compressor oils, circulation oils, etc.

Flash point open	From 490°F. to 580°F.
Specific gravity	From 0.875 to 0.895
Saybolt viscosity at 212°F.	100 sec. to 160 sec.
Color, in reflected light	Green, amber
Color in transmittent light	Deep red
Setting point	40°F. to 80°F.

Red Oils.—Red oils are fire-distilled (with or without steam) acid treated oils. They represent a large portion of the medium and heavy viscosity oils used for general lubrication of engines, shafting and machinery of all kinds. Mixed with filtered cylinder oil, red oils produce very heavy viscosity engine and machinery oils.

They must not be used for circulation service as in steam turbines, because they do not separate well from water, causing emulsification and objectionable deposits.

Red oils, made from paraffin base crude, are not very satisfactory for making oils for internal combustion engines, as they produce a great deal of hard and brittle carbon. When made from asphaltic base crudes, they produce less carbon deposit and it is of a soft crumbly nature.

The heavy red oils, when mixed with from 5 per cent. to

20 per cent. of fixed oil (blown or unblown) produce some of the lighter viscosity marine and railway engine oils.

Flash point open	380°F. to 440°F.
Specific gravity	0.900 to 0.915
Saybolt viscosity at 70°F	600 sec. to 1,500 sec.
Color	Red
Setting point (paraffin base)	20°F. to 30°F.
Setting point (asphaltic base)	0°F. to 20°F.

Pale Oils.—Pale oils are fire distilled (with or without steam), heavily acid treated or heavily filtered oils. They are of light to medium viscosity, and are used for lubricating quick-running machinery, such as high speed shafting, electric motors, textile machinery, also for manufacturing yellow lubricating greases. Further, they are used largely for lubricating small and medium size internal combustion engines of all kinds, either alone or mixed with from 3 per cent. to 10 per cent. of fixed oil, or filtered cylinder oil (when a heavy viscosity oil is required).

Pale oils produce less carbon deposit than red oils when used for lubricating internal combustion engines.

Flash point open	275°F. to 420°F.
Specific gravity	0.870 to 0.910
Saybolt viscosity at 70°F	60 sec. to 850 sec.
Color	Pale
Setting point (paraffin base)	15°F. to 25°F.
Setting point (asphaltic base)	0°F. to 15°F.

Neutral Oils.—Neutral oils are steam or fire distilled oils (freed from paraffin wax, if wax is present), sunbleached and filtered through Fuller's earth and when not acid treated are called filtered neutral oils. Most neutral oils are filtered rather than acid treated.

Neutral oils are of light or medium viscosity and used for similar purposes as pale oils; neutral filtered oils are more suitable than pale oils for self oiling bearings, where the oil is used over and over again. Neutral filtered oils are largely used as circulation oils (for enclosed type steam engines and steam turbines) either alone or mixed with filtered cylinder oil, as they separate well from water.

By redistillation, or "reducing," the neutral oils are separated into (*a*) viscous and (*b*) non-viscous neutral oils.

(*a*) *Viscous Neutral Oils.*

Flash point open	350°F. to 400°F.
Specific gravity	0.850 to 0.900
Saybolt viscosity at 70°F	180 to 500 sec.
Color	Pale to light red
Setting point (paraffin base)	15°F. to 25°F.
Setting point (asphaltic base)	0°F. to 15°F.

(*b*) *Non-viscous Neutral Oils.*

Flash point open	320°F. to 360°F.
Specific gravity	0.840 to 0.890
Saybolt viscosity at 70°F	70 to 180 sec.
Color	Pale
Setting point (paraffin base)	15°F. to 25°F.
Setting point (asphaltic base)	0°F. to 15°F.

Dark Lubricating Oils.—Dark lubricating oils are such undistilled residues from the crude or from the redistillation of lubricating oil distillates which, because of too low a viscosity or for other reasons, are considered unsuitable as cylinder oils. Dark lubricating oils are usually mixtures of such residues with low viscosity lubricating oils to produce the required viscosity.

Dark lubricating oils are used for rough machinery in collieries and steel works, as cheap oils for lubricating the axles of railway carriages and for making black lubricating greases, for rough service.

Flash point open	300°F. to 450°F.
Specific gravity	0.890 to 0.950
Saybolt viscosity at 140°F	200 sec. to 350 sec.
Color	Dark green or brown to black
Setting point	10°F. to 60°F.
Asphalt	Less than 5 per cent.

Viscous Low Setting Point Oils.—These oils are fire distilled and made from non-paraffinic base crude, acid treated and filtered. They are chiefly used in the manufacture of heavy viscosity railway and marine engine oils, compounded with from 10 per cent. to 25 per cent. of fixed oil (blown or unblown); they are also largely used in the manufacture of heavy viscosity oils for internal combustion engines, as they produce only a little carbon deposit, and the carbon is soft. As motor car oils they give easy starting from cold on account of their low setting points.

Flash point open	385°F. to 415°F.
Specific gravity	0.910 to 0.950
Saybolt viscosity at 70°F	1200 to 4000 sec.
Color	Pale to red
Setting point	Zero F. to 20°F.

Non-viscous Low Setting Point Oils.—These oils are either fire distilled or steam distilled, acid treated or acid treated and filtered; they may possess a naturally low setting point (when made from a non-paraffinic base crude) or they are cold pressed at zero or an even lower temperature to extract the wax and to give the desired low setting point.

Non-viscous low setting point oils are chiefly used in the manufacture of oils for refrigerator compressors on account of their low setting points; very low setting point oils are used for lubricating certain parts of high-flying aeroplanes.

Flash point open	280°F. to 380°F.
Specific gravity	0.850 to 0.900
Saybolt viscosity at 70°F	80 to 360 sec.
Color	Pale or red
Setting point	−40°F. to zero F.

Bloomless Oils.—Bloomless oils are neutral oils which have been highly filtered and may also have been sunbleached; they are very light in color and of light viscosity.

To remove the bloom entirely they must be treated with nitronaphthalene or other chemicals.

Bloomless oils are used for adulterating edible oils; also in the manufacture of stainless loom and spindle oils.

White Oils.—White oils are pale spindle oils which have been treated with fuming sulphuric acid or liquid sulphur dioxide, Fuller's earth filtration, etc.; in order to remove the color completely. They are easily made from Russian crudes and are largely used as non-sludging transformer oils. It is very difficult to remove color entirely from oils produced from paraffin base crudes.

Medicinal White Oils.—Medicinal white oils are white oils which have been so treated as to remove not only color but also all taste and odor.

CHAPTER II

FIXED OILS AND FATS

Vegetable oils and fats	Vegetable oils and fats	Animal oils and fats	Animal oils and fats
Castor oil	Olive oil	Tallow	Dolphin jaw oil
Rape oil	Cocoanut oil	Tallow oil	Melon oil
Blown rape oil	Palm oil	Lard oil	Menhaden oil
Cottonseed oil	Palm kernel oil	Neatsfoot oil	Cod oil and other fish oils
Blown cottonseed oil	Peanut oil	Sperm oil	Wool grease
Linseed oil	Mustard seed oil	Whale oil	
	Rosin oil	Porpoise jaw oil	

Animal and vegetable oils are called "fixed" oils because they cannot like mineral oils be distilled without decomposition. They also differ from mineral oils in that they contain from 9.4 per cent. to 12.5 per cent. oxygen.

The distinction between fixed oils and fats is only a matter of temperature; all fixed oils become fats at or above 0°F. and all fats become oils at or below 125°F.

Animal oils are obtained by heating the fatty tissues of animals, *i.e.*, by "rendering" the fat or by boiling out the fatty oil with water. Vegetable oils occur mostly in the seeds or fruits of plants or trees and are obtained either by pressing or by chemical extraction with solvents. Animal oils are usually either colorless or yellow. Vegetable oils are colorless, yellow, or slightly green (chlorophyll present).

All fixed oils are devoid of bloom except rosin oil, and each variety generally has a distinctive odor, by which it can be identified. Their specific gravities range from 0.860 to 0.970. Rosin oil is an exception; its specific gravity may be as high as 1.0. Sperm oil has the lowest viscosity of all fixed oils and castor oil the highest, but each kind of oil has its own peculiar viscosity, which varies only slightly.

All fixed oils have a tendency to combine with oxygen, and as a result are sooner or later converted into solid elastic varnishes. As a result of this tendency, cotton waste, when saturated with fixed oils or lubricating oils very rich in fixed oils, has been known occasionally to heat gradually and finally to burst into flame. Dirty cotton waste, which contains fixed oil must therefore be kept in receptacles with closed lids.

When the tendency to absorb oxygen is marked, the fixed oils are called drying oils, as for example, linseed oil. When the tendency is moderate or only slight, the oils are called semi-drying or non-drying oils respectively, and it is only from these two types of fixed oils that lubricants are selected.

Mineral lubricating oils are practically free from any tendency to oxidize and therefore do not gum or develop acid as fixed oils do, which may lead to corrosion of the bearing surfaces.

All fixed oils are chemical combinations of alcohol radicles and fatty acid radicles. The character of fatty acids is indicated in Table No. 2. The alcohol radicle occurring in the vegetable oils and most of the animal oils is glyceryl: C_3H_5, which is trivalent, and therefore combines with three fatty acid radicles. Olein, for example, which is the chief constituent of many fixed

TABLE 2.—FATTY ACIDS OCCURRING IN FIXED OILS

(*Journ. Soc. Chem. Ind.*, XVIII (1899), p. 346)

Series	Name of acid	Formula	Occurs chiefly in
Acetic $C_nH_{2n}O_2$	Isovaleric	$C_5H_{10}O_2$	Porpoise jaw oil.
	Caproic	$C_6H_{12}O_2$	Cocoanut oil.
	Caprylic	$C_8H_{16}O_2$	
	Capric	$C_{10}H_{20}O_2$	
	Lauric	$C_{12}H_{24}O_2$	
	Myristic	$C_{14}H_{28}O_2$	
	Palmitic	$C_{16}H_{32}O_2$	Palm oil; also tallow, olive oil and cocoanut oil.
	Stearic	$C_{18}H_{36}O_2$	Tallow; also palm, castor and rape oils.
	Arachidic	$C_{20}H_{40}O_2$	Earthnut, rape and mustard oils.
	Lignoceric	$C_{24}H_{48}O_2$	
Oleic $C_nH_{2n-2}O_2$	Oleic	$C_{18}H_{34}O_2$	Olive oil and the animal oleins.
	Rapic	$C_{18}H_{34}O_2$	Rape oil.
	Erucic	$C_{22}H_{42}O_2$	
Linolic $C_nH_{2n-4}O_2$	Linoleic	$C_{18}H_{32}O_2$	The drying oils; also in olive and palm oils.
Recinoleic $C_nH_{2n-2}O_3$	Ricinoleic	$C_{18}H_{34}O_3$	Castor oil.
	Isoricinoleic	$C_{18}H_{34}O_3$	
$C_nH_{2n}O_4$	Dihydraxystearic	$C_{18}H_{36}O_4$	Castor oil.

oils, such as tallow, lard, neatsfoot and olive oils, has the chemical formula: $C_3H_5(C_{18}H_{33}O_2)_3$, in which C, H and O signify carbon, hydrogen, and oxygen atoms respectively. Stearin: $C_3H_5(C_{18}H_{35}O_2)_3$ and Palmitin: $C_3H_5(C_{16}H_{31}O_2)_3$ predominate in solid fats, olein in the fluid oils. It will therefore be seen that the nature of the fatty acid radicle determines the character of the fixed oil.

Sperm oil is made up differently, being known as a liquid wax. All fixed oils, however, can be split up into alcohols and fatty acids, by heating with water under pressure, by heating with sulphuric acid, by heating with alkalis, etc. By such actions the fixed oils are said to be saponified. For example, by heating olein with water under pressure, the following change takes place:

$$\underset{\text{Olein}}{C_3H_5(C_{18}H_{33}O_2)_3}+\underset{\text{Water}}{3H_2O}=\underset{\text{Glycerin}}{C_3H_5(O.H)_3}+\underset{\text{Oleic acid}}{3C_{18}H_{34}O}$$

This change takes place in steam cylinders, when too high a percentage of fixed oil is used in the cylinder oil; the fatty acids thus liberated eat away the metal and form metallic soaps.

By heating olein with an alkali, potash for example, the following change takes place:

$$\underset{\text{Olein}}{C_3H_5(C_{18}H_{33}O_2)_3}+\underset{\text{Potash}}{3KOH}=\underset{\text{Glycerin}}{C_3H_5(OH)_3}+\underset{\text{Potassium oleate}}{3KC_{18}H_{33}O_2}$$

It will be seen that the fatty acid is not now liberated, but has combined with the potash and formed a soap.

This action distinguishes fixed oils from mineral oils, which are not saponified when heated with an alkali, but remain unchanged.

CHARACTERISTICS OF SOME FIXED OILS AND FATS

(See also Tables Nos. 3 and 4, Pages 23 and 24)

Vegetable Oils and Fats. *Castor Oil (Non-drying).*—Castor oil is obtained from the seeds of the castor tree or shrub, which grows in all tropical and sub-tropical countries. The kernel forms 80 per cent. of the seed and yields about 50 per cent. of its weight in oil. By cold pressing of the seeds medicinal castor is produced. By hot pressing "first pressings" and "second pressings" are afterwards produced. Castor oil may also be extracted by solvents. Crude castor oil is refined by steaming and filtration. When properly refined castor oil keeps well and does not easily turn rancid.

Castor oil is liable to deposit a solid fat in very cold weather, but congeals only at very low temperatures. It is nearly colorless or slightly greenish-yellow; it has the highest specific gravity and viscosity of all fixed oils; it is soluble in alcohol but not in petroleum spirit, nor does it mix to any large extent with mineral oils. It mixes with refined rosin oil in all proportions. It will absorb a maximum of about 12 per cent. of pale, low setting point mineral lubricating oil, whereas mineral oil will not absorb much more than 3 per cent. of castor oil.

All fixed oils, except castor, mix readily with mineral oils, and it is quite easy to make clear mixtures of castor oil and mineral oil in the presence of another fixed oil, such as lard oil or rape oil.

Castor oil is an excellent lubricant, possessing great oiliness. It is used for lubricating bearings subjected to great pressure, such as heavy type marine engines, and is extensively used for aeroplane engines, particularly the rotary types, which cannot be lubricated satisfactorily with any oil other than pure medicinal castor. It is also used in the manufacture of soluble oils, in the manufacture of greases for pistons with India rubber or leather fittings, as a preservative for rubber and leather belting, etc. The possibilities of castor oil as a lubricant appear to be far from exhausted. For example, little work has been done with blown castor oil, nor does there appear to be any satisfactory method developed to make miscible castor oil. One method is to heat castor oil for a few hours at 4–5 atmospheres pressure; this treatment changes its nature and makes it more miscible with mineral oil.

Treated with sulphuric acid, castor oil takes up 25 per cent. of water and becomes "Turkey red" oil used in preparing cotton fiber for dyeing.

Rape Oil (*Colza*) (*Semi-drying*).—Rape oil is obtained either by expression or extraction from rape seed, grown chiefly in India and Russia. Crude rape is dark in color and contains slimy impurities which are removed by treatment with sulphuric acid, followed by agitation with steam and hot water. If not sufficiently treated with acid, the slimy impurities choke the lubricating grooves; it is preferable to prolong the acid treatment and make sure of the elimination of the impurities, notwithstanding the development of a little extra free fatty acid.

Black Sea rape oil—Ravison Rape—is expressed from seeds of the Wild rape of the Black Sea district; it is inferior to ordinary rape oil, being about 10 per cent. lower in viscosity and having a greater tendency to oxidize (more "drying").

Blown rape oil is rape oil which has been blown with air at a temperature rising during the process from 160°F. to 250°F. The oil is oxidized, increases greatly in specific gravity and viscosity, and develops free fatty acid. The specific gravity may be increased from 0.915 to as much as 0.985.

When rape oil is blown, the color darkens for about 3 hours, then the oil becomes pale, but at the finish of the operation it darkens to a deep red; it gives off considerable odor, but the finished oil has no odor. The viscosity at first decreases correspondingly with the pale color, then increases, becoming 200″ Saybolt at 212°F. after 22 hours, 720″ Saybolt after 34 hours and so on.

Rape oil or blown rape oil, is chiefly used in the manufacture of railway and marine engine oils, from 10 per cent. to 25 per cent. being mixed with heavy viscosity (preferably low setting point) mineral oils at a temperature of about 140°F. Rape oil is also used in the manufacture of soluble oils and as a quenching oil for steel.

Rape oil mixes in all proportions with mineral oil, but with blown rape oil there is a minimum percentage, below which the blown rape will not mix with the mineral oil. This minimum percentage is less at lower temperatures, so that sometimes in cold weather the blown oil separates out. The blown oil also separates out, if oil containing blown rape is diluted sufficiently with mineral oil.

Cottonseed Oil (*Semi-drying*).—Cottonseed oil is obtained by expression from cotton seed. On account of its drying properties, it should not be used for lubrication; it is however often used to adulterate olive oil, rape oil or lard oil. Blown cottonseed oil is used as a substitute for blown rape oil in the manufacture of marine engine oils, but is not to be recommended. As a cutting oil it is used to give a high degree of "finish."

Linseed Oil (*Drying*).—Linseed oil is obtained from the seed of flax, is pale yellow in color and is the best known of the drying oils. It cannot be used as a lubricant.

Olive Oil (*Non-drying*).—Olive oil is obtained by expression from the fruit of the olive tree. Fine olive oils are pressed cold and are used as salad oils as well as for lubrication. Olive oils from the second pressing (hot) are used for lubrication, but are inferior to cold pressed olive oil; they are more inclined to "dry" contain a rather high percentage of free fatty acid, and easily become rancid. Olive oils have now practically gone out of use for lubrication, having been displaced by mineral oils or mixtures of such oils with rape oil.

Olive oil is largely used as wool oil in the high class woollen industry; it is unsurpassed for this purpose, lubricating the woollen fibers during manufacture and being completely scoured out of the yarn when completed. It is used for lubricating high quality cloth looms or finishing machines, as if it gets on to the cloth the stains disappear entirely in the scouring process.

Cocoanut Oil (Non-drying).—Cocoanut oil is produced from cocoanuts, the fruits of a certain kind of palm tree. The kernels are cut up and dried in the sun, producing the so-called "Copra" from which cocoanut oil is obtained by expression.

Cocoanut oil is fluid in tropical climates, solid in colder climates the melting point being 70°F.–80°F. By cold pressing a fluid, cocoanut oleine, is obtained which is used for lubricating purposes; the solid portion is used as an edible fat.

Cocoanut oleine is used to the extent of from 3 per cent. to 10 per cent. in the manufacture of oils for internal combustion engines.

Palm Oil, Palm Kernel Oil (Non-drying).—Palm Oil and Palm Kernel Oil are obtained from the fruit of the African oil palm. The palm oil is produced from the fleshy layer or pericarp surrounding the hard woody shell, within which is the seed kernel. The palm kernel oil is produced from the kernels and is quite different from palm oil; it closely resembles cocoanut oil; but usually contains a large proportion of free fatty acid and is not used for lubrication.

Palm oil varies in color from yellow to deep red; the odor is pleasant; the melting point ranges from 80–110°F., the higher values corresponding with high percentages of free fatty acid, which are present to the extent of 10 per cent. to 40 per cent. or even more. Palm Oil is used in the manufacture of railway lubricating greases.

Peanut Oil, Also Called Earthnut Oil, Ground-nut Oil, Arachis Oil (Non-drying).

This oil is obtained from the nuts of a creeping plant called *Arachis hypogœa.* It is pale greenish yellow in color, of a nutty flavor and odor, but is now made nearly colorless and tasteless for edible purposes. It contains about 5 per cent. of free fatty acid and is a non-drying oil. Peanut oil is used in the same manner as cocoanut-oleine in the manufacture of oils for internal combustion engines.

Mustard Seed Oil.—Mustard seed oil is said to have lubricating properties similar to those of castor oil, but it does not appear to have been much used as yet for lubrication.

Rosin Oil (Semi-drying).—Rosin oil is produced by destructive distillation of colophony (common rosin). The first products distilling over are rosin spirits. The rosin oil distils over above 300°C. (572°F.) and may amount to 85 per cent. of the total products. The residue in the still is rosin pitch, or, if the distillation is carried to dryness, coke.

Crude rosin oil is a brown, viscous liquid with a strong blue or violet fluorescence. By heating to 150°C. for three or four hours the fluorescence changes to green and it loses from 1 per cent. to 5 per cent. of its more volatile constitutents. It contains a considerable percentage of rosin acids.

Pale rosin oils can be produced by refining the crude rosin oil. The bloom can be removed by sunbleaching in shallow vessels, or by treatment with nitronaphthalene, hydrogen peroxide, etc.

The specific gravity ranges from 0.96 to 1.01.

Rosin oil is not used as a lubricant in the ordinary way, but both rosin and rosin oil are successfully used in the manufacture of soluble oils, belt dressings, etc. It is also used in the manufacture of low quality lubricating greases.

Animal Oils and Fats. *Tallow* (*Non-drying*).—Beef tallow is obtained from cattle; mutton tallow from sheep and goats. In rendering tallow for lubrication, it is important to use only fresh fat, which has not become decomposed and to remove by settling and straining all water and membrane.

Tallow from 60°F. to 80°F. is a mixture of solid and fluid fats. When used for lubrication it should preferably not contain more than 4 per cent. of free fatty acid. Beef tallow is less inclined to become rancid than mutton tallow.

Tallow is used in the manufacture of white tallow greases, also in most other lubricating greases to form the saponified base which "holds" the lubricating oil in the grease. Unrendered tallow—suet—is sometimes used for lubricating badly worn, open-type bearings.

Tallow Oil (*Non-drying*).—If tallow is subjected to pressure, the liquid portion can be separated out and is known as tallow oil. Acidless tallow oil is carefully made tallow oil and is used chiefly in the manufacture of steam cylinder oils, the admixture of tallow oil being from 3 per cent. to 15 per cent. It is also used in the manufacture of cutting oils. It should have a low content of fatty acid and a clean sweet odor; it should be colorless or pale yellow, and free from suspended matter.

Lard Oil (*Non-drying*).—Lard oil is a fluid oil expressed from pig's fat. Winter pressed lard oil has a lower setting point than summer pressed lard oil. The setting point depends entirely upon the temperature at which the oil has been pressed; it may range from 32°F. to 60°F.

Prime lard oil is nearly colorless or pale yellow.

Tinged lard oil is a second quality lard oil, being more or less colored (yellow to brownish red) and containing a high percentage of free fatty acid, from 8 per cent. to 15 per cent. or more.

The best grades of lard oil are used in the manufacture of cutting oils (5 per cent. to 100 per cent. lard oil); in the manufacture of internal combustion engine oils (3 per cent. to 10 per cent. lard oil); also in the manufacture of stainless oils. Tinged lard oil is nearly always used instead of prime lard oil in making cutting oils, but not in a greater proportion than 15 per cent. to 25 per cent. on account of its bad odor and greater gumming tendency than prime lard.

Neatsfoot Oil (*Non-drying*).—Neatsfoot oil is obtained by boiling the hoofs and bones of cattle in water and skimming off the oil from the surface. When the oil is chilled and pressed, a low setting point neatsfoot oil is produced, which is much used for lubrication of watches and scientific instruments; it is used for lubricating the air-operated engines in torpedoes; also for lubricating lace-making machinery on account of its clinging and stainless properties. The high price of neatsfoot oil has confined its use as a lubricant to such special purposes.

Neatsfoot oil in its general properties resembles lard oil and is largely used for treating leather.

Sperm Oil (*Non-drying*).—Southern sperm is obtained from the head or blubber of the cachelot whale, which is generally found in tropical or temperate seas. A large cavity in the head of the whale is filled with crystalline matter called "Spermaceti." Arctic sperm is obtained from the blubber of the bottlenosed whale, which is found in the Northern seas, hence the name, Arctic sperm.

The crude sperm oil is cooled, so that most of the spermaceti separates out, then pressed. The spermaceti is used for making candles.

Sperm oil has only a slight tendency to oxidize, a low setting point, and the lowest viscosity and specific gravity of all fixed oils. It is a valuable lubricant for high speed spindles in textile mills; being generally used mixed with low viscosity mineral oils (5 per cent. to 25 per cent. sperm).

Whale Oil (*Semi-drying*).—Whale oil is obtained from the blubber of the Greenland and other whales. The specific gravity of whale oil is much higher than that of sperm oil. Whale oil has marked drying properties, but the pale grades are used successfully as lubricants when mixed in small proportions (5 per cent. to 10 per cent.) with mineral spindle oils for textile purposes or as cutting oils. Dark whale oils are lower in quality and cannot be used for lubrication but are excellent as tempering or quenching oils used in the manufacture of tools, guns, case-hardened materials, etc.

Seal oil is similar to whale oil and is obtained from the blubber of seals.

Porpoise Jaw Oil, Dolphin Jaw Oil and Melon Oil (Non-drying).—These oils, which are very similar, are obtained from the soft fat of the head and jaw of the porpoise and the dolphin.

Melon oil is made from a melon shaped lump of fat in the head of the dolphin; the crude oils, obtained in the usual way, are chilled and pressed to remove solid fat. These oils are used particularly in the United States for lubricating watches and other delicate mechanism, and command a high price.

Menhaden, Cod or Other Fish Oils (Semi-drying).—Menhaden, cod or other fish oils are obtained by boiling fish in large pans with steam; after standing some time the oil rises to the surface and can be skimmed off. The color varies according to the freshness of the fish and the length of boiling.

Fish oils are chiefly used in the leather industry, but blown cod oil, blown in a similar manner to blown rape oil and to similar viscosities, has given fair satisfaction in the manufacture of marine engine oils. Fish oils have also been used as quenching and tempering oils.

TABLE 3.—CHARACTERISTICS OF FIXED OILS AND FATS

	Specific gravity	Setting point in °F.	Open flash-point in °F.	Iodine value	Saponification value	Per cent. of free fatty acid	Drying character
Castor oil	.960– .966	0–10	530–560	80–90	176–186	.1–6	Non
Rape oil	.913– .916	12–26	530–560	96–108	170–176	.3–3	Semi
Ravison rape	.918– .922	......	....	108–120	178–179	2–6	Semi
Blown rape	.960– .985	......	....	....	....	....	Semi
Cottonseed oil	.921– .926	32	560–625	100–120	192–195	....	Semi
Linseed oil	.931– .936	−15–10	550	170–200	192–195	.4–4	Drying
Olive oil	.915– .918	20–50	475–600	80–90	185–196	3–20	Non
Cocoanut oleine	.925– .930	40–70	530	8–9	250-260	2–20	Non
Palm oil	.922– .925	80–110	450	50–56	196–202	10–60	Non
Peanut oil	.918– .925	27–37	540–620	90–102	187–191	1–5	Non
Tallow, beef or mutton	.935– .950	100–125	550–590	34–48	195	2–10	Non
Tallow oil	.913– .918	32–40	540–600	55–60	195	1–5	Non
Lard oil	.914– .918	32–60	500–600	65–75	195	3–25	Non
Neatsfoot oil	.914– .917	0–40	470–580	65–75	195	.2–25	Non
Sperm oil	.878– .882	32	505	80–94	120–140	.5–3	Non
Whale oil	.924– .925	40–50	475	110–130	187–197	2–10	Semi
Porpoise jaw oil	.916– .927	......	....	22–48	....	....	Non
Menhaden oil	.930– .933	20–25	530	140–170	*191	3–6	Semi
Cod oil, fish oil	.921– .928	20	470	145–170	*189	1–15	Semi
Rosin oil	.960–1.01	......	360	25–115	70–80	0–35	Non to semi
Wool grease	.944– 960	100–130	450	15–30	*100	50–60	Non

* Single values only.

Wool Grease.—Wool grease is obtained in the process of wool-washing; the alkaline scouring liquors containing the wool grease are run into settling tanks; the fatty matter accumulating on the surface is collected and drained in filter bags. The scouring liquors may also be treated with sulphuric acid in conjunction with injection of live steam; the acid separates the fatty matter and three distinct layers are formed; greasy matter on the top, water and soda in the middle, and earthy matter at the bottom.

The extracted grease is dirty and contains water; the water is removed by cold and hot pressing, followed by strong sulphuric acid treatment. The wool grease thus prepared is known to the trade as "Yorkshire Grease" and is used in the manufacture of rolling mill greases, railway and colliery greases.

On the Continent a process of wool cleansing by means of solvents (ether or carbon bisulphide) is often employed; the solvents are afterward recovered by distillation and the wool grease remains behind. Such wool grease is usually distilled with superheated steam, and produces woololein and woolstearin, etc. One use of woololein is in the manufacture of wool oils.

TABLE 4.—VISCOSITIES OF SOME FIXED OILS AND FATS

	Saybolt viscosity, seconds	
	At 104°F.	At 212°F.
Castor oil	1100–1200	90–100
Rape oil	240	57
Tallow, beef or mutton	....	52–54
Lard oil, neatsfoot oil, olive oil, peanut oil	190–220	50–53
Cottonseed oil	170	50
Cocoanut oil, whale oil, cod oil, Menhaden oil	135–155	41–45
Sperm oil	106	38

CHAPTER III

SEMI-SOLID LUBRICANTS

Semi-solid lubricants are lubricants which do not flow at ordinary room temperatures. Animal or vegetable fats, such as tallow or palm oil, or poor cold test cylinder stock may be classified as semi-solid lubricants. Most semi-solid lubricants are, however, made from mineral oils and saponified fats or fixed oils, and may be divided into two main groups, *i.e.*, cup greases, and solidified oils or fats.

Cup greases are boiled greases and consist of 80 per cent. to 90 per cent. of mineral oil mixed homogeneously with 10 per cent. to 20 per cent. of saponified fat, preferably clarified beef tallow. The tallow is mixed with limewater and heated in a steam-jacketed kettle (60 to 90 lb. steam pressure) for three to four hours until the *base* for the grease is completely formed. The mineral oil is gradually (5 to 6 hrs.) mixed with the base until the right consistency of the grease has been obtained, the mixture being constantly agitated mechanically or by compressed air.

The grease is then run out during the next couple of hours, during which time the consistency becomes gradually softer due to the agitation, notwithstanding that the speed of the stirrers is reduced towards the finish. Some manufacturers run the grease out of the boiling kettle into a grinding mill, in which all lumpy matter and impurities are reduced and the grease made of a uniform consistency (the more the grease is kneaded the softer it becomes).

Grinding the impurities fine does not, however, remove them; it is better to strain the grease when it leaves the kettle. This is best done by forcing the grease, when hot and fluid, under great pressure through fine layers of gauze. The gauze retains all the impurities, so that the grease is perfectly clean when filled into the packages. It is surprising to see the amount of impurities that can be retained in this way from grease which one might consider practically clean.

The ideal amount of grease made in one batch is 20 to 25 barrels.

Cup greases should be free from fillers, such as chalk, china clay, gypsum (sulphate of calcium), barytis (sulphate of barium), asbestos, talc, wax, etc.; they should be free from uncombined lime, gritty impurities, rosin oil, rosin or resinates, free from mineral or fatty acids, alkalies or deleterious impurities; the yield of ash should be less than 2 per cent. for a medium grease and less than 3 per cent. for a hard grease; the contents of water should be less than 2 per cent.

The melting points of ordinary cup greases range from 75°C. to 95°C., being higher for the harder consistency greases than for the softer greases.

The consistencies of greases range from very soft to very hard and are frequently indicated by numbers, as follows:

No. 1	No. 2	No. 3	No. 4	No. 5
Very soft	Soft	Medium	Hard	Very hard

The softer the grease the more oil does it contain.

The mineral oils used for making cup greases are pale mineral oils (pale to give the grease a light color). Red oils might quite well be used; the drawback is that they do not give the grease such a nice appearance as the pale oils. The viscosities of the mineral oils used range from 150″ to 1200″ at 70°F.

Graphite lubricating grease is cup grease which has been mixed with from 5 per cent. to 20 per cent. of amorphous or flake graphite.

Cold neck greases are black lime greases made with black heavy viscosity oils and are used for lubricating "cold" rolling mill necks in steelworks.

Fibre greases are of a "fibrous" nature, but contain no fibres of any kind. They are usually made by saponifying a fixed oil with caustic potash, or caustic soda and a little water. After saponification the water is boiled out and the mineral oil is worked in. Fibre greases of good quality can be melted and cooled again without altering their consistency.

Some fibre greases have very high melting points, ranging from 145°C. to 260°C.

Solidified oils or fats are made in a similar manner to cup greases, but are made cold and with carbonate of soda or caustic soda as the saponifying agent in place of lime water. These greases may be made in small quantities, as it is only a question of mixing the right proportions of the various ingredients together, cold or at fairly low temperature, and stirring the mixture till it sets. It is obvious that the ingredients cannot be so perfectly mixed and combined as with cup greases which are boiled; the result is that certain parts of the grease will often contain excess soda, which is detrimental to good lubrication.

Many so-called soap thickened oils are a kind of solidified oil, various soaps being added to a mineral oil. Sometimes special "thickeners" are sold for the purpose of increasing the viscosity of mineral oils; aluminum soap for example is used, consisting of 20 per cent. aluminum oleate or palmitate and 80 per cent. mineral oil, in which the soap is dissolved. Mineral oils thickened with aluminum soap have a peculiar non-homogeneous nature; the viscosity is unstable and the oil is of a slimy nature, forming threads when dropping. In contact with water and steam the aluminum soap is precipitated and clogs the machinery.

White greases are usually made from animal fat and a small amount of mineral oil, solidified by soap. The melting points are lower than the melting points of cup grease, ranging from 45°C. to 70°C.

Certain white greases contain finely pulverized mica and are sold under the name of mica greases.

Railway Wagon Grease.—The yellow grease used in the axle boxes of railway wagons is usually composed of tallow, palm oil, soda-soap and water.

According to a number of formulæ quoted by Mr. Archbutt, the specifications are approximately as follows:

Saponifiable oils	30 to 45 per cent., occasionally partly replaced by mineral oil.
Anhydrous soap	10 to 30 per cent.
Water	40 to 60 per cent.
Insoluble matter	0.02 to 2.8 per cent.

Usually 3 per cent. to 5 per cent. more water is used in the winter greases than in the summer greases.

A good wagon grease should melt at about 40°C. without separating; cup greases are unsuitable for railway wagons, as they have too high melting points and when continuously exposed to high temperature in the axle boxes the oil separates out, leaving the soap behind.

Rosin grease is made by stirring together rosin oil, slaked lime and usually black mineral oil or neutral coal tar oil.

The rosin acids present in the rosin oil combine with the lime forming a soap, which solidifies the mixture of the various oils. Water to the extent of up to 20 per cent. is sometimes present in rosin greases.

Rosin greases are used to lubricate rough machinery in collieries and steelworks.

Hot neck greases are very hard greases made from heavy residues such as wool pitch, stearine pitch, petroleum pitch, heavy asphaltic base petroleum lubricating oils—thickened with soap or rosin grease and containing finely pulverized talc or graphite. Hot neck greases are used for lubricating "hot" rolling mill necks in tinplate works and steelworks.

Pinion greases are closely related to hot neck greases; they frequently contain pine tar oil and are very sticky and adhesive.

Special Greases.—*Gear grease* can be made by mixing a heavy viscosity mineral oil with fibre grease, or with paraffin wax. Such mixtures are reasonably stable when used in the gear boxes of motor cars.

Solidified oils are not satisfactory as gear greases, nor are those cup greases the bases for which have been made from rape oil or cottonseed oil. Such greases have too high melting points, separate under heat, and the soap which is left cakes and carbonizes. Cup greases made from a tallow lime base give reasonable satisfaction, but are also too high in melting point and inclined to cake.

Yarn grease is a mixture of ordinary cup grease or fibre grease and cotton waste or woollen yarn, preferably the latter. The strands should not be too long; 1½" to 2½" is a suitable length; longer strands get entangled and it becomes difficult to divide the grease when applying it to bearings.

Black floating grease is made by mixing dark heavy-viscosity lubricating oils with powdered talc, in about even proportions; this grease is still used in some collieries as a car grease. It is low in price and causes great friction and wear, but the bearings rarely seize or get scored.

Petroleum grease is either a petroleum jelly (see page 9) or a mixture of petroleum jelly with thin mineral oil; these greases have low melting points and little lubricating value, but they contain no moisture and are for that reason recommended by several makers of small ball and roller bearings.

Scented Grease.—Many greases—cup grease, solidified oil, etc.—particularly when made from rancid fats or fatty oils are scented with oil of citronella or with nitro-benzine to cover up the bad odor. Such scenting should be discouraged, as it is difficult to know whether a scented grease is of good or bad quality.

CHAPTER IV

SOLID LUBRICANTS

Several kinds of solid materials are used for lubricating purposes, such as graphite, talc, soapstone, mica, flowers of sulphur, white lead, etc. Some of these solid lubricants, as flake graphite or mica, possess a tough flakey foliated structure which enables them to resist pressure without disintegration. Others, such as amorphous graphite or flowers of sulphur, are easily crushed into a fine powder when exposed to pressure.

Again, solid lubricants may be so finely divided as to enable them to be suspended in colloidal form in a liquid carrier. The colloidal graphite preparations, aquadag and oildag, made by Dr. Acheson's process, are examples of such lubricants, being diffusions of colloidal graphite in water and oil respectively.

CHARACTERISTICS OF SOLID LUBRICANTS

Graphite.—Graphite is the most important of all solid lubricants. It is not attacked by acids or alkalis, nor affected by high or low temperatures.

Graphite is also called "black lead" or "plumbago," but these names are slowly going out of use. Before the true chemical nature of graphite was established as being pure carbon, it was thought that it contained lead, and it was called "black lead" in consequence.

Natural Graphite.—The greater part of the world's supplies of natural graphite comes from Austria, Ceylon, Italy, Bavaria, Madagascar, the United States, Canada, Mexico, Japan, Siberia, and England.

Natural graphite is found in two forms—flake graphite and amorphous graphite; the former is of a tough, flakey structure and has a pronounced lustre, whereas the amorphous graphite has no such lustre.

Natural graphite, as it is obtained from the graphite mines, contains some impurities, chiefly silica, alumina and ferric oxides. Three methods of purification are employed which may be classified as hand sorting, mechanical (dry or wet method), and chemical.

The specific gravity of natural graphite (2.2) and some of its impurities are so nearly identical that it is difficult to remove the impurities completely by mechanical means. For this reason, ingredients like mica and talc usually remain associated with purified natural graphite to a greater or less extent according to the process employed.

It is said that it is easier to purify the flake variety of natural graphite than the amorphous form; it is unquestionably a fact that most of the natural graphite employed for lubricating purposes is of the flake variety. The flake formation is retained even if it be ground into a fine powder. It is manufactured in several degrees of fineness, as for example by the Joseph Dixon Crucible Co. who obtain a high grade natural graphite from their Ticonderoga mines, which is practically free from impurities.

Several grades of flake graphite of British manufacture and marketed by the Graphite Products, Ltd., have been analzyed by L. Archbutt, as shown later; it is evidently possible to produce commercially a graphite practically free from impurities.

Flake graphite may be used either dry, or in admixture with semisolid lubricants. It cannot be used mixed with oil in ordinary lubricators or lubricating systems, because of its high specific gravity, which causes it to separate out and choke lubricators, oil pipes and oil grooves.

Artificial Graphite.—Amorphous graphite is produced artificially by Dr. Acheson in the electrical furnace. He is able by his process to produce graphite of a soft, unctuous, non-coalescing nature and almost chemically pure.

The varieties produced for lubricating purposes are guaranteed to contain 99 per cent. of pure carbon, but usually contain more. In one variety of graphite, No. 1340, 98 per cent. of the graphite particles are less than $\frac{1}{338}$ of an inch in diameter. From this or similar graphite Dr. Acheson produces what he calls deflocculated graphite by kneading it for a long time with water in the presence of a vegetable extract, such as tannic acid. The graphite particles in this process disintegrate into particles one thousand times less in diameter; in fact, Dr. Acheson estimates that each particle of the "1340" graphite becomes divided into 700,000 particles, a smallness of size bordering on the molecular. The graphite becomes diffused in the water in colloidal form and each particle, being protected by an envelope of organic colloidal matter, remains in suspension for an indefinite time in the water.

Dr. Acheson manufactures the colloidal solution of graphite in water in the form of a concentrated paste under the name of "aquadag." It may be diluted by the addition of pure water to the required strength without the graphite separating out. By a further process the concentrated aquadag is mixed and kneaded with mineral lubricating oil until all the water is replaced by oil; this product is called "oildag," and may be diluted with good quality neutral mineral oil without any appreciable separation of the graphite, without "flocculation," as Dr. Acheson calls it.

In Germany, colloidal solutions of graphite have been produced commercially by E. de Haen, similar to aquadag and oildag, the corresponding names being hydrosol (corresponding to aquadag) and oleosol or kollag (corresponding to oildag). These German products are made from natural graphite by suitable corrosion "stabilizing," etc., and from an examination by Prof. D. Holde of Berlin, they appear to have the same stability (when diluted with water or oil respectively) as the colloidal artificial graphites made by Dr. Acheson's process. According to Prof. Holde,[1] in both forms of colloidal graphites there are graphite particles of a size from 1μ to 6μ but the majority are submicrons, less than 1μ in size (1μ equals 0.001 m.m.) which are not easily separated out by centrifuging, whereas the larger particles from 1μ to 6μ are easily separated out in this manner.

Prof. Holde found that by dissolving oleosol in benzol and filtering it through finely powdered bleaching earth, such as Fuller's earth, all the graphite was retained in the earth, which owing to its absorbing properties acted as an ultrafilter, although the action was different from the mechanical pore action of the ultrafilter.

Colloidal solid lubricants may be produced from materials other than graphite. It will appear that some successful attempts have been made with talc and mica.

Talc.—*Talc* consists of hydrogen magnesium silicate ($H_2Mg_3Si_4O_{12}$) and occurs as foliated or scaly compact masses. Its specific gravity ranges from 2.6 to 2.8.

The term *Steatite* is restricted to the compact massive varieties of talc.

Soapstone is an impure form of steatite.

French Chalk is talc or steatite in powder form.

Talc scales feel greasy or soapy, possess a perfect micaceous cleavage, have a pearly to silvery lustre, and are flexible but not elastic, thus differing from mica.

Talc is very soft and can readily be scratched with the finger nail; it is selected as No. 1 in Mohs's hardness scale, although the

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[1] Zeitschrift f. Elecktrochemie (1917) $^{23}/_{16}$.

harder varieties of talc may have a hardness of 2.5 to 4. The color of talc varies from silvery white for the best and softest varieties to greyish or greenish for the harder steatite varieties.

Talc resists acids and alkalis and also heat (no water being lost below a red heat) and cold. It is obtained chiefly from the United States, but is found also in many countries such as Cornwall, Bavaria, France, Italy, Austria, and India.

Mica.—The name "mica" is applied to a group of minerals characterized by the facility with which they split into thin lamina which are flexible and more or less elastic. The hardness of the micas is between 2 and 3, while their specific gravity ranges from 2.7 to 3.1.

The chemical composition is subject to considerable variations in different species—broadly speaking, there is a group of potash micas, generaly pale in color and a group of magnesium or ferric magnesia micas, usually dark in color.

All the micas are complex silicates containing aluminum and potassium generally associated with magnesium but rarely with calcium.

Water is always present and many micas contain fluorine.

Mica is prepared for the market by splitting the blocks of rough mica into plates which are cut into the required patterns by means of shears.

The refuse mica when finely ground forms the material used for lubricating purposes. The small particles of mica still retain their thin lamellar structure.

Flowers of Sulphur.—Flowers of sulphur is not used much for lubricating purposes, but is used to some extent for curing hot bearings. It is a fine powder consisting of pure sulphur largely in the form of minute crystals. The specific gravity is approximately 2.

White Lead.—White lead is used to some small extent for curing hot bearings. It is an extremely fine powder consisting chemically of basic carbonate of lead, generally said to have the following formula:

$$2PbCO_3 \cdot Pb(OH)_2$$

CHAPTER V

TESTING LUBRICANTS

In the early days, when mineral lubricating oils were nearly all made from Pennsylvania or Russian crudes, only a few varieties were manufactured, and simple physical and chemical tests sufficed to identify the oil. This state of affairs no longer exists; lubricating oils are now made from a great variety of crudes, and great experience is required to judge the merits of an oil on the basis of a laboratory analysis.

The selection of an oil for certain engines or machinery requires many years of experience in comparing and testing different lubricants under actual running conditions. Laboratory tests and investigations alone are of no avail, as chemists usually have no engineering experience; on the other hand lubricating engineers cannot develop their experience and judgment without the very best chemical assistance; in fact, it is only by co-ordinating field engineering experience with careful laboratory investigations that it is possible to accumulate the kind of knowledge which is required to enable one to give sound recommendations as to the grades of lubricants which should be selected for a given purpose, as well as the best methods of application and use.

It is a well-known fact that the vast majority of oil firms operate on the principle of getting samples of oils in use, analyzing these samples more or less roughly, and then offering oils more or less similar in character. As the customer in most cases does not trouble much about the quality of the oils, as long as "the price is right," and as long as nothing serious happens to his machinery, the prevailing standard of lubrication is usually exceedingly low. The author, who for many years has been in charge of a large staff of lubrication engineers, can testify that very few works exist where a lubricating engineer, after a thorough works inspection, cannot point out means by which great economies can be affected from the point of view of saving in power (with all its attendant benefits), saving in lubricants, greater safety of operation, etc., all due to better lubricants or better methods of handling them from the moment they are received at the stores till the moment the last drop has been consumed in the works.

It should not be necessary for a capable lubricating engineer to have samples of the lubricants in use in order to recommend the correct grades of his firm's products. His general lubrication knowledge of engines and machinery and his observations during the inspection ought to be sufficient for that purpose. But if he is to give an accurate estimate of the possible saving in power or consumption to be obtained by introducing better or more suitable lubricants, then an analysis of the lubricants in use and of the consumption in all departments is required.

Speaking generally, in order to satisfy certain lubricating requirements, the lubricant:

1. Must possess sufficient viscosity and lubricating power—oiliness—to suit the *mechanical conditions* and conditions of *speed, pressure* and *temperature.*

Too little oiliness means excessive wear and friction; too high a viscosity means loss of power in overcoming unnecessary fluid friction.

2. Must suit the *lubricating system.*

When, for example, the oil pipes are exposed to cold, a lower cold test oil is required than when the oil pipes are not so exposed.

3. Must be of such a nature that it will not *produce deposits* during use, exposed to the *influence of air, gas, water or impurities* with which the oil may come into more or less intimate contact while performing its duty.

The particular physical and chemical tests needed will depend on the class of work for which the oil is to be used, and will become more apparent from the chapters in this book devoted to particular types or sections of engines and machinery.

In the manufacture of lubricating oils it is of the greatest importance that the various grades be kept always as closely as possible to certain predetermined standards. Engineers who have to do with the practical application of oils fully appreciate this point. For example, a drop feed lubricator on a bearing is set to give a certain feed of oil which has been found satisfactory; a new supply of oil is received of a lower or higher viscosity than the former supply; the feed of the lubricator will then be either greater, which means oil wasted, or smaller, with the result that the bearing may run warm.

Physical and chemical tests of lubricants are therefore of great value to the oil manufacturer for controlling the manufacture of lubricating oils during the distillation, refining and compounding operations, up to the point when the oil is placed in the stores ready for shipment. Physical and chemical tests are also extremely valuable for the purpose of identifying an oil or for detecting adulterations.

In the following chapters the author will endeavor to show the importance of physical, chemical and mechanical testing methods, but with the exception of one or two, which he feels may not be generally known, it is not proposed to describe the apparatus.

The author has divided "Testing Lubricants" into two sections, namely, "Physical and Chemical Tests" and "Mechanical Means of Testing Lubricants," the latter section dealing briefly with friction testing machines and works methods of carrying out comparative tests on engines and machinery.

PHYSICAL AND CHEMICAL TESTS

Physical Tests

Density and Specific Gravity.
Coefficient of Expansion.
Flash Point and Fire Point.
Volatility—Loss by Evaporation.
Distillation.
Specific Heat.
Cold Test, Pour Test and Cloud Test.
Melting Point.
Color and Fluorescence.
Viscosity of Oils.
Viscosity of Semi-solid Lubricants.
Capillarity.
Emulsification.
Surface Tension.

Chemical Tests

Acidity.
Oxidation and Gumming.
Ash.
Carbon Residue.
Asphalt and Tar.
Oiliness.
Impurities (Dirt, Glue, Water).

PHYSICAL TESTS

Density and Specific Gravity.—The specific gravity of a substance is the weight compared with that of an equal volume of water as unity.

In the United States and Great Britain the specific gravity is the 60°F./60°F. value, which means that the specific gravity is measured at 60°F. as compared with water at 60°F. as unity.

On the Continent the 15°C./4°C. value is generally used, which means that the specific gravity is measured at 15°C. and compared with water at 4°C. as unity, this being the temperature at which water has its maximum density.

Density in the C.G.S. system (metric system) means the weight of one milliliter (= cubic centimeter) of a substance as compared with the weight of one milliliter of water at 4°C. The specific gravity 15°C./4°C. therefore represents in the metric system the density of the substance at 15°C. The 15°C./4°C. specific gravity is obviously less than the 60°F./60°F. value, but as the coefficient of expansion of water is exceedingly small, the difference in value is only slight.

As indicated in the table, p. 23, the specific gravities of the various fixed oils do not differ much from one another, whereas the specific gravities of mineral oils differ considerably, depending not only upon the crude itself, but also upon the method of distillation and refining.

For oils made from similar crudes by similar methods the specific gravity increases with the viscosity. Speaking generally, asphaltic base oils and Russian oils have higher specific gravities than paraffin base oils, the difference for similar viscosity oils being from 0.020 to 0.040. Oils treated by acid and cracked oils have higher specific gravities than oils treated by filtration and uncracked oils respectively. Coal tar oils and rosin oils have specific gravities in the neighborhood of 1.0, coal tar oils always being above 1.0.

The specific gravity is therefore important, since when coupled with other tests it assists in identifying an oil as coming from a certain type of crude, etc. The specific gravity has, however, no *direct* bearing on the lubricating value of a lubricant.

The specific gravity may be determined by pyknometer, hydrometer, or the Westphal balance. The pyknometer method (specific gravity bottle or the Sprengel tube) is applicable to all liquids and is the most accurate method for lubricating oils. The hydrometer and the Westphal balance are less accurate, but both methods are capable of giving sufficiently accurate results for commercial purposes and are handier to use than the pyknometer, especially the hydrometer.

The Beaumé gravity is measured by a hydrometer and is much used in the United States. The conversion of gravity from degrees Beaumé to specific gravity can be carried out according to the formula:

$$\textit{Specific Gravity} = \frac{140}{°Be. + 130}$$

The conversion table No. 5 has been calculated from this formula.

As one litre water weighs one kilogram, the weight of one litre oil in kilograms is expressed by its specific gravity. As one imperial gallon weighs ten pounds, the weight of one imperial gallon of oil in pounds is equal to ten times its specific gravity. This rule cannot be applied to American gallons, one American wine gallon equalling five-sixth imperial gallon.

Table 5.—Table of 60°F./60°F. Specific Gravities

(Corresponding to Each Tenth of a Degree of Beaumé's Hydrometer Between 15.0 and 50.0 Degrees for Liquids Lighter than Water)

15.0-.9655	19.0-.9396	23.0-.9150	27.0-.8917	31.0-.8605
.1-.9649	.1-.9389	.1-.9144	.1-.8912	.1-.8690
.2-.9642	.2-.9383	.2-.9138	.2-.8906	.2-.8685
.3-.9635	.3-.9376	.3-.9132	.3-.8900	.3-.8680
.4-.9629	.4-.9370	.4-.9126	.4-.8894	.4-.8674
.5-.9622	.5-.9364	.5-.9120	.5-.8889	.5-.8669
.6-.9615	.6-.9358	.6-.9114	.6-.8883	.6-.8663
.7-.9609	.7-.9352	.7-.9109	.7-.8877	.7-.8658
.8-.9602	.8-.9346	.8-.9103	.8-.8871	.8-.8652
.9-.9596	.9-.9340	.9-.9097	.9-.8866	.9-.8647
16.0-.9589	20.0-.9333	24.0-.9091	28.0-.8861	32.0-.8642
.1-.9582	.1-.9327	.1-.9085	.1-.8855	.1-.8637
.2-.9576	.2-.9320	.2-.9079	.2-.8849	.2-.8631
.3-.9569	.3-.9314	.3-.9073	.3-.8844	.3-.8626
.4-.9563	.4-.9308	.4-.9067	.4-.8838	.4-.8621
.5-.9556	.5-.9302	.5-.9061	.5-.8833	.5-.8615
.6-.9550	.6-.9295	.6-.9055	.6-.8827	.6-.8610
.7-.9543	.7-.9289	.7-.9049	.7-.8821	.7-.8605
.8-.9537	.8-.9283	.8-.9044	.8-.8816	.8-.8599
.9-.9530	.9-.9277	.9-.9038	.9-.8810	.9-.8594
17.0-.9524	21.0-.9271	25.0-.9032	29.0-.8805	33.0-.8589
.1-.9517	.1-.9265	.1-.9027	.1-.8800	.1-.8584
.2-.9511	.2-.9259	.2-.9021	.2-.8794	.2-.8578
.3-.9504	.3-.9253	.3-.9015	.3-.8789	.3-.8573
.4-.9498	.4-.9247	.4-.9009	.4-.8783	.4-.8568
.5-.9492	5-.9241	.5-.9003	.5-.8777	.5-.8563
.6-.9485	.6-.9235	.6-.8997	.6-.8772	.6-.8557
.7-.9479	.7-.9229	.7-.8991	.7-.8766	.7-.8552
.8-.9472	.8-.9223	.8-.8986	.8-.8760	.8-.8547
.9-.9466	.9-.9217	.9-.8980	.9-.8755	.9-.8542
18.0-.9459	22.0-.9210	26.0-.8974	30.0-.8750	34.0-.8536
.1-.9453	.1-.9204	.1-.8969	.1-.8745	.1-.8531
.2-.9447	.2-.9198	.2-.8963	.2-.8739	.2-.8526
.3-.9440	.3-.9192	.3-.8957	.3-.8734	.3-.8521
.4-.9434	.4-.9186	.4-.8951	.4-.8728	.4-.8516
.5-.9428	.5-.9180	.5-.8946	.5-.8723	.5-.8511
.6-.9421	.6-.9174	.6-.8940	.6-.8717	.6-.8505
.7-.9415	.7-.9168	.7-.8934	.7-.8712	.7-.8500
.8-.9409	.8-.9162	.8-.8928	.8-.8706	.8-.8495
.9-.9402	.9-.9156	.9-.8922	.9-.8701	.9-.8490

TABLE 5—(*Continued*)

35.0–.8485
.1–.8480
.2–.8475
.3–.8469
.4–.8464
.5–.8459
.6–.8454
.7–.8449
.8–.8444
.9–.8439
36.0–.8434
.1–.8428
.2–.8423
.3–.8418
.4–.8413
.5–.8408
.6–.8403
.7–.8398
.8–.8393
.9–.8388
37.0–.8383
.1–.8378
.2–.8373
.3–.8368
.4–.8363
.5–.8358
.6–.8353
.7–.8348
.8–.8343
.9–.8338
38.0–.8333
.1–.8329
.2–.8324
.3–.8319
.4–.8314
.5–.8309
.6–.8304
.7–.8299
.8–.8294
.9–.8289
39.0–.8284
.1–.8279
.2–.8274
.3–.8269
.4–.8264
39.5–.8259
.6–.8254
.7–.8249
.8–.8244
.9–.8240
40.0–.8235
.1–.8230
.2–.8226
.3–.8221
.4–.8216
.5–.8211
.6–.8206
.7–.8202
.8–.8197
.9–.8192
41.0–.8187
.1–.8183
.2–.8178
.3–.8173
.4–.8168
.5–.8163
.6–.8158
.7–.8153
.8–.8149
.9–.8144
42.0–.8139
.1–.8135
.2–.8130
.3–.8125
.4–.8120
.5–.8116
.6–.8111
.7–.8106
.8–.8101
.9–.8097
43.0–.8092
.1–.8088
.2–.8083
.3–.8078
.4–.8074
.5–.8069
.6–.8065
.7–.8060
.8–.8055
.9–.8050
44.0–.8046
.1–.8042
.2–.8037
.3–.8032
.4–.8027
.5–.8023
.6–.8019
.7–.8014
.8–.8009
.9–.8005
45.0–.8000
.1–.7996
.2–.7991
.3–.7986
.4–.7982
.5–.7977
.6–.7972
.7–.7968
.8–.7963
.9–.7959
46.0–.7954
.1–.7950
.2–.7946
.3–.7941
.4–.7937
.5–.7932
.6–.7928
.7–.7923
.8–.7918
.9–.7914
47.0–.7910
.1–.7905
.2–.7901
.3–.7896
.4–.7891
.5–.7887
.6–.7883
.7–.7878
.8–.7874
.9–.7869
48.0–.7865
.1–.7860
.2–.7856
.3–.7852
.4–.7847
48.5–.7843
.6–.7839
.7–.7834
.8–.7830
.9–.7826
49.0–.7821
.1–.7817
.2–.7813
.3–.7808
.4–.7804
.5–.7799
.6–.7795
.7–.7791
.8–.7786
.9–.7782
50.0–.7778

The Twaddell gravity scale is sometimes used for liquids heavier than water, such as coal tar products, caustic potash, sulphuric acid and other chemicals. To convert degrees Twaddell to specific gravity use the following formula:

$$\text{Specific Gravity}\ \frac{1000+5\times\text{degrees Twaddell}}{1000}$$

COEFFICIENT OF EXPANSION

The coefficient of expansion is the expansion or contraction per unit volume following a change in temperature of one degree.

The coefficient of expansion is the same for all mineral oils of the same specific gravity and can be taken near enough for practical purposes as being:[1]

	Specific gravity	Coefficient of expansion	
		Per °F.	Per °C.
For gasolene	.620–.760	.00050	.00090
For kerosene	.780–.830	.00040	.00072
For lubricating oils, including fixed oils	.850–.970	.00036	.00065

The density of an oil will vary, with a certain change in temperature, an amount equal to the coefficient of expansion multiplied by the number of degrees the temperature has changed.

To know the value of the coefficient of expansion is therefore useful for converting the gravity measured at a temperature different from the standard temperature (which is 60°F. in United Kingdom and United States) to the gravity at the standard temperature. Also for measuring the stock of oil in an oil storage tank, as the volume must always be corrected to represent volume at a standard temperature.

In correcting the specific gravity for variation in temperature, the correction coefficient is not, as is often assumed, the coefficient of expansion, but the product of the latter and the specific gravity taken at the temperature of the oil. It may be useful to show how the true correction is calculated.

The change in volume due to change of temperature is expressed in the fundamental formula:

$$V_T = V_{60}\ [1 + C(T - 60)]$$

Where V_T = Volume of a certain weight of oil at the temperature T.

V_{60} = Volume of the same weight of oil at 60°F.

C = Coefficient of expansion.

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[1] U. S. A. Bureau of Standard Technologic paper No. 77: Density and Thermal Expansion of American Petroleum Oils.

The weight of the oil equals the volume multiplied by the specific gravity, so that:

$$V_{60} \times S_{60} = V_T \times S_T; \text{ or } V_T = \frac{V_{60} \times S_{60}}{S_T}$$

where S_{60} and S_T are the specific gravities of the oil at 60°F. and T°F. respectively.

We can now rewrite our formula as follows:

$$\frac{V_{60} \times S_{60}}{S_T} = V_{60}\,[1 + C\,(T - 60)] \quad \text{or}$$

$$S_{60} = S_T + S_T \times C \times (T - 60)$$

In other words, the specific gravity at 60°F. equals the specific gravity at T°F. plus the product of (1) the difference in temperature between T and 60, (2) the coefficient of expansion, and (3) the specific gravity at T°F.

FLASH POINT AND FIRE POINT

The *Flash point* of an oil is the temperature at which the oil gives off sufficient vapors to ignite momentarily when exposed to a flame or spark. The oil must be heated at a uniform rate, and not too rapidly, as that would give too low a flash point.

The *open flash point* is the flash point determined when heating the oil in an open cup.

The *closed flash point* is the flash point determined when heating the oil in a closed vessel, which rather prevents the vapors escaping, so that the closed flash point is always lower than the open flash point. The difference is greater the higher the flash point of the oil.

The *fire point* of an oil is the temperature at which the oil gives off sufficient vapors to ignite and continue to burn when exposed to a flame or spark. The test is made with the same apparatus as is used for determining the flash point, the oil being heated beyond the flash point until the fire point is reached.

No oil is used for lubricating purposes with an open flash point less than 300°F. The open flash points of all lubricating oils, including fixed oils range from 300°F. to 650°F. The closed flash point of a lubricating oil is recorded only for special oils, such as air compressor oils, and transformer oils.

The apparatus employed for testing flash and fire points vary for different countries. Thermometers are usually standardized with the bulb and stem at the same temperature. As the stem of the thermometer when determining flash and fire points is not exposed to high temperature, the results should be corrected by adding to the thermometer readings the following degrees F.

275—300— 5
300—325— 6
325—350— 7
350—375— 8
375—400—10
400—425—11
425—450—13
450—500—16
500—550—20
550—600—23
600—650—27
650—700—30

Pensky-Martens apparatus is more widely used for lubricating oils in many countries than any other apparatus.

The *Gray* instrument is an adaptation of the Pensky-Martens apparatus, and the two instruments give identical readings.

The *Abel* instrument is principally used for taking closed flash points of spirits and illuminating oils.

Fixed oils do not evaporate until they begin to decompose, whereas mineral oils commence to evaporate long before their flash points are reached. When fixed oils are heated sufficiently to give off vapors, destructive distillation has already commenced, and it will be seen from Table No. 3 page 23 that the flash points of fixed oils are much higher than for mineral oils of similar viscosities, the open flash points ranging from 460°F. to 630°F.

The difference between the open flash point and the fire point of lubricating oils is approximately as follows:

	Difference between open flash point and fire point, °F.
1. Straight mineral distilled lubricating oils.	40 to 55
2. Cylinder oils (undistilled)	50 to 75
3. Mixtures of mineral distilled oils with cylinder oils or fixed oils...............	40 to 75

The *evaporation point* is the temperature at which an oil begins to give off vapors; this temperature is normally about 150°F. to 180°F. lower than the flash point, but is so difficult to determine accurately, and depends so much on the human element, that its determination is of no practical importance.

VOLATILITY—LOSS BY EVAPORATION

Oil exposed to a high temperature for a certain number of hours loses a certain amount in weight, which is called "loss by evaporation."

The oil is usually heated in an open beaker, and experience shows that the loss by evaporation is greatly influenced by the size and shape of the beaker, the amount of oil used, air currents, etc. When giving figures for loss by evaporation, one should therefore state all such particulars for the test to be of any value at all.

The evaporation test is seldom of any great value; if a lubricating oil has an open flash point above 300°F. the loss by evaporation will usually be of no importance; the flash point will prove a safe guide as to whether the oil contains light petroleum fractions of a kerosene or gasolene nature.

Where oils are known to be contaminated with low flash products, the evaporation test can be used to determine the percentage present of these products, as for example with used oils from the crank case of petrol or oil engines.

Lubricating oils used for high vacuum pumps (in the manufacture of electric bulbs) must have a low volatility in vacuum and should have their vapor tension tested, when exposed to vacuum and at a temperature approximating the working temperature.

Transformer oils are often subjected to the evaporation test, as many of these oils are low flash oils (occasionally flashing below 300°F.) and the loss by evaporation during use may easily become an important feature.

Air compressor oils are sometimes tested with advantage for evaporation losses, particularly when the compressed air is used for tunnel work or for operating tools or engines in confined spaces, or in underground mines, as the presence of an appreciable amount of oil vapor in the compressed air will affect the eyes and throats of the workers.

Archbutt has designed a simple vaporimeter,[1] in which the oil is placed in a boat inside a 7/8 inch internal diameter tube, through which is passed hot air or steam, the whole heated to the desired temperature by means of a gas burner. The apparatus appears to give very consistent results and to lend itself well to standardization.

The vessels used for evaporation tests should be porcelain or glass; metal vessels have a catalytic effect, which influences the results.

From tests carried out by Archbutt and others, it is evident that no simple relation (if any relation at all) exists between the volatility of an oil and its flash point.

Distillation. In rare cases lubricating oils are subjected to distillation tests with a view to finding out the percentages of low viscosity, medium viscosity, and high viscosity oils of which they are composed.

All lubricating oils are mixtures of hydrocarbons having different viscosities and while it is not of any considerable interest to further analyze from a distillation point of view the eight main types of oils referred to on page 11, yet it may be of interest to find out whether a certain lubricating oil is a mixture of cylinder

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[1] Archbutt & Deeley: Lubrication and Lubricants, page 215.

stock and a lower viscosity distilled lubricating oil, and in that case what the percentage of cylinder stock amounts to.

An interesting series of distillation tests were carried out by J.G. O'Neill, Chemist, U.S. Naval Experiment Station, Minneapolis, published in the May 1916 Journal of the American Society of Naval Engineers. Mr. O'Neill distills the oil by means of superheated steam, but does not employ a vacuum. By distilling a number of oils into their various fractions and further analysing these fractions, he brings out the typical characteristics of asphaltic base and paraffin base oils.

Other experimenters distill the oils under a high vacuum which, however, is rather a delicate test to carry out in the laboratory and more complicated than distilling without the use of vacuum. There is, however, no standard method adopted for a distillation test of lubricating oils, nor does this test seem to be of particular interest to ordinary consumers. On the other hand, it may be of considerable interest to oil refineries or lubricating oil companies with a view to finding out the characteristics and component parts of competitive products.

Specific Heat. The specific heat of a lubricating oil means the amount of heat required to raise the temperature of 1 lb. of oil 1°F., or 1 kilo of oil 1°C., as compared with the amount of heat required to heat 1 lb. of water 1°F. or 1 kilo. of water 1°C., respectively. The specific heat of water is therefore 1.00.

A considerable amount of work in connection with specific heats of oils has been done by Prof. Charles F. Mabery (Proceedings of the American Academy of Arts & Sciences, Volume 37 page 20, March 1902). Prof. Mabery has shown that the specific heats of the paraffin series of hydrocarbons are higher than the specific heats of the naphthenes, olefines, and other hydrocarbons less rich in hydrogen than the paraffins.

The specific heat is higher for the lower viscosity oils than for those of higher viscosity, although the difference amounts only to a few per cent. The specific heat also increases slightly with increasing temperatures.

For practical purposes, however, the specific heat may be taken as follows:

	Character of hydrocarbons	Specific heat @ 50°C.
Paraffin base distilled low viscosity oils	C_nH_{2n+2}	.49
Russian oils and heavy viscosity Pennsylvanian oils, etc	C_nH_{2n}	.47
Many asphaltic base oils	C_nH_{2n-2}	.44

The above values for specific heat show a characteristic difference between the different lubricating oils, which is of some importance in connection with lubrication, as the frictional heat developed during the operation of machinery heats the oil film, thus reducing its viscosity. The lower the specific heat the greater will be the temperature rise of the oil in the film and therefore the greater will be the reduction of viscosity. If abnormal heating takes place, oils having a low specific heat will quickly thin out, the practical result of this being that such oils offer less security under severe conditions than oils having a high specific heat.

COLD TEST, POUR TEST AND CLOUD TEST

When lubricating oils are cooled they do not congeal suddenly, as does for example water when it turns into ice, but being mixtures of products of different nature, they gradually become more and more viscous until they finally set solid; the temperature at which they congeal is called the *setting point,* or *cold test.*

The lowest temperature at which the oil will flow or pour out of a receptacle, is usually taken as being 5°F. above the setting point and is called the *pour test.*

The temperature at which the oil commences to become cloudy-paraffin wax separating out—is called the *cloud test,* but it is difficult to determine this temperature with accuracy and the cloud test is nowadays rarely spoken of in connection with lubricating oils.

Stirring.—When the setting point of mineral oils is being determined, the oil must not be stirred, as by stirring the network of solid hydrocarbons is broken up and the setting point will be from 5°F. to 10°F. lower than when the oil is cooled without stirring. Archbutt, however, recommends stirring when testing fixed oils.

Russian oils, Californian and other non-paraffinic base oils, have no "cloud test," as they contain no solid paraffin; their setting points are therefore lower—from 20°F. to 40°F. lower than those of paraffin base oils.

Sometimes heavy viscosity paraffin base oils become chilled during transit in cold weather, as a result the amorphous wax commences to solidify in oily lumps throughout the body of the oil. The oil will therefore be much thicker than its standard (real) viscosity and will not be homogeneous. To bring the oil back to its normal viscosity, it is necessary to heat it sufficiently to melt the paraffin wax, say to 160°F. or 170°F., the melting points of paraffin wax ranging from 100°F. to 130°F.

When light viscosity lubricating oils become chilled, some of the paraffin wax sometimes crystallizes out in the form of shiny needles floating in the oil; they will only dissolve in the oil if heated to a temperature above their melting point.

Heating.—When testing the setting point of oils containing paraffin wax they should for the reasons just given always be previously heated to a temperature of 160–170°F.

Cooling.—The oil should be cooled slowly, as rapid cooling means that the setting point, as determined, will be too low. This is particularly important for fixed oils. The test tube or bottle containing the oil should therefore be placed inside another tube ½″ larger in diameter, the air space between the tubes preventing too rapid cooling.

Apparatus.—There is a variety of apparatus employed for testing the setting point, pour test and cloud test of oils. Some aim at determining the setting point, as the temperature at which the oil in the vicinity of the thermometer ceases to flow, when the vessel or tube is tilted for ten minutes. Others aim at determining the pour test, as the temperature at which a definite quantity of the oil will just flow from end to end of a test tube of definite dimensions when placed horizontally or inverted; this method is largely used for cylinder oils and black oils.

The determinations of setting point or pour test are usually accurate within 5°F.

Cooling Mixtures—For oils congealing above 35°F. pounded ice is used. For oils congealing at from 35°F. to −5°F. a mixture of snow or pounded ice and salt is used, the salt preferably being added gradually to bring down the temperature 5°F. at the time.

For oils congealing below zero, solid carbon dioxide can be used or calcium chloride (crystals) and ice (−40°F.), or solid carbon dioxide may be added to dry acetone, by which a temperature as low as −70°F. can be obtained.

The setting point of an oil must be low enough so that the oil will flow readily under working conditions and that a sufficient amount will reach the bearings or parts to be lubricated. Many mishaps have been caused by the oil solidifying in the lubricators or refusing to run through exposed oil pipes to the bearings. While, therefore, in tropical or warm climates the setting point of lubricating oils ordinarily is of no importance, this feature is certainly important in temperate climates and particularly so in colder climates like Canada, Northern Scandinavia, northern Russia, etc.

Oils used for refrigerating machines and other special machines must always have low setting points, independent of the climatic conditions. Low setting point must be given special consideration in connection with engines or machinery operating in the open, such as railway rolling stock, certain machinery in mines and quarries, aeroplanes, automobiles, etc., etc. Oils used for engines or machinery operating inside buildings do not require the same consideration as regards setting point.

Whenever low setting point oils are required, the winter conditions are of course more severe than summer conditions, and so frequently two sets of oils are used, for summer and winter use respectively.

MELTING POINT

The melting point of an oil, fluid at ordinary temperatures, is the same as its setting point, or rather its pour test; in fact, the latter is sometimes determined by freezing the oil solid, then allowing it to melt exposed to the room temperature, under continuous stirring, until the oil commences to pour. The melting point of fats, lubricating greases or oils, non-fluid at ordinary temperatures is not a definite temperature, as they become soft and gradually melt, when heated.

Melting points of fats and greases may be determined in several ways, as described by Archbutt[1]; no uniform system has been agreed upon, and there are great discrepancies between the results when different apparatus is used and by different observers.

Low melting point greases (M.P. 40°C. to 50°C.) are required for railway axle box lubrication. Medium melting point greases are used for general lubrication, such as cup greases or solidified oils (M.P. 75°C. to 95°C.). High melting point greases are used for high temperature bearings for rotary cement kilns, dryer-journals and callendar journals on paper machines, Beeter bearings, etc. (M. P. 150°C. to 250°C.).

COLOR AND FLUORESCENCE

Fixed oils are transparent and either almost colorless or slightly yellow or greenish-yellow in transmittent light.

Distilled mineral oils are transparent and range in color from water white, through yellow, to deepest red in transmittent light.

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[1] A. & D. L. and L., pages 223–229.

Undistilled mineral oils—cylinder stocks—are very dark in color; dark cylinder stocks range from dark brownish red to black, whereas the filtered cylinder stocks are lighter in color and range from deep red to deepest red in transmittent light.

Lovibond's tintometer may be used to determine by comparison with standard colors the color of oil in a 1-inch cell. The darker the oil the higher is the color number. If determined in a cell of different thickness the thickness of the cell should be stated, so that the color number may be calculated in terms of a 1-inch cell.

Wearham has designed an apparatus which gives the color of an oil or any other material, liquid or solid, in terms of percentages of primary red, blue and yellow. The color determined in this manner is definitely expressed and can be reproduced in the apparatus to act as a standard for matching colors at the refineries or oil blending works.

The color of an oil in reflected light is called "bloom" or fluorescence.

Paraffin base oils have a greenish bloom; Russian and many asphaltic base oils have a bluish bloom. Dark cylinder stocks are dark brown or black, whereas highly filtered cylinder stocks show the fluorescence clearly, and are usually green, being produced from paraffin base crudes.

Oils which during use have been oxidized (turbine oils, crankcase oils, etc.) almost immediately change their bloom and assume a brownish color in reflected light. Oils which contain moisture become cloudy or even opaque and appear to be darker in color than when dry.

Oils are made paler by filtration, so that neutral oils are rather pale, although usually not so pale as the acid treated pale oils.

Pale oils are more easily produced from Russian crude, Californian, Texas and similar crudes.

The coloring matter in paraffin base oils is only removed with difficulty; hence white transformer oils and white medicinal oils are usually made from non-paraffinic base crudes, Russian crudes in particular.

Coloring matter in oil consists of very complex unsaturated hydrocarbons, which easily decompose under heat or when exposed to oxidation. Dark red oils when used for internal combustion engines or air compressors therefore produce more carbon than pale oils, and dark colored circulation oils are more inclined to produce deposits in steam turbines and enclosed type steam engines than pale oils. Similarly, dark cylinder oils produce more carbon than filtered cylinder oils when used for steam engines employing superheated steam.

Where oils are not exposed to great heat or oxidation, it is immaterial whether they are lighter or darker in color.

VISCOSITY

The viscosity of an oil is a measure of its resistance to flow—its internal friction—and is inversely proportional to its fluidity. A viscous or high viscosity oil is "thick" and flows with difficulty; a low viscosity oil is "thin" and flows readily.

The most accurate method of determining viscosity which is chiefly used in science is that of Poiseuille, by measuring the rate of flow of the oil through a capillary tube (a very narrow tube) under known conditions of temperature and pressure.

For commercial purposes the viscosity is usually determined by measuring the time taken in seconds for a certain volume of oil to flow out through a short vertical tube of standard dimensions.

Poiseuille's Method.—Poiseuille's method is based upon two facts, which he proved experimentally:

1. That the rate of flow of liquid through a capillary tube of suitable dimensions is proportional to the pressure and inversely proportional to the length of the tube.

2. That the rate of flow through a capillary tube of cylindrical bore is proportional to the fourth power of the radius of the bore.

The viscosity of the fluid in absolute measure is then given approximately by:

$$\textit{Absolute Viscosity} = \eta = \frac{\pi g d h r^4 t}{8Va}$$

in which "g" is the acceleration due to gravity, "d" the density of the liquid, "h" the mean head, "r" the radius of the bore of the capillary tube in centimetres, "t" the time in seconds, "v" the volume of liquid discharged in cubic centimetres, and "a" the length of the tube in centimetres.

Prof. Reynolds has shown that Poiseuilles formula is substantially correct when $\frac{r.v.d.}{\eta}$ is less than 700 where "v" is the mean velocity of the fluid.

To obtain the true viscosity, corrections must be made:

1. For the viscous resistance to the flow of the liquid at the ends of the tube.

2. For the abnormal flow of the liquid on first entering the tube.

3. For the kinetic energy with which the liquid leaves the tube.

4. For the resistance due to surface tension effects at the discharge orifice.

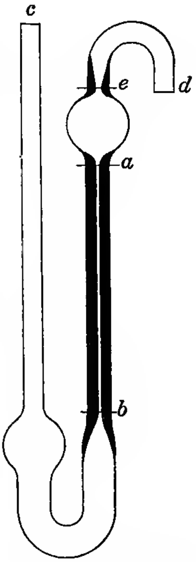
Corrections (1) and (2) have not yet been devised but errors due to these effects may be reduced to very small proportions by making the tube long. Correction (3) is made by deducting from the mean head a quantity $\frac{v^2}{g}$; this correction may be made very small by using a tube so narrow and so long that the movement of the liquid is very slow. The error due to surface tension effects which may be serious is so variable that correction (4) is best eliminated altogether by immersing the discharge orifice in the liquid and making a suitable deduction from the head.

In the absolute viscometer used by Archbutt and Deeley a capillary tube 0.6180 mm. diameter and 21.991 cm. long was employed. The absolute viscosity of water at 20°C. determined by this apparatus was 0.01028 dyne per sq. cm., which agrees well with results by other experimenters.

The absolute viscosity of a liquid may be defined as: "The force which will move a unit area of plane surface with unit speed relative to another plane surface from which it is separated by a layer of the liquid of unit thickness."

The absolute viscosity is therefore correctly expressed in dynes-second per sq. cm. but is usually referred to as dynes per sq. cm.

The term "*Poise*" has been coined from the name of Poiseulle and signifies "one dyne-second per sq. cm." As an absolute viscosity of 1 Poise means a fairly viscous oil, the term "*Centipoise*" is used, representing one-hundredth of a poise, the same as one centimetre equals one-hundredth part of a metre.



FIG, 1.—Ostwalds' viscometer.

Ostwald's viscometer, Fig. 1, is capable of giving the true relative viscosity in terms of the viscosity of water or other standard liquid, which is called the *specific viscosity*, when compared with the viscosity of water at 20°C. as unit. It consists of a glass U-tube, one limb of which is a capillary tube from *a* to *b*. A known volume of oil is introduced into the wide limb at *c*, and sucked up at *d*, until the level is above *e*. The time occupied in flowing back through the capillary *ab* whilst the level falls from *e* to *a* is noted.

If $t.d$ and $t_1.d_1$ are the time of flow and density of the liquid and water respectively, and if the viscosity of water is taken as unity, then the

$$Specific\ Viscosity = \frac{t.d}{t_1.d_1}$$

Commercial Viscometers.—The most widely used instruments are Saybolt (United States), Redwood (Great Britain) and Engler (Continent).

The standard dimensions of outflow tubes, etc., are as follows:

	Efflux Tube Dimensions	Volume of oil discharged	Oil charges
Saybolt.........	13 mm. × 1.8 mm.	60	70
Redwood........	10 mm. × 1.5 mm.	50	130
Engler..........	20 mm. × { 2.9 mm. top 2.8 mm. bottom	200	240

These instruments are described in greater detail in most standard handbooks.

The viscosities for Saybolt and Redwood are given in seconds, whereas with the Engler instrument, the Engler number equals the outflow in seconds divided by the efflux time of water at 20° C., which is 50″–52″, varying slightly for different instruments. The Engler number is therefore a kind of specific viscosity and can be converted into absolute viscosity by the formula, page 51.

All three viscometers have efflux tubes so large and comparatively short that a large proportion of the energy of flow, particularly for low viscosity liquids, is carried away in the issuing stream of liquid and not used for overcoming the fluid friction inside the efflux tube. For example, with the Engler viscometer the percentage of energy used in overcoming fluid resistance within the efflux tube is 95 per cent. or more in the case of a heavy viscosity oil, whereas with water it is only about 12 per cent.

The relation between the absolute viscosity of an oil and its kinematic viscosity, as measured by Saybolt, Redwood or Engler viscometers, is fairly uniform for medium or heavy viscosity oils, but when the kinematic viscosity is lower than say 100″ Saybolt, the absolute viscosity falls away more rapidily than the corresponding kinematic viscosity figures. W. H. Herschell[1] and W. F. Higgins[2] give formulæ for calculating the absolute viscosity at a certain temperature when the specific gravity and kinematic viscosity are known for this same temperature.

In the following formulæ:

"Specific Gravity" means the specific gravity value as compared with water at 60°F.

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[1] U. S. Department of Commerce, Technological Paper No. 100.

[2] "On Methods and Apparatus for Petroleum Testing," National Physical Laboratory, Collected Researches.

"Saybolt" means Saybolt Viscosity measured in seconds.

"Engler" means Engler efflux time, measured in seconds, not the Engler number. (The Engler apparatus employed gave an efflux time of 50.3 secs. for water at 20°C.)

"Redwood" means Redwood Viscosity, 50 c.c. test, measured in seconds.

The figures for absolute viscosity, specific gravity, and kinematic viscosity are corresponding values at the same temperature.

$$\text{Absolute Viscosity} = \text{Specific Gravity}\left(0.00213\ \text{Saybolt} - \frac{1.535}{\text{Saybolt}}\right). \quad \text{(Herschell)}$$

$$\text{Absolute Viscosity} = \text{Specific Gravity}\left(0.00147\ \text{Engler} - \frac{3.74}{\text{Engler}}\right). \quad \text{(Herschell)}$$

$$\text{Absolute Viscosity} = \text{Specific Gravity}\left(0.00260\ \text{Redwood} - \frac{1.715}{\text{Redwood}}\right). \quad \text{(Higgins)}$$

Workshop Viscometers.—Various rough and ready methods have been suggested for comparing the viscosity of two oils or for approximate determination of viscosity, such as allowing a drop of oil to run down an incline, counting the number of drops falling from a pipette in a given time, watching the rate at which, when a narrow test tube is almost filled with oil and inverted, the air bubble travels up through the oil, etc. All these methods are inaccurate and there are so many influencing factors that the results are apt to be very misleading.

The only attempt at solving this problem that appears to be of promise is the viscometer designed and patented by Michell, the inventor of the "Michell bearing." The viscometer is illustrated in Fig. 2 and consists of a cup (1) into which fits a steel ball (2); an oil film is interposed between the two, its thickness being determined by the three raised spots (3) which in one of the instruments protrude 0.001 of an inch beyond the cup surface. The handle (4) is hollow to receive a thermometer for registering the temperature of the cup.

There is a groove (5) in the cup which holds a supply of oil by capillary attraction. When the ball is suspended the relatively large amount of oil retained in the groove is drawn upon to feed the film between the ball and the cup, until the film breaks and the ball drops.

The author has made a few experiments with this viscometer and used it in the following two manners:

1. A few drops of oil were placed in the cup, the ball inserted and the two pressed together until the ball was felt to grip. The instrument was then inverted, the time for the ball to drop was recorded in seconds and also the temperature of the cup.

2. Both the ball and cup were immersed in a sufficient amount of oil to cover them, the whole being heated to the required temperature and that temperature being maintained for 15 minutes. The ball was then pressed into the cup, the instrument lifted out of the oil and the time required for the ball to drop was recorded.

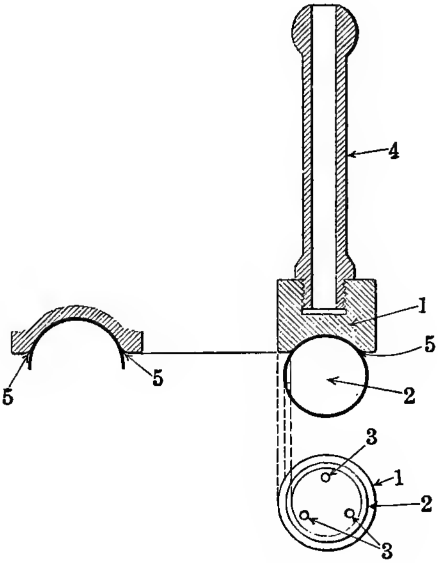

Fig. 2.—Michell's workshop viscometer.

The first method is very convenient for workshop use, but the viscosity readings may easily err as much as ±25 per cent. from the true viscosity on account of the uncertainty of the oil film temperature being correctly recorded. The second method is slightly more elaborate, but is capable of giving results which are almost as accurate as the usual commercial viscometers.

Each Michell instrument is marked with a conversion factor, which multiplied by the time in seconds taken for the ball to drop gives the *absolute viscosity* of the oil.

Using the Michell viscometer with reasonable care, the author found that the average of ten consecutive readings obtained by the immersion method and the viscosity obtained by a Redwood viscometer (when converting the latter readings into absolute viscosities) never differed more than 1 per cent., the oils tested ranging in viscosities from 0.8 to 6.4 Poise (approximately 385″ to 2,900″ Redwood). Individual readings of the ten consecutive readings on the Michell instrument differed only about 3 per cent. at the maximum.

Conversion Tables.—The Tables Nos. 6, 7 and 8 have been compiled by the U. S. Bureau of Standards (Report of Committee D-2, American Society for Testing Materials).

TABLE 6*a*.—MULTIPLYING FACTORS TO CONVERT ENGLER NUMBERS TO SAYBOLT OR TO REDWOOD TIMES

Engler number	Factor to convert Engler number to Saybolt time	Factor to convert Engler number to Redwood time
1.00	28.1	26.7
1.05	28.4	27.0
1.10	28.8	27.2
1.15	29.1	27.5
1.20	29.5	27.6
1.25	29.8	27.8
1.30	30.2	28.0
1.35	30.5	28.2
1.40	30.8	28.3
1.45	31.1	28.5
1.50	31.4	28.6
1.60	32.0	28.8
1.70	32.5	29.0
1.80	33.0	29.2
1.90	33.5	29.4
2.00	33.9	29.6
2.10	34.2	29.7
2.20	34.5	29.9
2.30	34.8	30.0
2.40	35.1	30.1
2.50	35.3	30.2
2.60	35.5	30.3
2.70	35.7	30.3
2.80	35.9	30.4
2.90	36.1	30.4
3.00	36.2	30.5
3.50	36.7	30.7
4.00	37.1	30.9
4.50	37.3	31.1
5.00	37.4	31.2
6.00	37.5	31.3
8.00	....	31.3
50.00	37.5	31.3

Table 6b.—Multiplying Factors to Convert Saybolt Times to Engler Numbers or to Redwood Times

Saybolt times, seconds	Factor to convert Saybolt time to Engler number	Factor to convert Saybolt time to Redwood time
28	0.0357	0.95
30	.0352	.95
32	.0346	.95
34	.0342	.94
36	.0337	.94
38	.0333	.93
40	.0330	.93
42	.0327	.92
44	.0323	.92
46	.0320	.92
48	.0317	.91
50	.0314	.91
55	.0308	.90
60	.0302	.89
65	.0297	.88
70	.0293	.87
75	.0289	.86
80	.0286	.86
85	.0284	.86
90	.0282	.85
95	.0280	.85
100	.0279	.85
110	.0276	.84
120	.0274	.84
130	.0272	.84
140	.0271	.84
160	.0269	.84
180	.0268	.84
200	.0267	.84
250	.0267	.84
300	.0267	.84
1800	.0267	.84

Viscometers should be calibrated by testing the viscosity of a standard liquid, as water, mixtures of glycerine and water, cane sugar solutions, etc. Rape oil or sperm oil as recommended by some for standardizing viscometers vary too much in viscosity to be used for standardizing purposes.

It is important that the efflux tubes should not wear by use, as the viscosity readings will then be too low. Redwood uses an agate tube which he reports has shown no wear over a number of years. Engler uses a platinum tube, and as the Engler number is given as compared with water, the instrument is frequently calibrated, and slight wear of the tube accordingly does not affect

Table 6c.—Multiplying Factors to Convert Redwood Times to Saybolt Times or to Engler Numbers

Redwood time	Factor to convert Redwood times to Saybolt time	Factor to convert Redwood to Engler number
28	1.05	0.0377
29	1.05	.0372
30	1.08	.0368
32	1.06	.0364
34	1.07	.0361
36	1.07	.0358
38	1.08	.0355
40	1.09	.0353
42	1.09	.0351
44	1.10	.0349
48	1.11	.0347
48	1.12	.0345
50	1.13	.0344
55	1.14	.0340
60	1.15	.0337
65	1.16	.0335
70	1.16	.0333
75	1.17	.0331
80	1.18	.0330
85	1.18	.0339
90	1.19	.0388
95	1.19	.0327
100	1.19	.0386
110	1.19	.0325
120	1.20	.0384
130	1.20	.0328
140	1.20	.0381
160	1.20	.0321
180	1.20	.0320
200	1.20	.0320
250	1.20	.0320
300	1.20	.0320
1500	1.20	.0320

the accuracy of the Engler numbers. The Saybolt instrument has a bronze efflux tube, carefully calibrated.

When particulars of the viscosity of an oil are given, important details are often omitted. Sometimes the name of the viscometer is not given, or the temperature at which the viscosity is taken. Further, if it is desired to calculate the absolute or the specific viscosity, it is necessary also to know the specific gravity.

Temperatures.—Viscosity figures quoted at 70°F. are going out of use, and rightly so, as the oil is very rarely at this temperature during actual use. For oils used externally, the important viscosities are those taken at 104°F. (40°C.) and 140°F. (60°C.) as the temperature of the oil film will range somewhere between 30°C. and 50°C. for ordinary bearings and between 50°C. and 70°C. for *bearings* in steam turbines, enclosed high speed steam engines and many internal combustion engines.

For steam cylinder oils the viscosity should be taken at 212°F. To test the viscosity at higher temperatures in addition to the 212°F. figure does not appear to be of any value; although viscosity is important, there are other and more important properties than viscosity which determine the lubricating quality of cylinder oils.

For oils like air compressor oils and internal combustion engine oils, where fairly low viscosity oils are used, the viscosity should be measured at 104°F. and 212°F.

When the setting point of an oil is known and at least two viscosities, preferably three, a viscosity curve can easily be drawn from which can be measured the approximate viscosity figures at intermediate temperatures. Commercial measurements of viscosity are usually accurate within one per cent.

Oils change in viscosity with change in temperature (ranging normally from .6 per cent. to 6.0 per cent. per °F. between 104°F. and 212°F.) The change per °F. is greater for mineral oils than for fixed oils, greater for high viscosity oils than for low viscosity oils, greater (at high temperatures) for asphaltic base and Russian oils than for paraffin base oils. The increase per °F. becomes very great when approaching the setting point temperature of the oil. As non-paraffinic base oils have low setting points, their increase in viscosity at low temperatures is usually less than for paraffin base oils. Hence, for cold conditions or climates the former oils have better viscosity curves at the working temperatures.

The following figures show the difference in character between paraffin base and non-paraffinic base oils.

Saybolt viscosity	Californian oil	Russian oil	Paraffin base oil	Texas oil	Paraffin base oil
At 212°F.	48	51	49	73	74
At 140°F.	147	150	110	360	250
At 104°F.	430	400	269	1,200	700
Cold test	0°F.	0°F.	25°F.	20°F.	40°F.
Average change in viscosity per deg. F. in %					
From 212°F. to 140°F.	2.9%	2.7%	1.7%	5.4%	3.3%
From 140°F. to 104°F.	5.4%	4.6%	4.0%	6.5%	5.0%

At temperatures below 104°F. the viscosity curves are very steep and the increase in viscosity per °F. is still higher, particularly so for oils having poor cold tests, as is the case with paraffin base oils, or mixtures containing poor cold test cylinder stock or a large amount of fixed oil or fat. When the viscosity curve is very steep around 70°F. it means that if the oil is supplied through gravity feed oilers, syphon oilers and the like, even slight changes in temperature will appreciably affect the oil feed which is an undesirable feature.

At high temperature the fixed oils maintain their viscosities remarkably well, which is probably one of the reasons why fixed oils are better lubricants for bearings which are inclined to heat because of bad mechanical conditions, excessive bearing pressures, etc.

The viscosity of oils, when measured under great pressure[1] is much greater than the ordinary viscosities, which are measured under atmospheric pressure; the increase in viscosity is several times greater for mineral oils than for fixed oils.

When oils are standardized for viscosity, it is customary to allow a manufacturer's variation of 4 per cent. to 6 per cent. above and 2 per cent. to 3 per cent. below the standard; the permissible variation above the standard is the greater of the two, because too high a viscosity is usually less objectionable under the conditions of service than too low a viscosity.

Comparing two oils having the same kinematic viscosity, say the same Saybolt viscosity, the heavier oil of the two (the one having the highest specific gravity) really is the more viscous, because being heavier it flows out of the viscometer more rapidly than it would if it were lighter in specific gravity. The real viscosities of non-paraffin base oils are therefore about 5 per cent. higher than their kinematic viscosities lead one to expect, when comparing them with paraffin base oils. Much confusion has been caused by expressing the viscosities of oils in terms of kinematic viscosities, and it would be very desirable if users of oil would insist upon viscosities being measured or specified as *absolute viscosities*, which represent their *true viscosities* and consequently form a much better basis for comparing the utility or suitability of different oils.

The viscosity is frequently the most important property of a lubricating oil. With perfectly lubricated frictional surface (complete oil film) the friction is directly proportional to the viscosity of the oil and mineral oils are always used. With less per-

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[1] Experiments by Dr. T. E. Stanton and Mr. I. H. Hyde, Nat. Phys. Lab., Teddington.

fectly lubricated surfaces the oiliness of the oil becomes important and compounded oils are frequently used. Under very severe conditions of pressure (incomplete oil film) the viscosity value of the lubricant is no guide at all; the oiliness becomes the all-governing factor, and fixed oils or oils very rich in fixed oils have to be used.

Speaking generally, high viscosity oils are required for conditions of high temperature or great pressure or slow speed. Low viscosity oils are required for conditions of low pressure or high speed. For low temperature conditions it is low setting point that governs the selection of oil more than viscosity.

Viscosity of Semi-solid Lubricants.—Cup greases, solidified oils, etc., are generally sold in five standard consistencies, very soft, soft, medium, hard and very hard.

The consistency varies with the temperature of the grease and it is a matter of personal judgment developed by experience what the consistency of a sample of grease is. Several attempts have been made to devise an instrument for measuring the consistency—viscosity—of a grease, but none have been of any practical value. Several instruments have a weighted needle, which is allowed to penetrate for a certain number of seconds, or until it stops due to skin friction; the observations are very irregular even with the same sample of grease, due to local variations in consistency. In other instruments the grease is squeezed through a small opening by a definite force; here again results are most erratic and misleading.

One reason, probably the chief reason, for these failures is that all greases have a peculiar "set" or "honeycomb" nature; once the grease has been handled, the honeycomb structure is broken up and the grease becomes softer and more oily in appearance. To show this effect, the author forced a certain amount of a medium cup grease through a 3/8-inch nozzle by the force of a 28-lb. weight. The grease came through the first time in 126 seconds. On putting the same grease back in the test cup and repeating the performance, the efflux times for the succeeding three tests were: 47 seconds, 13 seconds, and 6 seconds.

Many engineers will have noticed that when working grease by the fingers and hand it becomes softer and softer. The author also tried various petroleum jelly greases by a grease viscometer and found the results fairly consistent, presumably because these greases do not possess that peculiar structure characteristic of cup greases and other soap-containing greases.

Capillarity.—All lubricating oils have the property of rising into syphons or wicks made of wool or cotton, but their capillary power differs considerably for different oils.

Railway and steamship companies, many of which employ to a large extent syphon lubrication or pad lubrication, find it very useful to compare lubricating oils for capillary power, as it is upon this property that their syphoning ability largely depends. Obviously, the best method is to test the oils in an actual box of the exact type used on the railway or steamer, and to test the oils over the whole range of temperatures to which they may be exposed during service.

The quality of the wool is important. Berlin wool, which is of a soft loose texture, has greater syphoning ability than closely twisted worsted yarn.

The syphoning ability of lubricating oil is largely influenced by the viscosity of the oil and by its nature, whether pure mineral or containing a percentage of fixed oil. The lower the viscosity the quicker will the oil syphon from the lubricator cup into the bearing.

Emulsification.—Circulation oils which are used in connection with steam turbines, enclosed type steam engines, etc., come into contact with water and must not form an emulsion with water. Animal and vegetable oils emulsify quickly when churned together with water, so that it is out of the question to use these oils in circulation systems where there is danger of water being present. Mineral lubricating oils have a low affinity for water, but experience has proved that it is sufficiently strong in most of them to cause frequent trouble. The tendency to emulsify differs considerably for different oils, and it therefore becomes necessary to subject circulation oils to an emulsification test.

This test may be carried out by shaking definite quantities of oil and water either by a reciprocating motion in a bottle or by churning the oil and water together by a paddle wheel revolving at high speed. The water may be either distilled water, salt water, or a caustic soda solution, according to the requirements which the oil has to meet. Marine turbine oil for example must separate from salt water in such cases where a leakage of salt water into the system cannot easily be prevented.

Where boilers prime and boiler impurities are likely to be carried over into steam turbines or enclosed type steam engines, it may be of interest to use a caustic soda solution or even the boiler water itself when making the emulsification test.

The test should be carried out at about 130°F. which is the average temperature of circulation oils when in service, and the mixture should be allowed to settle at a similar temperature.

Ferric oxide or iron salts have a most powerful emulsifying effect on circulation oils in the presence of water. If only a fraction of 1 per cent. iron salts is added to the water used for the emulsification test nearly all oils will show a very considerable percentage of sludge. It will appear that it is the presence of a quite small percentage of certain unstable hydrocarbons, sulphur compounds, naphthene salts, etc., which causes emulsification.

Neutral filtered oils show less tendency to emulsification than acid treated oils and should therefore be used in preference to the latter oils in the manufacture of circulation oils. As most neutral filtered oils have a low viscosity, it becomes necessary to mix them with filtered cylinder stock when manufacturing heavy viscosity circulation oils. Filtered cylinder stock has not been treated with acid, but merely filtered to remove unstable hydrocarbons, etc., and is therefore eminently suitable for the purpose. Well filtered cylinder stocks have only a slight tendency to emulsification.

Speaking generally, low viscosity, low specific gravity oils give better service as circulation oils than heavy viscosity, heavy specific gravity oils, because they separate quicker from water, dirt and other impurities.

Attempts have been made to express the tendency of an oil to emulsify in terms of its "emulsification value," an emulsification value of 98 per cent. meaning that 98 per cent. of oil separated out in the emulsification test, 2 per cent. being retained in the sludge.

Even if an oil shows great resistance to emulsification, it is desirable to know how rapidly the separation takes place. When in an emulsification test the mixture of oil and water is allowed to separate, some oils will separate out in a few minutes, whereas others may take half an hour or more, and yet the final separation may not show any formation of sludge. Obviously, quick separation is exceedingly important, as in most circulation oiling systems, the oil is not given much time to free itself from water.

An apparatus to determine the demulsibility (*i.e.* resistance to emulsification) of an oil and to express same by a figure has been devised by W. H. Herschell (described in U. S. Dept. of Commerce, Bulletin No. 86). It consists of a 100 c.c. glass container, with an internal diameter of approximately 26 mm. into which is poured 20 c.c. of the oil to be tested and 40 c.c. of distilled water (or other water, as may be desired). A paddle 89 mm. long, 20 mm. wide and 1.5 mm. thick is connected to and driven by a vertical electric motor at a speed of 1,500 r.p.m. The glass container is placed in a brass vessel filled with water and heated by a Bunsen burner to maintain the oil and water mixture in the glass container at a temperature of 55°C. (131°F.) during the test. The oil and water are churned by the paddle for five minutes, the container then lowered free of the paddle and a record taken of the time in minutes taken for separation.

The demulsibility figure (D) is calculated as the rate of oil settling out per hour, and is therefore expressed as:

$$D = 60 \times \frac{v}{t}$$

where: v is the volume of oil in c.cs. which has separated out.
t is the time in minutes taken for the oil to separate out.

The maximum demulsibility figure is 1,200, *i.e.*, the entire volume of oil (20 ccs.) separates out in 60 seconds. If with a poor oil only 10 ccs. separate out in say 15 minutes, the demulsibility value is:

$$60 \times \frac{10}{15} = 40$$

Surface Tension.—There can be no doubt that the surface tension of an oil has some influence on the condition and strength of thin oil films in contact with metallic surfaces. Lubricating oils wet metallic surfaces, as their surface tensions are lower than those of metals. Differences in surface tension as between various lubricants will therefore mean different behavior as to their tendency to wet metallic surfaces, but the exact nature and importance of surface tension in connection with lubrication is still a practically unexplored subject.

CHEMICAL TESTS

Acidity.—Free acid in lubricating oils may be present as free mineral acid, petroleum acid, fatty acid or rosin acid.

(*a*) *Free sulphuric acid* or other mineral acid which has been used in the refining of the oil. It is very rare nowadays to find any objectionable percentage of free acid from this source, but in the case of transformer and switch oils, it is of great importance that the percentage of mineral acid be exceptionally low, so that, whereas for ordinary purposes a percentage of 0.03 in terms of $S.O_3$ may be permitted, the percentage in the case of transformer oils must not exceed 0.01.

(*b*) *Petroleum acid* may be present in the original crude or may be produced during distillation and refining. Petroleum acids develop in circulation oils during continuous use, due to oxidation. Petroleum acids are very weak in their action and do not affect metals except lead and zinc; mineral oils usually contain less than 0.01 per cent. of petroleum acids, but the presence of a larger percentage is not harmful as long as the percentage does not exceed 0.3 per cent. in terms of SO_3 (used circulation oils).

(*c*) *Free fatty acid* is only present in lubricating oils which contain fixed oils. The percentage of free fatty acid in a fixed oil is not objectionable as long as it does not exceed 0.5 per cent. in terms of SO_3. A higher percentage of acid is permissible in certain cutting oils. A mixture of fixed oil and mineral oil will of course contain proportionally less of free fatty acid the greater the percentage of mineral oil.

When the contents of free fatty acid is high in a lubricating oil it has the effect of attacking the metallic surfaces with which the oil comes into contact. Metallic soaps are formed, which choke up the oil pipes and lubricating channels in the machinery. In contact with brass parts verdigris is formed. The softer metals like lead and zinc are very quickly attacked and the effect is marked in bearings lined with white metal containing a high percentage of these metals.

When oils containing fatty oils are stored in storage tanks or cabinets which are either unlined or merely galvanized the free fatty acid attacks the metal surface, forming metallic soaps. It has been found, however, that tin is not attacked to any degree by the free fatty acid and for this reason all oil cabinets and oil tanks should be tinned on surfaces in contact with the oil. This also applies to other parts of the cabinets, such as oil pumps, strainers, etc.

During continuous use all oils containing fixed oils oxidize (air) and hydrolize (moisture), the result of which is the formation of free fatty acid and of sticky gummy varnish-like deposits, which may cause trouble.

(*d*) *Rosin acids* indicate the presence of rosin or rosin oil which is always objectionable in lubricating oils.

Saponification Value.—The saponification value is the number of grams of potash (KOH) required to saponify the fatty (vegetable or animal) constituents present in 1,000 grams of the oil. The saponification value is therefore useful in determining the character and percentage of a fixed oil present in a mixture of fixed oil and mineral oil. When there are two or more grades of fixed oil present it is difficult to identify them with certainty.

Iodine Value.—The iodine value is the number of grams of iodine absorbed by the unsaturated constituents present in 100 grams of the oil.

It has been mentioned that fixed oils have a great affinity for oxygen and that during continual use they will oxidize and form deposits. The iodine value is an indication of this tendency and is based on the fact that iodine will quickly combine with those ingredients in the oil which have a tendency to oxidize.

As might be expected the iodine value of drying oils like linseed oil is very high, whereas the iodine value of mineral lubricating oil is very low. Below is given typical iodine values for various oils:

Drying oils, such as linseed oils	Above 170
Semi-drying oils, such as cottonseed, ravison rape, fish and whale oils	From 100 to 170
Non-drying oils, such as animal oils, (except whale oil), and vegetable oils (except cottonseed and ravison rape)	50 to 100
Scotch shale oil 0.890	23
Russian mineral lubricating oils	7
American mineral lubricating oils (paraffin base)	10 to 16

The cause of the high iodine value of Scotch shale oil is the large percentage of unsaturated hydrocarbons present in this oil.

Oxidation and Gumming.—In order to get an idea of the tendency of lubricating oils to oxidize and gum, many tests have been devised; in one test one gramme of the oil is heated on a watch glass for a certain length of time at certain temperatures, after which the oil is examined. Another test measures the increase in weight, *i.e.*, the amount of oxygen absorbed and the percentage of free fatty acid formed. All such tests are of value in comparing one oil with another. The iodine value, however appears to be the nearest approach to a correct indication of the tendency of an oil to oxidize.

Under "Color" it was mentioned that the color of an oil is due to the presence of unsaturated hydrocarbons. It is therefore to be expected that oils dark in color are more easily oxidized than pale oils, and experience has proved this to be the case. Where machinery is exposed to sunlight, as for instance, steam rollers, steam tractors, etc., it has been found that red oils produce a tenacious dark brown skin on the metal parts, whereas pale asphaltic base oils have very much less tendency to form such deposits.

Frequent complaints have also been made that machine parts in engine rooms get tarnished, also the bright parts of spindle frames in textile mills unless very pale oils are used. This tarnishing effect is very unsightly in the case of high-class machine tools. In order to avoid machine parts becoming tarnished, it is therefore best to use pale colored oils, either straight mineral or mixed with a small percentage of animal oil. The presence of the animal oil has a peculiar effect, making it quite easy to wipe the bright parts clean. Possibily, the free fatty acid present is helpful, preventing the film from forming, owing to a very slight corrosive action between the acid and the metal. An admixture of vegetable oil would increase the oxidizing tendency of the oil.

For oils which are used in connection with transformers and air compressors, it is obvious that they must have the smallest possible tendency to combine with the air. Circulation oils (for steam turbines, etc.) are also in more or less contact with air and therefore subject to oxidation. It would therefore seem desirable to examine oils to be used for such purposes by subjecting them to an oxidation test on lines similar to the sludging test described under transformer oils.

Ash.—Ash is present in appreciable quantities only in lubricating oils which have been soap thickened or badly refined. Distilled mineral lubricating oils should not contain more than 0.02 per cent. ash, and for undistilled oils like steam cylinder oils, the ash should be less than 0.1 per cent. The ash may consist of iron rust from the still or it may be alkali from the refining.

Carbon Residue.—Oils which during use are vaporized or burnt, as is the case with all oils used for internal combustion engines, produce more or less carbon deposit. It is difficult to duplicate these conditions in a laboratory test, but it would seem desirable to have some kind of a test for the tendency to carbonize, the results to be compared with actual practice in order to ascertain its value.

One apparatus has been suggested by P. H. Conradson, as illustrated. This method is a modification of his original method and apparatus for carbon test and ash residue in petroleum lubricating oils. (See "Proceedings Eighth International Congress of Applied Chemistry," New York, September 1912, Vol. 1, page 131. Also reprint in the "Journal of Industrial and Engineering Chemistry," Vol. 4, No. 11, November, 1912.)

Description of Conradson's Apparatus (Fig. 3).—(*a*) Porcelain crucible; wide form, glazed throughout, 25 to 26 c.c. capacity, 46 mm. in diameter.

(*b*) Skidmore iron crucible 45 c.c. (1½ oz.), 65 mm. in diameter, 37 to 39 mm. high, with cover, without delivery tubes and one opening closed.

(*c*) Wrought iron crucible with cover, about 180 c.c. capacity, 80 mm. diameter, 58 to 60 mm. high. About 10 mm. of sand placed in bottom to bring Skidmore crucible nearly flush with top.

(*d*) Triangle medium size, pipe stem covered, projection on side to allow flame to reach all sides of the crucible.

(*e*) Sheet iron or asbestos hood 5 inches in diameter and 2 inches high provided with slanting roof ¾ of an inch high, terminating into chimney, the chimney being 2 inches high, and 2⅛ to 2¼ inches in diameter. This serves to distribute the heat uniformly.

(*f*) Asbestos or sheet iron block, 6 to 7 inches square, and 1¼ inches to 1½ inches high, provided with opening in centre which is 3¼ inches in diameter at the bottom, and 3½ inches in diameter at the top of the block. This block acts as a shield for the flame resulting in even distribution of the flame around the iron crucible during the test.

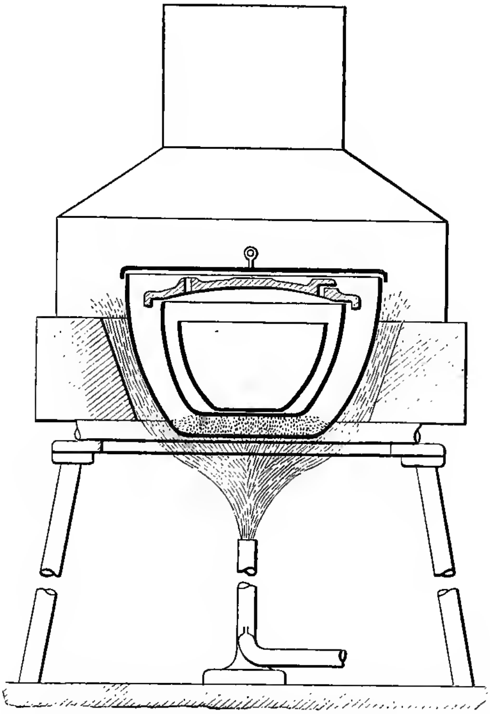


FIG. 3.—Conradson's carbon residue apparatus.

(*g*) Tripod: Tripod or stand should be of such height that the distance between top of burner and bottom of large iron crucible is 1 to 1½ inches depending upon the kind of burner used.

(*h*) Gas Burner: Where gasoline or artificial gas is used the Méker or Scimatco burner 155 mm. in height having 24 mm. section of flame is recommended. With natural gas the above burners or any improved form of Bunsen burner may be used.

Method of Test.—Weigh 10 grams of the oil to be tested into a tarred porcelain crucible and place the latter in the centre of the Skidmore crucible. Place the Skidmore crucible in the exact centre of the iron crucible, and put on the covers of the Skidmore crucible and iron crucible. Set the apparatus up as indicated in Fig. 1.

Heat is applied to the apparatus with a Bunsen or other burner with a hot flame for from four to seven minutes depending upon the body of the oil being tested; this flame should encompass as far as possible the whole crucible; it must then be reduced to two or three inches and the first appearance of vapors carefully watched for after the period of strong heating is over, in order that the vapor flame may not get too high and the oil in the crucible not be in danger of boiling over. The flame should never get more than three inches above the chimney and it should be kept at an average of about two inches above it during the period in which vapors come off. After the vapors cease to be evolved (as evidenced by the inability to ignite them) the heat is increased to a maximum obtainable and maintained for five minutes. The bottom of the iron crucible should be red hot; then allow to cool for five minutes with the chimney removed, transfer the crucible to a desiccator, cool and weigh. The entire procedure should be completed in about thirty minutes depending upon the nature of the oil.

Precautions.—(1) The first appearance of vapors must be watched for very closely; the burner may be momentarily removed occasionally to facilitate seeing them. From experience the range of four to seven minutes with a Bunsen or Tirril burner appears to be about right for oils varying between a gun oil and a Liberty Aero Oil, but this time will vary with the gas and burner obtainable. It is therefore necessary that very close attention be paid to the operation at this point.

2. If the vapors get too high at any time the burner may be removed for short periods although this is not advisable if it can be reduced sufficiently low to keep the vapors ignited about two inches above the chimney.

3. Dimensions of the apparatus as shown must be strictly adhered to.

Asphalt and Tar.—It is seldom necessary to test lubricating oils for the presence of asphalt and tar, except in the case of dark cylinder oils, particularly those used for superheated steam.

A distinction is made between hard asphalt and soft asphalt, the hard asphalt being the more objectionable of the two, as it will form hard brittle carbonization deposits inside the engines.

Filtered cylinder oils contain less asphalt than dark cylinder oils, and are therefore to be preferred in all such cases where carbonization ordinarily may be expected to take place.

Oiliness.—The property in a lubricant which causes it to adhere to metallic surfaces is generally referred to as its oiliness. Experience appears to have shown that oiliness bears no relation to the physical properties of an oil; although it is greater for heavy viscosity oils than for low viscosity oils of the same character, yet two oils may have the same viscosity and the oiliness be much greater in the one than the other. It is common knowledge that all fixed oils, or mixtures of mineral oils and fixed oils, possess greater oiliness than straight mineral oils. From the writer's experience it seems also certain that a mixture of low viscosity distilled mineral lubricating oil and filtered cylinder stock has greater oiliness than a distilled mineral lubricating oil of the same viscosity as the mixture.

No means have as yet been devised by which the power of a lubricant to adhere to metallic surfaces can be directly measured; if lubricated surfaces are pulled apart, the lubricating film itself is severed, but the lubricant still adheres to both surfaces, so that it is only the cohesion of the film that can be determined in this manner.

That distilled lubricating oils are improved in oiliness by the admixture of fixed oil or filtered cylinder stock may perhaps be explained by the fact that molecules of the fatty oil or cylinder stock adhere to the metallic surfaces in preference to the molecules of the distilled mineral oils; such coating of the surfaces with strongly adhering molecules would explain why it is possible with such blended oils to sustain almost as great pressures as if the fixed oil or filtered cylinder stock were used alone.

Impurities.—The impurities most frequently met with in lubricating oils are dirt, glue and water.

Dirt.—Dirt is easily detected when the oil is transparent. It is more difficult in the case of dark oils, such as cylinder oils and the like. The best way of testing a lubricating oil for dirt is to draw a few gallons of oil from the bottom of the barrel or the tank in which the oil is stored, and then strain the oil through muslin or silk cloth. Anything that remains on the cloth can be freed from oil by treatment with petrol, and it is then generally easy enough by the aid of a magnifying glass or perhaps even with the naked eye to judge what the impurities are.

If metallic iron in the form of iron scale is present (from the steel drum or barrel) a magnet will detect it; the small particles being drawn up at the approach of the magnet; or the metallic ingredients can be identified chemically.

Cotton waste, small pieces of wood, etc., are easily recognizable, and it is not unusual that they find their way into the oil when the barrel is being broached.

The bung should be loosened by striking the staves with a mallet and it should never be removed by the use of an augur.

Glue.—Glue is used in forming a coating on the inside of wooden barrels and serves two purposes: firstly, *the prevention of oil leakage* through the wooden staves; secondly, the *prevention of moisture from entering the oil.*

The importance of the first mentioned object is obvious and the desirability of preventing moisture from entering the oil is explained in the next paragraph under "water."

Sometimes large quantities of glue are found in a barrel due to the barrel not having been properly drained of the hot liquid glue during the glueing process. The glue will, however, not mix with the oil except in the presence of moisture, and can always be detected easily by the consumer, when the oil is being strained before use. If the glue is not detected, the results may be disastrous, as it will cause excessive heating and wear and develop sticky deposits in lubricators, in circulation oiling systems and oil pipes; it will cause irregular working of lubricators, especially those having fine openings, as hydrostatic displacement cylinder lubricators. When such fine openings get choked, steam valves and pistons cry out for oil if the trouble is not observed in time.

Water.—Water gives an oil a cloudy appearance and its presence is therefore easily perceived in oils, which in dry condition are transparent.

When the oil is heated to a few degrees above 212°F. it will soon become transparent, if the cloudiness is due to water; and if more than a trace of moisture is present, it will partly evaporate and partly separate out as visible drops of water at the bottom.

Mineral oils are more easily clarified than oils containing fixed oils, as the latter have a strong affinity for water and easily become emulsified.

The presence of even a trace of moisture is very detrimental in transformer and switch oils. A simple test (apart from testing dielectric strength or specific resistance) is the hot-iron test. An eight-ounce bottle is half filled with transformer oil; an iron rod, say 1/4 of an inch in diameter is heated for about 1/2 an inch to a dull red heat and slowly lowered into the oil. If more than 0.01 per cent. of water is present the tiny particles of water will suddenly turn into steam with a crackling noise; if no water is present, there will only be a slight hissing noise from the oil vapors.

The presence of a slight amount of moisture in oils, other than transformer and switch oils, is not detrimental, so far as the influence of the water itself is concerned; and yet, in nearly every case where the oil is moist, more or less trouble is experienced.

Ring spindles and other textile spindles rust and run warm; internal combustion engines develop an excessive amount of carbon deposit; the pistons heat up and wear rapidly; the oil is reported to be "thinner than usual" (because the excessive heating of the oil film thins the oil) and the oil comes out of the pistons and bearings in a chocolate colored or blackened, dirty condition.

This very remarkable effect of the presence of small amounts of moisture is explained by the fact that moisture nearly always gets into the oil through exposure of the wooden barrels to the weather. During warm and rainy weather the staves expand and absorb moisture; during nights they contract and the effect of such alternate expansion and contraction is that moisture gets through to the inside of the staves, loosens and dissolves some of the glue coating and spreads it throughout the contents of the barrel. This is the most dangerous form in which glue can be present in the oil and it is usually the glue that causes lubrication troubles, more so than the water. Wooden barrels, when in transit, should therefore preferably be covered with tarpaulins and should be stored under cover in a dry place. When barrels are stored out of doors from lack of space under roof, they should be covered with waterproof covering or stored on their sides; when stored on end the moisture collects over the staves and there is a greater likelihood of the water getting inside than when they are stored on their sides.

MECHANICAL MEANS OF TESTING LUBRICANTS

Mechanical Testing Machines.—As the usual physical and chemical tests of lubricants do not always definitely indicate whether one oil will be more satisfactory than another for certain machines, many investigators have designed friction testing machines with a view to comparing the lubricating properties of different oils. There are a great variety of these machines, chiefly for testing bearing oils, and they have been extremely useful in discovering important laws of friction and in comparing the efficiency of different lubricating systems. The results of such experimental work have been of interest to oil manufacturers and lubrication engineers, but from an oil consumer's point of view they are, speaking generally, of no value so far as the selection of suitable oils is concerned.

The difficulty is that the testing machine has only one bearing, usually with beautifully finished rubbing surfaces and operated under conditions of oil feed, pressure, speed and temperature quite different from practical conditions. In most works there are such a variety of bearings that it is quite impossible to reproduce all these conditions on the one bearing of a testing machine.

The following two examples may prove instructive:

Example 1.—A certain Government had a *Lahmeyer oil testing machine,* with which all of the oils offered by various firms were tested. The oils were intended to be used on the propelling machinery of warships.

In the Lahmeyer testing machine two heavy flywheels are carried, one on each end of a shaft; the shaft is supported by a central ring oiling bearing, which serves for testing the oil. The machine is driven by an electric motor, which can be connected to the flywheel shaft by a pin coupling. The method of testing is as follows:

The bearing is supplied with the oil to be tested. The motor is started and the flywheel rotated at full speed: 1,500 to 1,700 r.p.m. The motor is then uncoupled and the time noted which elapses before the flywheel comes to rest.

The longer the time taken by the shaft to come to rest, the better is the quality of the oil supposed to be, and this is true for *this particular bearing.*

Before the next sample of oil is tested the bearing is quickly cleaned by benzine passed through it, and it is dried out with an air current.

It will be understood that an oil manufactured to meet the conditions of a high speed ring lubricated bearing will give the best results when tested on this machine.

In order to convince the Government in question as to the futility of testing oils in this manner, a good dynamo oil was submitted and it was found that the shaft revolved three times as long as with the marine oil, which in actual practice gave the best results. It was obvious to every one concerned that the dynamo oil was absolutely unsuitable for the work required.

Example 2.—One of the best oil-testing machines on the market is Thurston's machine. The machine consists of a shaft supported by two bearings; the shaft at one end has an overhanging bearing fitted with two brasses, on which the oil is tested. Suspended from the bearing is a hollow pendulum containing a spring, by means of which a certain bearing pressure may be maintained. When the shaft revolves the oil film interposed between the shaft and the brasses causes the pendulum to swing outward and it remains in a certain position according to the oil in use.

The less the out-swing, the less is the coefficient of friction, and the better the oil, for this particular bearing and for the particular conditions prevailing.

When tests were carried out to find out which was the most suitable oil for shafting bearings running at a certain speed and bearing pressure, a Thurston testing machine was made to run under as nearly as possible similar conditions; it was found, however, when testing different oils that the coefficient of friction was the least for pure kerosene which would, of course, be useless for the lubrication of shafting bearings.

This result will be easily understood when one takes into consideration that shafting in actual practice is always more or less out of line and that the bearing surfaces are never perfectly smooth. The pressure, therefore, will not distribute itself so uniformly over the entire bearing surfaces, as will be the case with the bearing of Thurston's oil tester.

The limitations of testing machines are now beginning to be generally recognized; it is only where, as in the case of railways, a great many bearings are alike and operating under similar conditions that it seems at all worth while to attempt the construction of a testing machine; even then there is ample evidence that variations in the results obtained with the same oil in use, may easily amount to 50 per cent. and rarely fall below 10 per cent.

The author feels that, from the consumer's point of view, the coefficient of friction of various oils as determined by a testing machine is not of much use; the oil which gives the least friction on the testing machine may often prove to be unsuitable in actual use.

In the foregoing no reference has been made to testing machines for testing oils for internal lubrication of steam cylinders, gas engines, etc. Not a few attempts have been made in these directions, but as far as the author knows, the results have been of doubtful value, if not altogether misleading. It must be kept in mind that in the internal lubrication of, for example, steam cylinders and internal combustion engine cylinders, the lubrication is nearly always imperfect and subject to so many influencing factors that it is much more difficult to reproduce the conditions in a testing machine than in the case of bearings. Besides, the value of a lubricant often becomes apparent only after several weeks or months of use; such properties as tendency to carbonize, emulsify, oxidize, etc., may become of paramount importance, as compared with the friction-reducing properties of the oil, as will be made clear later on in the various chapters devoted to the different kinds of engines.

Works Tests.—The author has come to the conclusion, and most lubrication engineers will, he feels certain, agree with him that *the only reliable way of testing lubricants* is to test them *under actual working conditions,* by applying them to the machinery upon which they are to be used, and watching the results.

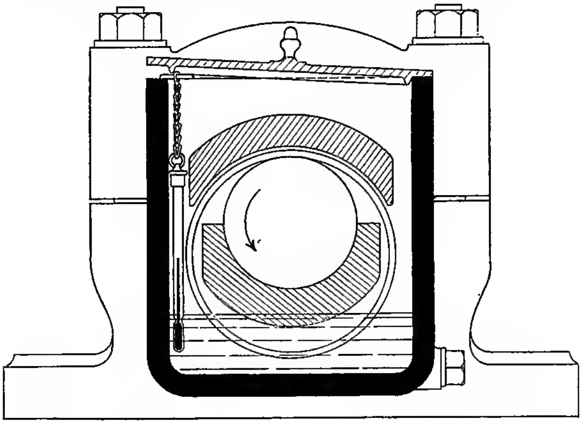


FIG. 4.—Taking the temperature of a ring oiling bearing.

Temperature Tests.—The simplest method of comparing two oils is to compare the frictional temperature rise of typical bearings, using first one oil and then the other. Any difference in quality or suitability between the two oils will be shown by a different frictional rise in temperature above the surrounding

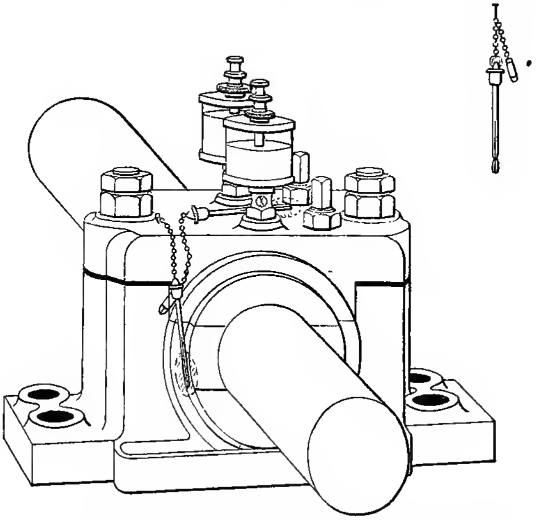


FIG. 5.—Taking the temperature of a pedestal bearing.

air temperature. The difference in temperature between a bearing and the air close to it will remain the same, independent of the air temperature, as long as the same oil is in use.

Figs. 4 and 5 show the method of taking the oil temperature of a ring oiling bearing and a pedestal bearing. In the first case the thermometer bulb is immersed in the oil; in the second case the bulb is covered with a lump of fairly stiff grease or putty, so that the bulb may be held in contact with the metal and as accurately as possible record the correct temperature.

The following is a typical example of a temperature test on a ring oiling bearing, comparing a viscous oil with an oil of the correct light body:

Time	Temperature of engine room in °F.	Temperature of dynamo bearing in °F.	Frictional rise in temperature in °F.
9.45 a.m.	60	120	60
10.0 a.m.	61	121	60
10.30 a.m.	62	121	59
11.0 a.m.	Change made to low viscosity oil.		
1.0 p.m.	63	99	36
1.30 p.m.	63	97	34
2.0 p.m.	62	93	31
3.0 p.m.	61	90	29
4.0 p.m.	59	88	29

It sometimes takes several weeks before the minimum temperature is reached, especially when there is a great difference between the two oils.

Special thermometers are used for taking spindle rail temperatures; one method is to fix a shallow box to the rail; the bottom of the box near the rail has a long slit into which the thermometer is fixed, the bulb being pressed lightly against the rail; the box has a hinged lid, which is lifted only long enough for the temperature to be read.

Temperature tests are extremely useful for comparing oils in actual use, and the tests should be repeated from time to time with a view to checking the quality of the oils in use. If the mechanical conditions do not change, the rise in temperature of the bearings above the surrounding air should remain very nearly constant.

In order that reliable temperature readings may be taken, quick registering and accurate thermometers should be used. Most engineers' thermometers are sluggish and liable to be fractured when carried in the pocket or dropped to the ground. The author's staff of engineers broke so many thermometers of the type illustrated in Fig. 6 that he designed a special thermometer and case, as shown in Fig. 7. The thermometer head is flexibly secured in the cap, which fits into the case with a bayonet joint, and when in position the bulb of the thermometer is kept central out of contact with the case by means of a spring pad. When the thermometer is carried in the pocket, it cannot be broken, and it is prevented from dropping out by the safety pin fastened to the clothing. The introduction of this thermometer reduced the number of breakages practically to nil.

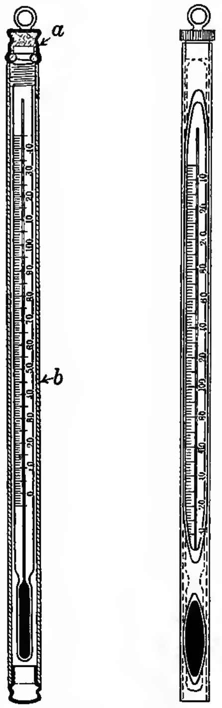


Fig. 6.—Engineer's thermometer.

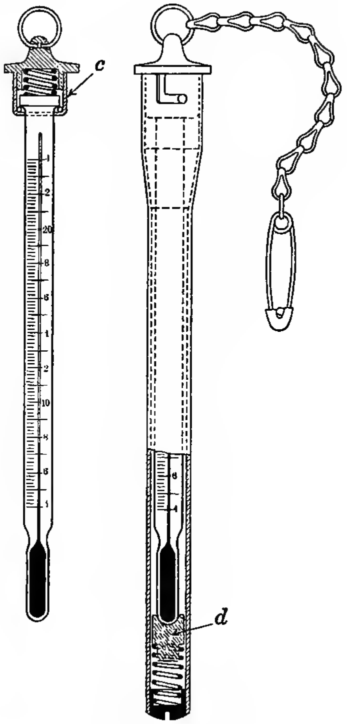


Fig. 7.—Thomsen's engineer's thermometer.

Dynamometer Tests.—Several dynamometers, such as Emerson's and Bailey's dynamometers, are employed for measuring the power consumed by individual machines, such as spinning frames, but only for small horse powers.

Emerson's machine (Fig. 8) is the first instrument that was ever used in the oil business for the purpose of showing the value of good lubrication. It is fixed to the driving shaft outside the loose pulley. The pull of the belt goes through the arms which pull back levers, just like an ordinary weighing scale, and the pointer shows the number of pounds exerted. The diameter of the wheel is two feet. The speed is measured in r.p.m. and the H.P. is calculated from the formula:

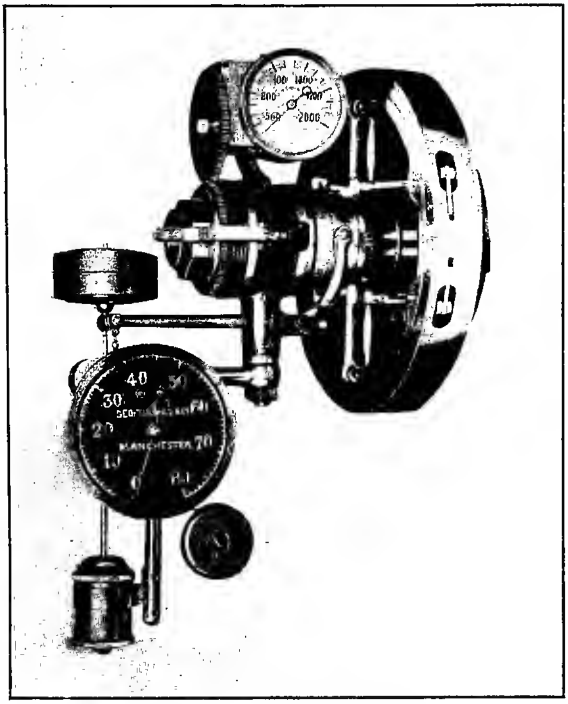


FIG. 8.—Emerson's dynamometer.

$$H.P. = \frac{Net\ weight \times 2 \times R.P.M.}{33{,}000}$$

These instruments are so finely adjusted that if two or three spindles are stopped by hand, the pointer immediately registers the increased friction.

Electrical Tests.—Where a machine or a group of machines is driven by electric motors, it is a simple matter to record the power consumption. But apart from the electrical measurements (volts, amperes, k.w. or B.T.U.'s per hour, as the case may be) it is desirable or necessary to record, as with the spinning frame tests, the temperature and relative humidity of the air, the speeds of motor, shafting and machines, and the frictional temperatures of important bearings, all with a view to getting as complete indications as possible of the alterations caused by a change in lubricants or lubricating methods.

Steam Engine Tests.—To record the power consumption of a factory or mill by means of indicator diagrams taken from the engine requires extreme care for the purpose of making a comparison between two sets of lubricating conditions. The load always varies, even under the most ideal conditions; the governor is continuously altering the amount of steam admitted, and diagrams taken quickly after one another may differ appreciably.

The only accurate method is to take a great number of indicator diagrams (preferably on Tuesdays, Wednesdays or Thursdays) at regular working intervals, say, every 10 or 15 minutes during, say, 4 working hours; the indicator pencil motions may be fitted with magnets, so that by the closing of a switch, all diagrams can be taken simultaneously.

An accurate note must be made of machines stopped in the mill; if, for example, a machine consuming 8 H.P. is stopped for half an hour, the equilavent value over the 4 hours is 1 H.P. If the values of all such stoppages are added together and amount to 17 H.P., and the average indicated horse power, calculated from all diagrams, is 805 H.P., then it may be assumed that the mill would consume an average of 822 H.P. if all the machines had been working continuously.

If on the comparative test, say, 3 months later, the average power with other oils works out at 742 H.P. and the value for machines stopped is 14 H.P., then the comparative power value with the new oils is 754 H.P., which represents a saving of 68 H.P., assuming that the conditions as regards temperature, relative humidity, etc., are similar.

Gas Engine Tests.—The usual particulars should be recorded; the gas consumption can be taken when a gas meter is installed, and should be reduced to a basis of 32°F. gas temperature, and 28″ mercury barometric pressure, so that the amounts of gas consumed on both tests may be made comparable. The temperature and pressure of the gas should therefore be recorded, also the calorific value of the gas. The temperature of water inlet and outlet for the water jacket, temperature of intake air, the position of air intake on engine (if variable), and the number of actual explosions per minute should be recorded as they may prove important in comparing the results of two sets of oils.

Where the gas consumption cannot be recorded, indicator diagrams may be taken, from which the power consumption can be calculated.

"Free Revolution" Tests.—An approximate comparison between two sets of lubrication conditions may be made by running a number of transmission shafting, counter shafting, and machines *idle* at normal speed, and then suddenly shutting off steam, gas, electricity or whatever moving power is employed. The prime mover (steam engine, gas engine, electric motor, etc.) will continue to operate for a certain number of revolutions and for a certain length of time. By improving the lubrication, the prime mover will run for a longer period and a greater number of "free revolutions" before it comes to a standstill. This method is not very scientific, but is simple to carry out and often very useful.

Similar effects are noticed on spinning frames; with improved lubrication they run for a longer time when the belts are thrown on to the loose pulleys. In the same way, the driver of a hoisting engine finds that he opens his throttle later and closes it earlier when the lubrication of valves and cylinders is improved. It will generally be found that engine attendants or machine operators who have handled their machines for a long time.have some way of judging the state of lubrication efficiency. They know at once if there is a change, although many of them do not know how to express themselves in technical terms.

General Remarks.—As to selecting a suitable part of a factory for a test, it is difficult to give general rules. It will often be found that the engineer of an up-to-date works has a favorite piece of plant on which he makes all his trials and tests. Such a plant should always be given preference, providing of course that it meets all requirements, as he will be more familiar with the running of such machinery, and will the more readily notice any improvement achieved by changing the lubricant.

Where it is possible a compact group of machines should be chosen. It is desirable that the group be compact, so that the whole of the plant may be under observation of the operator while running; the stoppage of a machine, the breaking of a belt, or the heating of a bearing, can be seen at once, a note made of the time the machine is put out of action, and allowance made for it in the final results.

It must not be forgotten that a considerable time must usually be allowed between two comparative tests, to ensure that conditions with the new lubricants in use have become uniform. Where speeds are high and both sets of oils are pure mineral in character, a few weeks will be sufficient; but where speeds are lower and pressures heavier, and particularly if the oils in the first set are compounded and in the second set straight mineral, or if there is a great difference in viscosities, the author has found that the change in power consumption may easily take three months to be fully accomplished.

CHAPTER VI

THE LAWS OF FRICTION

Without friction, life in the various forms in which we are acquainted with it would exist only for a very short time. Any moving mass would retain and continue its motion. If it were sliding down an incline and accelerating, it would reach another incline and rise to a certain height, then move to another position at the same height above sea level, and continue without ever coming to rest.

Everything except the solid rocky formations would start sliding. Towns and cities would be swept away with the country; steamers on the open sea, at the moment friction ceased to be, would not be able to accelerate or decrease their speed, as the friction between the propeller and the water and between the particles of water themselves would be non-existent. Sailing ships would be in the same plight, as the wind would have no effect on the sails. Locomotives would not be able to move, as there would be no rail friction.

Friction can be defined as the resistance created by the surface of one body moving over the surface of another. If no lubricant is introduced between the surfaces, the friction is what may be termed solid friction. If there were nothing but solid friction, very little machinery could be kept in operation, fast-going steamers and railway expresses would be unknown, and only the crudest forms of slow-running machinery could be operated.

Solid Friction.—All surfaces are more or less rough; even surfaces which are well machined and polished show under the microscope small projections and depressions. It is the interlocking of these minute projections which causes *Solid Friction* when two unlubricated surfaces are pressed together and move relative to one another.

When the rubbing surfaces are very smooth and in intimate contact an additional resistance to motion may be created by adhesion between the surfaces caused by molecular attraction. This adhesive force is shown by Johnson's Swedish limit gages used in many engineering works. When two or more of these gages are brought into close contact, they adhere with a force several times that of the atmospheric pressure, and it is difficult to slide one surface over another, notwithstanding the absence of external pressure. It is only in very rare cases, with surfaces which fit exceedingly well, that this adhesive force makes itself felt. Speaking generally, the laws of solid friction are as follows:

The frictional resistance with solid friction is

(*a*) directly proportional to the total pressure between the surfaces;

(*b*) independent of the rubbing speed of the surfaces, at low speeds, but decreases at very high speeds;

(*c*) independent of the areas of the surfaces;

(*d*) dependent to a considerable extent on the roughness and hardness of the surfaces.

These laws apply whether the motion is rolling or sliding; they apply therefore to ball and roller bearings.

That the friction decreases at high speeds is well illustrated by the greatly diminished brake-effect of automobile brakes at very high speeds. The action of the brakes may become so reduced that it may not be possible to regain control of the car when going down a steep hill.

Contaminated Surfaces.—It is an important fact that surfaces are never perfectly clean. Chemically clean surfaces soon abrade and weld themselves together, when rubbing over one another; fortunately, all surfaces are covered with what may be called contamination films of a more or less greasy nature; these films are due to the action of air, moisture, dust and impurities on the surfaces, and they help to some extent in preventing abrasion, at any rate under low pressure conditions; in fact, they act very much like thin lubricating films. Archbutt and Deeley mention the following experiment to illustrate the effect of contamination.

> "A smooth file passed over a freshly prepared clean surface will be found to cut well even when only gently pressed against the metal; but if the hand be passed over the metallic surface, the film of grease therefore deposited will so lubricate it, that considerably greater pressure on the file is now needed to cause it to cut."

Owing to the surface irregularities of the rubbing surfaces wear takes place, the softer surface being more rapidly abraded than the harder. The wear and friction are much less for hard and smooth surfaces than for soft and rough surfaces.

Surfaces of exactly the same material are more inclined to seize and weld than dissimilar surfaces; hence the reason why materials of different hardness and composition are used for all rubbing surfaces, as for example, a steel journal in a white-metalled bearing, soft cast-iron piston rings against a harder cast-iron cylinder, etc.

Although the friction between solid surfaces is independent of the area in contact, the wear is obviously the greater the smaller the area because of the greater pressure per square inch.

By the introduction of a suitable third medium between the frictional surfaces, which medium may be solid (such as graphite, talc, white-lead and the like), or of an oily nature (such as lubricating grease or lubricating oils), the solid friction may be partially or wholly eliminated, and, with the latter mentioned mediæ, replaced with soft—solid or fluid friction. Roller bearings and ball bearings are excepted in this connection.

Fluid Friction.—The object of all lubrication is that the lubricant should attach itself to the rubbing surfaces, and form a film between them, which under the conditions of speed, pressure and temperature prevailing will not be squeezed out, but will keep the frictional surfaces apart. This object is not often attained, except in high speed bearings, as for example, stream-fed bearings lubricated by a circulation oiling system as in steam turbines and high speed steam engines, many ring oiling bearings, Michell bearings, etc.

In bearings thus perfectly lubricated the "rubbing" surfaces never touch one another and the friction is entirely dependent on the lubricant. The laws governing fluid friction are totally different from the laws for solid friction, and may be summarized as follows:

The frictional resistance with fluid friction

(*a*) is independent of the pressure between the surfaces;

(*b*) increases with speed of rubbing surfaces;

(*c*) increases with area of rubbing surfaces;

(*d*) is independent of the condition of the rubbing surfaces, or the materials of which they are composed.

(*e*) depends entirely on the viscosity of the lubricant at the working temperature of the oil film.

If the frictional resistance is F and the total pressure between the rubbing surfaces P, then the friction equals P multiplied by the coefficient of friction C, *i.e.:*

$$F = C \times P$$

and:

$$C = \frac{F}{P}$$

The coefficient of friction for unlubricated surfaces ranges from 0.1 to 0.4, but with fluid friction the coefficient of friction ranges from 0.002 to 0.01 according to the viscosity of the oil. It is therefore worth while, wherever possible, to design bearings so that fluid friction, or a condition approaching fluid friction, can be brought about.

For journal bearings a formula is mentioned, page 105, indicating a relation between pressure and surface speed, which ensures fluid friction.

Michell obtains fluid friction in his design of thrust bearing by means of self-adjusting, tilting bearing blocks.

Semi-lubricated Surfaces.—Under conditions of low speed and high pressure it is impossible or extremely difficult to obtain pefect film formation, nor is it possible in the great majority of bearings, which are not stream-fed but only supplied with a limited amount of oil per minute, to produce anything approaching perfect film formation. The surfaces accordingly are in an imperfectly lubricated or semi-lubricated condition, for which the coefficient of friction will range from 0.01 to 0.10 according to whether the surfaces are very poorly lubricated—approaching the condition of unlubricated surfaces, or fairly well lubricated—approaching the condition of perfectly lubricated surfaces.

There are no Definite Laws Governing the Lubrication of Semi-lubricated Surfaces.—The frictional resistance is composed partly of solid friction and partly of fluid friction, and the more the solid friction predominates, the more important is the property known as oiliness, and the less important the viscosity of the lubricant. The object of lubrication of such surfaces is to make the best possible compromise between reduction of wear and reduction of fluid friction. For conditions of low pressure and high speed, the reduction of fluid friction is usually the most important point to consider and demands *low viscosity oils* of great oiliness; whereas for conditions of high pressure and low speed, the reduction of wear must be given prime consideration and therefore calls for viscous oils of *great oiliness.*

In ball and roller bearings the friction is usually not influenced by lubrication and is lower than the friction in even the best lubricated plain bearings.

Below is given approximate values for the coefficient of friction for the sake of comparison.

Condition of surfaces	Coefficient of friction	
	Range	Average value
Unlubricated or very poorly lubricated surfaces.	.1 to .4	.16
Semi-lubricated surfaces....................	.01 to .10	.03
Perfectly lubricated surfaces................	.002 to .01	.006
Surfaces in rolling contact:		
Ball bearings...........................	.001 to .003	.002
Roller bearings.........................	.002 to .007	.005

The author does not propose in this book to go into greater detail as to the range in value of the coefficient of friction for particular types of surfaces, or the variations brought about by alterations in speed, pressure, temperature, method of application, etc.

The practical aspect of the case will gradually emerge and present itself in the various chapters; the theoretical aspect of lubrication would be best treated in a volume by itself in order to do full justice to such an important subject.

Static Coefficient of Friction.—The values given above for the coefficient of friction are the kinetic values, applying to surfaces in motion. When surfaces have been at rest for some time the oil film is more or less completely squeezed out and a certain amount of metallic contact takes place. As a result, the starting effort, when the surfaces are again brought into motion, is much greater than the running effort; in fact, the static coefficient of friction usually approximates the values for solid friction.

When the speed of the rubbing surfaces is very low, the kinetic coefficient of friction may be even higher than the static value, as there is added to the solid friction the resistance caused by the presence of a lubricant, it being understood that the speed of rubbing is too low to allow the lubricant to produce any appreciable separation of the rubbing surfaces. As the speed increases and the lubricant begins to produce a film, the solid friction quickly decreases and the kinetic coefficient of friction is likewise reduced, until perfect film formation is brought about.

The high values for the static coefficient of friction explain the great effort often required to start engines or machinery from rest, and form one of the chief reasons why ball and roller bearings are used, as with surfaces in rolling contact there is practically no difference between the static and the kinetic coefficient of friction.

The static coefficient of friction will obviously depend on:

1. *The condition and hardness of the surfaces;* it being lower for hard and smooth surfaces than for soft and rough surfaces.
2. *The pressure between the surfaces;* the greater the pressure, the more effectively is the lubricant squeezed out.
3. *The length of time the surfaces have been at rest;* the longer the time the greater chance has the pressure of displacing the lubricant.
4. *The nature of the lubricant.*

Solid lubricants like graphite are not displaced, so that in bearings lubricated entirely by solid lubricants the static and kinetic coefficients of friction (within resonable limits) are very similar. Semi-solid lubricants cannot be entirely displaced by pressure during a period of rest; this is an advantage as compared with oils which occasionally may be of importance. Mineral oils are almost completely displaced, but experience proves that fixed oils, or mineral oils compounded with fixed oil, leave a better film in between the surfaces, and that therefore the static coefficient of friction with the latter oils is considerably less than with straight mineral oils. As a result, not only is the starting effort reduced, but also the wear caused by metallic abrasion during the initial moments of starting.

CHAPTER VII

LUBRICATING APPLIANCES

The main types of lubricators and lubricating appliances are described under "Bearings." It will carry the author too far to elaborate further on the many types and constructions of lubricators in existence; he hopes that sufficient is said under "Bearings" to convey his views on the merits or demerits of the various principles involved.

As, however, mechanically operated lubricators are coming much into prominence, and as the author has taken a particular interest in these appliances, he feels that a critical review of the main types may prove useful.

Mechanically operated lubricators are now widely used for delivering a small or moderate supply of oil automatically and at a uniform rate of feeding, against a pressure ranging from a few pounds to as much as 1,000 lb. per sq. in.

Mechanical lubricators are used for feeding oil to the cylinders and valves of steam engines, and air compressors, the cylinders and bearings of gas engines, kerosene engines, semi-Diesel engines, Diesel engines, the piston rod glands of certain ammonia compressors, certain large and important bearings, which for some reason or other must have the oil forced in under pressure to prevent wear, etc.

In order to analyze the merits or demerits of the very numerous types of mechanically operated lubricators, some of the important features will be discussed as follows:

SIGHT FEEDS
PUMP PLUNGERS
VALVES
TYPES OF DRIVE
FEED ADJUSTMENT
STRAINER
CHECK VALVES.

Sight Feeds.—From this point of view, mechanically operated lubricators may be classified as follows:

Mechanically operated lubricators *without sight feeds.*

Mechanically operated lubricators *with sight feeds on the suction side of the pumps.*

Mechanically operated lubricators *with sight feeds on the discharge side of the pumps.*

Mechanically Operated Lubricators Without Sight Feeds.—The Mollerup (so called after the inventor, a Danish engineer) mechanically operated lubricator is the most widely used lubricator of this type in Europe. A large-diameter plunger is slowly forced into a cylinder filled with oil by means of a ratchet actuating motion combined with a worm gear drive. The oil thus driven out is passed through piping to the engine.

When the lubricator is being filled, air may be drawn into the cylinder, so that the lubricator does not start feeding immediately the engine starts, and lubrication difficulties may therefore arise before the lubricator commences to discharge the oil.

Due to the absence of sight feeds, irregular working of these lubricators, such as leakage past the pump plunger, is not always observed in time to prevent trouble.

Some American mechanically operated lubricators have oil blinkers in the discharge line which act as the equivalent of sight feeds; they blink every time oil is forced through, but do not indicate the actual amount of oil passing.

Other makers put two-way test cocks in the delivery pipes. When the handle of these cocks is turned to a horizontal position, the oil is delivered out through a test pipe into the atmosphere under no pressure; it is assumed that when the handle is turned vertical, the same amount of oil will be fed to the engine against pressure. If, however, the pump is not efficient or if it is out of order, this will not be the case; less oil will be forced to the engine than is indicated by the test cock.

In a multiple feed, mechanically operated lubricator of this type, if one feed is choked and the other feeds are working normally it is impossible to locate the defective pump until the part of the engine supplied gives clear evidence of the lack of lubrication.

Mechanically Operated Lubricators with Sight Feeds on the Suction Side of the Pumps.—Some mechanically operated lubricators of this type (Fig. 9) have a container from which the oil is fed by gravity through sight feeds; the oil feeds are controlled by adjustable needle valves and whatever oil drops into the pumps is forced to the engine, less possible leakage past the plungers.

The disadvantage of these lubricators is that the oil feeds irregularly, due to variation in oil level and oil temperature. Furthermore, dirt is liable to choke up the needle valves and cause erratic oil supply. As the oil feeds are started and stopped by hand, these lubricators are not entirely automatic in action.

Other mechanically operated lubricators, although they have the sight feeds on the suction side of the pumps, are fully automatic in action, the oil feeds starting and stopping with the engine. One type of these lubricators (Fig. 10) has a single plunger which on the suction stroke draws oil through a sight feed glass filled with water; on the delivery stroke the suction valve closes and oil is forced out through a spring-loaded delivery valve. One important drawback to this arrangement is that the water in the sight feed glass gradually disappears and is replaced by oil; this occurs even if a suction valve be placed below the glass, as it cannot be spring loaded; the author can see no virtue in the sight feed glass not being under pressure. Sight feed glasses seldom break because of internal pressure; they are either knocked to pieces or they are fractured because of excessive strains set up when placing them in position. If the sight feed glass is broken, the oil feed stops, as air is sucked into the sight feed in place of oil.

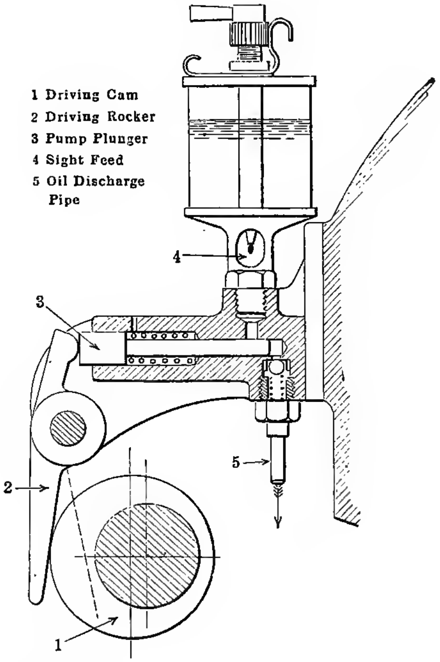


Fig. 9.—Mechanically operated lubricator with gravity sight feeds.

All water-filled sight feed glasses are liable to be fractured in the cold, if the water freezes. This is prevented by adding ordinary salt or glycerine to the water.

With most lubricators, which have the sight feed arrangement on the suction side of the pumps, one cannot be certain that the true oil feed is shown. If the pump plunger leaks on the delivery stroke, some of the oil will leak back to the oil container; this cannot easily be observed, and if the leakage is appreciable, it means that more oil passes through the sight feed than is actually discharged by the pump to the engine.

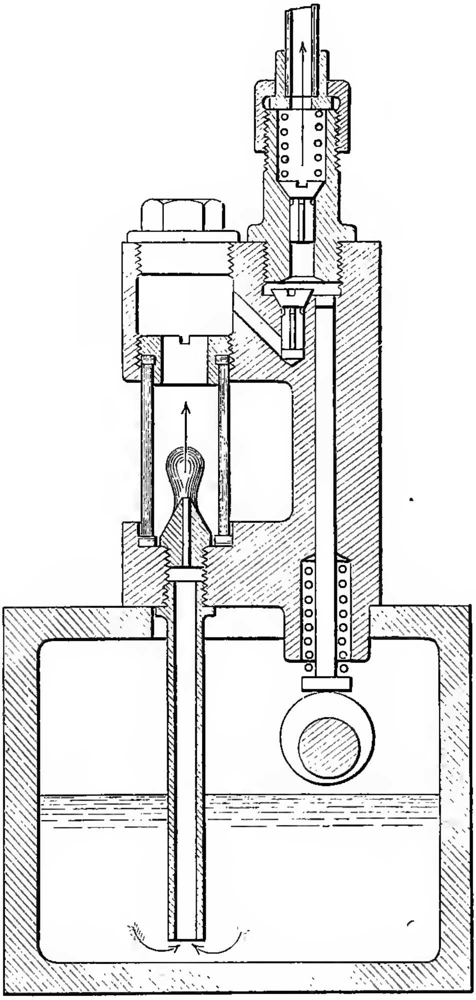


FIG. 10.—Mechanically operated lubricator; sight feed glass on suction side.

Some lubricators have "dummy sight feeds." One plunger pumps the oil through a sight feed, while a similar plunger pumps, *what is believed and hoped to be,* a similar amount of oil to the engine; the oil drops through the sight feed back to the oil container. Cases have occurred where one plunger was pumping oil merrily through the sight feed while the corresponding plunger was air locked. Strange to say, thousands of such lubricators have been sold and engineers have not even taken the trouble to ascertain whether the sight feeds were true sight feeds or were merely dummies.

Several types of lubricators have two plungers for each oil feed. A measuring pump draws the oil from the container and discharges it under low pressure through a sight feed, whence it is sucked into the delivery pump chamber and discharged through a check valve to the engine.

Instead of two separate plungers, a two-diameter plunger is sometimes used, the small diameter part acting as the discharge plunger. If there be any leakage from the discharge plunger, the oil can generally be seen filling up in the sight feed and steps can be taken to rectify the trouble. With a two-diameter plunger properly constructed, *all* the oil passing through the sight feed is forced to the engine, never less, as with leaky single plungers.

Mechanically Operated Lubricators with Sight Feeds on the Discharge Side of the Pumps.—Sight feeds which show the oil in the form of drops rising through water are true sight feeds, as they show the oil after it has left the pump and is actually on its way to the engine; it cannot go anywhere else.

Figs. 11 and 12 show a cylindrical sight feed glass and Fig. 13 a single bull's-eye sight feed arrangement; the former sight feed will stand 300–400 lb. and the latter 800–1,000 lb. per sq. inch quite safely, when well made.

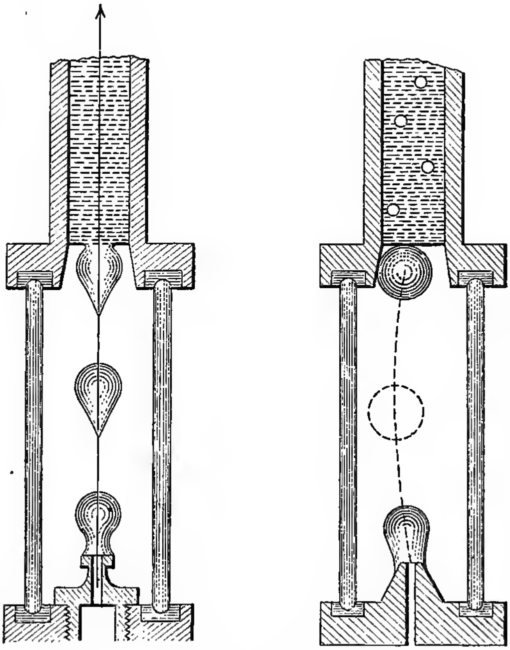
The glass in Figs. 11 and 12 has both ends rounded and ground by a circular grinder, so that there are no sharp edges, whence fractures might emanate.

In a dark engine room it may be difficult to see the oil feed in the bull's-eye shown in Fig. 13, so a better arrangement is to have a double bull's-eye with glasses both front and back. To keep the oil drops away from the glass it is good practice to have a climbing wire inserted in the nozzle from above (Fig. 11); the oil drops form, move up the wire and unite with the oil at the top without removing any water; when there is no wire (Fig. 12), the drops wobble up through the water and usually lean against a corner, each drop enclosing and carrying away with it a small globule of water, so that the glass soon fills up with oil; this is avoided by having a climbing wire, as shown.

Another useful feature is shown in the shape of the nozzle

(Fig. 11), this being narrow below the head. This prevents oil drops from sagging and creeping down the side of the nozzle and smearing the sight feed glass, as in Fig. 12.

A third point of importance for keeping the water in the glass is a spring loaded check valve below the nozzle; if this valve be not loaded, it "floats" after the delivery stroke has been completed, and if it is not seated at the beginning of the suction stroke a little water may be sucked into the mouth of the nozzle; the result is that the glass slowly fills with oil.



FIGS. 11–12.—Sight feed glass under pressure.

In very cold weather steam cylinder oil becomes very sluggish; the oil drops become bigger, and even with a climbing wire, etc., the drops are inclined to take "pin pricks" of water away with them and slowly empty the glasses of water.

If the pump is a good one and will pump water, a simple way of driving out accumulated oil from a sight glass and replacing it with water is to pour a small quantity of water into the lubricator container gradually, until the water begins to make its appearance at the sight feed nipple in place of oil. Then add a little more, say an egg-cupful or what seems necessary, and the water will be pumped up by the action of the lubricator, refilling the glass and driving the oil out. If the engine can be stopped the proper method is to uncouple and clean the glass, and fill up in the usual way. The method described is, however, useful where an engine runs continuously.

Many engineers appear to be under the impression that a mechanical lubricator pumps oil only when a drop rises in the sight feed glass. This is, of course, erroneous. Let us assume that it takes ten strokes of the pump for one drop to rise through the glass; then for every stroke of the pump, the drop forming on the nozzle grows in size with a quantity equal to one-tenth of a drop, but as the glass is full of water and the oil pipe leading to the engine completely filled with oil right to the check valve fitted at its extreme end, it must be clear that for every stroke of the pump one-tenth of a drop is forced into the sight glass at the nozzle and one-tenth of a drop is simultaneously discharged at the other end through the check valve. When the pump has made ten strokes, the drop of oil formed on the nozzle becomes sufficiently large to overcome by its floating power its adhesion to the nozzle; the drop then rises, which simply means that it changes its position in the sight feed glass, moving from the nozzle up to the top of the glass; this movement does not

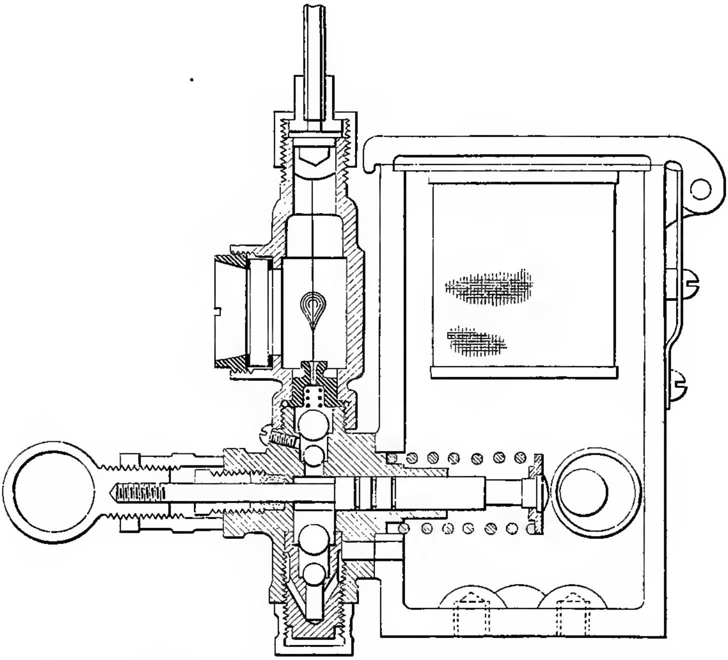


FIG. 13.—Mechanically operated lubricator with bull's-eye sight feed.

in any way affect the discharge of oil from the check valve end of the oil pipe, which continues to be one-tenth of a drop every time the pump plunger completes its delivery stroke.

Pump Plungers.—These should not be too large in diameter, as then the pump strokes have to be very short and easily become irregular. Two-diameter plungers are advantageous, as the difference between the two diameters (see Fig. 13) can be made very small, say 1/64″ (1/4″ × 17/64″); if the plungers have to operate at high speed and must only supply a small amount of oil (Diesel engine cylinders, for example) the stroke will still be perceptible, whereas with single plungers, 1/4 inch diameter, it would be well nigh impossible to adjust the stroke to the required length *and maintain it with certainty.*

Pump plungers should preferably not operate vertically with the oil below them, as they then easily become air locked, and it is difficult to let the air out. Plungers should either operate horizontally or, if vertical, should have the oil above the plunger discharge end.

Outside plungers with packings should be avoided, as, if the plungers get scored, the leakage is difficult to overcome. It is better to have plungers inside the oil container and sealed by the oil; if the plungers are hardened and ground to a good sliding fit, they will pump against considerable pressure with no or only slight leakage.

It is bad practice to have two horizontal plungers operating together on opposite sides of the container and firmly connected; it means that when they are a good fit, it takes great force to move them, it being impossible to drill the pump cylinders in perfect alignment. Such a plunger arrangement causes excessive strain and wear of the driving mechanism.

Valves.—Most lubricators have single suction and delivery valves. If a valve becomes inactive by a piece of dirt getting on to the valve seat, the lubricator may stop feeding. The author strongly recommends two suction and two delivery valves, so that one valve will act while the other valve is given a chance to get free of the dirt. The second delivery valve should be spring loaded to secure prompt closing. Spring loaded suction valves are unsatisfactory, as the springs have to be very weak indeed, if they are not to interfere with the pump action on the suction stroke.

The valves should be easily accessible, the suction valves in particular. Fig. 13 shows one method of placing the suction valves in a detachable cage. The pump should preferably be capable of freeing itself from air. With a spring loaded delivery valve it becomes necessary to let the air out, in case of an air lock; this may be done as shown in Fig. 13 by having a small air vent between the two delivery valves. This is opened, until all air is driven out and oil appears at the vent; it is then closed and the oil having already passed the bottom valve will force open the top valve.

Some pumps do not have suction valves, but suction ports, which are uncovered and closed by the movement of the plunger. A complete vacuum is created on the suction stroke, and when the suction port is uncovered oil is sucked in; but with viscous oils like steam cylinder oils, the pump motion must be very slow, to ensure that the pump draws in a full charge of oil. A few lubricators have no valves at all, but control the oil inlets and outlets by plungers very much like a piston valve arrangement in steam engines; this arrangement requires most excellent and accurate workmanship to give satisfaction for high pressure conditions. Whatever the valve arrangement may be, it is always desirable that the suction passages be as short and wide as possible (to avoid wire drawing of the oil), and that the plungers operate with small pump chamber clearance.

Types of Drive.—The principal methods of driving mechanical lubricators are:

Direct Lever Drive
Direct Rotary Drive
Worm Gear Drive
Spur Gear Drive
Ratchet Drive and Ball or Roller Clutch Drive.

Lever Drive (Fig. 14).—The plunger is operated by a rocker, which gets its motion from some part of the engine, as for example, the half time shaft on a gas engine, Fig. 179, page 441. In this way the movement of the plunger can be made to synchronize with the piston movement, and the oil injected at a definite moment in the cycle.

In large, slow speed, long stroke steam pumping engines, the oil can in this way be forced into the steam just at the moment when it is required. It must be noted, however, that such timed injection of the oil can take place only in lubricators which pump oil alone, and not oil and air, as most lubricators do in which oil drops through a sight feed into the delivery pump. If air gets pumped into the oil pipes, it has a cushioning effect and oil is discharged only when the back pressure is at its minimum.

Rotary Drive.—The lubricator shaft has a driving pulley outside the container; the shaft revolves and may by means of a cam actuate the plunger. Obviously, this form of drive can in this way be adapted to time the injection of oil from the various plungers, by suitably spacing the cams on the lubricator shaft.

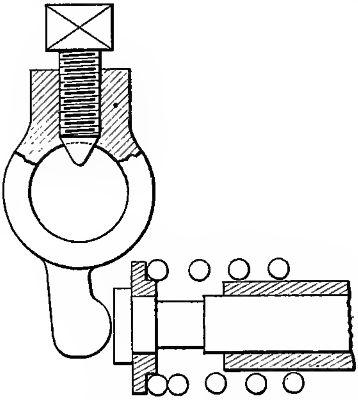


FIG. 14.—Lever drive.

In most lubricators the cams do not actuate the plungers direct, as in Fig. 13, but by some intermediary mechanism, which in the majority of cases is rather unmechanical. The most common form is that of a cam revolving eccentrically between two jaws or inside a slot, as indicated in Fig. 15, but a cylindrical surface does not wear well together with a flat surface; the result is therefore more or less rapid wear; such motions fairly soon develop considerable backlash, which enhances the wear. Fig. 13 shows one method of preventing wear with a cam drive; the cam has a loose roller, which, when pressed against the plunger head by the cam, remains stationary during the de-

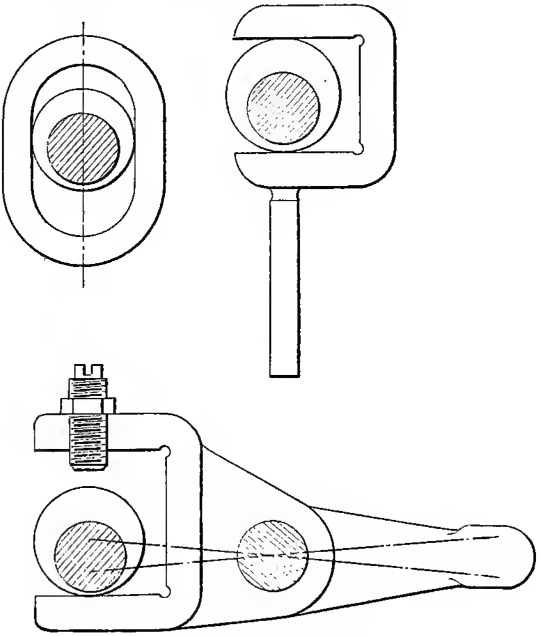


FIG. 15.—Cam motions.

livery stroke; the cam revolves inside the roller, and it being well lubricated there is no wear whatever.

Worm gear and spur gear drives are used for operating lubricators on high speed engines or machinery, so that the pump plungers may be made to operate at a comfortable speed and with fairly long strokes.

Ratchet drive and ball or roller clutch drive is used when the motion is taken from some reciprocating part of the engine, as for example, one of the valve rods on a steam engine (see Fig. 16). Ratchet drive is usually preferable to clutch drives, except at low speeds, when there may not be much to choose between them. At high speeds, the balls and rollers in clutches wear out the casings, and slipping commences with the too frequent result that the lubricator stops working.

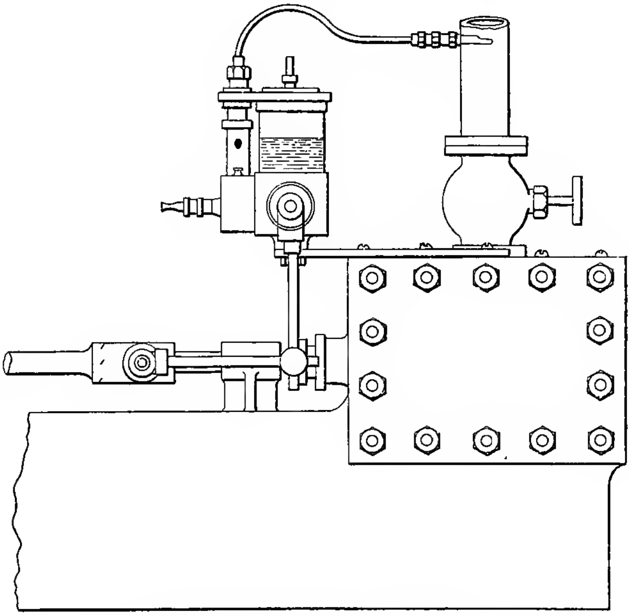


FIG. 16.—Ratchet drive arrangement.

High speed ratchet drives must be carefully designed; the ratchet wheel should be made of case-hardened tool steel and screwed on to the shaft in such a manner that the motion tends to keep it in place. The driving as well as the backlash pawls should be made very light, preferably of thin folded steel plate, which presses only lightly against the teeth in the ratchet wheel; heavy pawls, due to inertia forces, do not act promptly, unless backed by powerful springs, in which case rapid wear takes place. The ratchet should be rather small and should not move more than two or three teeth per stroke; otherwise the driving pawl will strike the teeth too hard. Occasionally, a ratchet wheel will jump forward several teeth, due to lack of resistance; this chiefly occurs when the lubricator has only one or two plungers to operate, and can be overcome by tightening the gland packing on the lubricator shaft, where it passes through the container, or by fitting some sort of brake on the shaft.

Lubricators for exposed conditions, as for example, loco lubricators, should have the ratchet wheel enclosed in an oil tight casing filled with oil, or the ratchet should be inside the container.

Feed Adjustment.—With ratchet drive an alteration in feed is made by altering the leverage or angular movement of the actuating arm, which means a greater or smaller *number of strokes per minute.* An alteration in the amount of *oil fed per stroke* can be made by having a by-pass on the delivery side, by wire drawing the oil inlet (suction passage), by altering the stroke of the plunger, by keeping the suction valve or port open part of the delivery stroke, etc., etc.

The first two methods are very unsatisfactory, particularly with viscous oils, as any alteration in viscosity means an alteration in oil feed. One method of altering the plunger stroke is shown in Fig. 13, namely, by altering the position of the two adjusting nuts; they may be so adjusted that the plunger is never touched by the cam roller — no-stroke position; or they may allow the cam roller to touch the plunger all the time — full-stroke position; any intermediary position can also be secured.

Keeping the suction ports or valves open during part of the delivery stroke has the same effect as shortening the plunger stroke and with a well-designed arrangement is capable of giving good results. With the two last-mentioned methods the oil feed, assuming that the valve arrangement is satisfactory, will be maintained uniform and independent of the viscosity of the oil, as long as the speed is low enough and the oil fluid enough at the working temperature to entirely fill the pump space on the suction stroke. With steam cylinder oils the number of long strokes per minute must not exceed 20 to 30 to get perfect pump action, say above 90 per cent. volumetric efficiency; with medium viscosity, internal combustion engine oils, a speed of 250 to 300 short strokes per minute may be permitted.

There are multiple feed lubricators in which one large master pump supplies oil for a number of delivery pumps, the feed to each of them being controlled by a drip-sight feed; the surplus oil delivered by the large pump over and above what is taken by the delivery pumps is by-passed back to the container through a loaded check valve. In this arrangement the oil feeds are much influenced by alteration in viscosity of the oil (temperature changes); also, an alteration in one of the feeds affects the other feeds.

For these reasons the author is a strong advocate of separate, independent and interchangeable pump units for each oil feed, as for example, the pump unit in Fig. 13 which represents a design patented by A. Kirkham and the author. But this principle of separate pump units for each feed can, of course, be applied to any number of designs.

Heating Arrangement.—Lubricators which are exposed to low temperatures and have to pump viscous oils, as for example, lubricators on locomotives, steam traction engines, etc., must be fitted with heating tubes. Usually a straight tube through the container as near the suction ports as possible, or even a short hollow tube screwed into the container, will prove adequate; they must be connected to the steam supply, say, ten minutes before starting, so as to liquefy the oil sufficiently to ensure good pump action.

Strainer.—Most lubricators have a shallow perforated strainer through which viscous steam cylinder oil passes so slowly that the average driver never troubles to use the strainer but takes it out when he fills the lubricator; even if they are not removed, they retain only coarse impurities. Strainers are best made of gauze which has finer openings than perforated plate and yet a considerably greater area of openings to pass the oil. The strainer should be deep, as shown in Fig. 13 and with a solid bottom and rim, so that any dirt or water in the oil may accumulate here while the oil filters through the sides of the strainer.

Check Valves.—At the extreme end of the oil pipes should be fitted spring loaded non-return valves to prevent the oil pipes emptying themselves; the force of the spring should be 20–25 lb. per square inch, so as to prevent a vacuum from opening the valve and sucking oil out of the pipe and lubricator; this is not an unusual occurrence with badly made check valves. To ensure good seating of the valve, the author favors ball valves with the spring soldered on to the ball; this prevents the ball from rotating and it forms a good permanent seating which should preferably be very narrow.

Fig. 17 illustrates one type of check valve which the author has used with great success. Fig. 163, page 399, shows a locomotive pattern check valve.

Desirable Features in Mechanically Operated Lubricators.—In the author's opinion the things to aim at in the manufacture of a first-class mechanically operated lubricator are the following:

1. Oil feeds independent of each other.
2. Oil feeds independent of viscosity, oil level or back pressure.
3. Sight feeds showing the correct amount of oil actually passing out from the lubricator.
4. Oil feeds capable of quick adjustment between wide limits.
5. Freedom from air lock.
6. All adjustments outside.

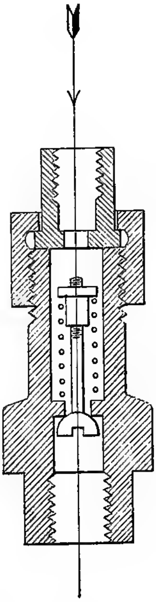


Fig. 17.—Check valve.

7. All parts easily accessible for adjustment, examination or cleaning
8. No joints under pressure except final discharge.
9. Low wear of parts.
10. Efficient strainer.
11. All pump units made up of standard, interchangeable parts.
12. Adaptability for ratchet drive, direct rotary drive, worm gear drive, spur gear drive, or oscillating lever drive.
13. Simplicity and compactness of design.
14. Low cost of manufacture.

CHAPTER VIII

BEARINGS

(Bearings in General)

Bearings are used to support the revolving or oscillating parts of engines and machinery, and the problem of bearing lubrication is therefore the oldest of all lubricating problems.

In the early days, bearings were crudely designed and low-speed conditions prevailed. The lubricating mediæ were vegetable oils such as olive oil, rape-seed and castor oil, and animal fats and oils, such as tallow, lard oil, sperm oil and whale oil.

The enormous development of modern engines and machinery has brought into existence a variety of bearings operating under higher speeds, higher pressures or higher temperatures than at any time before. Lubricating oils to suit modern conditions have of necessity undergone a similar great development, made possible by the production of mineral lubricating oils manufactured from a variety of petroleum crudes. The subject of Bearing Lubrication will be divided into several sections as follows:

Construction
Bearing Materials
Workmanship
Operating Conditions
Oiling Systems
Frictional Heat
Bearing Troubles
Lubrication
Selection of Oil
Bearing Oils
Semi-solid Lubricants
Solid Lubricants.

CONSTRUCTION

Bearings are made in all sizes from very small to very large and there are two main types of bearings, as follows:

Journal bearings	Thrust bearings
(*a*) Solid bearings.	(*a*) Plain thrust bearings.
(*b*) Two-part bearings.	(*b*) Ball and roller thrust bearings.
(*c*) Four-part bearings.	
(*d*) Ball and roller bearings.	

Journal Bearings. (*a*) *Solid Bearings.*—Horizontal solid bearings are always small in size, used as inexpensive bearings for loose pulleys and small shafts and in a variety of machinery where slow speeds or low bearing pressures prevail or where the lubricating conditions are so excellent that little or no wear is anticipated. This type of bearing is used as gudgeon or wrist-pin bearing in the great majority of high speed steam engines and internal combustion engines.

When more than slight wear is likely to take place a bushing is frequently provided so that when the bushing is worn it can be replaced.

Vertical solid bearings are used as neck bearings and footstep bearings for high speed spindles in textile mills, also as footsteps for vertical shafts.

(*b*) *Two-part Bearings.*—The majority of bearings are of this type. For shafting bearings the two bearing halves are usually of cast-iron and the bearing comparatively long. They may be hand oiled, drop-feed oiled, or may be arranged for ring oiling.

In larger journals bearing brasses are fixed in the top and bottom part of the bearing and between the top and bottom brasses are placed "liners" which are thin strips of metal. When the bearing wears, one or more of these strips may be removed, so as to bring the two bearing brasses closer together around the shaft. Two-part bearings are often lined with anti-friction metal.

When the pressure is always taken by one of the brasses, say the lower one, as in many bearings, the top half of the bearing need not be very strong nor does the top brass need to fit the journal closely; in many cases the top half then simply acts as a dust cover and to hold the lubricator. Railway axle-boxes, for example, have only a top brass, the pressure being directed upward, and below the journal is a cellar, holding a pad oiler or waste packing for the purpose of lubricating the journal.

A two-part bearing is not suitable where the pressure from the journal is directed against the joint of the two bearing halves; large bearings operating under such conditions are therefore frequently designed as four-part bearings.

(*c*) *Four-part Bearings.*—These bearings are used principally as main bearings in large horizontal steam engines and gas engines. The bearing surface is built up of four parts, *i.e.*, a top and bottom brass and two side brasses.

(*d*) *Ball and roller bearings* are described in a special chapter.

Thrust bearings are designed to take up pressure in the direction of the shaft, as for instance, the propeller thrust in the case of marine steam engines and turbines, etc. A special chapter is devoted to the description of plain thrust bearings, and ball and roller thrust bearings are described under ball and roller bearings.

BEARING MATERIALS

With perfect oil film lubrication the nature of the rubbing surfaces does not influence lubrication, but most bearings are imperfectly lubricated; they wear more or less and the various bearing metals behave differently.

Bearings are chiefly metals, but wood, rawhide, fibre, agate and jewels are used for special purposes.

Bearing Metals.—The journal and the bearing should preferably be of dissimilar materials to work well together, and the bearing surface is usually of a softer material than the journal. If wear takes place it will then be chiefly on the bearing surface, which is cheaper to replace than the journal.

Good bearing metals must possess the following properties:

1. *Sufficient strength to sustain the load.*
2. *Low running temperature,* which means high thermal conductivity; white metals containing a high percentage of lead are inferior in this respect to those rich in tin and containing little or no lead.
3. *Low Coefficient of Friction.*—Hard bearing materials, such as the rigid bronzes (copper tin alloys low in lead) are best in this respect, assuming that the bearing surfaces are carefully fitted to the journal; otherwise white metals give lower friction as they yield slightly and distribute the load more uniformly.
4. *Durability.*—The rigid bronzes, and alloys containing zinc, wear more than those alloys which are rich in lead, but the latter have a higher coefficient of friction. According to Dr. Dudley those bearing metals will wear the least which have a fine granular structure and combine great elongation with great tensile strength, the elongation, however, being the more important property of these two.
5. *Low Journal Wear.*—The white metals excel over other metals.
6. *Ease of Replacement.*—Again here the advantage lies with the white metals.
7. *Resistance to Corrosion.*—Tin and antimony resist corrosion best; iron, copper, lead and zinc are more easily corroded, particularly the two latter. When the oil is likely to contain a large amount of free fatty acid, the white metal should preferably contain no lead and little or no zinc.

The following combinations of bearing metals represent current practice:

Hardened Crucible Steel on Steel or Bronze.—For high pressure and low or moderate speed, as for example, hard steel toggles working against mild steel seats in stone breakers, presses, etc.

Mild Steel on Bronze.—For moderate pressures and low or moderate speeds, as exist in many important bearings.

Mild Steel on White Metal.—For low or moderate pressures and moderate or high speeds. This is the combination used in the great majority of machinery bearings.

Mild Steel on Cast Iron.—For low or moderate pressures and low speeds, as in textile machinery and the like; also used for small or medium size shafting bearings; the bearings are long and the pressures low; with higher bearing pressures, the cast iron must be lined with white metal.

Cast Iron on Cast Iron.—For low pressure, chiefly used for piston rings, cylinders, crossheads and crosshead guides in steam engines and internal combustion engines.

Hard Steel, Bronze or Brass.—With all hard bearing metals it is important that the bearing surfaces be well scraped together with the journal and that the bearings be carefully erected, so that the pressures will be evenly distributed over the entire bearing surfaces; otherwise, certain parts of the bearings will be excessively loaded and cause heating.

White metals (anti-friction metals) are combinations of hard metal, such as antimony, embedded in a soft plastic ground mass, such as lead.

When lined with suitable anti-friction metal, which has more or less resilience, the journal easily beds itself down and distributes the pressure uniformly over the entire bearing surface.

In high speed steam and internal combustion engines, where three, four or five bearings support the crank shaft, the bearings are nearly always lined with white metal, with a view to distributing the load equally over all the bearings.

If bronze is used and if, say, one bearing is slightly out of line, the bronze, not yielding, will create excessive bearing pressure in that particular bearing and cause heating.

It is the hard grains in a white metal surface which sustain the load; if the load is excessive at any point, the plastic body of the metal will yield until the load is evenly distributed over a great many hard grains; this will assist the lubricating oil in maintaining a good film everywhere and means increased safety in operation. If there are only a few hard grains in a white metal, it will be soft and will stand only low bearing pressures; if there are too many hard grains, the points of the hard crystals will engage one another and form a solid network throughout the body of the metal, which will then be found to be brittle. Tri-metal alloys appear to give better service than those white metals which are composed of only two metals.

Cast iron is porous and granular in structure; close grained cast iron is best and can be obtained harder or softer as required. It is capable of attaining a very smooth, hard and glazed surface, but if this surface is cut, it takes considerable time to reproduce the hard glossy "skin" so very desirable from a lubrication point of view.

Cast iron when not exposed to undue pressure and well lubricated is a very satisfactory bearing metal.

The use of graphite in connection with cast iron is capable of giving excellent results, as mentioned under "solid lubricants."

Wood, Rawhide and Fibre.—Hard and dense wood is used to some extent for spur and bevel gearing in windmills, watermills, etc. For certain bearings, such as footsteps for water turbines and stern tube bearings, lignum vitæ is favored, as it will stand great pressure, is of a greasy nature, not easily abraded, and works well with water.

Rawhide and fibre, also compressed paper, are sometimes used for pinion wheels and give silent running.

Agate and Jewels.—In watches and light machinery, which cannot be regularly lubricated, agate and various jewels are used as bearings for hard steel pins.

WORKMANSHIP

Workmanship may be defined as the attention which has been given to:

1. the finish of the bearing surfaces;
2. the bearing clearance;
3. the alignment of the erected bearing.

Finish of Bearing Surfaces.—The rubbing surfaces are never exactly true and smooth. If a new shaft is put into new bearings without oil, it will, when revolving, touch the bearing surfaces only at certain points, distributed more or less evenly over the surface. It is for this reason that bearings are "scraped together." It is an advantage to have the surface of the shaft made as smooth as possible and the high points in the bearing surfaces are scraped down until finally the shaft bears uniformly on the whole of the bearing area.

Bearing Clearance.—The diameter of the shaft is slightly smaller than the inside diameter of the bearing. The difference between the two diameters—the bearing clearance—should be about 1/1000 of an inch per inch diameter of the shaft, rather more than this for small bearings and rather less than this for large bearings.

When the bearing surfaces are well lubricated and particularly when they are supplied with a continuous stream of oil, which carries away the frictional heat, the bearing clearances can be made smaller, and more efficient lubrication can be obtained than where bearings are semi-lubricated and the journals therefore are more likely to heat and expand.

Alignment.—When machinery and shafting are erected, it is very important that the various bearings be truly and accurately fitted. If, for instance, a length of shafting is supported by a number of bearings, and some bearings are placed too high and others too low, this will set up stresses in the shafts and in the bearings, creating difficult lubricating conditions.

OPERATING CONDITIONS

Size of bearing (diameter)
Speed of shaft (surface speed per minute)
Bearing pressure (pounds per square inch)
Bearing temperature (degrees Fahrenheit)
Mechanical conditions (good or bad).

Size of Bearing.—The surface of the shaft or journal is never perfectly smooth nor round, but will possess a roughness which, if not visible to the naked eye, can be seen through a magnifying glass. The imperfection in manufacture will have a tendency to produce metallic contact between the rubbing surfaces. This tendency is greater, the larger the bearing, and experience has proved that other things being equal, the larger the bearing, the heavier in body must be the oil to provide efficient lubrication.

Speed of Shaft.—A revolving shaft will draw the oil into the bearing due to the oil adhering and clinging to the shaft. Speaking generally, this action increases with the speed of the shaft and the body of the oil. When bearings operate at low speed, the oil used *must* be heavy in body and grease may be preferable in some cases. At higher speeds, an oil light in body should preferably be used, and for very high speeds, oils very light in body *must* be used.

At extremely high speeds, *air* even has been used as the only lubricant, as in the case of spindle bearings for traverse spindle grinders used in watch factories. The spindles are one-half inch in diameter. Both spindles and bearings are of hardened steel and fitted together with extreme care; the fit is so close that when they are not running it is difficult to slide the spindle through the bearing.

When starting up, the spindles will give a grating noise for a few seconds but when attaining their normal speed of about 12,000 R.P.M. they run quite smoothly and with so little friction that when the driving belt is thrown off, they continue to run for a couple of minutes until the air film breaks and the spindles quickly stop. The surfaces must be kept very clean by rubbing with alcohol and tissue paper. If the bearings or spindles are not perfect, a little kerosene needs to be used to give smooth running.

Bearing Pressure.—Bearing pressures range from a few pounds per square inch for cast iron piston rings rubbing against cast iron cylinders, to as much as 3,000–4,000 lb. per square inch for hardened steel rubbing against steel, as in slow speed punching machines. The bearing pressures are chiefly governed by the nature of the bearing materials, the character of the load and the degree of lubrication efficiency desired.

For ordinary conditions the bearing pressures permissible for various metals are indicated in the following table:

	Pressures in lb. per sq. in.
Hardened crucible steel on steel	2,000
Hardened crucible steel on bronze	1,200
Unhardened crucible steel on bronze	800
Mild steel with smooth compact surface on bronze	500
Mild steel with ordinary surface on bronze	400
Mild steel with ordinary surface on white metal	500
Mild steel on cast iron	300
Cast iron on cast iron (journal bearings)	100

These figures may be increased 50 per cent., 100 per cent., or even more, if the load is intermittent; also if the bearings are well cooled, as in locomotive crankpins and crossheads.

The figures must be reduced if the pressure is always in one direction and never relieved; also, if it is important that no wear should occur, as in many electrical machines and other high speed engines, such as enclosed type steam engines, gas engines, etc., lubricated by a circulation oiling system. If wear must not take place, it means that the bearings must have perfect oil film lubrication at all times; with high surface speed, higher bearing pressures may be allowed, as indicated in the following formula by H. F. Moore, giving the maximum load which can be carried before the film breaks:

$$p = 7.47 \times \sqrt{v}$$

in which p = pounds per square inch

v = surface speed in feet per minute.

In order to ensure perfect film lubrication, the bearing pressure must be less than that calculated by Moore's formula; a factor of safety may be chosen ranging from two to eight according to how important it is to prevent wear.

All other things being equal, it is obvious that the greater the pressure on the bearing and the lower the speed, the heavier in body must the oil be to sustain the pressure without being squeezed out too rapidly. If the pressure on the bearing is slight, light bodied oil can be used, and at moderate or high speeds a moderate oil supply will be sufficient to maintain a complete oil film. If the pressure on the bearing is great, an oil heavy in body must be used and if in addition the speed is low, it is very difficult, if not impossible, to maintain a complete oil film and to prevent metallic contact of the rubbing surfaces. It is under such conditions that certain solid or semi-solid lubricants may prove more efficient than lubricating oils.

Bearing Temperature.—Where machinery is operating in cold surroundings, or at very low speeds, bearing temperatures may be *low* (from 70°F to 90°F.). When bearings operate in very cold surroundings, light bodied oils and oils with low cold tests should be employed, so as not to congeal and cause difficulty in feeding.

The majority of bearings operate at *medium* temperatures, from 90°F. to 120°F. High speed bearings frequently operate at temperatures higher than 120°F., but seldom above 160°F. Bearing temperatures above 120°F. must be termed high and should ordinarily never be allowed to exceed 140°F. (See Turbines.)

If the bearing temperature is higher than 160°F. the conditions should be carefully looked into, as such temperatures are dangerous and show either that the mechanical conditions are wrong and should be corrected, or that the quality of the oil used is unsuitable, or that an insufficient quantity of oil reaches the parts to be lubricated.

If bearing temperatures are high, notwithstanding that the mechanical conditions are correct, that carefully selected good quality oil is used and in sufficient quantity, the conditions are evidently so severe that the heat developed in the bearing cannot be radiated quickly enough from the bearing surface. In such cases, a circulation oiling system should be introduced, in order to remove the frictional heat and reduce the bearing temperature sufficiently for safe operation.

Mechanical Conditions.—Bearings in time will usually wear or get out of alignment; it is important that the bearings be kept in good alignment and repair, by renewing bushings, brasses or anti-friction linings, by adjusting bearings for wear, etc., etc.

When trouble or irregularity in operation occurs the cause should be traced and the conditions rectified, rather than that the trouble should be allowed to continue until it becomes serious.

By *good mechanical conditions* is understood, bearings of good design, journals and bearing surfaces of good material, well finished and with suitable bearing clearance; bearings in good alignment and not appreciably worn; also that reasonable attention be given to regular oiling of the bearings.

By *bad mechanical conditions* is understood bearings that are crudely designed, or of good design, but allowed to get out of order; bearings made of poor or unsuitable material; bearing surfaces rough or worn, bearings out of alignment; also lack of attention in keeping the oiling system in its most efficient state.

Speaking generally, bad mechanical conditions necessitate the use of oils heavy in body; whereas under good mechanical conditions oils lighter in body can be employed, resulting in more efficient lubrication of the bearings.

OILING SYSTEMS

The various systems by which oil is applied to bearings may be divided into seven main groups, as follows:

Individual Bearings	Hand Oiling Drop Feed Oiling Pad Oiling Ring Oiling Bath Oiling
Groups of Bearings	Splash Oiling Circulation Oiling

Oiling Systems for Individual Bearings.—**Hand oiling** is the oldest system employed for lubricating bearings; it is the least efficient and the most wasteful of all oiling systems. Hand oiling is employed for lubrication of low speed shafting and low speed bearings in a variety of machines, such as machine tools, textile machinery, printing machines, etc. It is largely employed for oiling small parts of valve motions, valve spindles, etc., in steam engines, internal combustion engines and other power producers. It is also employed on various types of machines exposed to heavy vibration or rough usage where any kind of lubricating appliance would be shaken off.

In the bearing is a hole, usually in the top part. The oil is applied by an oil can preferably of the press-button type, by which it is possible to deliver one drop or a few drops of oil as required, in order not to waste too much. The oil runs down the hole, spreads over the bearing surfaces and gradually works its way toward and out through the ends of the bearing. After each oiling, the oil film in the bearing gradually becomes thinner, and finally the bearing runs practically without lubrication until such time as it is oiled afresh.

The lubrication will gradually decrease to a state of inefficiency, dependent upon the body of the oil in use, the length of time between oilings and the operating conditions.

In order to prevent the entrance of dust or fluffy matter, which would tend to choke up the oil hole or would enter the bearing and cause trouble, the entrance to the oil hole may be fitted with an oil hole protector (see Figs. 117, 118, 119, page 290). Another method is to provide a felt pad in the oil hole into which the oil is poured. This method insures more uniform feeding of the oil.

In many cases the oil is not applied through an oil hole, but simply to the end of the bearing, as for example with textile machinery.

Drop Feed Oiling.—The drop feed oiling system includes all appliances by which a moderate and more or less regular supply of oil is fed to the bearing.

There are four types of such appliances, namely:

Syphon Oiler
Bottle Oiler
Sight Feed Drop Oiler
Mechanical Lubricator.

Syphon Oiler.—When in the early days of engineering hand oiling proved inadequate for lubricating heavy-duty bearings, the syphon oiler was the first improvement introduced. It (Fig. 18) consists of a container (1) in which oil is filled to a certain level; the syphon oil tube (2) projects above the oil level; the syphon wick is introduced into the oil tube, its lower end being at a lower level than the end immersed in the oil. The oil level should not be allowed to be higher than the top of the oil tube, as the surplus oil will then be wasted through the tube.

With syphon oilers the oil feed varies with the oil level in the container; also with the temperature of the oil, as cold and thick oil will feed more slowly than warm and thin oil.

The syphon wick consists usually of one or several strands of woollen yarn, preferably of loose texture, which feed more freely than yarns of tight twist and close texture. The higher the oil level in the container, or the thinner the oil, or the deeper the syphon is introduced into the oil tube, or the greater the number of strands in the syphon, the greater will be the oil feed. When so many strands are used that they choke the oil tube, a point is reached where the addition of more strands will reduce the oil feed because of the greater resistance in passing through the tight syphon; choke trimmings used in locomotives (Fig. 106, page 274) are of this type.

The container should always be fitted with a lid, so as to prevent the entrance of dust, dirt and water into the oil. Syphons in time get choked with impurities and become inoperative; they should be renewed at suitable intervals.

Syphon oilers are rather wasteful but very reliable where a moderate oil feed is required; they are not suitable for very small feeds. Where machines or engines are running intermittently, the syphons should be lifted out of the oil tube and left in the oil container every time the machinery stops; otherwise, they keep on feeding and oil is wasted; oil should be added to the container at frequent intervals so as to keep the oil level as constant as possible.

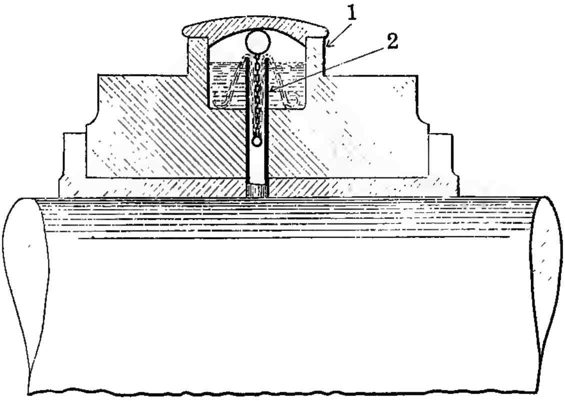


FIG. 18.—Syphon oiler.

Syphon oilers are employed for lubrication of locomotives, marine steam engines, main bearings of old-type stationary steam engines, and other prime movers, as well as for the lubrication of medium size bearings of shafting and in a variety of machines of all kinds.

The oil container may have several syphon tubes, each tube being served by a separate syphon; such multiple feed syphon boxes are occasionally fitted with sight feed glasses below the container, so that the oil feed from each syphon tube is visible.

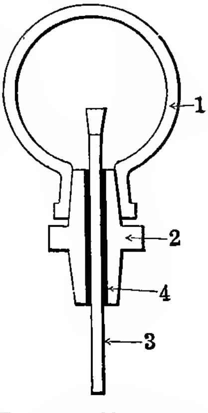
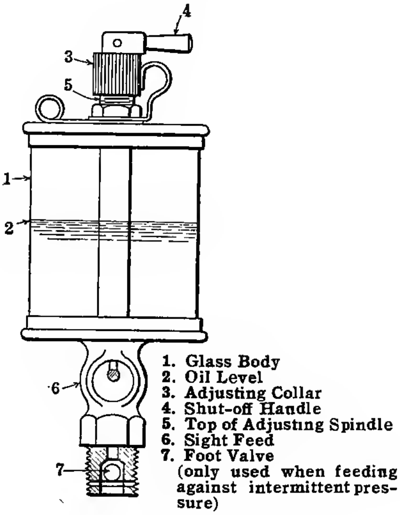


FIG. 19.—Glass bottle oiler.

The bottle oiler (Fig. 19) has been specially developed for the lubrication of light and medium-size shafting bearings operating at low to moderately high speed and under conditions which make a small constant feed desirable. The glass bottle (1) has a stopper (2) fitted with a brass tube (4). A copper or steel needle (3) fits loosely inside the brass tube, its lower end resting on the shaft in the bearing.

The shaft, when revolving, gives the needle a very slight up-and-down motion, which has the effect of drawing a sparing supply of oil from the glass bottle, the oil creeping down over the surface of the needle and finally reaching the bearing surface.

The bottle oiler is automatic in action, starting and stopping with the motion of the shaft. If the bearing gets warm, the needle heats up; the oil surrounding the needle becomes thinner and more oil will be fed. If the bearing vibrates, the greater movements of the needle will result in more oil being fed. If it be found that the amount of oil supplied through the bottle oiler is insufficient, the oil feed can be increased by using a thinner needle or by filing a flat on the side of the needle.



1. Glass Body
2. Oil Level
3. Adjusting Collar
4. Shut-off Handle
5. Top of Adjusting Spindle
6. Sight Feed
7. Foot Valve (only used when feeding against intermittent pressure)

FIG. 20.—Sight feed drop oiler.

The stopper should preferably have a brass tube, as shown, in which the needle has a loose sliding fit; without this tube the opening in the stopper varies considerably and in time causes the oil feed to stop on account of the swelling of the stopper.

Bottle oilers cannot be used on machinery exposed to rough usage, as being of glass they are easily broken.

The sight-feed drop oiler (Fig. 20) has largely replaced the syphon oiler. The sight-feed drop oiler can be adjusted to feed one drop of oil per minute or more. It consists of a container, usually having a glass body so that the level of the oil can be observed. The adjusting needle or valve spindle (5) is guided into a conical hole in the bottom of the oiler. By turning the milled collar (3) the needle can be raised or lowered so as to give a greater or smaller feed. If the handle (4) of the top of the adjusting needle (5) is turned to its horizontal position, the needle drops by spring tension and shuts off the oil supply; when it is again raised, the feed will be the same as previously adjusted.

Sight-feed drop oilers have the same disadvantages as the syphon oiler as regards variation in oil feed, due to higher or lower oil level or due to the oil being cold and thick or warm and thin; in addition, when adjusted to feed a very small amount of oil, grit and dirt may easily choke the oil outlet from the oiler, so that the feed stops altogether. The sight-feed drop oiler has the advantage over the syphon oiler in that the feed can be quickly adjusted, quickly started and stopped and the oil level as well as the oil feed is clearly visible.

Sight-feed drop oilers may be arranged to have more than one feed. An oil container may for example have six oil outlets, controlled by six different needle valves, the oil dropping through sight feeds into oil tubes which guide the oil to the different bearings.

Sight-feed drop oilers are extensively used on modern steam engines and power producers of all kinds.

When feeding oil to the crank pins of steam engines, gas engines and other prime movers, the so-called crank pin banjo oiler is often employed (see Fig. 179, page 441).

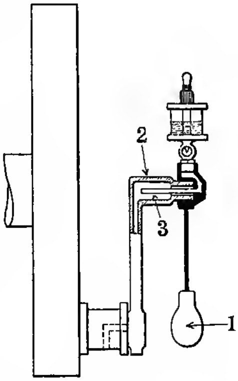


FIG. 21.—Nugent crank pin oiler.

The Nugent crank pin oiler, much used in the United States, is shown in Fig. 21. The sight-feed drop oiler is held in a vertical position by the weighted pendulum (1) to which it is attached. The part (2) revolves centrally, receives the oil through the tube (3) and guides it to the crank pin.

Mechanically operated lubricators, either single feed or multiple feed, are occasionally employed for feeding oil to important bearings. The advantage is that, being operated from some moving part of the engine, the mechanically operated lubricator starts and stops with the engine and feeds the oil more uniformly and regularly, therefore with less waste, than when sight-feed drop oilers or syphon oilers are used; also a much more viscous oil can be fed, if required. The various feed pipes are preferably fitted with check valves at their extreme ends in order to ensure that the pipes are always filled with oil, so that as soon as the engine starts, and therefore the lubricator, the oil will immediately be delivered from the ends of the oil pipes.

Sight-feed arrangements are either fitted in the lubricator itself, one sight feed for each oil feed, or they may be fitted at the extreme ends of the oil pipes, the oil dropping from the check valves through sight feeds into the bearings.

Pad Oiling.—Lubrication by pad oilers or oil-soaked waste is chiefly used in railway practice and described under railway rolling stock.

Ring Oiling.—This method is very efficient and is described in a special chapter.

Bath Oiling.—This system is employed only for vertical bearings, such as ball bearings, high-speed bath spindles employed in textile mills, or the footsteps of vertical, heavy shafts, sometimes found in textile mills, flour mills, vertical water turbines, vertical hydro-extractors, gyratory crushers, etc. (See under respective headings.)

Oiling Systems for Groups of Bearings.—**Splash oiling** is employed for lubricating a number of bearings enclosed in an oil-tight casing, this system being frequently employed for lubricating enclosed vertical or horizontal steam engines, air compressors, gas engines, kerosene engines, gasolene engines, and motor cycles.

The enclosed crank chamber is filled with oil to a certain level; means should be provided to maintain this level as constant as possible. Dippers fixed to the crank pin bearings (big ends) dip into the oil and produce inside the crank chamber a spray of tiny drops of oil which reach and lubricate the main bearings, crank pins, gudgeon or wrist pins, cams, and various other bearings or parts. The bearings have oil holes or oil troughs which catch the oil from the spray and guide it into the bearing surfaces.

In some small steam engines, in motor cycle engines, and certain types of automobile engines, the crank disc or the flywheel revolving inside the crank chamber may be arranged so that it dips into the oil, and as the oil adheres to the revolving rim an oil spray will be produced. Oil wells or pockets may be cast on the inside of the casing, collecting the oil and assisting it through various channels, tubes or troughs, in reaching all parts.

If the *oil level is too low,* too little oil spray will be formed; some of the parts will be starved, resulting in inefficient lubrication. If the *oil level is too high,* too much oil spray will be formed, which always results in waste of oil, the oil spray escaping from the bearings or from the air vent usually provided in the crank chamber.

Excessive oil spray in the case of automobile engines and motor cycles, and other internal combustion engines, is detrimental, producing excessive carbonization on the hot pistons. In the case of vertical steam engines, excessive oil spray means that too much oil passes the pistons and finds its way through the engine with the exhaust steam; this means always waste, and sometimes trouble where it is important that the exhaust steam should be as free from oil as possible.

Circulation Oiling.—There are two main systems embodying the circulation principle, viz:

Gravity Feed Circulation.
Force Feed Circulation.

The Gravity Feed Circulation System is a central automatic oiling system for lubricating a number of bearings and parts, as for instance, the main bearings, crank pins, crossheads, crosshead guides, etc., etc., comprising most of the external moving parts in medium or large size open type steam engines, gas engines, Diesel engines, steam turbines, groups of large shafting bearings, etc.

Oil is fed by gravity from a top supply tank through a distributing pipe and its branch pipes leading to the various bearings. Adjusting cocks are fitted in these branch pipes so as to regulate the oil feeds, and sight feeds are frequently fitted in the oil inlet or outlet pipes to the bearings so that the oil feeds are clearly visible. Sometimes, as in the case of steam turbines, the sight feeds are fitted in the outlets from the bearings, showing the amount of oil which *has passed* through the bearings. Having done its work, the oil drains back from the various parts through return oil pipes to a bottom receiving tank. The oil pump driven by the engine takes the oil from the receiving tank and delivers it either through an oil cooler or direct into the top supply tank. If more oil is delivered to the top tank than is required for the bearings, the surplus oil passes through an overflow back into the bottom receiving tank.

Drain pipes are fitted to the top tank and bottom tank to enable the operator to drain out water, sludge or impurities when required; also the whole or part of the contents of the tanks may be withdrawn for treatment in a separation and filtration plant.

It is always difficult to avoid some loss of oil. Oil is lost in the form of oil spray, particularly when the speeds are high, and is wasted through tiny leaks difficult to avoid and often difficult to locate. The loss of oil can be reduced somewhat by reducing the amount of oil fed to each bearing, but this is doubtful economy, if the lubrication becomes less efficient; sufficient oil should be fed so that a good oil film will be maintained, and friction and wear reduced to a minimum.

A heavy viscosity oil will cause less loss by leakage or oil spray than a low viscosity oil; but here again, the bearing friction is usually increased, so that very viscous oils should be introduced from an oil loss point of view only if the leakage losses are quite abnormal. It pays to provide good savealls and splashguards, not only to save oil, but also to save the foundations. Oil-soaked parts of a foundation are weak and crumbly, and a constant source of danger for the engine.

The force feed circulation system operates on lines exactly similar to the gravity feed circulation system, the difference being that the top tank is omitted and the oil passes direct into the distributing pipe, which should preferably be fitted with an adjustable relief valve, a portion of the oil being by-passed back into the bottom tank. The oil is thus delivered under pressure as direct as possible to the various bearings and parts requiring lubrication.

This system is largely employed for lubricating all sizes of enclosed type steam engines, Diesel engines, vertical kerosene engines, gasolene engines, steam turbines, etc.

Daily Treatment.—In the cases of both splash oiling and oil circulation it is good practice to remove two to six gallons of oil every day for treatment in a heated separating tank to separate out water, sludge and impurities, and afterward to pass the oil through a good filter; the purified oil, mixed with a little fresh oil should be returned to the system at the same time that a corresponding quantity of oil is removed from the system for treatment. When the oil tank capacity in the system is small, it is particularly desirable to recommend this practice. In this way the vitality of the oil is kept up to as high a standard as possible and the life of the oil is greatly increased.

In very large plants, the separation and the filtration apparatus are preferably constructed as a part of the circulation system, so that either the whole of the oil in circulation or a certain percentage of it is constantly passed through the purifying apparatus.

Care of Oiling Systems.—Whatever oiling systems may be employed, it is important that the necessary attention be given to institute a regular routine for maintaining the oiling systems at their highest efficiency.

Bearings that are hand oiled should be oiled at sufficiently frequent intervals to ensure the presence of an oil film and prevent excessive heating. The oil containers in syphon oilers, bottle oilers, sight-feed drop oilers, mechanically operated lubricators should be filled at correct intervals, and a regular system should be employed for putting the oilers into and out of service as may be required. Lubricators never should be allowed to run empty or to get choked with dirt, and they should be cleaned occasionally.

OIL DISTRIBUTION

Reaching the bearing, the oil is conducted to the bearing surfaces through drilled holes; in order to prevent oil being wasted between the bearing cap and brass a tube should be tightly fitted at this point. The edges of the brasses at the side where the oil enters should be chamfered, so as to facilitate the entrance of the oil to the bearing surface. This is of paramount importance.

In bearings employing the ring oiling, splash oiling and circulation oiling systems, where the bearings are copiously supplied with oil, oil grooves are nearly always detrimental; there is usually only an oil distributing groove, which runs nearly the whole length of the bearing. This oil distributing groove should be on the side of the bearing where the direction of the revolution of the shaft is downwards, and its lower edge should be chamfered so as to facilitate the entrance of the oil.

In bearings that are hand oiled or lubricated by a drop feed system, in which only a moderate supply of oil is introduced into the bearings, and where a perfect oil film does not exist, it sometimes becomes desirable not only to have an oil-distributing groove, but also to have other suitably cut oil grooves to distribute the oil to the bearing surface.

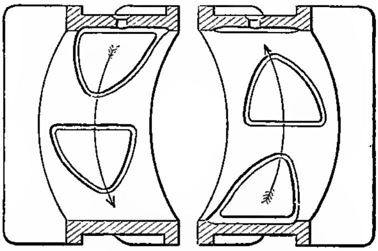


Fig. 22.—Oil grooving a large crank pin bearing.

Under the influence of the bearing pressure the oil is squeezed toward the edges of the brass; if the surface speed is high, it will be only a small portion which escapes, and the loss is replaced at the place where the oil enters the bearing. If the surface speed is low, the oil received by a certain part of the journal gets time to escape and leave the journal surface unlubricated long before that particular point has completed a revolution and can receive more oil. It is under these conditions that a very viscous oil of good body should be used and that oil grooving is desirable. The oil grooves should be so cut as to feed oil to several points in the bearing and so renew the oil film at these points. Oil grooving is frequently much overdone. Cutting large oil grooves removes the bearing surface which supports the shaft; it is only in large, slow speed, heavy duty bearings that oil grooving may become desirable.

Fig. 22 illustrates oil grooving in a large crank pin bearing. The oil is introduced at the top, and the action of the oil grooves is partly to distribute the oil and partly to guide it back toward the middle of the bearing, in order to prevent it from escaping too freely over the ends of the bearing.

Oil grooves should always be cut shallow and have rounded edges; they should not come too close to the end of the bearing brasses; if they are cut close to the ends, oil runs away too freely, is wasted, and the bearing will be inclined to heat.

FRICTIONAL HEAT

The frictional heat developed in a bearing spreads into the journal and into the bearing itself. Where bearings are not watercooled or lubricated by a circulation oiling system, the whole of the heat developed must leave the bearing or journal by radiation into the atmosphere. Bearings, therefore, assume a temperature higher than the surrounding room temperature, and the higher the friction the greater will be the difference between the temperature of any part of the bearing and the room temperature. The difference is termed the *frictional rise in temperature,* or simply the *frictional temperature,* and forms a true guide as to the quality of the oil in service. Any reduction in the frictional temperature brought about by introducing another lubricant will mean that this lubricant is better in quality or more suitable for the conditions.

The frictional temperature remains practically constant for all room temperatures; *i.e.*, if the bearing temperature is 86°F. and the room temperature is 70°F., the frictional temperature is 16°F. If the room temperature rises to 74°F. it will be found that the bearing temperature will rise to 90°F; the friction developed is practically the same, and the bearing temperature must therefore be correspondingly higher, in order to radiate the same amount of heat into the atmosphere.

When bearings operate under conditions of high speed or pressure the heat developed may become so great that it cannot be radiated from the bearing surfaces sufficiently rapidly. Under such conditions it becomes desirable or necessary to introduce a circulation oiling system by which the flow of oil going through the bearings not only serves to lubricate, but also removes a large portion of the heat developed, so that this heat, carried away with the oil, can be radiated into the atmosphere from the oil tanks, oil pipes, etc., or, if necessary, can be removed by an oil cooling arrangement, as in steam turbines.

BEARING TROUBLES

Where trouble occurs, it is usually indicated by a tendency of the bearings affected to heat up. It will be instructive to analyze a number of the causes leading to heated bearings.

When the barrels of oil have been delivered, it is important that they be *stored under cover;* they should not be left in the open, exposed to sun and rain, as, particularly if the barrels are stood on end, rain water will find its way through the staves, resulting in the glue lining on the inside of the barrel being dissolved and spread throughout the oil. When such oil is used, the presence of lining material will cause excessive heating in the bearings.

When *opening a barrel,* the bung should be loosened by striking the staves with a mallet; if an auger be used, fine chips of wood, and dirt from the outside of the barrel, may easily find their way through the opening into the oil. The oil should therefore always be *poured through a strainer* into the oil cans. If this be not done, the small chips of wood and other impurities may get into the bearings and cause trouble.

When the oil is given out from the barrels direct, the overflow oil runs on to the floor or into savealls, which are not always clean, and there is the danger that some of this oil, including the dirt present will be given out for lubrication.

It is good practice to *keep the oils in cabinets,* preferably padlocked, so that the oil is not interfered with by unauthorized persons; there is then no waste oil.

Dirty oil cans are responsible for many hot bearings, and they should therefore be kept scrupulously clean; they should be closed at the top or provided with covers, so as to prevent, as far as possible, the entrance of dirt.

An oil can should never be used for more than one class of oil, and in order to prevent mistakes the name of the oil should be marked on the can.

Numerous hot bearings have been caused by the *wrong oil* being used. If, say, a spindle oil is used instead of an engine oil, it will cause heating, because it is too light in body to provide lubrication. If a very heavy oil is used in place of spindle oil, it will cause heating and the fluid friction will be excessive, because it is too heavy to spread over the bearing surfaces, owing to the high speed at which the spindles operate.

In some cases, oils like *linseed oil* or *turpentine* have been used by mistake; in other cases, the use of *badly filtered oil* or *waste oil,* instead of fresh oil, has caused great trouble.

When hand oiling is employed, bearings will be inclined to heat up if the *oilings are not sufficiently frequent.*

When drop feed oiling is employed many hot bearings are caused by the *lubricator running empty* particularly when the oil containers are of small capacity. Sometimes bearings heat up because the *oil congeals* in the lubricator or in the feed pipes and does not reach the bearings.

Sometimes parts of the lubricator, or the oil feed pipes from the lubricator to the bearings get *choked up with deposits* of various kinds, which may cause a reduction in the oil feed, reducing it to such an extent that the bearing heats up.

Fine sawdust in saw mills, or wood-working shops, flour dust in flour mills, lint in cotton mills, etc., have been responsible for such trouble. In one case the sight-feed drop oilers were invaded by thousands of tiny little flies, which, after a while, completely *choked the feed pipes* from the lubricators to the bearings.

Cotton waste, still largely used for cleaning down engines and machinery, should not be used for this purpose, as fine fluffy matter from the waste gets into the lubricators and oil, causing trouble. *Mutton or silk cloths* are much to be preferred, as they are free from fluffy matter and can be readily cleaned.

Oil may escape between the bearing keep and the bearing brass, instead of entering the bearing. With a liberal oil feed, the bearing will give no trouble, but when even a small reduction in the oil feed is attempted, the bearing will heat up, as it is only the surplus oil that reaches the bearing itself.

Very long bearings sometimes give trouble if they have *too few entrances* for the oil. For instance, a bearing more than 10 inches long and having only one oil inlet by the drop feed method, in the centre, will always be inclined to give trouble.

Some bearings are difficult to lubricate because the *pressure is upward,* instead of downward, which makes it difficult for the oil to spread, unless it is introduced at the bottom of the bearing.

In the case of *ring oiling bearings,* water of condensation from a very moist atmosphere may enter and accumulate in the bottom of the bearing, and will lift the oil out of the bearing, until finally the *oil rings revolve in water* and heating occurs. In ring oiling bearings, deposits formed by the oil itself or by impurities entering the bearing may cause the *oil rings to stick,* so that the oil supply fails and the bearing heats up.

Bearings lubricated by the *splash oiling system* may heat, due to the oil level being too low to provide adequate oil spray, or due to *emulsification of the oil,* by the presence of water of condensation and cylinder oil coming from leaking glands.

Water, either from the engine itself, such as condensed steam from leaking piston rod glands, or leaking cooling water, etc., etc., may find its way into the bearings and displace the oil; the bearings start heating as soon as the oil film is destroyed by the water.

Where the entrance of water cannot very well be avoided, the system of *daily treatment* of the oil (see under "Turbines") will always bring about an improvement.

In *circulation oiling systems* bearings may heat due to *deposit choking the oil inlet pipes.*

Deposits may be due to unsuitable or improperly manufactured oil, or to the *mixing of water and oil, or of two different oils.* If, for example, an oil heavily compounded with blown vegetable oils gets into the mineral oil in circulation, a large portion of the compound will separate out in the form of a sludge.

If mineral oil has been a long time in circulation and has become very dark in color and considerably weakened, the addition of a large quantity of fresh oil will throw down a dark colored deposit.

Oil distributing grooves or oil grooves in the bearings may be choked up for various reasons already given and thus cause trouble, in preventing the proper distribution of the oil.

Speeding up of the machinery, in order to increase production, may cause heating, as obviously higher speed will produce higher friction and may demand the selection of a more quick-acting or higher quality oil to give good results.

If the *load* on an engine is *increased,* it is not unusual to find that some of the bearings are not able to sustain the increased strain, and therefore heat.

Excessive strains in the bearings may also be produced by the settling of foundations, which throws the bearings out of alignment.

Excessive vibration may produce similar results.

Light load on a steam engine may cause heating of the crank pin bearing, there being an insufficient quantity of steam in the cylinder to cushion properly the movement of the heavy piston, so that the crank pin is subjected to excessive pressures.

Eccentric straps may heat due to bad internal lubrication, which increases the resistance in moving the steam or exhaust valves.

Driving belts and ropes after a time become slack and must be shortened. If they are shortened too much, they produce *excessive pressure* on the bearings supporting the pulleys over which the belts or ropes run.

Excessive moisture in the atmosphere causes cotton belts or ropes to shrink, whereas leather belting stretches.

In textile mills where a number of the high speed spindles are operated by cotton tapes and bands, the shrinkage of the cotton due to excessive moisture puts *excessive pressure* on the spindle bearings and causes heating.

Increased temperature will thin the oil, so that it may not be able to withstand the bearing pressures; for example, a new addition to a boiler plant in close proximity to the power house increased the temperature of an engine room so much that all bearings heated until an oil heavier in body was introduced.

Excessive load on an electric motor or the electrical part being out of order, will cause high temperature in the rotor; the extra heat thus conducted into the bearings may cause the oil film to break down, indicated by excessive heating.

In many classes of rough machinery, it is still frequent practice to replace bearings without any attention being given to *scraping them together with the shafts;* in fact, the bearings are allowed to "run themselves in," developing considerable heat and necessitating a liberal feed of heavy bodied oil during the first few days. Needless to say, this is a crude and undesirable practice.

Whenever a bearing has been excessively hot, the *bearing brasses warp,* the cheeks of the brass closing against and nipping the shaft; it is necessary to file away and *chamfer the edges* so as to facilitate the entrance of the oil.

Cracked bearing brasses allow the oil to leak away; the oil film is destroyed, and even with a liberal oil feed the bearing will be sensitive and inclined to heat.

Too soft white metal often causes heated bearings; as it yields to the pressure and slowly flows out of the bearings, so that the bearing surface constantly changes and never assumes a good working skin.

Too hard bearing metal frequently results in heating, because the bearing pressures are not uniformly distributed over the surfaces.

Rebabbitting of a bearing should be done in one pouring; if done in two pourings, the white metal already in the bearing will have partly solidified and will not melt properly together with the white metal poured in last. The result will be that in operation cracks will develop and the white metal will break loose. This also occurs when the white metal has been poured too cold, as it does not adhere closely to the shell.

After a bearing is rebabbitted, the bearing edges should be rounded off, and all necessary *oil holes and distributing grooves properly made.* Failure in these respects will cause heating of the bearing.

If appreciable wear takes place, the edges of the *oil grooves become sharp* and act as oil scrapers rather than oil distributors. The edges must be kept well rounded and the oil grooves should therefore occasionally be examined, particularly if trouble has occurred.

When worn bearing brasses have been replaced, the bearings sometimes heat because the new brasses have not been properly fitted or scraped together.

With crank shafts and the like which have recessed journals for the main bearings provided with filleted corners, heating may occur if the shaft has *insufficient room to float sideways,* as the shaft will bear hard against the fillet; expansion of the shaft may be the cause of this kind of heating; another cause is mentioned on page 163 for electric dynamos.

If the *bearing clearance is too small,* through too close adjustment, heating will occur, as there is insufficient room for the oil to produce a satisfactory film, and it becomes difficult for the oil to spread.

If the *adjustment of a bearing is too loose,* the oil escapes from the bearing too freely, and particularly in the case of bearings like crank pin bearings, which are subjected to intermittent heavy pressures, the oil will not be able to give sufficient cushioning effect to prevent metallic contact; pounding or knocking of the bearing takes place, resulting in heating and wear.

In *starting up* after a stoppage, say, over Sunday, certain bearings may be inclined to heat, as the power necessary to drive the mill or works is always a good deal higher than normal.

When *engines and machinery have been shut down for a longer period,* very special attention should be given to the lubricators and lubrication of all parts before recommencing operation; driving belts and ropes are stiff after the long standstill, and it must not be expected that the plant can be quickly run up to speed without trouble.

Excessive deflection of a shaft due to various causes will result in overheating of the nearest supporting bearings, as the shaft will bear more heavily on one side of the bearings, the heat developing and spreading from here.

When *bearings of electric motors or generators wear,* the slight lowering of the rotor due to this wear will cause the magnetic field to exert a strong downward pull on the rotor, thus increasing the tendency to wear and causing excessive heating.

Where *oils of vegetable or animal character,* or at least heavily compounded oils have been used, and where the new oil introduced is straight mineral or nearly so, the change over should take place gradually, as vegetable and animal oils produce a sticky, varnish or rubber-like coating all over the bearing surfaces and in the oil pipes. *If the change is made quickly,* heating is bound to occur or even seizure of the bearing surfaces, as the coating is loosened in lumps or flakes, preventing proper oil film formation. It takes time for the bearing surfaces to adapt themselves to the new oil.

When *introducing a new oil* which is appreciably different in character from the oil previously in use, it will nearly always be found that some bearings heat up. This may be due to a mineral oil dissolving deposits produced by a compounded oil, which on being too quickly loosened cause trouble, acting in the same way as grit or dirt.

The use of a *grease* containing dirt (which is not visible as in oil) and coarse graphite tends to choke oil pipes and oil grooves and is often responsible for heated bearings.

It is not unusual to find that a number of bearings in a mill are *using far too heavy an oil,* because a few bearings, operating under bad mechanical conditions have demanded its use to prevent overheating. It would be better economy to use the heavy oil on these few bearings only, or better still, to correct the mechanical conditions so that the proper grade of oil can be used throughout.

Cooling Heated Bearings.—When *small bearings* heat up they are usually easy to cool down, as the total amount of heat present in the bearings is not very great; usually a liberal supply of the oil in use is all that is required; if the bearing is heated to such an extent that it has been distorted or the white metal has started to flow, it must be dismantled and put in thorough working order.

When *large bearings* heat up, the case is very different, as large bearings may absorb and contain a great deal of heat; and when once a large journal starts heating and expanding, there is relatively so little clearance that the oil film is easily squeezed out and the bearing may seize. The first thing to do when a large bearing heats up is therefore to increase the bearing clearance by slacking back the bearing brasses.

If the bearing has not seized but only is extremely hot, it is usually sufficient to feed the bearing with a liberal supply of steam cylinder oil (which possesses superior lubricating properties under high temperature) until the bearing cools, when gradually the normal practice of oiling the bearing can be re-instated.

If the bearing has commenced to seize, a little graphite, talc, flower of sulphur, white lead, salt, sapolio, or like ingredients mixed with cylinder oil, may be used, as these solid ingredients help to smooth down the parts that have started to cut, thus enabling the cylinder oil to form a film. Even more drastic "remedies" like brick dust or grindstone dust have been known to cool bearings, when more greasy ingredients failed to separate the surfaces.

Castor oil is often employed for cooling bearings, but should be avoided where a circulation system is employed, because it mixes with the engine oil, and afterward develops deposits. Once a bearing has become accustomed to the use of castor oil it is not always a simple matter to change back to the original conditions.

The practice of *using water for cooling the bearings* from the outside is very undesirable, as the result of the sudden cooling is nearly always distortion of the bearing brasses, so that they have to be filed and scraped before satisfactory operation can again be expected.

LUBRICATION

The object of bearing lubrication is, firstly, to form a lubricating film between the rubbing surfaces and thus *replace the metallic friction with fluid friction,* as far as possible; secondly, to *reduce the fluid friction in the oil film itself* to the lowest safe point, considering the operating conditions.

No Lubrication.—If a journal revolves in its bearing without lubrication, metallic contact will cause abrasion of the metal and the bearing will not operate very long before the frictional heat developed will be so great that the bearing surfaces will be destroyed.

Oil-less bearings are an exception; they are made of some metal alloy or compressed wood, mixed with graphite, talc or other solid lubricant; or the graphite is firmly placed in the bearing in the form of spiral grooves or strips, or again, the whole bearing may be compressed talc, soapstone or graphite. Such bearings will often run without lubrication, and without seizure, but the friction is very high as also the bearing temperature.

Semi-lubrication.—By introducing a lubricating medium between the rubbing surfaces, the lubricant will adhere to the journal, as well as to the bearing, thus replacing part of the metallic friction with fluid friction; there will be less abrasion, therefore less wear, friction and heat.

The vast majority of bearings are semi-lubricated, *i.e.,* the rubbing surfaces are never kept completely apart, so that more or less wear does occur, and the loss in friction is not so low as it might be.

As all fixed oils are more oily than mineral oils, an admixture of a few per cent. to the mineral oil will increase its oiliness and assist in separating the rubbing surfaces more completely.

If it were not for the high price of fixed oils and their tendency to gum (particularly the vegetable oils) they ought to be much more widely used than is the case at present. It is particularly for heavy pressures and slow speed that great oiliness is so very desirable, necessitating the use of fixed oils. It is a well-known fact that castor oil and rape oils are extremely useful for very severe conditions of this kind.

Compounded oils also have the property of combining and emulsifying with water, so that their use is desirable where water gains access to the bearings. Water will displace a straight mineral oil and cause trouble, but will combine with a compounded oil and form an emulsion or lather, which particularly in the case of marine steam engines, is very desirable. If a bearing under such conditions heats up, the lather escaping from the bearing will lose its milky appearance and become semi-transparent, this being an indication of excessive bearing heat.

Compare remarks under textile machinery, marine steam engines, locomotives, stainless oils, etc.

Oil Film Lubrication.—By introducing a sufficient quantity of oil it is possible to form between the rubbing surfaces a complete oil film, which means that there will be no wear, and that the friction developed is reduced entirely to the fluid friction within the oil itself. Given the necessary surface speed, a suitable bearing pressure and the required flow of oil, as will often be the case with circulation oiling, ring oiling and bath oiling systems, the friction is entirely fluid friction determined by the viscosity of the oil, the surface speed and the area of the rubbing surfaces; oiliness is of no importance (except when starting and stopping); it is the viscosity alone which maintains the oil film. The higher the viscosity the more easily will the film be formed at low speeds; but at high speeds, high viscosity oils may give trouble and low viscosity oils should always be preferred.

Michell thrust bearings operate with perfect film formation, see page 170, and Michell has also applied this same principle to journals.

SELECTION OF OIL

In order to obtain efficient lubrication oils must be selected to suit the operating conditions and the oiling system employed.

Operating Conditions.—As mentioned under "Operating Conditions" the oil must be selected to suit the conditions of size, speed, pressure, temperature and mechanical conditions.

Speaking generally, *oils light in body* should be employed for such conditions as small bearings, high surface speed, low bearing pressure, low room temperature, and good mechanical conditions.

Speaking generally, *oils heavy in body* should be employed for large bearings, low surface speed, high bearing pressure, high room temperature, and bad or indifferent mechanical conditions.

Oiling Systems.—The oil must also be selected to suit the oiling system employed.

Hand Oiling.—Hand oiled bearings are rarely well lubricated; they are usually only semi-lubricated and demand the use of heavier bodied oils than would be required with a more efficient oiling system. This system wastes both oil and power. Unless the waste of oil is very abnormal compounded oils should be preferred for hand oiling, as such oils have greater oiliness than straight mineral oils, therefore last longer and give less friction.

Drop-feed Oiling.—In drop-feed oiled bearings less oil is wasted than in hand oiled bearings, and owing to the more regular oil feed, the oil film in the bearings is kept more uniform and more complete; the lubrication is therefore more efficient, *i.e.*, there is less friction and less wear. Under high pressure conditions compounded oils should preferably be used; for low or moderate pressures straight mineral oils will render good service.

Ring Oiling.—By the ring oiling system the bearing surfaces are constantly flooded with oil, so that the lubrication becomes as efficient as possible with the particular grade of oil in use. Straight mineral oils should be used, as compounded oils will cause gumminess on the oil rings and in the bearings.

Splash Oiling.—The oil should be light in body so as to splash easily to all parts, yet sufficiently heavy in body to produce satisfactory lubrication.

Circulation Oiling.—As the oil is forced in large quantities to the bearings, the oil is given every assistance to produce complete and perfect lubrication, and the heat is so rapidly removed that it becomes possible to operate engines employing this system at the highest speeds and yet maintain a great margin of safety in operation. The oil must, however, be of such a character as to maintain its nature, notwithstanding that it circulates continuously and is exposed to the oxidizing influence of air and impurities, the emulsifying influence of water, etc. Also, the oil must be of such a nature as to separate quickly from water and impurities, so that sludge or deposit developed may be easily removed from the oil in circulation. As to the nature of such oils—circulation oils—see remarks under "Turbine Lubrication," page 235.

The best oils used in splash oiling, ring oiling or oil bath systems possess similar characteristics.

Where hand oiling or drop-feed oiling systems are employed, the oil, after passing through the bearings once, is frequently run to waste and not used over again, in which case the slight alteration which takes place in the oil passing through the bearing is of no importance and compounded oils can be used without trouble.

When the oil, after passing through the bearings, is collected and filtered for the purpose of using it over again, either on the same bearings or for less important work, mineral oil may be preferred, particularly if it be used over and over again a great number of times on important bearings and with only slight loss.

Selection of Oil.—It will now be understood that when selecting oils for bearings operating at high speed, with low bearing pressures, and employing a good lubricating system, the chief object should be to reduce the fluid frictional losses, as here the question of wear is less apt to become an important factor.

For high-speed spindles in textile mills, high-speed shafting and machinery of many types, oils of the correct *light body* and quality should therefore be selected, and the result will be an appreciable reduction in power.

In bearings operating at slow speed, with heavy bearing pressures and using a less efficient oiling system, the danger of wear is great, and the chief object of lubrication here becomes minimization of wear, rather than the reduction of fluid friction.

For such bearings as are employed in large open type steam engines, heavy pumping plant, heavy machinery bearings, oils of the correct *heavy body* and qualtity should be selected.

There are many plants in which it is declared that there is no trouble. Whether this be so or not, there is a long distance from this no-trouble standpoint to perfection in operation; it is only by analyzing the actual conditions, carefully grouping various portions of the machinery, and using specially selected oils for each group to give maximum lubrication service, that perfect results can be obtained and maintained.

There are many types of modern machinery, such as steam turbines, high-speed steam engines, and internal combustion engines of all kinds and other high-speed machinery, where the conditions demand the use of the highest quality oil obtainable, almost regardless of its cost, and where smooth and safe operation and low frictional losses count many times more than the cost of the oil itself. On the other hand, where the class of machinery in use is rough or in bad repair, where wasteful and inefficient oiling systems are employed, and particularly where the care and attention given to the plant are indifferent or bad, it is not always possible to justify the use of the best quality lubricating oils. So much oil may be wasted to no useful purpose, that the cost of the oil thus literally thrown away will more than outweigh the value of the better lubrication which might be brought about by the use of better oils.

BEARING OILS

To satisfy the bearing requirements of the great variety of engines and machinery in existence, a great number of bearing oils are needed. Many of these oils will be mentioned under the class of machinery for which they are recommended, such as:

CIRCULATION OILS	For steam turbines, enclosed type steam engines, etc.
MARINE ENGINE OILS	For marine steam engines and other severe service.
LOCO ENGINE AND CAR OILS	For locomotives, tenders and cars.
SPINDLE AND LOOM OILS	For textile machinery.
BLACK OILS	For mine cars and rough machinery.
STEAM CYLINDER OILS	Used for bearing lubrication of enclosed type, splash oiled steam engines.

In all these cases there are service conditions which call for some special property in the oil, and therefore justify grouping such bearing oils in the way indicated above.

With *bearing oils* the author proposes to refer to oils intended to be used and recommended for all types of machinery, where the service conditions do not present any specially difficult features.

In other words, bearing oils are oils whose prime duty it is to lubricate and which are not required to withstand oxidation or emulsification (as circulation oils), or to lubricate heavy bearings in the presence of water (as loco and marine engine oils), or to possess stainless properties (as loom oils), etc.

Bearing oils are oils ranging in color from light red to deepest red; they must be refined but need not be specially well refined; in fact, excessive acid treatment or earth filtration removes many active unsaturated hydrocarbons, some of which are quite as good if not better lubricants than the saturated hydrocarbons.

A certain degree of refining is, of course, needed to remove a sufficient amount of the most unsaturated elements which, if left in the oil, would cause excessive gumming in the bearings.

The oiliness of distilled mineral lubricating oils can be improved by admixture of a small percentage, say from 5 per cent. to 10 per cent. of fixed oil, or a certain percentage of filtered cylinder stock. To make this point clearer, the author has found that when using oils compounded in this manner (*i.e.*, admixture of fixed oil or filtered cylinder stock) lower viscosity oils can be selected to render certain service, than if a distilled mineral lubricating oil were to be employed; the result is therefore, lower friction and wear.

Such savings in power accomplished by using lower viscosity compounded oils are mentioned page 318 for textile machinery. In the same way, power savings can be obtained by replacing a distilled mineral oil of a certain viscosity by a lower viscosity oil, which is made by mixing a spindle oil (or a blend of a spindle oil and a medium red oil) with a certain amount of filtered cylinder stock.

Without going more deeply into this matter, the author gives below approximate Saybolt viscosities at 104°F. for six bearing oils, which will be found to cover a wide range of service.

LUBRICATION CHART NO. 1, FOR BEARINGS

	Saybolt viscosity at 104°F., seconds	Recommended for
Bearing oil No. 1.......	95	Very light duty and high speed.
Bearing oil No. 2.......	120	Light or medium duty and medium or high speed.
Bearing oil No. 3.......	175	Medium duty and medium or high speed.
Bearing oil No. 4.......	250	Medium or heavy duty and medium or high speed.
Bearing oil No. 5.......	450	Heavy duty and slow or medium speed.
Bearing oil No. 6.......	700	Heavy duty and slow speed.

The author hesitates to give the above service recommendations which of necessity are very crude, but under the various sections of engines and machinery following this chapter he has endeavored to convey his ideas and experience in a more definite manner.

SEMI-SOLID LUBRICANTS

The various methods by which semi-solid lubricants are applied may be classified as follows:

Contact feed
Stauffer cups
Compression cups
Mechanical feed
Grease bath.

Contact Feed.—By this method the grease is placed direct on the journal, as, for example, in the dryer bearings of paper machines, the roll neck bearings in steel mills, etc. The grease adheres to the journal, melts away or softens and gradually wears away. Hard greases are generally employed. With soft greases the consumption is usually great, particularly when the bearing is worn as in that case the grease adhering to the journal is pulled into the large clearing space between the journal and the keep and is quickly consumed.

When soft grease is applied direct to the shafting it must be protected by a layer of yarn fibre grease, as for example in shafting bearings for weaving sheds and in bearings used in connection with the rollers which support rotary kilns in cement works. Such bearings have a large cavity at the top (Fig. 23); the yarn grease is placed all around the walls of this cavity and sometimes also there is a bottom layer touching the journal. In the pocket thus formed is placed ordinary cup grease or fibre grease, the grade being selected in accordance with the temperature conditions; exposed to the heat, the grease in the pocket melts slowly through the yarn grease and lubricates the journal.

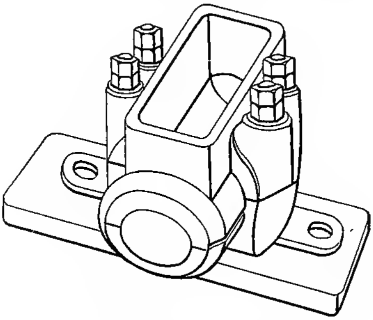


FIG. 23.—Contact grease feed arrangement.

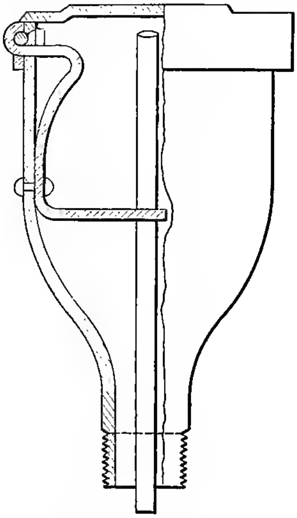
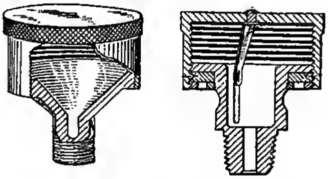


FIG. 24.—Gravity grease feed arrangement.

Fig. 24 shows a gravity feed grease cup designed for the use of low melting point greases or oils which are slightly soap-thickened, so as to be non-fluid at ordinary room temperatures.

The needle, in touching the shafting gets warm, melts a little of the grease and acts very much like the needle in glass bottle oilers (Fig. 19, page 109).

Stauffer Cups.—Fig. 25 shows an ordinary plain cup; the bottom is preferably sloping to facilitate the grease being forced out of the cup. The cover is given an occasional turn and a quantity of grease is forced into the bearing; it is gradually consumed until the cover is given another turn. To prevent thin grease from leaking out, the thread must be a good fit or a leather packing must be introduced as shown in Fig. 26. This drawing also shows a catch-pawl which prevents the cover from slacking back. .


Figs. 25–26.—Stauffer cups.

Compression Cups.—Compression cups may be operated either by a spring or by compressed air. Fig. 27 shows a typical spring compression cup. The spring (1) pushes against the piston (2). The feed can be adjusted by the screw (3). Only greases of No. 1 and No. 2 consistency can be used in this type of cup.

For harder greases of No. 3 or No. 4 consistency, a grease cup must be used like Phillips crank pin grease cup shown in Fig. 28. By turning the milled collar (1) grease is forced up into the small cylinder (2) raising the piston against the force of a strong spring, which subsequently feeds the grease until the indicator knob (3) shows that another feed must be given.

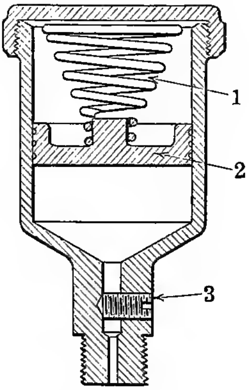


Fig. 27.—Spring compression cup.

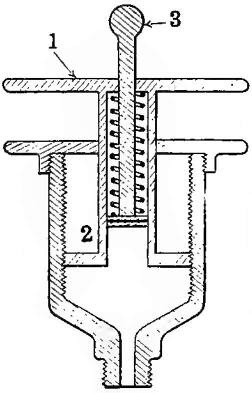


Fig. 28.—Phillips crank pin grease cup.

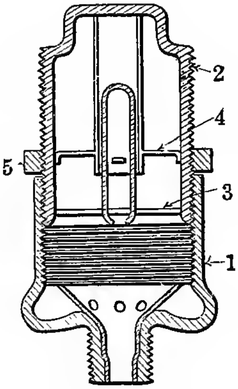


Fig. 29.—Menno grease cup.

Fig. 29 illustrates the Menno compressed air cup in which compressed air is employed for forcing out the lubricant. The lubricant is filled into the bottom portion (1) of the cup; this part is threaded to receive the upper portion (2) which on being screwed into the lower portion causes a certain air pressure to be formed above the grease. The object of the thin metal disc (3) which is guided vertically is merely to rest on top of the grease and keep it level. The fixed disc (4) forms the top of the air compression chamber. After giving the upper portion (2) a certain number of turns, it is locked to the bottom portion by means of a lock nut (5) and the air pressure will maintain a fairly regular feed. If the journal gets warm, the heat is conducted up into the cup through a thin funnel. The effect of this rise in temperature is to soften the grease, increase the air pressure, and give an increased feed of lubricant.

In grease cups for lubricating loose pulleys the centrifugal force acting on a piston may be made use of to force thin grease, or non-fluid oil, to the bearing.

Mechanical Feed.—In very large colliery winding engines or steel works rolling mill engines, hard greases, usually white greases, may be forced into the crank pins by means of mechanically operated lubricators as indicated in the sketch (Fig. 30).

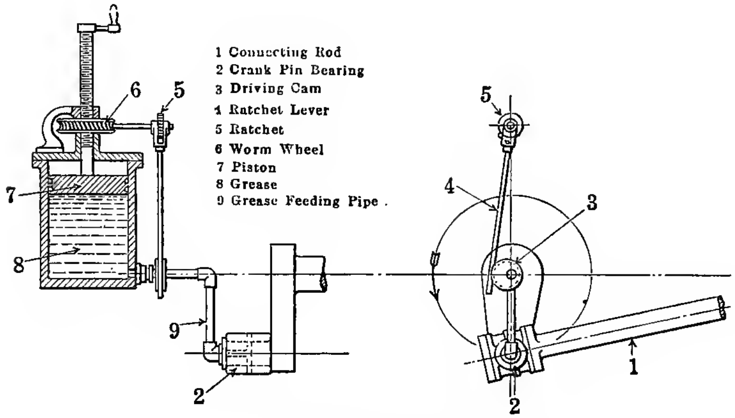


Fig. 30.—Mechanical grease lubricator.

The arrangement is very similar to the banjo oiler. A cam on the feed pipe (3) operates a ratchet lever (4). The motion of the ratchet wheel (5) and worm gear (6) actuates a piston (7) which forces the grease below the plunger through the feed pipe (9) into the crank pin. Another method is to place the lubricator complete on the crank pin itself. The lever (4) is then weighted at its lower end and swings to the right and left between two adjustable stops, owing to the motion of the crank pin. The lever in this way oscillates sufficiently to operate the ratchet, and the feed may be adjusted within certain limits, say, 1, 2 or 3 teeth per revolution.

The advantage of a mechanical feed as against compression cups is that the lubricant, whether soft or hard, is delivered absolutely uniformly, notwithstanding changes in temperature which either harden or soften the grease and the result of which with ordinary grease cups is that a uniform feed cannot be maintained.

Grease Bath.—A bath of grease may be employed in connection with ball and roller bearings, gear boxes of automobiles, gear chambers in pneumatic tools, etc.

The reasons why grease is employed are outlined under these several headings and are mainly to keep dust or grit out of bearings or to prevent excessive leakage of lubricant.

Greases of Nos. 1 and 2 consistencies are used for grease baths; harder greases create undue friction, are inclined to cake exposed to heat, and do not distribute themselves with sufficient ease.

GREASE LUBRICATION IN GENERAL

The conditions for which semi-solid lubricants are advantageously employed will be indicated in the following, fuller information being given under the various sections of machinery, etc., referred to.

In *dusty and dirty surroundings, e.g.*, cement mills, bakeries, colliery screening plants, etc., grease keeps the bearings clean; it entirely fills the bearing cavities and the clearance space and forms a fillet round the bearing ends, which prevents the entrance of dust and dirt. This is particularly important for ball and roller bearings.

When oil is used in *weaving sheds*, it is necessary to fix savealls below the bearings. For this reason grease is sometimes preferred to oil, because there is less likelihood of the spent lubricant dropping from the bearings on to the looms and soiling the goods.

When bearings are in *inaccessible places* and cannot be lubricated with oil by ordinary means, grease cups can be fitted, and the grease forced through tubes into the bearings from any angle.

Greases of high melting point—fibre greases and other greases—are required occasionally where the bearing temperatures or room temperatures are unusually high, such as the hot necks on dryers in paper mills, hot journals supporting the rotary kilns in cement works, hot roll necks in tin-plate mills and steel mills, etc.

Grease should be used only where there are special reasons against the use of oil. Wherever grease is used under conditions that are quite suitable for oil lubrication, the introduction of the correct grade of oil will always result in an appreciable saving in power. Grease lubrication means a heavy frictional resistance in the bearings, as obviously the grease does not commence to lubricate until the frictional temperature has increased to such an extent that the grease melts or becomes sufficiently soft to be "abraded" by the revolving journal.

The suitability of a grease depends on four things:

1. The purity of the grease and the absence of filling matter.
2. The consistency of the grease (to suit the method of application).
3. The quality of the oil and other ingredients in the grease.
4. The melting point of the grease (to suit the temperature conditions).

Purity is very important in greases which are used under conditions of high pressure or speed. Such greases should preferably be strained hot as mentioned, page 25.

Filling matter is non-lubricating; it lowers the manufacturing cost of grease, but usually detracts from its lubricating value. For rough mechanical conditions or for very high bearing pressures and slow speed, filling matter like graphite, talc, or mica may, however, prove advantageous, helping to fill up unevenness in the rubbing surfaces and preventing seizure. Filling matter containing gritty or hard impurities will cause wear, but may prove beneficial as a temporary remedy in the case of hot bearings

Consistency.—The consistency of grease is largely governed by the feeding appliances. If grease is applied through compression cups or gravity feed cups it must be soft, either No. 1 or No. 2 consistency, also when used for high speed bearings, ball and roller bearings.

For Stauffer cups, No. 2, No. 3 or No. 4 consistency can be employed.

A grease of No. 4 or No. 5 consistency may be selected for contact feed application in connection with slow speed open bearings, the grease resting direct on the rotating shaft.

Quality.—The quality of grease depends largely on the quality of the lubricating oil used in manufacture.

For medium and high-speed work, with no excessive bearing pressures, a grease should be chosen which contains a light-bodied lubricating oil.

For medium and slow-speed work with fairly heavy bearing pressures, the grease should preferably contain a more viscous oil; and for extreme conditions of pressure and slow-speed, fatty oils or fats must form part of the grease, as great oiliness is required. A percentage of solid lubricants may also be of advantage as mentioned under "Filling Matter."

Changing Grease.—When a change is made from white and other greases which contain much tallow or other fat or fatty oils to a mineral grease, as cup grease, the process must be gradual to avoid heating, this being just as necessary as when changing from, say, castor oil to a mineral oil.

SOLID LUBRICANTS

In order to determine the proper range of service for the various solid lubricants in the field of lubrication, the subject will be divided into the following sections:

The Action of Solid Lubricants
Methods of Application and Use
Observations on Results Obtained by the Use of Solid Lubricants.

In order to avoid having to refer repeatedly to the use of solid lubricants throughout the book the Author has at this place dealt with the entire field of service for solid lubricants in such a manner that further references to this subject may perhaps be considered unnecessary.

THEORY OF THE ACTION OF SOLID LUBRICANTS

It is generally agreed that the friction created in engines or machinery of all kinds is chiefly composed of what may be termed solid friction or fluid friction, or a combination of both; the latter condition representing the state of affairs in the great majority of cases.

In the following the influence of solid lubricants on each of these various kinds of friction will be dealt with separately. Reference will also be made to the use of solid lubricants for treatment of hot bearings.

Solid Lubricants and Solid Friction.—When a solid lubricant is introduced between otherwise unlubricated surfaces, the more or less finely divided particles of the lubricant associate themselves with one or other of the rubbing surfaces, filling in the pores and depressions and acting, as far as possible, as a smoothing and polishing agent, covering the original surfaces with a thin smooth layer of the solid lubricant. As a result, the coefficient of friction is reduced; the solid friction between the more or less rough original rubbing surfaces is replaced by the lesser solid friction between the smooth surfaces formed by the solid lubricant.

When abrasion takes place, it occurs not so much between the original surfaces (which possess great cohesion) as between the particles of the solid lubricant which have but little cohesion. Artificial amorphous graphite, for example, has practically no cohesion. If solid lubricants are employed, cutting and abrasion of the bearing surfaces are therefore much less likely to occur.

There are a variety of conditions for which dry solid lubricants have proved advantageous, as for example, in bearings or in such parts of machinery as are apt to be neglected from a lubricating point of view, and which operate at *low pressures and low speeds.* When such surfaces are well coated with graphite, for example, and particularly if they are rubbed down to a dense glazed finish, they will work upon each other for a long time with comparative freedom and without danger of cutting or wear taking place.

Solid Lubricants and Fluid Friction.—The application of solid lubricants to bearings in which a perfect oil film is established would at first sight appear to be of no value; the journal floats on a film of oil and the presence of small particles of a solid lubricant does not increase the viscosity to any appreciable extent. The friction under running conditions is therefore not increased unless the solid lubricant is present in such an amount that the particles "crowd" the oil film at the "point of nearest approach" between journal and bearing, and commence to act as an abrasive powder.

It has repeatedly been noticed in experimental work that immediately after a temporary application of solid lubricant in powder form the friction is much increased, but is reduced afterward, when the particles have had time to attach themselves to the rubbing surfaces and form a smooth coating. *The virtue in the employment of a solid lubricant lies entirely in the effect it produces on the rubbing surfaces themselves.* With perfectly lubricated bearings the chief advantage of using a solid lubricant is apparently the effect on the friction at the moment of starting, which results in a reduction in the static coefficient of friction.

Static and Kinetic Friction.—The effect of the use of a suitable solid lubricant or a solid colloidal lubricant, is, as we have seen, to reduce the tendency to abrasion and to produce a smoothness of the surfaces. As the solid lubricant cannot be displaced by pressure, the static coefficient of friction is reduced as compared with the result obtained when oil alone is used, assuming that the solid lubricant is of such a nature and used in such a manner that it has actually increased the smoothness of the rubbing surfaces.

Makers of the flake variety of graphite claim that this type of graphite lends itself better to the production of very smooth and slippery surfaces than the amorphous varieties; in bearings with rough or very rough surfaces the flakes adhere to one another and easily build up a surface. When the bearing surfaces are reasonably well finished, this "building up" action of flake graphite does not appear to be of special value; in fact, it may be detrimental where small clearances exist, particularly if fed in excess.

Solid Lubricants and Solid and Fluid Friction.—Under these conditions there appear to be great possibilities for the use of solid lubricants. Their object will be:

(*a*) To reduce the solid friction.

(*b*) To produce a smoothness of the rubbing surfaces, which will assist in distributing the load evenly over all parts of the bearing and thus enable a lower viscosity lubricant to be used and the fluid friction to be reduced.

(*c*) To reduce the wear of the original surfaces and the risk of abrasion or cutting of the surfaces which ordinarily leads to the production of hot bearings.

(*d*) To reduce the consumption of lubricant.

To obtain these advantages the solid lubricants must be of suitable nature, purity, fineness and hardness, and must be used in the right amount.

Nature.—A good solid lubricant must possess ability to adhere to metallic surfaces and it must be capable of producing a smooth surface. Graphite possesses both of these properties to a marked degree. When rubbed between metallic or non-metallic surfaces, graphite whether of the flake or amorphous variety produces a coating which is smooth and unctuous. Talc and mica do not adhere to surfaces as well as graphite does, nor do they produce as smooth a surface.

The quality of unctuousness in the surface produced is undoubtedly important; it is not possessed by materials such as flowers of sulphur or white lead which act more as abrasives than as lubricants.

Purity.—A high degree of purity of the solid lubricant is necessary in connection with lubrication of all high class machinery, whereas for rough bearings operating under extreme conditions and on the verge of seizure, a small amount of impurities may not be detrimental.

L. Archbutt has analyzed various samples of "Foliac" flake graphites (Graphite Products, Ltd.), amorphous graphite (Dr. Acheson's No. 1340) and colloidal graphites (Dr. Acheson's aquadag and oildag) as shown in Table No. 7. He makes the following remarks with regard to the colloidal graphites, indicating the presence of the vegetable deflocculating agent:

> "I have found that it is impossible to wash out the whole of the oil in 'Oildag' with ether and consequently the extracted graphite still contains some oil. I have had a similar experience in the analysis of 'Aquadag.' Although this was very largely diluted and slightly acidified with hydrochloric acid the precipitated graphite after filtering and thoroughly washing until perfectly free from chlorides and drying lost 9 per cent. when heated in a closed crucible. On heating some

of this graphite in a dry test tube, white fumes were given off with a smell of burning vegetable matter, and a brown oily distillate condensed on the tube."

TABLE 7.—ANALYSES OF LUBRICATING GRAPHITES, SUPPLIED BY THE GRAPHITE PRODUCTS, LTD., BATTERSEA

Description	Foliac flake graphite No. 100	Foliac flake graphite B.1371	Foliac flake graphite No. 2	Foliac flake graphite No. 1	Foliac flake graphite No. 101
Moisture	1.26	.32	.20	.29	.05
Further loss on heating 5 min. at faint redness in closely covered crucible	.09	.49	.42	.44	.34
Mineral matter (ash)	.37	4.79	1.93	9.87	.05
Graphite (by difference)	98.28	94.40	97.45	89.40	99.56
	100.00	100.00	100.00	100.00	100.00
Composition of mineral matter:					
Silica	....	3.00	1.06	4.84	
Alumina	Mainly	.67	.33	3.32	
Ferric oxide	Ferric	.86	.46	1.55	
Lime, etc. (by difference)	Oxide	.26	.08	.16	
		4.76	1.93	9.87	

ANALYSIS OF ACHESON GRAPHITE, GRADE No. 1340

Moisture	.07
Further loss on heating 5 minutes at faint redness in closely covered crucible	.23
Mineral matter (ash)	.66
Graphite (by difference)	99.04
	100.00

Composition of Mineral Matter:

Silica	.07
Alumina	.31
Ferric oxide	.25
Lime, etc. (by difference)	.03
	.66

ANALYSIS OF "AQUADAG"

The sample smelled distinctly of ammonia, and was found to contain:

Insoluble in water after coagulation by acidifying slightly	15.06
Water extract (by difference)	84.94
	100.00

Analysis of this gave the following results:

Loss on heating 5 minutes at faint redness in closely covered crucible	9.12
Mineral matter (ash)	1.20
Graphite (by difference)	89.68
	100.00

Composition of Mineral Matter:

Silica	.24
Alumina	.18
Ferric oxide	.65
Lime, etc. (by difference)	.13
	1.20

ANALYSIS OF "OILDAG"

Graphite, etc., insoluble in ether	11.2
Ether extract (oil)	88.8
	100.0

It was found impossible to free the graphite completely from oil by washing with ether. Analysis of the "graphite," as extracted, gave the following results:

Loss on heating 5 minutes at faint redness in closely covered crucible	7.01
Mineral matter (ash)	2.25
Graphite (by difference)	90.74
	100.00

Composition of Mineral Matter:

Silica	.21
Alumina	.35
Ferric oxide	1.02
Lime, etc. (by difference)	.67
	2.25

For convenience of comparison, the above analyses have all been recalculated on the moisture-free and volatile matter-free samples, and the results are given below:

	Acheson graphite No. 1340	"Aquadag"	"Oildag"	"Foliac" No. 100	"Graphite" B. 1371	"Foliac" No. 2	"Foliac" No. 1	"Foliac" No. 101
Per cent. of graphite	99.34	98.68	97.58	99.62	95.17	98.06	90.06	99.95
Per cent. of mineral matter (ash)	.66	1.32	2.42	.38	4.83	1.94	9.94	.05
	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

The "Foliac special large flake graphite No. 101" is almost chemically pure. The flakes have a pure silvery lustre when reflecting light; when not reflecting they appear absolutely black; a little of the graphite lying at the bottom of a deep narrow trough of white paper looks black and white, as if it were a mixture of two substances.

The "Foliac" No. 100 is apparently the same graphite as No. 101, ground very fine, and it contains more impurity, chiefly iron from the mill. The "Acheson graphite No. 1340," though of great purity, is less pure than the natural graphite, and it is of interest to note that the conversion of this into "aquadag" has introduced more impurity, and the further conversion of this into "oildag" still more. In all the Acheson graphites the principal impurities are iron and alumina. In the "Foliac" graphites, silica is the chief impurity. Another point to note, which may be of considerable importance, is the tenacity with which the vegetable matter and oil used in preparing "aquadag and "oildag" cling to the particles of graphite and cannot be removed by solvents."

Fineness.—In the case of well finished rubbing surfaces very finely divided graphite must obviously be used, and the coating of the surfaces is easier to accomplish than with rough surfaces. Under these conditions, makers of amorphous graphite claim that a flake graphite when used in excess is apt to build up too thick a surface and reduce the working clearance to a dangerous extent, whereas with amorphous graphite, excessive use can have no ill effects; the soft crumbly amorphous grains are easily crushed; in fact a surface of fine amorphous graphite under pressure moves within itself like a film of oil, and the particles are non-coalescing and offer little resistance to movement.

With highly finished and polished surfaces operating with small clearances it would seem undesirable to use powdered lubricants, however finely they may be pulverized. Colloidal lubricants appear to be the only solid lubricants likely to give satisfaction under such conditions.

The author has examined Dr. Acheson's graphite No. 1340 and the various Foliac flake graphites for fineness, the grading being given in Table No. 8. Foliac flake graphite No. 100 is exceedingly fine, although not so fine as Dr. Acheson's No. 1340.

Note 1.—The figure given for any mesh sieve means the amount passing through that sieve and retained on the next sieve, for example:

Foliac graphite No. 1 contains 20 per cent. of particles passing the 30/30 mesh sieve, but too large to pass the 40/40 mesh sieve.

TABLE 8.—GRADING OF GRAPHITES

Sieve, No. of meshes per inch	Acheson's graphite No. 1340, per cent.	Foliac flake graphite No. 100, per cent.	Foliac flake graphite B.1371, per cent.	Foliac flake graphite No. 2, per cent.	Foliac flake graphite No. I, per cent.	Foliac flake graphite No. 101, per cent.
10/10	....	....	....	....	2.0	10.0
20/20	....	....	....	....	15.0	40.0
30/30	....	....	....	....	20.0	24.0
40/40	....	....	....	1.0	22.0	20.0
50/50	....	1.0	.2	2.0	37.0	6.0
80/80	....	1.0	.2	2.0	2.0	
100/100	2.0	4.0	36.4	56.0	1.0	
200/200	98.0	94.0	63.2	39.0	1.0	
Flour...	95.5	89.6				

Note 2.—The per cent. of "Flour" (impalpable powder) is an arbitrary figure, determined by Petersen's florometer which consists of a vertical torpedo-shaped glass vessel, with a widest diameter of 4 inches, 4 feet 6 inches high with a 1-inch opening at the top and drawn out to a slender ½-inch tube at the bottom. An air current under 21 mm. pressure is passed up through the vessel for 15 minutes. Five grams of the graphite are emptied into the vessel and after the air current is switched off, the amount of graphite not blown away is weighed, the percentage of flour being thus easily determined.

Hardness.

HARDNESS OF SOLID LUBRICANTS

	Relative hardness
Pure graphite	1.0
Best quality of talc	1.0
Lower qualities of talc or soapstone	2.5 to 4.0
Micas	2.0 to 3.0

The admixture of a hard solid lubricant, like hard talc or mica, to a grease, particularly if an excessive amount is added, may cause a great deal of continuous but uniform wear, much more than would be caused by the grease used by itself, yet no cutting or excessive heating of the bearing may occur.

Amount.—Makers of flake graphite recommend the admixture of 3 per cent. to 4 per cent. of fine flake graphite with oil; if too much graphite be used, the friction is increased because there is more graphite introduced into the bearing than is required to keep the rubbing surfaces properly graphited. The surplus graphite present between the rubbing surfaces creates extra friction and heating.

If appreciably less graphite is added than 3 per cent. a point will be reached when the graphite coating will no longer be fully maintained and the full benefits from the use of graphite will not be obtained.

Makers of graphite greases recommend a percentage of graphite ranging from 3 per cent. to 10 per cent. More graphite is required with grease than with oil, because grease is usually employed for rougher conditions than oil, and more graphite is needed to build up the surfaces and maintain them in a smooth condition.

The effect of adding a solid lubricant to a lubricating grease is that in time the solid lubricant will attach itself to the rubbing surfaces, and by smoothing and polishing them will make it easier for the lubricant to do its duty. As a result, a softer grease, or a grease containing a lower viscosity oil can be employed than when no solid lubricant is added to the grease.

Makers of colloidal graphite find that a very small percentage of graphite is ordinarily required in the diluted colloidal lubricant. Dr. Acheson recommends a graphite content of 0.35 per cent. for most purposes. That this small amount has been found sufficient is probably explained by the fact that colloidal lubricants are chiefly used on high class machinery with reasonably well finished bearing surfaces.

Hot Bearings.—Hot bearings may be caused by excessive stresses or vibrations, by the accidental entrance of gritty impurities, by a shortage of lubricant, etc., etc. Whatever the cause may be the oil film becomes entirely displaced from a small portion of the bearing surface, a "dry" spot is formed, the surfaces enter into intimate metallic contact, the local temperature rises rapidly, the bearing seizes, and if it is lined with white metal, the latter may melt and flow out. Under such conditions, when a bearing gives warning by heating, the usual procedure is to resort to the use of a fixed oil, like castor or rape oil, or to a viscous mineral oil, like steam cylinder oil; the effect of using such oils is to produce a better film, which separates the metallic surfaces and reduces the temperature.

When the surfaces have commenced seriously to abrade one another, oils may prove of no avail and solid lubricants must be used, such as graphite. The graphite particles by coating and impregnating the surfaces make it difficult for the metallic surfaces to seize and if slight abrasion takes place in certain places, the graphite may often succeed in repairing the damage and make it possible for the normal lubricant again to take care of the condition.

Flowers of sulphur and white lead are often used to cure hot bearings; they act not so much as lubricants but rather as mild abrasives; they grind away the rough spots and produce a smooth surface.

Much more drastic remedies, such as salt, brick dust, and grindstone dust have been successfully employed in very serious cases of large hot bearings; their function is to grind away quickly the rough parts which have commenced to seize. They may be applied mixed with thick steam cylinder oils or castor oil, in order to produce a thick film. The oil should be applied liberally in order to clean away the gritty powder after it has done its duty.

In bearings which are inclined to run hot, it is good practice occasionally to apply a small amount of graphite to produce a graphitized surface, or to mix colloidal graphite with the normal lubricant, so as continuously to make up the wear on the graphite coating. In overloaded worm gears, for example, which are continuously inclined to seize, it is good practice to mix a small amount of flowers of sulphur or fine graphite with the oil; they serve to prevent seizure and the wear becomes more uniform.

METHODS OF APPLICATION AND USE

Solid lubricants may be applied in three different ways:

(*a*) Dry Application.
(*b*) Mixed with Semi-solid Lubricants.
(*c*) Mixed with Liquid Lubricants.

Dry Application.—Solid lubricants are applied dry in cases where for special reasons it is inadvisable or impossible to use an ordinary liquid or semi-solid lubricant. The finely powdered solid lubricant is put into a linen bag and the bag is pounced or struck against the parts requiring lubrication; or a syringe like that used for applying insect powder may be employed to inject a cloud of lubricating powder into the bearings.

The following examples are illustrative:

Lace-making Machines.—On certain reciprocating parts powdered graphite is used in place of oil, to avoid staining the fabric.

Bottle-making Machines. Galvanizing Machines.—Certain parts are exposed to extremely high temperatures; oil would burn away and leave a carbonaceous residue which would cause the parts to stick.

Chocolate Machinery.—To avoid oil dropping into the chocolate, all bearings may be lubricated entirely by dry graphite powder. The pressures and speeds are low, so that the friction developed is not too great for comfortable running.

Oil-less Bearings.—Oil-less bearings are referred to page 123.

For the lubrication of rubbing surfaces made of wood, graphite is very suitable; it is not absorbed, as is the case with oil. The graphite may also be applied mixed with grease, for the sake of convenience of handling.

Steam Cylinders and Valves.—Dry graphite in the form of small cylindrical sticks has been used in conjunction with oil for lubricating locomotive valves and cylinders, the oil being supplied by a separate lubricator. The graphite sticks are placed in a vertical tube and rest upon an abrasive wheel, which obtains a rotative or oscillating motion from some reciprocating part of the engine (the valve rod, for example). In this way, the abrasive wheel continuously abrades the bottom graphite stick and the graphite powder drops down a vertical passage direct into the engine.

Mixture of Solid and Semi-solid Lubricants.—The use of a solid lubricant in powder form is resorted to only in special circumstances. When there is no particular objection to the use of a fluid or semi-solid lubricant and it is desired to use a solid lubricant, it is obviously desirable to mix the two together. Semi-solid lubricants are eminently suitable as carriers for solid lubricants because being non-fluid, they prevent separation of the graphite, and, as they are themselves gradually consumed, they automatically supply the solid lubricant to the parts which they lubricate.

The admixture of solid lubricant usually ranges from 3 per cent. up to 10 per cent., rarely exceeding the latter amount.

Speaking generally, semi-solid lubricants are always improved by the admixture of a small amount of finely pulverized pure flake or amorphous graphite. Exceptions are bearings with highly polished surfaces and small clearances, and high class ball and roller bearings for which colloidal solid lubricants are the only solid lubricants that can be considered.

Mixture of Solid and Liquid Lubricants.—Ordinary solid lubricants cannot normally be applied mixed with liquid lubricants, because, however finely the solids may be pulverized, their high specific gravity causes them to settle out in the lubricators, oil pipes, etc. The finer the particles, and the more viscous the oil, the slower does separation take place, so that slight agitation may be sufficient to prevent separation. Mixtures of very finely pulverized solid lubricants and viscous oils, such as gear oil for automobile gear boxes may be kept mixed by the stirring motion set up by the gears.

Certain mechanically operated graphite-oil lubricators for steam engines are fitted with stirrers in the lubricator container as well as in the oil pipe leading from the lubricator to the engine, to assist in preventing the graphite and oil from separating.

This problem of preventing separation of the solid lubricant is one that is causing many difficulties and cannot be said to have been satisfactorily solved, on account of the mechanical complications which are involved.

Chapman and Knowles have patented a mixture of finely pulverized graphite and glycerine for lubricating steam engine cylinders. Before being mixed with the glycerine, the graphite is impregnated with a sufficient amount of petroleum or other hydrocarbon insoluble in glycerine, to reduce the specific gravity of the mixture to that of glycerine. As a result, the "graphite-petroleum" specks will remain in suspension in the glycerine, and the mixture can be pumped by a mechanical lubricator and supplied to the steam engine in the ordinary way.

Solid lubricants can, of course, be mixed with oil and, in the form of a more or less liquid paste, may be applied by hand to the bearings or parts requiring lubrication. This method is the one employed when "curing" hot bearings.

It would appear that the only really satisfactory way in which a solid lubricant can be automatically applied mixed with a liquid lubricant is to bring the solid lubricant into such a finely divided state that the particles become of a size approximating that of submicrons. This state of fineness cannot be obtained by mechanical means alone, but has been attained by certain processes, such as Dr. Acheson's process already referred to. Colloidal solid lubricants, when diluted with pure oil (oildag, oleosol) or pure water (aquadag, hydrosol) do not separate out to any extent; they can be diluted indefinitely and can therefore be applied to any engine or machine, mixed with the dilutent which serves as a carrier.

Archbutt[1] has made some syphoning tests with oildag and has proved that deflocculated graphite will pass over with lubricating oil through worsted trimmings with but little loss of its graphite content.

Many mechanical lubricators employ a sight feed arrangement, through which the drops of oil rise through a sight glass filled with water; no difficulty is experienced with oil containing colloidal graphite, as the surface of the oil is not penetrated by the water. It is different with watery solutions of colloidal graphite such as aquadag; they obviously cannot be passed through water. Johnston has patented a lubricator with a sight

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[1] Archbutt and Deeley, "Lubrication and Lubricants," p. 152.

feed glass filled with kerosene, through which the drops of diluted aquadag sink down on account of their higher specific gravity as compared with kerosene. This arrangement has proved quite satisfactory for feeding aquadag into the steam pipes of engines using saturated steam.

Drawbacks to the Use of Colloidal Solid Lubricants.—One unsatisfactory feature of colloidal graphite solutions is their black, "inky" nature, which creates strong prejudice against their use on the part of operators of engines or machinery; colloidal graphite stains are difficult to remove from the hands, etc. Colloidal talc will probably prove less objectionable in this respect than colloidal graphite.

The great drawback to all colloidal solid lubricants is, however, their susceptibility to the action of electrolytes, as for example, acids and alkalis. The presence of electrolytes causes rapid destruction of the colloidal films and flocculation or separation of the solid lubricant from the liquid in which it is diffused. The following experiments with dilute diffusions of oildag and aquadag in oil and water respectively, containing various percentages of mineral acid, alkali, fatty acid, acetic acid and petroleum acid show the tendency to flocculation. The oil used for the oildag experiments was a neutral filtered spindle oil to which was added the amount of oildag recommended by the makers, giving a graphite content of 0.35 per cent. of the blended oil. The results are as follows:

Mineral Acid.—It was found that even the slightest trace of sulphuric acid (H_2SO_4) precipitated the graphite. 0.1 per cent. of sulphuric acid caused flocculation inside 24 hours; 0.005 per cent. caused complete flocculation in three days.

Alkali.—The results with an alkali (caustic soda) were very similar.

Dr. Acheson himself has realized the importance of the purity of the mineral oils or water used for mixing with oildag or aquadag respectively. He states:

> "With deflocculated graphite the very best results will be obtained when the water or oil is absolutely pure, but commercially we may perhaps always have a very slight sedimentation of the graphite. The manufacture of practically pure or neutral petroleum oil may be made quite commercial, the presence of impurities in the oil now placed on the market being almost solely due to the failure of manufacturers properly to wash the oil. True, in some instances, while thorough washing may be performed with water, the water itself is not pure, which would still cause impurities to be found in the oil that would be capable of causing sedimentation of the graphite, but this residue

which is left by natural waters when they be of an impure nature, could finally be removed by a finishing wash with distilled water."

It is a fact that most if not all acid treated oils on the market are quite unsuitable for mixing with colloidal lubricants. The most suitable oils are perhaps the so-called neutral filtered oils, which during the process of refining have not been in contact with acids or alkalis, but are refined by earth filtration only. Most neutral filtered oils are produced only with low viscosity, and so the more viscous neutral lubricating oils suitable for blending with colloidal lubricants may have to be made by mixing a neutral filtered oil with filtered steam cylinder oil.

Even with the best of neutral filtered oils, very slight sedimentation takes place, but it is so slight as not to be of practical importance. The purity required of the mineral oil is, however, so essential that users of colloidal lubricants should be warned not to mix them with the ordinary grades of oils, unless they have the assurance of their suppliers that none of the ingredients present contain acid or alkali or have been acid treated.

Fatty Acids.—The flocculating action of fatty acid is not so marked as with mineral acid. 0.3 per cent. of linseed oil fatty acid precipitated the graphite in four days; 0.1 per cent. of the same acid took two weeks to precipitate the graphite completely. Professor Holde states that "free organic acid need not always act as a coagulant even with colloidal graphite; small quantities may under certain circumstances act as a stabilizer."

This experiment shows that, if precipitation of the graphite be avoided, colloidal lubricants should not be mixed with fatty oils or compounded oils which contain a fair amount of fatty oil.

Most oils used for marine steam engines, locomotives and other severe services are heavily compounded with vegetable or animal oil (from 10 per cent. to 30 per cent.) and contain an amount of free fatty acid, usually exceeding 0.5 per cent.

Acetic Acid.—The action of acetic acid was found to be similar in intensity to the action of mineral acid.

Petroleum Acids.—Petroleum acids (of a fairly volatile organic character) may be produced, during use, in oils employed in circulation systems in automobile engines, gas engines, oil engines, and Diesel engines.

In the author's experiments, petroleum acid was produced in the oil by blowing air through neutral filtered spindle oil heated to a high temperature (360°F.–400°F.) to accelerate the oxidation and the formation of acid. To the oil thus prepared was added the prescribed amount of oildag. The presence of 0.1 per cent. of petroleum acid caused complete precipitation of the graphite in five hours. When the experiment was repeated with another sample of oil similarly treated, but only slightly "blown," containing 0.01 per cent. of petroleum acid, the flocculating action was much less marked, but after 2 weeks complete separation took place.

The amount of petroleum acid produced in the oil during prolonged use in an automobile engine will not be very great. 0.01 per cent. may be considered an average amount, assuming that the oil is a neutral filtered oil, and as oils for automobile use are fairly viscous, there is perhaps not much to fear from the presence of petroleum acid. Obviously, the more viscous the oil is the slower does the graphite separate out.

With splash oiling systems which do not depend on circulation of the oil by means of a pump, there is no danger in the use of colloidal lubricants, no matter what kind of oil is used, for if precipitation of graphite takes place, it will merely accumulate in the bottom of the engine and can do no harm. But with automobile engines employing an oil circulation system, highly purified neutral oils would appear essential in connection with colloidal lubricants, on account of the danger of choking up oil pipes, oil grooves, etc.

Oils taken from enclosed high speed gas and Diesel engines have been examined, containing over 3 per cent. of free carbon in suspension, which had produced no ill effects on the engine. The carbon had been formed by carbonization of the lubricating oil inside the cylinders, and had worked its way down into the crank chamber and mixed with the oil; probably a large amount of this carbon was present in colloidal form. It is a well-known fact that black waste oil from internal combustion engines of all kinds cannot be freed from its carbon content by filtration and that gravity separation in settling tanks may take months to accomplish and is rarely completely satisfactory.

The normal graphite content of 0.35 per cent. in an oil blended with colloidal graphite, if separated out in a engine, would be considerably less than the 3 per cent. of free carbon referred to above, but its nature being different, only practical experience can determine the actual risk incurred, if any, by the use of such "impure" oils as will cause precipitation of the graphite.

Emulsifying Effect of Water.—A quantity of diluted oildag was mixed with an equal amount of distilled water and shaken in a reciprocating bottle-shaking machine for five minutes at room temperature. All of the colloidal graphite emulsified with the water and formed a tenacious sludge which on standing separated out between the clear oil at the top and the clear water at the bottom. It would appear, therefore, that colloidal lubricants should not be recommended for use in circulation oiling systems, when water is likely to enter the system, as is invariably the case with steam turbines, enclosed type, force-feed lubricated steam engines, and the like.

In many enclosed type internal combustion engines (automobile engines, gas engines, etc.) there is no great likelihood of water mixing with the oil in service, and no objection can be raised to the use of colloidal lubricants from this point of view.

When it is desired to apply colloidal lubricants temporarily to certain bearings, there is no objection to mixing them with the lubricant in use, independent of the character of the oil, because the mixture is immediately introduced, and there is no time for the colloid to separate out and cause trouble.

If mixtures of "impure" oil and colloidal lubricants are used continuously for a period by one of the many comparatively slow feed oiling arrangements (bottle oiler, syphon oiler, drop feed oiler, pad oiler, etc.) the colloid will flocculate and accumulate, the flow of oil not being sufficient to wash it away. As a result, narrow oil passages are choked, the supply of lubricant ceases, and trouble may easily occur.

Summary.—Finely pulverized solid lubricants cannot be automatically used mixed with oil unless they are kept continuously mixed by a special stirring mechanism or by the motion of the parts to be lubricated.

With colloidal lubricants, there is no difficulty in obtaining a perfect mixture, but it is imperative that only very pure oils be used for making the mixture, unless the conditions of service are such that flocculation of the colloid is not likely to lead to difficulties or trouble of a serious character.

OBSERVATIONS ON RESULTS OBTAINED BY THE USE OF SOLID LUBRICANTS

Bearings.—There are numerous experiences which testify to the value of solid lubricants, and of graphite in particular for use in bearings.

One British railway reports that good results have been obtained by using either colloidal graphite or flake graphite mixed with their ordinary loco engine oil. The graphite is not used for regular running (the compounded loco engine oil would cause flocculation of colloidal graphite, and flake graphite cannot be suspended in the oil), but only as a temporary remedy, whenever important bearings are inclined to heat.

Several works report that by continuous use of colloidal graphite mixed with pure mineral oils they have obtained excellent results on heavy duty bearings (heavy pumping engines, etc.) which previously gave trouble, even when using oils heavily compounded with fixed oil. Not only did the bearings run cooler, but also with an appreciable reduction in consumption of oil and without flocculation of the graphite.

Where no care has been taken to provide specially pure mineral oils, flocculation has occurred and choking of oil channels, etc., has resulted.

Some bearings of high speed fans, which were troublesome with oil alone, ran reasonably cool when using the same oil mixed with colloidal graphite.

A maker of dictating machines found that customers did not trouble to oil the motors; they tried oildag and found that, even when the motors received no oil for several months after the initial application of oildag, no scoring occurred, owing to the graphitized surfaces produced in the bearings.

One maker of jaw crushers lubricated the Pitman bearing by a continuous flow of water mixed with some Hudson's soap extract and bicarbonate of soda. The Pitman always groaned for about 15 to 20 minutes after starting up; after aquadag was used mixed with the water the groaning entirely ceased.

Saving in power has been reported by several firms resulting from the admixture of colloidal graphite with the oil in use.

One important maker of ball and roller bearings deprecates the use of graphite altogether for such bearings, reporting several decided failures as a result of using graphite.

As the chief object in providing lubrication for ball and roller bearings is to maintain the highly polished hard surfaces in good condition, and little lubricating properties are required, it would appear inadvisable to use powdered or flaky solid lubricants for this purpose, as they would probably not improve the surface of the balls, rollers or races; only colloidal lubricants seem to have a chance of success for such bearings. The only ball and roller bearings in which the nature of the lubricant has an influence on the friction are those in which pure rolling does not take place *i.e.*, in three- or four-point contact ball bearings and in roller bearings which develop end thrust; here some rubbing takes place under extreme pressures, and if the surfaces are impregnated with an exceedingly fine solid lubricant they are likely to operate with less wear and friction.

Some large lifts have vibrator wheels about 5 ft. in diameter, which travel along a smooth shaft of 8 in. to 9½ in. diameter.

These wheels are bushed with cast iron and require careful and reliable lubrication. It has been found that by replacing ordinary lubricating grease with a grease containing artificial amorphous graphite the number of scored shafts and the amount of wear were materially reduced.

The lubrication of worm and worm wheel reduction gears is always difficult; the pressure between the teeth is very great; even with an abundant supply of oil, the friction consists of a certain amount of solid friction in addition to fluid friction. It is therefore to be anticipated that the use of graphite in connection with the gear oil would prove beneficial, and the results of experiments carried out at the National Physical Laboratory with oildag and flake graphite on Lanchesters worm gear testing machine show this to be the case. These experiments show that the addition of oildag to a mineral oil of relatively low oiliness improves the gear efficiency, so that the results are equal to those obtained by animal or vegetable oils.

Fine flake graphite (Foliac No. 100) also improved the efficiency with most of the mineral oils tested, and where an improvement was recorded it was greater than with oildag. The results appear, however, to be less consistent and there was distinct evidence of greater wear than with oildag.

When the temperature of the oil is increased, a critical point is reached at which the gear efficiency rapidly decreases. The effect of adding oildag or flake graphite was in every case to raise the critical temperature about 18°C. so that an increased margin of safety in operation was thus obtained; this happened even if the addition of solid lubricant did not increase the gear efficiency at lower temperatures.

Steam Cylinders and Valves.—In many steam plants great economies could be effected if the exhaust steam could be utilized for heating or drying purposes, for washing or cooking, or if the condensed steam could be used as hot feed water. One reason why this is not done more often is the presence of cylinder oil in the exhaust steam. The oil can be entirely eliminated from the condensed steam by electrical or chemical means, but not from the exhaust steam itself before condensation, although good oil separators may take out as much as 99 per cent. if the cylinder oil is pure mineral in character, *i.e.*, not compounded with fatty oil, such as tallow oil.

An interesting paper was read by Mr. E. W. Johnston in 1916 before the Birmingham Association of Mechanical Engineers in which he gave his experiences with the use of colloidal graphite (aquadag diluted with water), the graphite contents of the diluted mixture being 0.35 per cent.

When a suitable lubricator had been devised by Mr. Johnston, aquadag was adopted as cylinder lubricant in February, 1912, on a plant including three 50-kilowatt high-speed vertical steam dynamos, two deep bore-hole pumping engines, boiler feed, circulating, and other steam pumps supplied with saturated steam at 120-pound pressure.

The following results were quoted by Mr. Johnston in his paper:

"One of the high-speed engines, after accurate gauging of the valves and cylinders, was put on a six months' running test. At the end of this period the greatest wear at any point was found not to exceed one-thousandth of an inch, and it was particularly noticed that the walls of the high pressure cylinder and piston rings were in faultless condition, having mirror-like surfaces. Since uniformly satisfactory results were obtained also on the pumping engines and other auxiliaries, the entire plant has been working with aquadag as the sole cylinder lubricant from February, 1912, up to the present moment. All available condensed steam is now returned to the boilers, so that approximately 10 per cent. only of make-up water is added daily. The interiors of the boilers are free from grease, practically clean down to metal, save where patches of old scale still adhere, and entirely free from suspicion of "pitting." Formerly a considerable amount of scale of very tenacious character had to be dealt with, which resulted in loss of efficiency, extra labor and wear and tear to the boiler. Now, on the other hand, a feed water of considerably higher temperature and exceptional purity is available, resulting in further considerable fuel economy. After almost five years' daily use, there is found to be no deposit throughout the receivers, ports, valves and cylinders in excess of the thin coating formed in the first few weeks of use, and little if any trace in the exhaust pipes, condensers or other tracts beyond the engines."

Mr. Johnston kindly gave the writer a piece of a piston ring which had seen 9 years total wear, the last 2½ years with aquadag lubrication. It was arranged to take some microphotographs (Fig. 31) of the surface in order to examine the surface coating of graphite more clearly; it may be remarked that the graphited surface had a mirror-like polish; these photographs were prepared by Mr. S. Whyte, whose report is quoted herewith:

"Photos *A*, *B* and *C* are from the same spot on the polished face.

A is as received.

B after removing the polished surface with 0000 French emery paper.

C after etching with picric acid to show the original structure of the cast iron.

In each case the free graphite of the original cast iron is seen appearing as bands. The deposited graphite from the oil is fairly evenly distributed, and is exceptionally dense in the softer matrix of the eutectic, *i.e.*, in the pearlite areas. The cementite or iron carbide areas of the eutectic are very hard, and are seen standing in relief. The original cast iron contains patches of this eutectic (which is made up of pearlite and iron carbide bands) which, of course, is the principal constituent of a white cast iron; graphite plates and pearlite areas being the principal

Fig. 31*A*.

Fig. 31*B*.

Fig. 31*C*.

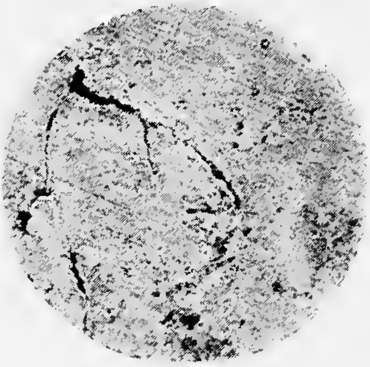

Fig. 31*D*.

Fig. 31*E*.

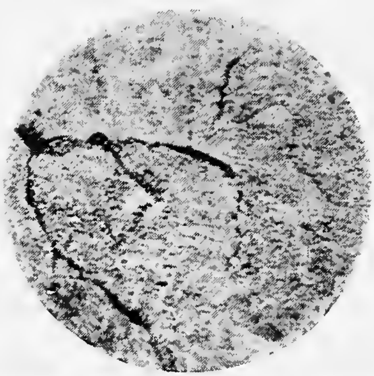

Fig. 31*F*.

constituents of a gray cast iron. Pearlite itself is made up of alternate bands of pure iron and iron carbide.

In microphotograph *B* all that is seen is the graphite plates of the original cast iron, and here and there among the eutectic area, specks of the deposited graphite which had penetrated about two ten-thousandths of an inch, and were not removed by the polishing.

Microphotograph *C* shows the pearlite area (banded structure, and also the eutectic areas faintly outlined. This structure is, of course, brought out by etching.

Enclosed also are three microphotographs *D*, *E* and *F*, from another field. The focus is bad as, with the curved surface, it is impossible to get a flat field. The same order of things prevail but the deposited graphite here is more evenly distributed, as the working pressures appear to have been higher on this surface and the cast-iron itself is deformed to a considerable extent. The softer portions of the iron on the surface have actually "flowed" as can be seen by the graphite plates being partially covered over—see microphotograph *D*.

Light polishing on 0000 French emery removed the deposited graphite, but did not remove the surface layer of deformed iron which had been forced partially over the graphite plates—see microphotograph *E*. This is confirmed by microphotograph *F* showing the broken up structure of the cast-iron underneath when etched with acid."

The photomicrographs show that the minute depressions or pores in the cast-iron have been filled up with graphite and that the graphite coating is essentially a *surface coating*, although slight penetration of graphite was observed in a small soft area of the surface (B).

It is reasonable to assume that Aquadag can be used on larger vertical engines than those referred to by Mr. Johnston, as it is fairly easy to lubricate vertical steam engines. The lubrication of horizontal engines is more difficult, and no experiments appear to have been made with Aquadag on such engines.

It would be interesting to know how far aquadag or some other aqueous colloidal lubricant can be used in connection with steam motor vehicles and the like where it is desired to use condensers for the exhaust steam; its use would make oil separators unnecessary and reduce scale formation in the boilers. The use of aqueous colloidal lubricants is probably limited to engines employing saturated steam and engines of small power; it must be kept in mind that if it were not for the water film produced by steam condensation in the cylinder, the friction would be very high indeed. In engines employing superheated steam, there is little or no condensation in the cylinders and it becomes necessary to provide a lubricating film in order to avoid excessive friction and wear.

Many experiments have been made with graphite and oil for the internal lubrication of steam engines employing superheated steam. Pure, fine flake graphite may be used, or colloidal graphite may be mixed with the cylinder oil, which should preferably be a pure mineral oil, not compounded with fatty oil, as is the case with most good quality steam cylinder oils. The results of graphite employed in this way have in many cases been very satisfactory; appreciable reductions in consumption of oil have been recorded, also less wear of internal moving parts. Alongside these results there are also a great many failures, although no failures have been reported with colloidal graphite. The failures with flake graphite have been due to excessive and injudicious use of the graphite, or to the use of coarse or impure graphite, or to breakdown of the complicated lubricators required to keep the graphite-oil mixture well stirred.

Under superheat conditions the surfaces are more difficult to lubricate than with saturated steam, and the necessity for not overfeeding with graphite will be readily understood. Excess graphite accumulates behind the piston rings and in the metallic packing, and will in time make the rings inflexible in their grooves, resulting in scoring of the surfaces, leakage of steam past pistons and piston rods, etc., etc. Great care must be exercised in the use of flake graphite for superheated steam conditions, and only the purest graphite must be used, in order to avoid excessive wear of pistons, piston rings, cylinders, piston rods, metallic packings, etc.

Graphite has been used by many marine engineers for lubricating large, unbalanced "D" type slide valves. Cast iron being more or less porous is a material particularly likely to benefit from the use of graphite: when the pores are filled and a graphite coating is produced it will be found that an exceedingly small amount of graphite is required to maintain the surfaces in good condition. Impregnation of such surfaces with graphite reduces the tendency to abrasion and makes it easier for the cylinder oil to maintain efficient lubrication.

When a mixture of flake graphite and cylinder oil is used for the internal lubrication of steam engines, the graphite will in time find its way out with the exhaust steam; it is easily separated from the steam and deposited in the oil separator or hot well. Flake graphite will adhere to the baffles in the separator, and accumulations should be removed at suitable intervals.

In all cases where the use of graphite has brought about a reduction in consumption of steam cylinder oil, it has also reduced the quantity of oil reaching the boilers, and therefore reduced the possibility of boiler troubles from this source.

Internal Combustion Engines.—The use of solid lubricants for the internal lubrication of internal combustion engines has been the subject of much controversy, and various opinions have been expressed regarding such features as preignition, carbon formation, sooting of sparking plugs, ease of starting, oil consumption, and reduction in friction.

Preignition may be due to accumulation of carbon deposits, but the cause of preignition appears to be not so much the carbon itself as the earthy and other impurities (road dust, lime, iron oxides, etc.) which may be present in the deposit. Artificial graphite whether in the amorphous or colloidal form seems here to possess advantages over most natural graphite, as the presence of minute earthy impurities is more easily avoided in artificial graphite. As compared with the use of oil alone, the tendency to preignition may be said to be increased, more or less, according to the purity of the graphite.

Carbon Formation and Sooting of Plugs.—Contradictory reports are received with reference to this point. In small engines, such as motor cycles, no difficulty is experienced; some records even report less sooting of plugs when using colloidal graphite, but that may perhaps be explained by a more economical use of the oil when using graphite.

The colloidal graphite is not consumed in the combustion space but in the form of an exceedingly fine dust spreads and adheres to the walls of the combustion chamber and the sparking plugs. The greater the consumption of oil, the more graphite is deposited.

The formation of oil-carbon depends on the amount of oil burnt inside the cylinders and on the nature of the oil; some oils produce more carbon than others, but the amount of oil carbon produced will normally never exceed 0.02 per cent, of the oil used. Although hydrocarbon oils contain over 80 per cent. of carbon, most of the oil is vaporized and decomposed into other hydrocarbons, with the result that the actual amount of oil-carbon formed is a very small percentage of the amount of oil consumed.

When mixing colloidal graphite with oil to give a graphite content of, say, 0.35 per cent. in the mixture, it must be remembered that this graphite is not consumed, and unless a large percentage of the graphite is swept out by the exhaust gases or a very large reduction in oil consumption takes place, the formation of carbon may easily be greater than with oil alone.

Ease of Starting.—Opinions appear to be unanimous that when graphite is used, engines (motor cycles, automobile engines, gas engines, etc.) start more easily and with greater freedom. The following contribution to "Motor Cycling" for January 23d, 1917, may be quoted:

> "I found when using oildag that carbonization was markedly reduced, even under the very heavy lubrication that I give my engine as a rule. Engine 'freeness' (allowing for the inherent freeness of the engine) is marked. The pressure of either valve spring acting on the engine via the tappet and cam was sufficient to rotate the back wheel of my T. T. single to the point of rest of the valve spring, so you can imagine there was not much friction in that engine. The cylinder walls took on a very high mirror-like polish. I found no concretion behind the piston rings, and what carbon deposit there was in the cylinder head and on the piston top was soft and easily removed. The effect of the graphite on the valve stems, particularly such a hot-working stem as that of the exhaust valve, was wonderful. The graphite was able to resist the heat, and gave the valve stems a similar 'mirror' surface to that of the cylinder. I further used it as a general lubricant for the cycle details. Carburetor slides polished and lubricated with

oildag worked very smoothly and with a minimum of air leakages. It was also useful as a dressing for screw threads liable to bind or stick, and on valve caps and plug threads; it made a good but easily broken joint."

Oil Consumption.—Saving in oil consumption, made possible by the use of graphite, is due to the smoother surfaces of pistons and cylinders and the more uniform and slightly smaller clearance space between them. Better compressions are also obtained due to less leakage past the piston. When the initial oil consumption is large, as with aircraft engines, the saving is apt to be overlooked; but with small engines and where adjustable mechanical lubricators are employed, the saving obtained may be quite considerable.

Reduction in Friction.—Speaking generally, half the friction in an internal combustion engine is piston friction; the lubricating oil film is probably never complete and so a certain amount of metallic contact (solid friction) invariably takes place. Porous cast-iron surfaces are easily filled and coated by graphite and an appreciable reduction in friction may be anticipated when the necessary care is taken in the judicious use of the right kind of graphite.

In the United States colloidal graphite appears to be extensively used for the initial "running in" of automobile engines; it is said to save considerable time in producing a good surface and gives the engines a good internal "skin" before leaving the builders' works.

Ropes, Chains and Gears.—Various greases are usually employed for the lubrication and preservation of ropes, chains and gears, and, as already mentioned, the admixture of a small amount of good quality finely divided graphite is beneficial. Messrs. Hans Renold, Ltd., find that with intermittently lubricated chain drives, graphite grease containing artificial amorphous graphite is very suitable. When the chain has been soaked in the hot liquid grease it will work without further lubrication for a long period, sometimes for several months, whereas with thin oil in use it must be applied at least once a week, and then the results are not always satisfactory, a reddish deposit (rust) being found in the bearings of the chain. With graphite grease this deposit does not form. The same firm also reports that the clutch band in their power clutches, when lubricated by graphite grease, requires no attention for long periods.

When chains or gears are enclosed in an oil tight casing, the use of an oil bath is preferable to grease; in this case the admixture of a small amount of finely pulverized graphite or colloidal graphite is also beneficial. Messrs. Hans Renold, Ltd., report some interesting results from the use of diluted oildag in connection with chains, lubricated by an oil bath. Their figures are as follows:

Power of motor	20 H.P.
Length of line-shaft	90 ft.
No. of line-shaft hangers	10
No. of chain drives	25
Total length of chain drives	275 ft.
Line-shaft speed	310 r.p.m.

RATE AT WHICH ELECTRICAL ENERGY WAS CONSUMED IN WATTS

Conditions	Starting up cold	After short run	After 105 hr. run	
			Starting up cold	After short run
Line-shaft hangers and chains lubricated with ordinary oil	5,000	4,000		
Chain lubricated with oildag	....	3,750		
Line-shaft hangers lubricated with oildag	..	3 500		
Chain and hangers lubricated with oildag	....	....	4,000	3,000
On further application of oildag to chains	....	....	....	2,500

Metal Cutting and Wire Drawing.—Colloidal solid lubricants—such as aquadag—have been used as coolants for cutting purposes. Experiments seem to indicate that colloidal solid lubricants are not satisfactory when used for this purpose by themselves. They do not flow to the tool point if it is greasy, and the tool point therefore wears; when they are mixed with ordinary cutting emulsions or soap and water, good results have been obtained, but the high first cost of colloidal lubricants militates against their use for cutting purposes; the staining effect of the graphite on the hands of the operators is also objectionable.

In metal wire-drawing operations semi-solid lubricants are used, such as mixtures of olive soap and powdered talc. There appears to be no reason why a vegetable soap mixed with a suitable amount of finely powdered graphite should not be capable of rendering good service.

Aquadag is used in wire-drawing the metal filaments (Dempsters Patent No. 17722 of 1911) used in electric lamps; the dies require a certain amount of lubrication to produce a satisfactory thread, and aquadag is apparently the only non-oily lubricant which has given satisfaction for this purpose.

CHAPTER IX

RING OILING BEARINGS

Ring oiling is largely employed on modern high-speed shafting bearings, practically all electric motors and electric generators, also small steam turbines. Main bearings in most gas engines, Diesel engines, and horizontal oil engines, as well as many steam engines, employ the ring oiling system for the crank shaft bearings.

The advantages of ring oiling over the drop oiling system are many, such as:

1. Better and more uniform lubrication.
2. Greater oil economy.
3. Greater factor of safety in operation.
4. Greater cleanliness.
5. Less attention required.

Ring oiling is used for small as well as large bearings, but not for the very smallest, say, below 2 inches, running at high speeds, as the rings frequently fail to operate and it is difficult to prevent frothing and waste of oil.

The bearing housing (Figs. 34*A* and 34*B*), forms an oil reservoir in which the oil is maintained at a certain level, preferably indidicated by an oil gauge which may also serve for the introduction of the oil.

On the shaft is usually suspended one or two rings or chains dipping into the oil; when revolving, the rings carry oil to the top of the shaft, from which it runs into the oil-distributing groove on the "on side" of the journal and spreads over the bearing surfaces. This groove extends to within ½ inch of the bearing ends and is well chamfered to facilitate the oil wedging its way into the bearing. If the motor is reversible, two oil-distributing grooves are obviously needed, one on each side. No other oil grooves should ordinarily be made, as the high surface speed assists the oil materially in getting in between the rubbing surfaces.

When the surface speed is low and the bearing pressure high, oil grooves may be advantageous, as explained page 115.

When speeds are low, or the oil becomes thick (cold mornings) oil rings may not start readily. Fig. 32 illustrates an oil ring with notches filed on the inside, which is said to assist the ring in starting, owing to the greater friction between the ring and the shaft.

For low-speed bearings, oil rings are sometimes replaced by chains, which touch the shaft over a longer arc and are therefore kept in motion with greater certainty than plain rings. At high speeds chains have the disadvantage that the links churn the oil, which leads to foaming and leakage of oil rom the bearings.

When the speeds are exceptionally low, say a few revolutions per minute, neither rings nor chains are satisfactory, and oil rings or collars fixed on the shaft are employed, whence the oil is removed by stationary scrapers in the upper part of the bearing, guiding the oil afterward into the oil-distributing groove. Such bearings are employed on the drying cylinders of paper-making machines and other slow speed machinery, but are also occasionally used for moderate speed machines. Oil rings are usually made twice the diameter of the journal, the oil level being at a distance below the shaft about half its diameter.

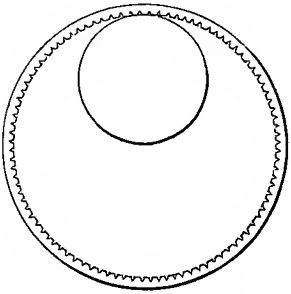

Fig. 32.—Notched oil ring.

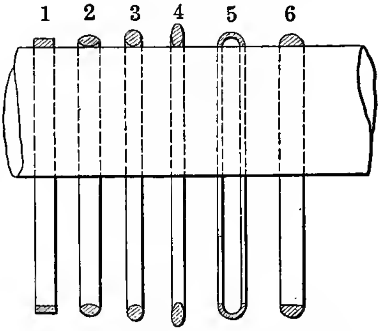

Fig. 33.—Various types of oil rings.

One oil ring will suffice for bearings up to 8 inches in length. Two oil rings are needed for bearings from 8 inches to 16 inches in length, and three oil rings for larger bearings.

As to the shapes of oil rings, there are a great many; some are indicated in Fig. 33. They should preferably be made undivided. When made in two halves and jointed, slight wear may cause the rings to operate irregularly or even refuse to revolve. Unevenness at the joint at high speed leads to foaming of the oil and oil spray. Unevenness or roughness on the two sides of the oil ring will have similar effects. Rings which are slightly oval, due to lack of care during manufacture, will obviously be inclined to stick.

In large bearings, cooling of the oil by introducing a cold water coil in the reservoir may be found desirable or even necessary under severe conditions. (See Turbines.)

Difficulties sometimes occurring with ring oiling are:

- (*a*) Foaming and spraying.
- (*b*) Leakage, endways or sideways.

Foaming and Spraying.—Troubles of this kind may be due to too high revolving speed of the oil rings, or to too low an oil level (which brings about quick speed of the rings owing to the smaller resistance offered to the movement of the rings through the oil). The oil is violently thrown away from the rings forming oil spray, oil foam being formed by the rings drawing air into the oil where they enter the oil well. Excessive foaming and oil spray always mean waste of oil, as the finest oil spray finds its way through the bearing ends or covers. Such loss of oil may become dangerous by lowering the oil level so much that the bearings will receive too little oil.

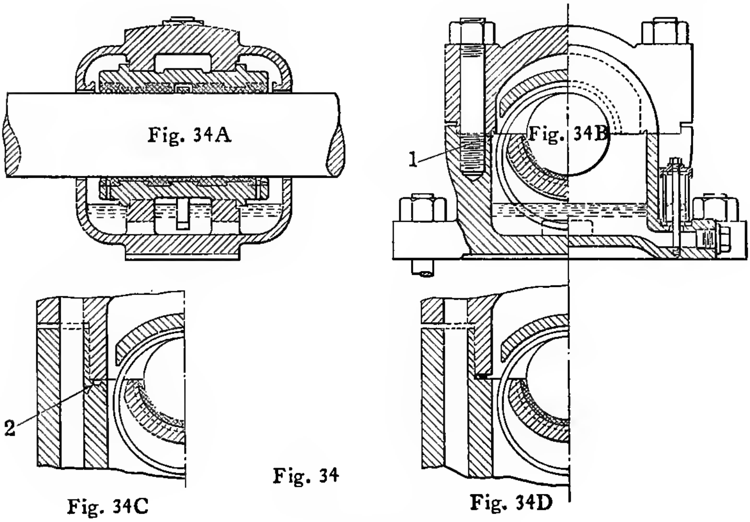

Fig. 34.—Ring oiling bearing.

Leakage through the side of the bearing between the top and bottom parts can be overcome by inserting a thin leaden wire which, when the bearing is put together, is squeezed flat and forms a seal (Fig. 34*D*). The lip (1) in Fig. 34*B* is intended to prevent such oil leakage; also the longitudinal drainage groove (2) in Fig. 34*C*, which is sometimes found in large bearings, draining the oil back to the reservoir at its two ends.

The proper remedy is, however, to have a type of oil ring suitable for the size and speed of the shaft. The speed of the oil rings is governed by the *propelling force* caused by oil adhesion between the ring and the journal, where they touch at the top, and the *retarding force* caused by the opposition to movement created by the speed of the ring through the oil in the well. It will be recognized that oil rings Nos. 2, 3, 4 and 5 will give lower ring speeds (more slip) than oil ring No. 1; whereas No. 6 will usually give greater speed than No. 1 owing to less surface in contact with the oil—therefore less resistance with the same propelling force. By finding out from practical experiments which type of ring gives a suitable speed, and oil feed, the majority of troubles with ring oiling bearings may be overcome.

It is particularly important to study this point when outside the bearing there is a pulley, which in revolving creates a suction, tending to increase loss of oil from the bearing. The oil when leaving the ends of the bearing drops back into the oil reservoir and is thus kept in constant circulation. If the bearing is well designed, there will be very little oil waste by leakage or oil creeping along the shaft. Sometimes the oil creeps spirally along the shaft and is thrown away where it is least desired, creating unsightly oily floors, or spoiling fabrics (cloth looms, for example). The remedy may lie in lowering the oil level or altering the type of oil ring, but the root of the trouble may be wrong shaping of the bearing surfaces. Fig. 34*A* shows how the edge must be rounded off, which helps to prevent oil creeping, whereas a sharp edge does not hinder the oil in passing along the shaft.

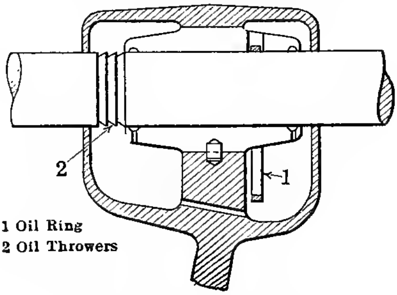

FIG. 35.—Simple oil thrower.

An excellent arrangement is to have a circumferential oil groove with *sharp edges* as shown in Fig. 34*A* with a drainage hole at the bottom; in addition, a longitudinal drainage groove also with sharp edges will assist in preventing excess oil reaching the bearing ends, as shown at the right-hand side of Fig. 34*A*. Other methods rely upon oil throwers formed on the shaft and suitable shapes of bearing housings at the end to receive the oil and convey it to the oil reservoir.

Fig. 35 shows the simplest form of oil throwers. This construction with a drainage passage from left to right through a centre wall in one case caused the oil to overflow from the left-hand chamber, owing to the passage being almost choked with dirt .

Bearing Clearance.—A clearance of 0.002 in. + 0.001 in. per inch of shaft diameter represents normal practice and will give satisfaction as long as the deflection of the shaft due to an overhanging pulley, heavy flywheel, or rotor close to the bearing does not exceed this clearance.

To take care of such shaft deflection medium and large size bearings are frequently self-aligning, being made with spherically seated housings.

Care of Ring Oiling Bearings.—When ring oiling bearings are well designed, with large oil wells and employing good quality oils, they will operate for long periods without undue attention or loss of oil. During the first few weeks of service the oil wells of new bearings should be emptied and recharged with fresh oil every few days in order to remove any molder's sand or grit which may still be present in the bearing. Once the bearing is clean and a good "skin" formed it will be sufficient to empty the wells every three months and recharge them with fresh oil, or a mixture of filtered and fresh oil. When the bearings are situated in dusty surroundings, more frequent changes of the oil may be desirable, as dust will find its way into the oil, notwithstanding precautions in the way of wooden or felt rings fitted in the bearing ends; of course such rings do reduce the amount of dust which enters. Where chemical fumes are present in the air, which have a destructive effect on the oil, it must also be changed frequently.

When good quality mineral oil is used it can be filtered and used over and over again, so that the oil consumption per year is usually very small. When oils with a mineral base, but compounded with animal or vegetable oils, are employed, they will develop gumminess in the bearings and necessitate cleaning. Such cleaning is unnecessary when straight mineral oils are employed; cases have been known where good quality oils have been in use for years without any real necessity for cleaning the bearings or the oil wells.

When a change is made from a compounded oil to a mineral oil, the latter will loosen the accumulations formed by the old oil. In such cases it is advisable to renew the charge after a few weeks' run; the oil when withdrawn will be very dark in color, due to the deposits and perhaps very slight initial wear due to the bearing surfaces adapting themselves to the new oil, but a fresh charge ought to work clean, if the new oil is of the right quality, and the bearing has been completely cleansed.

CHAPTER X

ELECTRIC GENERATORS AND MOTORS

Satisfactory bearing lubrication, *i.e.*, cool running and inappreciable wear, is very important. If wear takes place, the rotor is lowered, and the magnets will then exert a pull on the rotor in a downward direction, which further increases the bearing pressure and accordingly the wear. Most bearings therefore operate with bearing pressures of 50 to 100 lb. per square inch and are oil flooded.

Ring oiling bearings are most frequently used.

Ball bearings are also coming much into use, particularly as smaller size horizontal bearings and as vertical bearings, and in dusty surroundings, in which case grease is often used in preference to oil.

When a new generator or motor exhibits a tendency to develop heat in one bearing, the bearing should, of course, be examined. If it be found in good condition, the cause of the heating may be found in the thrust of the armature shaft against the bearing, which may result from one of two conditions. First, the machine may not be level and the armature shaft may "dip." Second, the magnetic centres of the pole pieces and armature may not be in line; that is, the pole pieces may not be exactly centered in their relation to the magnetic centre of the armature axially, and as the tendency of the armature is to run to the true magnetic centre, it will automatically tend to move toward that position, which may cause the shaft collar to rub against the bearing at one end, and cause heating.

The unbalanced magnetic condition may have been caused by forcing the armature not quite far enough or a trifle too far on to the shaft in the factory. Some motors are furnished with slots in the field magnet yoke through which the field magnet cores are bolted to the yoke, and the cores may be shifted a trifle to the right or left to compensate for any slight axial unbalancing of the magnetic centre as compared with that of the armature. Moving the magnet cores 1/16 of an inch will, as a rule, be sufficient to give relief. If the field magnet yoke is not slotted, a light cut may be taken off the shoulder of the shaft, at the end which rubs against the bearing, in order to obtain the necessary clearance.

Oil throwing from the bearings into the generator or motor is a troublesome disease often very difficult to cure. Several remedies have been mentioned under ring oiling bearings but they are not always effective with those types of electric dynamos which create a draught. When the generator is enclosed and the ventilation led in from below, this danger does not exist, or at any rate only to a slight extent; but when the generator is not enclosed, the oil finds its way into the ventilating ducts, tending to choke them with dirt and dust, which adhere to the oil. The oil also gets on to the commutator or slip rings and causes sparking.

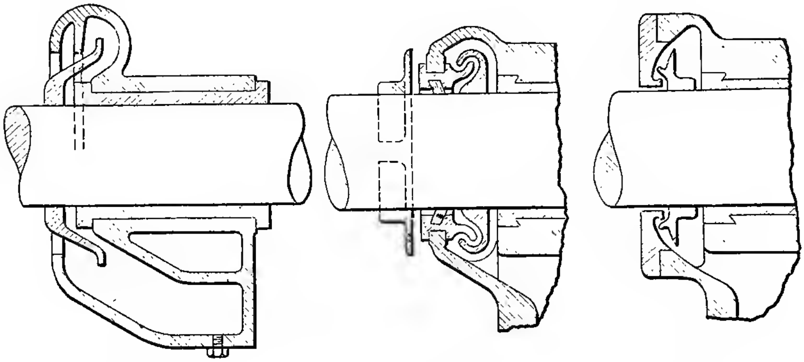

FIG. 36. FIG. 37. FIG. 38.

FIGS. 36–38.—Oil throwers.

In Figs. 36, 37 and 38 are illustrated some more elaborate methods adopted to prevent oil throwing. Fig. 37 shows a series of thin copper plates, which only lightly touch the shaft and thus create an effective labyrinth seal; but they are inclined to cause wear of the shaft, small gritty particles embedding themselves in the soft copper surfaces. Certain information on this subject is also given under "Turbines."

It is said, and it sounds quite feasible, that compounded oils do more damage when getting on to the windings than straight mineral oils, as they absorb moisture and thus reduce the insulation resistance of the armature more than straight mineral oils, which are not hygroscopic.

Commutator Lubrication.—Lamp oil (kerosene) used very sparingly is probably the best oil to keep the commutators clean and well lubricated. It also softens the mica and thus causes it to wear down so that it does not stand out beyond the bars.

DYNAMO OILS

Three grades of dynamo oils will take care of most requirements; they are all pure minerals oils, namely, Bearing oils Nos. 2, 4, and 5 (see page 128). The oil is somewhat exposed to oxidation during its continuous circulation in the bearings, but as long as the bearing temperatures do not exceed, say, 120°F. there is no need to have specially prepared dynamo oils; where the oil exceed temperature 120°F., circulation oils of the corresponding viscosities should be preferred to ordinary bearing oils.

A rough guide for selecting the correct viscosity of dynamo oil is given in the following chart:

LUBRICATION CHART NO. 2
FOR ELECTRIC GENERATORS AND MOTORS

Bearing Oil No. 2 *or Circulation Oil No.* 1.—For small electric generators or motors up to 50 H.P. and up to 100 H.P. when there is no excessive belt pull on the shaft close to the bearing.

Bearing Oil No. 4 *or Circulation Oil No.* 2.—For larger electric generators and motors under normal operating conditions, and for motors below 100 H.P. with excessive bearing pressures.

Bearing Oil No. 5 *or Circulation Oil No.* 3.—For generators or motors above 100 H.P. operating with excessive bearing pressures.

Ball bearing grease is employed only for smaller motors, operating in dusty surroundings or in hot and moist climates.

CHAPTER XI

PLAIN THRUST BEARINGS

Horizontal thrust bearings are designed to take up axial thrusts of revolving parts, as for example in horizontal centrifugal pumps or turbines or the propeller shafts in marine steam engines.

Vertical thrust bearings are employed to carry the weight of revolving parts, as in vertical water turbines or centrifugal pumps, vertical electric generators or motors.

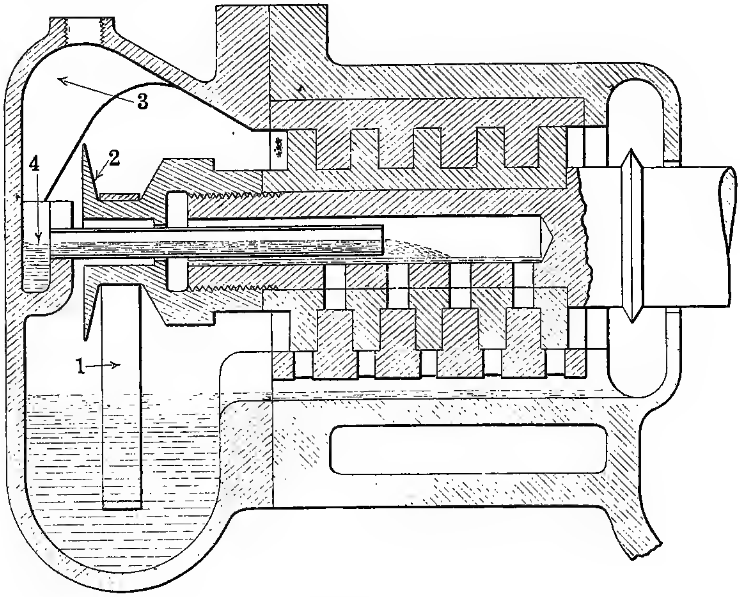

FIG. 39.—Ring oiled thrust bearing.

Collars on the shaft transmit the pressure to stationary collars, various means being employed to introduce an oil film between the rubbing surfaces, as described under "Turbines" and "Marine Steam Engines." Fig. 39 illustrates a method of oiling the thrust bearing in high-speed pumps by means of an oil ring (1); the oil is thrown off the collar (2) against the oil catcher (3) whence it runs into the oil cup (4) and reaches the hollow shaft, finally returning to the oil well. The lower part of the bearing is water cooled. Fig. 40 illustrates an unsatisfactory method, as the large oil disc (2) causes foaming and creates heat.

Fig. 41 illustrates an ingenious method of providing oil circulation in a vertical thrust bearing supporting a shaft revolving at 1,500 r.p.m. upon which is fitted an electric motor driving a centrifugal deep well pump at the lower end of the shaft.

The shallow spiral grooves on the part (1) lift the oil into the oil chamber (2); the oil pressure created here drives the oil through the oil drillings in the shaft; the oil after doing its work reaches the oil return channel (3) and the oil well (7) which is so arranged that the oil cannot overflow down the shaft. The drain plug (4) is removed when it is desired to empty the bearing, and when the bearing is being filled through the filling plug (5), the overflow plug (6) is removed so as to ensure a correct oil level. When thrust bearings have only one collar or one rubbing surface, they are called step bearings or pivot bearings.

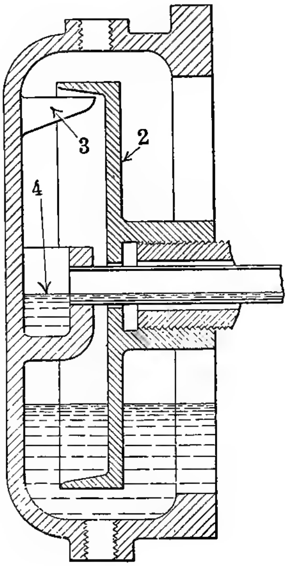

Fig. 40.

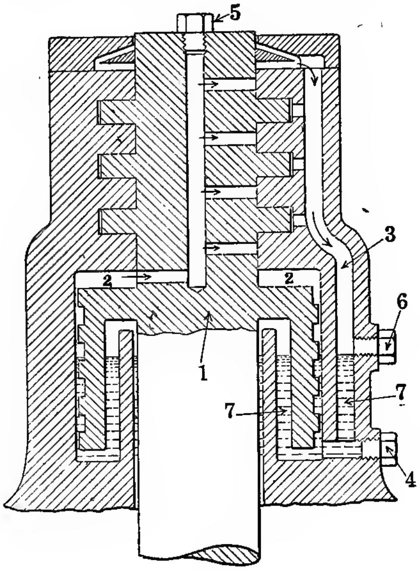

Fig. 41.—Vertical thrust bearing automatic oil circulation.

Fig. 42 illustrates the simplest form of step bearing; the revolving shaft rests on three washers; the top washer may be arranged to revolve always with the shaft, so as to save wear of the shaft itself. With low bearing pressure only one washer is needed; the higher the pressure the more washers are required. When one washer begins to heat and seize, it stops revolving and one of the cooler washers commences to revolve, so that they more or less divide the work between them, only one washer acting at a time.

The washers should always have shallow radial oil grooves cut in their rubbing faces, the grooves stopping slightly short of the edges, and the trailing edges of the grooves should be well rounded to facilitate the entrance of oil between the surfaces.

The oil enters the central hole, rises to the top, due to centrifugal action, and returns through the drain hole. When such bearings get uncomfortably warm, a remedy is to increase the flow of oil by means of a pump which forces the oil in under pressure: the oil returns from the top through a pipe into an oil reservoir, whence the pump draws its supply. In this way a greater radiating surface is obtained and the bearing will run cooler.

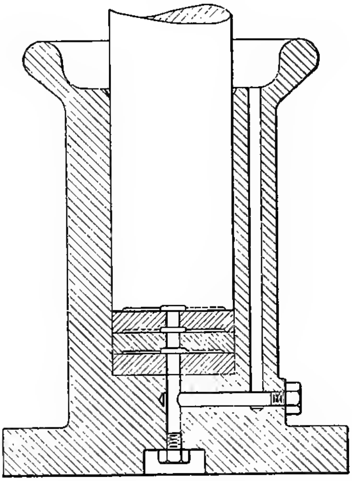

Fig. 42.—Step bearing.

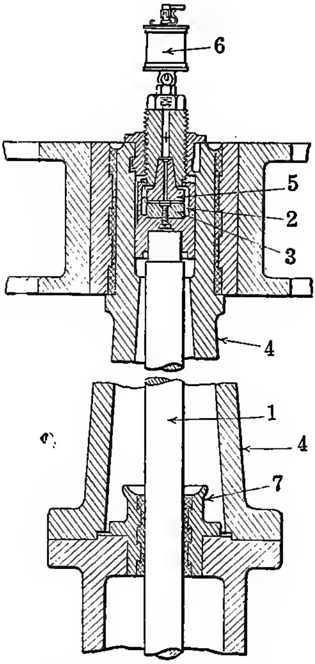

Fig. 43.—Water turbine bearing.

Vertical water turbines make use of bearings as illustrated in Figs. 43, 44 and 45. In Fig. 43 the weight of the turbine is taken by a stationary vertical shaft (1) which has an oil reservoir (2) at the top with a bronze washer (3). The hollow revolving shaft (4) carries the weight of the revolving parts and transmits the pressure through the hardened steel part (5) to the washer (3). Oil is fed through the top from a sight-feed drop oiler (6). The overflow oil runs down into the guide bearing (7), which is

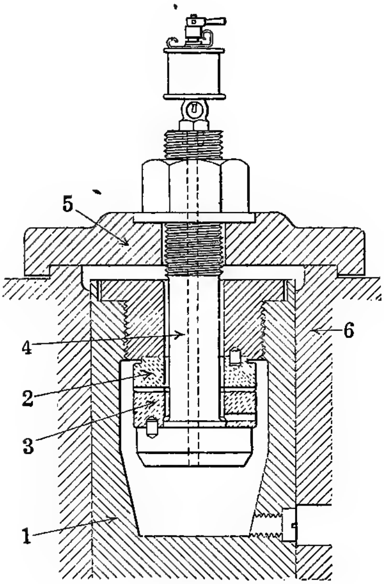

Fig. 44.

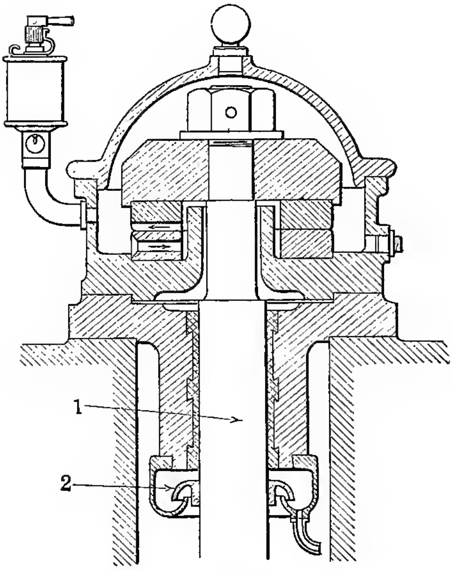

Fig. 45.

Figs. 44, 45.—Water turbine bearings.

under water; at the lower end there is a gland packing to prevent entrance of water into the hollow shaft, but as some water generally gets in, compounded oils, such as Marine Engine Oil No. 1 or No. 2 (see page 258) should be used, which will emulsify with the water and maintain efficient lubrication.

In Fig. 44 the shaft (1) and washer (2) revolve; the stationary washer (3) receives the full pressure and transmits it through the stationary shaft (4) and cover piece (5) to the casing (6). The oil circulates continuously through the oil grooves, which extend right to the edge. It will be noticed that the bearing surface in this design is very small; the bearing is very compact, so that a rich viscous oil, as Marine Engine Oil No. 1 must be used.

In Fig. 45 the bearing surface is much bigger, also the radiating surface is greater, which gives cooler running; ordinarily a slow oil feed from a sight feed drop oiler suffices, but where high pressure exists and the heat developed is great, an oil circulation system may be employed.

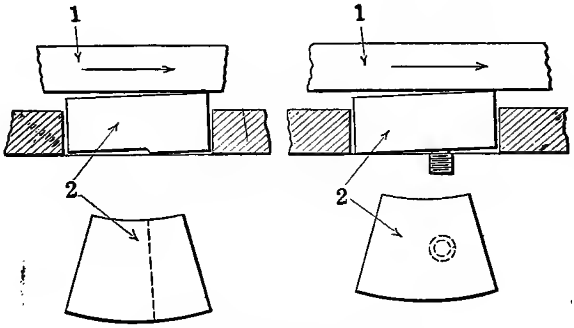

Fig. 46.—Michell thrust pads.

The oil to use in such bearings as Figs. 40, 41 and 45 may well be Circulation oil No. 1 or 2, as the bearing pressure is low, and the revolutions are usually high, say above 100 r.p.m.

A special type of step bearing is employed in the Curtiss vertical turbines, as described page 230.

By far the most satisfactory and reliable type of thrust bearing for heavy pressures, whether the speeds are high or low, is the Michell single collar thrust bearing. The collar or footstep rests upon a fixed bearing surface, which is divided into a number of segmental pads, each pivoted so that it is free to rock and take up any inclination to the moving surface, which the conditions of speed, pressure, and viscosity of the oil may demand. Fig. 46 shows two methods of supporting the pads, viz., pivoting along a line and on a point, the pivoting line or point being placed a

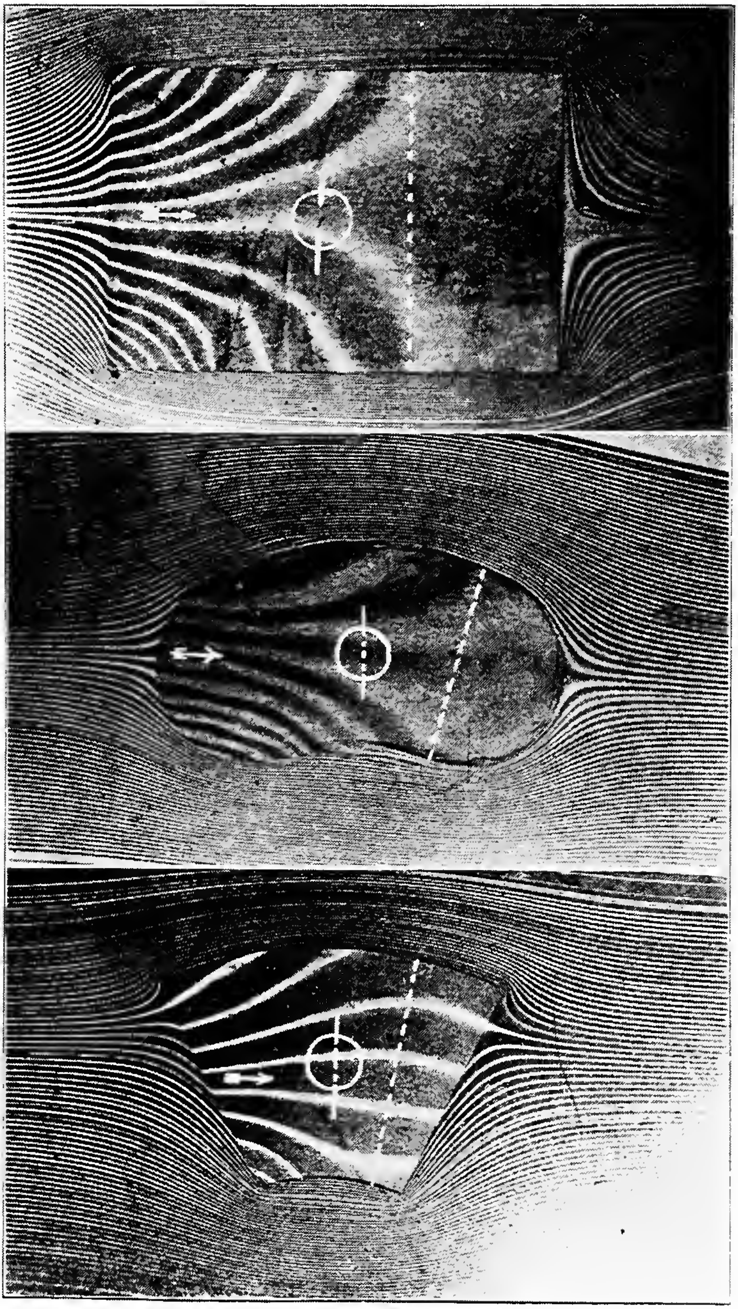

Fig. 47.

little behind the centre of each pad; experience shows this to be important to give a perfect film and therefore minimum friction. As the collar (1) moves over the pad (2) a wedge-shaped oil film is established; the oil is continuously drawn in at the leading edge, where the oil film is thickest, and escapes at the trailing edge, where the oil film is exceedingly thin. Some oil also escapes along the sides of the pad, as indicated in Fig. 47 which shows the directions of oil flow. These interesting photographs are reproduced by the courtesy of W. J. Hamilton Gibson, more details being given in his paper before "The Institution of Naval Architects," April, 1919.

In some interesting experiments made by Brown, Beven & Co. the effect of slightly rounding the leading edge of the pads was found to be an increased carrying power and a slight shifting further aft of the centre of pressure; these experiments also confirmed Mr. Michell's opinion as regards the shape of the pads, which should be approximately square to give the best results.

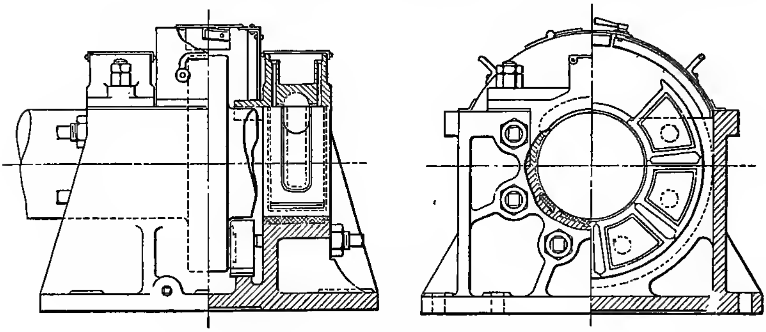

FIG. 48.—Michell marine thrust bearing.

The pads are usually white metalled, and one might ask, why go to this trouble, as there is no metallic contact. The character of the metal of the lubricated surfaces ought not to influence the results, as long as they are strong enough to stand the pressure; fine particles of grit or dirt may however get carried in between the surfaces with the oil; in that case the white metal will get abraded, and this is preferable to injuring the collar, which would occur were the pads made of hard material.

The thickness of the oil film is very thin, sometimes less than 0.001 inch, so that the bearing surfaces must be carefully scraped and oil grooves must on no account be cut, as they will allow the oil to escape and prevent proper film formation.

The heat generated in the bearing is entirely due to internal fluid friction in the oil film, there being no metallic contact;

the frictional heat is therefore dependent upon the area of the thrust pads, the rubbing speed and the viscosity of the lubricant. The makers supply particulars as to the amount of heat generated under specific conditions and the quantity of oil and cooling water required to give the best results.

The number of pads may vary, but is usually six. They may be arranged in the form of an inverted horseshoe, as in the self-contained marine thrust bearing (Fig. 48) suitable both for geared turbines and marine steam engines; or evenly distributed over the collar, as in the geared turbine thrust bearing Fig. 49.

In Fig. 48 the collar bears against two inverted horseshoe shaped surfaces (one for ahead and one for astern thrust). Each of these surfaces is subdivided into six pads pivoted on the ends of a corresponding number of screws. The shaft is supported by two ordinary journal bearings, and the well in which the collar revolves is filled about half full of oil, which lubricates the blocks; the journal bearings have upper keeps, fitted with syphon oilers, and a light sheet iron cover forms a dust shield.

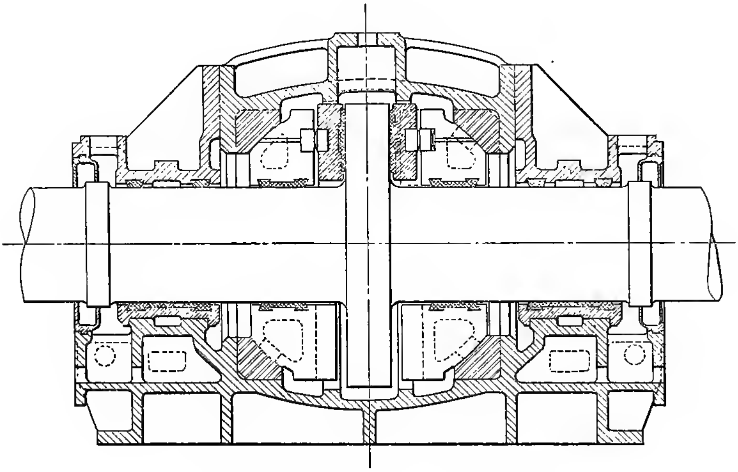

Fig. 49.—Michell turbine thrust bearing.

The housing consists of one main casting and is water jacketed in large size bearings, or when the speed is high.

In Fig. 49 the shaft is carried in two journal bearings, the same as in Fig. 48, but the housing is made in halves, and the blocks instead of being independently adjusted are mounted in spherical seats and adjust themselves automatically. This type of bearing is not self-contained as in Fig. 48, but must be connected to an oil circulation system, usually a branch from the main turbine oiling system. The blocks may be either "line pivoted" on the spherical seats, or "point pivoted," as shown.

For steam turbines, where the thrust bearing is combined with the main bearing at the high pressure end, and when the thrust does not exceed 5,000 lb., a much simpler form of Michell bearing is designed, one type having only one pivoted pad on either side of the collar. The Michell thrust bearing is also used with great success as vertical thrust bearings, required for vertical water turbines, centrifugal pumps, vertical electric generators, etc.

It will be recognized that a perfect oil film cannot be established in the ordinary form of thrust bearing in which the coefficient of friction is about 0.03,whereas in the Michell bearing it falls to 0.002 or even less. The Michell thrust bearings will safely carry a load of 400–500 lb. per square inch with rubbing speeds from 60 ft. to 100 ft. per second, without danger of metallic contact. Michell thrust bearings have run with no abnormal heat, carrying a pressure of five tons per square inch at which pressure the white metal surfaces of the pads began to flow like butter, thus showing that with perfect film formation the oil film will stand enormous pressures.

The Kingsbury thrust bearing is designed on very much the same lines as the Michell bearing. Prof. Kingsbury also divides the supporting surface in segmental pads, and the pads are made self-adjustable by rounding the supporting surface, as shown in Fig. 50. The pad (2) rocks over the support (3) and thus allows a wedge shaped perfect oil film to form between the pad and the revolving collar (1). Large Kingsbury bearings for supporting the vertical generating units at the McCalls Ferry plant of the Pennsylvanian Water Power Company were reported in "*Power*" to give the following results:

Outside diameter of collar, inches	48
Total load on bearing, pounds	410,000
Area of shoes, square inches	1,160
Unit pressure per square inch, pounds	350
Revolutions per minute	94
Mean surface speed, ft. per min	900
Oil flow through bearing per min., gallons	15
Kind of oil	Light mineral
Mean temperature rise of oil in bearing, deg. F.	4.5
Frictional loss in bearing, H.P.	9
Coefficient of friction	0.0008

The oils used for Michell thrust bearings are mineral oils of suitable viscosity. There is no need for compounded oils, as the film formation is not influenced by the oiliness of the oil.

All that is required is viscosity. For slow speed conditions, viscous oils are required, like Bearing Oil No. 4 or Circulation Oil No. 3; for high speed conditions, as in steam turbines, the same turbine oil is employed for the Michell thrust as for the turbine bearings.

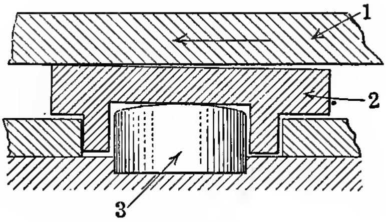

FIG. 50.—Kingsbury thrust pad.

Compounded marine engine oils may be used for steam engine thrust bearings for the sake of simplicity, but straight mineral oils operate cleaner, and should be preferred.

CHAPTER XII

BALL AND ROLLER BEARINGS

Ball and roller bearings operate on different principles from plain bearings; the *rolling contact* between the balls or rollers and the stationary or revolving surfaces (ball races, roller races) is theoretically only point contact in ball bearings, and line contact in roller bearings, whereas ordinary bearings have large surfaces in *rubbing contact* at all times. When machinery equipped with ordinary bearings is started the frictional resistance is great, several times as great as the resistance after a couple of revolutions when the oil film has been established; whereas in ball and roller bearings the friction at starting is the same as or only very little more than the friction during operation, and is always lower than in plain bearings.

It is this great advantage that ball and roller bearings have over plain bearings which is chiefly responsible for their ever widening use, particularly in machinery that frequently starts and stops or changes its direction of rotation, such as automobiles, motor cycles, bicycles, reversible electric motors, railway turn tables, etc.

Roller bearings may possibly stand rough usage, vibration and shocks better than ball bearings, but they will not carry heavier loads, as many people seem to think, and at very high speeds ball bearings are usually preferred. Prof. Goodman has made a lengthy study of ball and roller bearings, and the following remarks are largely based on the information given by him in papers read before the Institution of Civil Engineers, 1911–12, and the Institution of Automobile Engineers, in 1913.

ROLLER BEARINGS

The rollers are nearly always plain cylindrical. An inexpensive roller bearing is the Koppel bearing shown in Fig. 51. It has no cage and the ends of the rollers are rounded. Most bearings have a cage, as in Fig. 52 to hold the rollers in position.

The Hyatt bearings (Fig. 53) have rollers which are helical springs, alternately of right- and left-hand pitch, and are much used for line shafting.

In the Kynoch bearing the rollers (Fig. 54) are tubular rolled from a special steel stamping to avoid a longitudinal joint.

The bearing in Fig. 55 has short rollers one diameter in length; when hardened and ground with the same degree of accuracy as the best ball bearings this bearing gives excellent results.

The Timken roller bearing (Fig. 56) has two rows of tapered rollers and is largely used for automobiles.

Fig. 57 shows a roller thrust bearing with tapered rollers.

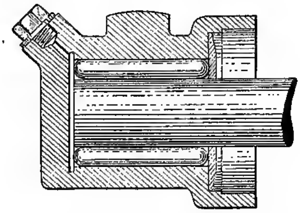

Fig. 51.—Koppel roller bearing.

The pressure on the narrow line of contact between roller and shaft is great; hence, soft materials are liable to be crushed and the wear is excessive. For high pressures the rollers, sleeve, and casing liner should be steel, hardened and ground so as to minimize the wear.

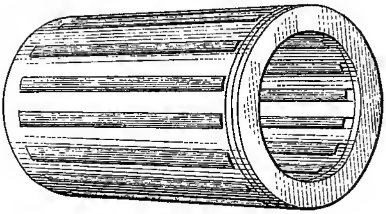

Fig. 52.—Roller bearing cage.

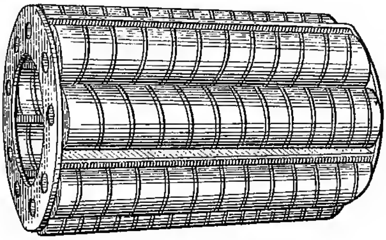

Fig. 53.—Hyatt rollers.

During operation the roller cage moves at approximately half the journal speed, and the rollers revolve at very high speed, rubbing with their ends against the cage, so that these points require lubrication, more especially because the rollers often

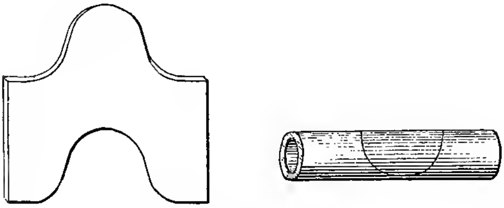

Fig. 54.—Kynoch roller.

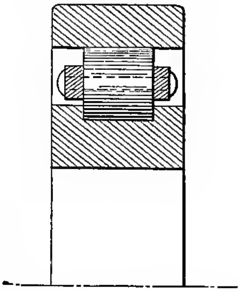

Fig. 55.—Short roller bearing.

create considerable end thrust. As such end thrust forces the cage against the inside of the bearing housing, lubrication is also required for these additional rubbing surfaces.

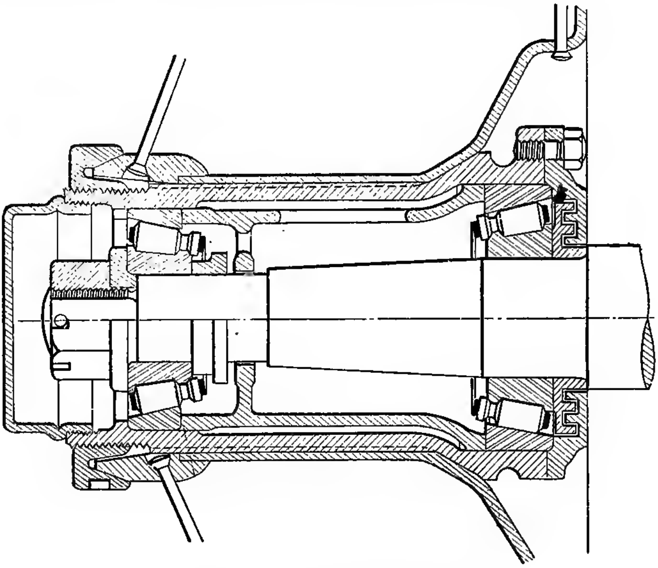

Fig. 56.—Timken roller bearing.

When the rollers are not absolutely parallel with the shaft or if they are the least bit taper, or if the shaft or sleeve against which they revolve is taper the rollers tend to roll in a helical path. They push themselves against one end of the casing until the pressure becomes sufficiently great, then they slip back suddenly and start rolling afresh in a helical path toward the same end of the casing as before. The amount of end thrust created is largely dependent upon the bearing load (it may be as high as 30 per cent. of the load) and does not appear to vary with the amount the rollers are out of truth.

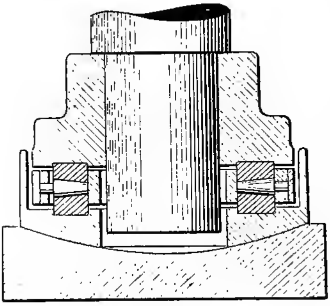

Fig. 57.—Roller thrust bearing tapered rollers.

The rollers have been known to wear right through their casing and nearly through the housing itself.

With change in direction of rotation the endthrust is always reversed. Speaking generally, the starting effort of roller bearings is only slightly greater than the running effort, but when there is considerable end thrust the starting effort may be even twice as great as the running effort.

The main evils of end thrust in roller bearings are:

1. It is largely the cause of the frictional resistance.
2. It causes excessive wear on rollers, cage, shaft and casing.
3. It causes the bearing to run hot.
4. It sets up vibration and rumbling in the bearing and its housing.

The makers of the Hyatt roller bearings claim that one-half of the helical rollers will tend to run toward one end of the casing and the other half toward the other end, and that end thrust is therefore eliminated. Prof. Goodman found that this was largely true and that, although the loads they carried were very small as compared with high-class roller or ball bearings, yet they were very successful for ordinary purposes, line shafting in particular.

In properly designed roller bearings, when there is little or no end thrust, the friction is practically independent of lubrication, but with a large amount of end thrust lubrication makes a great difference, for the reason, that when there is no end thrust there is pure rolling action, but when end thrust exists there is friction between the cage and the casing. This friction decreases somewhat at high speeds because of the better oil film—less metallic contact—so that in roller bearings with end thrust the coefficient of friction is inclined to decrease at high speeds, whereas in roller bearings with pure rolling, it is practically independent of the speed.

Speaking generally, roller bearings, even the simplest types, develop less friction than plain bearings, provided of course that they are erected with a reasonable amount of care. Bearing housings should be self aligning, so as not to set up undue stresses anywhere in the bearings.

To insure the best results both ball and roller bearings must be very accurately fitted and if worn must be renewed and not allowed to run. If they are slightly out of line or slightly worn, great stresses are set up; the friction is high, may even be higher than with plain bearings, and the balls or rollers may break.

The coefficient of friction of roller bearings is always higher for small than for high loads, and considerably increased when there is appreciable end thrust. The coefficient of friction ranges from 0.002 to 0.007; only for highly finished short rollers and bearings with little or no end thrust as the bearing indicated by Fig. 55, has the coefficient of friction fallen below 0.002, but then such a bearing approaches in action the ball bearing, as also in the great accuracy of its workmanship. The normal average values for the coefficient of friction may be taken as 0.003 to 0.004; but for bearings of the Hyatt and Kynoch types, the values are higher, ranging from 0.0045 to 0.007, the lower values corresponding to high loading.

Prof. Goodman summarizes the general results of his tests of roller bearings as follows:

1. The coefficient of friction of roller bearings is greater at low than at high loads, but it is much more nearly constant that it is in plain, lubricated bearings.
2. The coefficient of friction of roller bearings in which there is pure rolling is very nearly constant at all speeds, but when there is end thrust, the friction decreases as the speed increases.
3. The coefficient of friction is independent of the temperature of the bearings unless the end thrust is excessive.
4. The starting effort is very little greater than the running effort.
5. The friction in a well-designed bearing is not greatly affected by lubrication.
6. The wear of the rollers is often excessive if the whole of the rotating parts and the casing are not hardened and well finished, especially when the bearing shows end thrust.
7. The end thrust on the rollers varies almost directly as the load on the bearing, and usually diminishes as the speed increases. The direction of the thrust is usually reversed when the direction of rotation is reversed.
8. Other things being equal, the frictional resistance of bearings fitted with large rollers is less than with small rollers.
9. The safe load for a given bearing diminishes as the speed of rotation of the rollers increases.

BALL BEARINGS

Ball bearings cannot create end thrust; herein lies one of their great advantages over roller bearings, particularly at high speeds. They are less inclined to heat than roller bearings, as the friction is lower. The starting effort is the same as the running effort, and in consequence ball bearings, notwithstanding that they have only point contact as compared with line contact in roller bearings, are able to sustain as heavy loads as roller bearings.

Ball bearings must not be adjustable; once the bearing is assembled, all running clearances must be correct, and neither the balls nor the races must wear.

Four-point contact and three-point contact bearings (Figs. 58 and 59) are not so satisfactory as two-point contact bearings (Fig. 60) for the reason that there is a grinding action between the balls and the races, and the balls get scratched. Two-point contact bearings may have flat races as Fig. 60 and the results are very satisfactory; in fact, the coefficient of friction is lower than in other types of bearings, but the load-carrying capacity is 2 to 2½ times greater with grooved races, as in Fig. 61. With flat races the coefficient of friction decreases with increase in load, but with grooved races it may increase, possibly due to the increased area of metallic contact between the balls and the races. For heavy loads the grooved races are to be preferred, given good alignment and workmanship; but if there is any doubt as to these points, flat (or cylindrical) races may prove better, as a slight lack of alignment will not affect the balls on a flat surface, but may cause them to jamb and get cracked when running in grooved races.

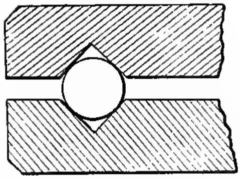

FIG. 58.—Four point contact ball bearing.

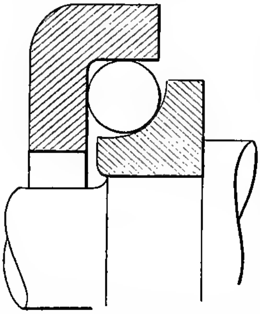

FIG. 59.—Three point contact ball bearing.

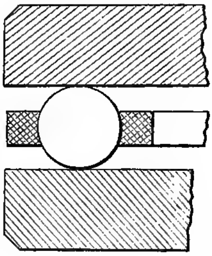

FIG. 60.—Two point contact ball bearing.

Prof. Goodman has found that the friction in ball bearings is never reduced by lubrication but is sometimes greater than when the bearings run dry. Bearings with flat races have run dry for long periods without any apparent ill effects; but bearings with grooved races soon begin to whistle and grind, probably because there is more actual rubbing between the balls and the grooves than with flat races. As, however, the absence of lubricant means that the surfaces in time will rust, which is fatal, lubrication is always provided.

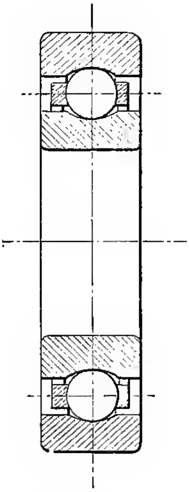

FIG. 61.—Ball bearing with grooved race.

It is important that the balls shall be all of the same size; if some of the balls are smaller than others, the big balls have to take more than their share of the load (being bigger they get more squeezed than the little ones); the smaller balls take less than their share, therefore slip more, and it is this slipping which causes the balls to deteriorate and get scratched.

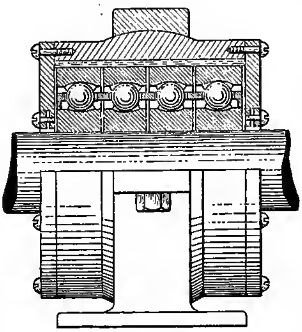

Fig. 62.—Multiple ring ball bearing.

All the best makers will guarantee first-class balls to be accurate within one ten-thousandth of an inch; it does not matter much whether 1-inch. balls are slightly more or less than 1 inch in diameter, but they must all be *exactly alike*, and with properly made bearings the wear will then be practically nil.

When balls are overloaded they become covered with tiny flakes of "snow," the flakes being tiny crystals which have broken away from the surface of the ball; these specks can only be seen under the microscope with 300 to 400 diameters magnification. When a ball finally breaks down it peals on one hemisphere, and curiously enough usually only on the one hemisphere.

For very heavy loads multiple ring bearings may be employed, as the four-ring radial bearing in Fig. 62. In order to ensure that each ring shall carry its proper share of the load, a sheet of linoleum is placed between the housing and the races. This same principle can also be applied to thrust bearings with multiple rows of balls, as in Fig. 63, which shows a railway

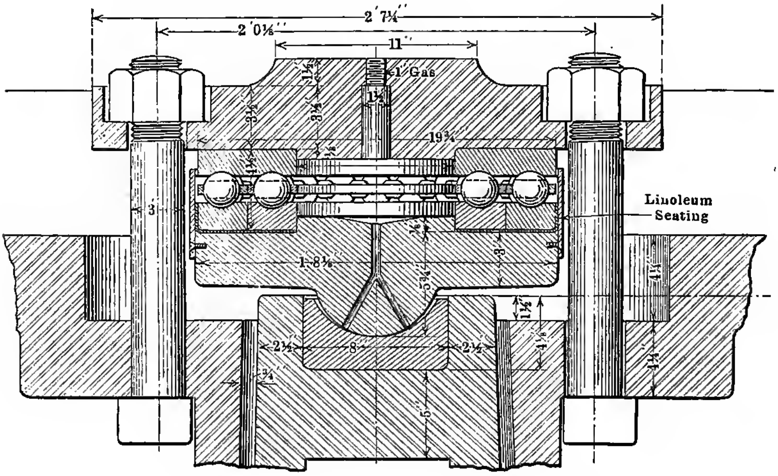

Fig. 63.—Skefko two row ball bearing.

turntable fitted with a Skefko two-row ball bearing. A brass shield fitted round the lower bearing housing retains the lubricating grease, which fills the bearing and keeps the dirt out.

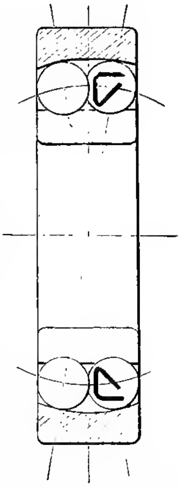
Fig. 64.—Skefko swivel bearing.

The question of alignment of ball bearings is as important as in the case of roller bearings, if not more so. The bearing housings are therefore usually made self aligning, but in one type of bearing, the "Skefko" ball bearing, the spherical outer ball race (Fig. 64) allows the inner race and balls to swivel out of their plane of rotation, so that they can adjust themselves to any lack of alignment of the shafting, whether owing to bending or bad erection, and the adjustment will of course take place with much greater ease than in the case of a self-aligning bearing housing.

This bearing has other features. As there are two rows of balls the load is distributed at any instant over three balls instead of on one or two balls, as in an ordinary ball bearing; this feature increases the load carrying capacity. The bearing is also capable of taking a certain amount of end thrust, as the balls touch the spherically shaped outer race at points where the pressure between them is at a slight angle with the vertical plane.

The inner race of a ball bearing must not be slack on the shaft; the shaft should preferably be ground to a light tapping fit for the inner race and the bearing secured against a shoulder by means of a nut (see Fig. 65). The outer race must not be a driving fit in the housing, but should have an easy sliding fit, as otherwise the balls will be unevenly loaded.

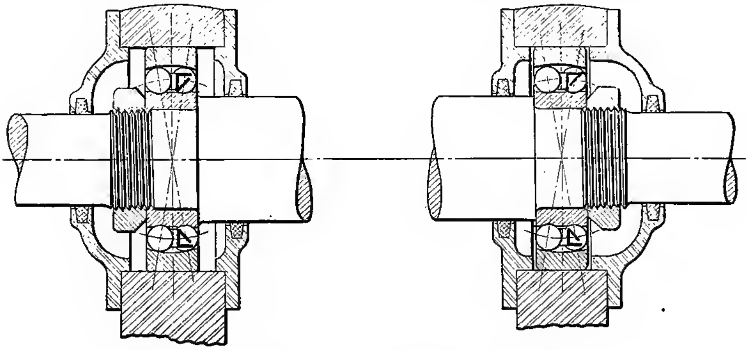
Fig. 65.—Ball bearings for electric motor.

Fig. 65 shows the correct method of mounting ball bearings on an electric motor; the right-hand outer race is not allowed much movement between the housing covers but the left-hand outer race has freedom to slide in its housing when the shaft expands or contracts.

The coefficient of friction of ball bearings is always greater with small than with high loads; it ranges from 0.001 to 0.003, the normal average value being 0.0015 to 0.002.

Prof. Goodman summarizes the results of his tests of ball bearings as follows, and his interesting remarks concerning a comparison between ball and roller bearings are also quoted:

LAWS OF BALL-BEARING FRICTION

1. The coefficient of friction of ball bearings with flat races decreases, and with grooved races sometimes increases, as the load is increased; but it is much more constant than that of plain, lubricated bearings.
2. The coefficient of friction of ball bearings is practically constant at all speeds, but has a slight tendency to decrease as the speed is increased.
3. The coefficient of friction is independent of the temperature of the bearing.
4. The starting effort is practically the same as the running effort.
5. The friction in a well-designed bearing is very slightly higher when the bearing is lubricated than when it is dry, but in badly designed bearings the friction, when they are lubricated, is lower than when they run dry.
6. The wear on the balls when they are not overloaded is extremely small and is almost negligible.
7. There is no end-thrust on ball bearings.
8. Other things being equal, the frictional resistance with large balls is less than with small balls.
9. The safe load for a given bearing diminishes as the speed of rotation of the balls is increased.

COMPARISON OF BALL AND ROLLER BEARINGS

Friction.—In general, the friction of ball bearings is considerably less than that of roller bearings, but both are very much better in this respect than plain bearings with ordinary lubrication.

The coefficient of friction of ball bearings is slightly less than that of plain bearings running in a bath of oil.

End Thrust.—There is no end thrust on ball bearings, but in many roller bearings it is often quite serious in amount.

Space Occupied.—Most roller bearings are longer for a given load carrying capacity than ordinary plain bearings. Fig. 55 is an exception but ball bearings are, as a rule, much shorter and occupy much less space than even the best plain bearings. There is, however, an exception in the case of bearings for connecting rod ends.

Cost.—Roller bearings, as a rule, do not cost much more than plain bearings designed to carry the same load, but ball bearings and roller bearings of the best quality cost three to four times as much.

In electrical machinery it is often found that when ball bearings are used the length and diameter of the armature-shaft may be materially reduced, as well as the length of the bed, owing to the fact that ball bearings are so much shorter than ordinary bearings; the net result is that the cost of the machine is little if any greater than when plain bearings are used.

Shafting Mounted on Ball Bearings.—For long lines of shafting, carrying pulleys and couplings, ball bearings are not so convenient as roller bearings. If a ball bearing on such a shaft fails, it is impossible to replace the ball races without taking down at least one length of the shafting, removing the couplings and pulleys, and fitting a new bearing. But with roller bearings, which are often used without a sleeve, there is no difficulty in replacing the whole bearing or any part of it without disturbing the shafting, because both cage and bearing liner are nearly always made in halves, a practice quite out of the question with ball bearings, in which extreme accuracy is required.

With long lines of shafting provision must be made for the expansion and contraction of the shaft. When plain (*i.e.*, not grooved) bearings are used there is no difficulty, but with grooved bearings the outer ring must be mounted in a housing in which it can slide. The efficiency of power transmission by shafting mounted on ball bearings is higher than can be obtained by any other known means.

LUBRICATION OF BALL AND ROLLER BEARINGS

On page 178 the various forms of friction which exist in a roller bearing are outlined, and it is obvious that in most roller bearings, owing to existing or possible end thrust, lubrication must be provided to reduce friction between the various rubbing surfaces.

In ball bearings there is less friction because of the absence of end thrust, but there is a certain amount of friction between the balls and the sides of the cage pockets in which they revolve. One form of friction which exists both in ball and roller bearings has not yet been touched upon; it is due to the fact that balls, rollers and races are somewhat elastic, and that consequently instead of point and line contact we actually get metallic contact over a small circular and rectangular area for balls and rollers respectively. The metal in front of and behind a roller, for example, is pushed up as shown exaggerated in Fig. 66, the surface of the race is slightly stretched where it touches the roller, and when the metallic contact ceases the surface contracts. At this point a certain small amount of rubbing therefore takes place between the roller and the race. It will be recognized that in front of the roller a similar small amount of rubbing takes place, as the surface of the race coming Into contact with the roller becomes stretched. It will be seen that the stretching and the unstretching of the race in front of and behind the roller both tend to impede the progress of the roller and therefore create resistance.

When the surfaces of the balls or rollers and races are very hard and lack elasticity, this kind of friction is less than with more elastic surfaces, but is always very small. Lubrication of these points is difficult, as the pressures must be very great; but even if lubrication of the rolling surfaces makes them more slippery, it must not be overlooked that compared with dry surfaces we are adding a certain amount of fluid friction. It is a fact that the total amount of friction remains very much the same whether the surfaces are lubricated or not.

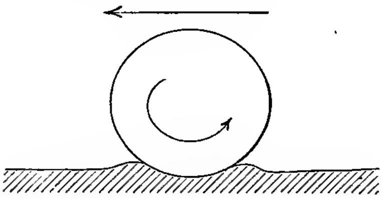

FIG. 66.—Rolling friction.

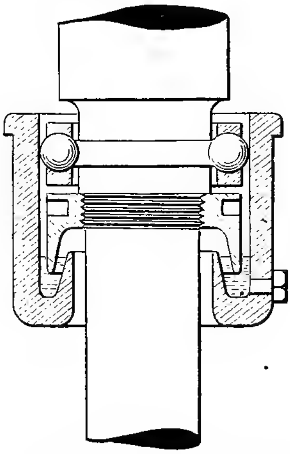

FIG. 67.—Vertical ball bearing, with oil bath lubrication.

As has already been mentioned, lubrication of ball and roller bearings is imperative to prevent rusting and to maintain the balls, rollers and races in a clean and highly polished condition. The entrance of moisture and dust must also be avoided, so that in humid or dirty surroundings the bearings must have efficient dust guards, or they must be completely filled with lubricating grease. In the latter case a fillet of grease will be formed at either end which seals the bearing against the entrance of dust and moisture.

Fig. 67 shows the application of a ball guide bearing to a vertical shaft; the housing is formed as an oil reservoir, and during operation centrifugal action forces the oil to rise and lubricate the balls.

Fig. 68 shows a vertical ball thrust bearing fitted for grease lubrication; with slight alteration this bearing could also be designed with oil lubrication without danger of oil overflowing down the shaft.

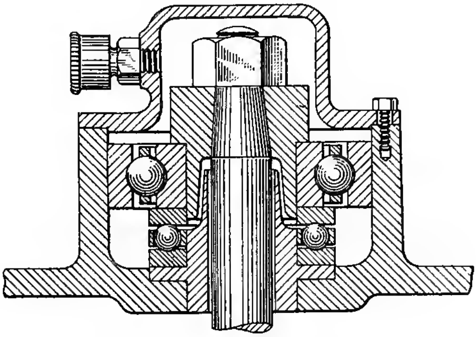

Fig. 68.—Vertical ball thrust bearing.

Fig. 69 shows a ball thrust bearing which may be used horizontally or vertically, and in which the shaft is allowed to swivel slightly on the surfaces indicated by the dotted circular line. These surfaces are ground and are submerged in oil. This arrangement will permit slight self-adjustment, and make the running easier.

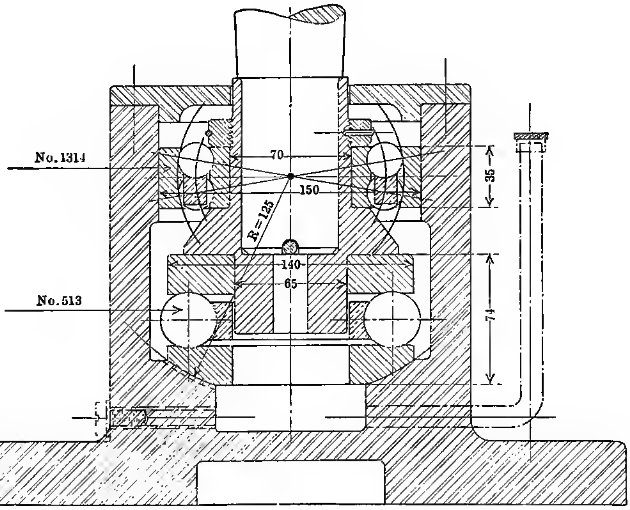

Fig. 69.—Self-adjusting ball thrust bearing.

Fig. 70 shows an axlebox with a Skefko ball bearing as used on a Swedish railway (Karlsbad-Munkfors Railway). The axlebox is completely filled with grease, and it has not been found necessary to inspect and replenish with grease more than once or twice a year.

Fig. 71 shows a ball footstep bearing used for mortar mills in India, grinding refractory material. The dust is very hard and is kept out from the bearing by means of an oil seal, as shown, which can be removed for cleaning purposes. These bearings are reported to give complete satisfaction.

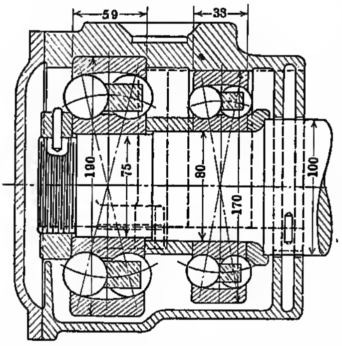

Fig. 70.—Skefko railway axle box.

It is extremely important, when handling ball or roller bearings to prevent dirt, filings, etc. from getting into them; many failures of bearings have been caused by carelessness of this kind. When, for example, bearings are cleaned in the average motor car repair shop, they are often dipped in dirty kerosene full of all sorts of sediment and impurities which get stirred up when the bearings are "cleaned."

A good cleaning agent is made from soda and boiling water (1 lb. of soda to 25 lbs. of water); the bearings may be dipped several times to remove all grease and dirt, then immersed in clean kerosene and given a swirling motion when all surfaces should appear bright and clean.

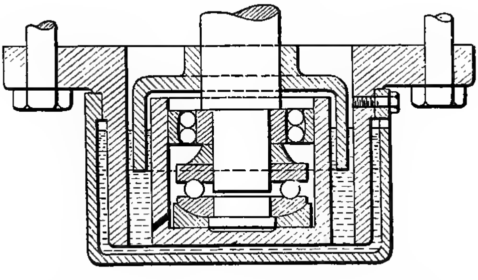

Fig. 71.—Oil sealed ball footstep bearing.

Many automobile bearings have been ruined by wearings from the gears or impurities introduced when the gear case or rear axle case has had its lid removed for inspection. Hence the design of oil filler as shown in Fig. 191, page 482, is to be recommended, also from the point of view of the safety of the ball or roller bearings, now so frequently employed in gear box or rear axle constructions.

When washing motor cars with water at great pressure, it is quite easy for the water to enter some of the bearings (which may not be completely filled and sealed with grease) and cause rusting, with the almost inevitable result that the bearings are destroyed.

As to whether oil or grease is to be employed, it appears to be preferable, wherever the surrounding air is reasonably clean and not too humid, to use oil. The fitting of a dust guard in the form of a felt packing is always advisable; the oil keeps the balls clean and must be an acid-free, pure mineral oil so as not to gum or corrode the surfaces. It should be sufficiently viscous not to cause excessive oil spray, but oil spray may also be caused by overfilling the bearings. As the friction in ball bearings is not influenced by the viscosity of the oil, the selection of oil may be entirely governed by the other conditions mentioned; of course when the oil is carried to the surfaces by centrifugal action it must not be *too viscous,* and at low temperatures the oil must have a reasonably low setting point, so as not to congeal in the bearings.

In roller bearings, particularly those in which a certain amount of end thrust is created, mineral oils of heavy viscosity *must be used* for high temperatures, for low speeds or heavy loads, to minimize wear. Compounded oils would give better lubrication than mineral oils, but must not be used for the reasons mentioned above.

When bearings are exposed to high room temperatures, say much above 140°F., the oil will oxidize in time and may produce a carbonaceous deposit; for such conditions, the oil must be changed at sufficiently frequent intervals to prevent trouble, whereas ordinarily the oil need not be changed more often than every three to six months.

Grease is often used, and should be used, when bearings operate in a dusty or very humid atmosphere. The grease must fill the bearing cavity completely, but must not be forced in so tightly as to impede the movements of the balls or rollers; high speed bearings have been known to develop abnormal heat due to this cause. Replenishing with grease should preferably be done with small quantities at a time; if a big amount of grease is forced in by the grease gun or grease cup, trouble of the kind described is apt to occur.

When the grease chamber is filled for the first time the grease may be melted by gentle heat (immersion in boiling water) and poured into the bearing; but when high melting point, fibrous greases are used, this practice is not to be recommended.

The grease must be as nearly neutral as possible, containing neither acid nor alkali, and it is essential that during manufacture it has been strained to remove all solid impurities.

The grease must not contain any filler, as chalk, gypsum, or the like, nor must it contain an excessive amount of water; in good quality boiled greases the water content is less than 1 per cent. and will not cause rusting, as in grease filled bearings the air has no access to the surfaces.

Some greases are quite free from water, being simply petroleum jelly or mixtures of this material with mineral oil in various proportions. The melting points of such greases are very low; the melting points of boiled greases—cup greases and fibrous greases—are higher,. particularly for the latter type which are therefore used under conditions of high room temperatures.

The grease should be of as soft a consistency as possible, say No. 1 or No. 2 consistency at the running temperature, so as to penetrate and cover all parts inside the bearings. Many automobile bearings have been ruined because too viscous greases have been employed, which cannot possibly penetrate to the points required.

At one time many manufacturers of ball and roller bearings favored the use of mineral jelly greases because of their freedom from moisture, but the general experience with these mixtures of mineral jelly and mineral oil has not been satisfactory on account of their deficient lubricating properties. For ball bearings with flat races which require hardly any lubrication, such greases have answered the purpose fairly well, but when some lubricating power is required boiled lime greases, either cup greases or fibrous greases, are much to be preferred.

For heavy duty roller bearings such greases should be made from a viscous mineral oil like Bearing Oil No. 5; whereas for light duty roller bearings and for all ball bearings an oil like Bearing Oil No. 3 is to be recommended.

Solidified oils must never be used for ball or roller bearings, as they are not nearly so uniform as the boiled greases; they frequently contain a slight excess of alkali or acid in tiny pockets due to the ingredients not being so thoroughly mixed and combined as is the case in boiled greases.

LUBRICATION CHART NO. 3

FOR BALL AND ROLLER BEARINGS

Bearing Oil No. 2.[1] For small and medium size ball bearings and for small roller bearings with little or no end thrust.

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[1] For Bearing Oils, see page 127.

Bearing Oil No. 4. For large ball bearings and for such smaller ball bearings in which Bearing Oil No. 2 causes excessive oil spray or leakage.

For small or medium size roller bearings with end thrust.

For large roller bearings with little or no end thrust.

Bearing Oil No. 6. For roller bearings, heavily loaded and with end thrust, or exposed to high temperatures.

Cylinder Oil No. 2 *F.S.M.* (see Table No. 19). For roller bearings under extreme conditions of pressure or temperature.

Cup Grease No. 1 (made with light oil). For small ball bearings.

Cup Grease No. 2 (made with light oil). For medium and large size ball bearings and for small roller bearings with little or no end thrust.

Cup Grease No. 2 (made with viscous oil). For all sizes of roller bearings.

Fibre Grease No. 2 (made with viscous oil). For use in place of Cup Greases No. 1 and No. 2 when the bearings are exposed to high room temperatures.

CHAPTER XIII

STEAM TURBINES

HORIZONTAL STEAM TURBINES

Small turbines from 5 H.P. to 300 H.P. operate at very high speed, from 3,000 to 30,000 R.P.M., and are used for driving exhausters, exciter sets, small lighting plants, high speed pumps, etc., both ashore and on board ships.

Large stationary turbines from 300 to 35,000 H.P. operate at lower speeds, from 750 to 3,600 R.P.M., and are principally used to drive electric generators in electric power stations, in collieries, steelworks, paper mills, textile mills, etc.

Marine steam turbines are used for the propulsion of nearly all warships, except submarines and some small naval craft. They are also used for the propulsion of steamers in mail passenger service where high speed is essential. Lately, the use of a special type of marine steam turbine, namely the geared turbine, has come into great favor not only for warships but also for cargo boats.

Installations have been made of from 4,000 to 70,000 H.P. in a single ship. Marine steam turbines are frequently constructed with high pressure turbines, intermediate pressure turbines and low pressure turbines, but sometimes there are only high pressure and low pressure turbines. It is usual to have two, three, or four propeller shafts, each shaft being driven by one or two turbines. On two of the shafts there are reduced pressure astern turbines which are only used for going astern. Generally, the low pressure turbines are mounted on the same shafts as the astern turbines, close together with a common exhaust. Combinations may be made between reciprocating engines and marine steam turbines, the exhaust steam from the steam engines being used for operating the turbines.

The speed of marine turbines used in the merchant service varies between 160 and 300 R.P.M., whereas in naval practice the speed may be anything up to 600 R.P.M. and on certain turbines in the United States Navy the maximum running speed goes as high as 900 R.P.M.

Geared Turbines.—The geared type of steam turbine is a recent development. It has been used in land installations but particularly for marine services. Installations have been made of from 4,000 to 20,000 H.P. on a single shaft. The turbine operates at high speed similar to the ordinary land steam turbine, and drives by means of gearing the propellor shaft at low speed. The result is that the steam is efficiently utilized in the steam turbine and the propeller efficiency is also high, so that the combined efficiency is considerably greater than where steam turbines drive the propeller shafts direct.

The Ljungstrom Turbine is a special type of geared turbine operating at very high speed, say from 4,000 to 7,000 R.P.M. driving through gearing two electric generators. When used in marine service the electric current produced drives high speed electric motors (say 900 R.P.M.) coupled through gearing to the propeller shafts (operating at say 90 R.P.M.).

Types of Turbines.—*Parson's Type Turbines.*—These turbines have a great number of revolving and stationary discs, the steam acting on the blades more by its pressure than by the speed at which it impinges on the blades. The speed rarely exceeds 3,000 R.P.M.

De Laval Type Turbines.—These turbines have only one revolving disc; the steam passes through several nozzles and impinges on the blades with very high velocity, the action being similar to that of a Pelton wheel. The De Laval Turbines run at a speed of 10,000 to 30,000 R.P.M.

The Parsons and De Laval types of turbine represent fundamentally different principles of operation, and all other types of turbines are adaptations or combinations of these two principles. The difference in design, however, affects only the arrangement of the revolving and stationary discs, steam distribution to these discs, etc., and does not greatly influence the methods of lubrication.

Steam.—According to the steam used, turbines are classified as follows:

1. High Pressure Steam Turbines.
2. Exhaust Steam Turbines.
3. Mixed Pressure Steam Turbines.

1. *High pressure steam turbines* take steam direct from the boilers at 160 to 200 lbs. pressure per square inch. The steam after leaving the boilers is frequently superheated.

2. *Exhaust steam turbines* principally use the steam exhausted from reciprocating engines, *i.e.*, steam hammers, rolling mill engines, or colliery winding engines. The pressure of this steam is only a few pounds per square inch. Before entering the turbine the steam passes an accumulator, which causes a steady flow of steam to the turbine. Exhaust steam is always very moist, carrying fine particles of water in suspension.

3. *Mixed Pressure Steam Turbines.*—Where there is not sufficient exhaust steam to operate a turbine regularly, or where the supply of exhaust steam varies considerably, and at times becomes inadequate, the requisite quantities of high pressure steam are automatically admitted to the turbine; hence the name "mixed pressure steam turbines."

Where exhaust steam is taken from large steam engines, it is important that the steam be thoroughly freed from cylinder oil and impurities before entering the turbine, as otherwise the turbine blades will be coated with oily deposit. The turbine blades can be cleaned easily by injecting at regular intervals, by means of a hand-operated pump, from 1 pint to 1 quart of kerosene per week. When the steam is very dirty or greasy a maximum amount of 1 pint per 12 hours should suffice.

LUBRICATION

Owing to the high speed at which all turbines operate, and to the fact that very little wear may cause disastrous results, the question of proper lubrication of the turbine bearings is of the greatest importance. If the oil supply fails, even for a very short period, or should the lubrication for other reasons become momentarily defective, the bearing in question will heat up quickly and seizure will occur almost certainly before it is possible to stop the turbine. As a rule turbine bearings either operate at a fairly normal temperature, or they are dangerously warm; for this reason every possible precaution should be taken to ensure a never-failing supply of oil of the highest quality to each individual bearing, and the bearing should be carefully designed with a view to giving the oil every chance to distribute itself quickly over the entire bearing surfaces. Turbine oils must be specially manufactured to withstand the destructive action of water, impurities and air during continuous service.

Lubricating Systems.—*Drop Feed Oilers.*—In the early days of the turbine, the bearings were fitted with sight-feed drop oilers, which could be regulated to give a certain number of drops per minute, the feed being entirely by gravity. As, however, the feed varied with the height of oil in the oil container, the oilers needed constant attention in the way of adjusting the needle valves controlling the feed, or filling up of the oil reservoirs. Apart from this, the "drop-feed method" soon showed its shortcomings when bearings were inclined to be troublesome, which was not infrequently the case, necessitating an increased oil feed and extra close attention on the part of the attendant.

The real cause of the small margin of safety was that the friction was high owing to the high surface speed, and further that all the heat in the bearing had only one way of escape, namely, through radiation to the engine-room from the outside of the bearing housings and pedestals. The bearings were always, operating at a temperature much above that of the engine-room, partly due to the frictional heat developed in the bearings, and partly due to the heat conducted along through the turbine shaft.

Ring Oiling.—In modern turbine practice the "drop-feed method" has been almost entirely superseded by continuous force-feed oiling systems, and in the case of some few makes of small turbines ring oiling bearings have been adopted for turbines below 200 H.P.

A more positive system than the ordinary ring-oiling arrangement is illustrated in Fig. 72, the oil ring (1) having a "U" section, and the oil being continuously diverted into the bearing by the stationary oil scoop (2). If the oil well contains a fair quantity of oil the heat can be readily conducted to the bearing pedestal, and radiate into the engine-room without the bearings getting uncomfortably warm. Water cooling of the oil has been resorted to in some cases with very good results: (*a*) in the shape of a cooling coil in each bearing pedestal; (*b*) by casting the two bearing halves with cavities for water circulation; or (*c*) by having a central oil cooler and an oil pump forcing the oil through the cooler and thence into the various bearing oil wells. The oil overflows from each bearing back into the tank from which the oil pump draws its supply, and circulates the oil afresh. Using ordinary ring oiling bearings without water cooling is, of course, cheaper than a forced-feed circulation system, but does not give

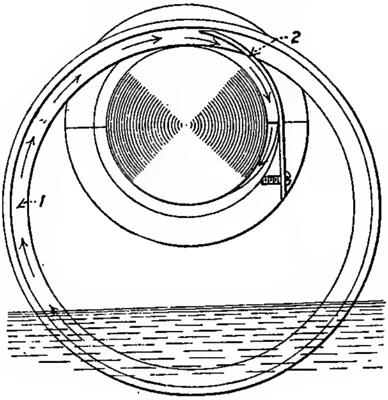

FIG. 72.

the same margin of safety. Care should be taken that the oil is changed at intervals of, say, three months. If the oil is of good quality it can be used over again after proper separation from water, dirt, and other impurities in a steam-heated settling tank, followed by filtration through an efficient steam-heated filter.

Force Feed Circulation.—This system is in general use for practically all turbines above 200 H.P. It is only in very rare cases that the oil has been forced into the bearings at the points of greatest pressure, lifting the shaft of the rotor and thereby keeping it "floating." In order to accomplish that, an oil pressure somewhat higher than the maximum bearing pressure per square inch is required. If several bearings are fed from the same oil distributing pipe, they must all have approximately the same load per square inch, as otherwise the bearing with lower bearing pressure would rob the other bearings of a portion of their share of the oil supply, the oil naturally taking the way of least resistance.

The term "force feed" therefore generally means that the oil is kept in circulation by means of a pump at a pressure usually much below the bearing pressures. The oil is introduced at the top or "on" side of the bearings, and wedging itself in between the revolving shaft and the bearing surfaces produces a complete oil film on which the whole weight of the revolving part "floats." If a continuous flow of oil through the bearings is provided, the oil carries away not only the greater portion of the frictional heat, but also the heat conducted along through the shaft from the highly heated parts of the turbine. The combined loss from friction and heat transmission into the bearings is estimated at about $\frac{1}{3}$ per cent. of the rated horse power of the turbine.

The Oil Cooler.—It therefore becomes necessary to cool the return oil from the bearings, and it cannot be too much emphasized that an efficient, well designed oil cooler of ample capacity is one of the best investments that can be made in a turbine plant, and is an excellent insurance against lubrication troubles. There is a variety of designs of oil coolers. In the early days they were often "built in" in the bed-plate. This practice seems now to be practically abandoned; because of the proximity of cold water and hot oil, extra stresses are set up in the turbine bed-plate, due to the unequal expansion of the various parts, and a cracked bed-plate has occasionally been the result.

Another reason for building the oil cooler separate from the turbine is the vibration which tends to disturb joints, etc. One curious result of heavy vibration was the wearing through of a cooling coil rubbing against the bottom of the oil cooler; it was finally perforated and the water leaking into the oil caused a lot of trouble. When a new coil was fitted it was raised above the bottom, and had small "feet" clamped on to the coils at intervals. This successfully overcame the trouble.

Oil coolers should be designed with a view to facilitating inspection and cleaning of the tubes, internally as well as externally, and the water spaces. The oil cooler should always have doors for inspection, large enough so that the tubes can be cleaned on the outside. The tubes should be solid drawn, seamless, with no unnecessary connections, which might cause leakage; frequently, they are so arranged that they can be withdrawn as a whole for inspection and cleaning.

In the earlier type of coolers the tubes were usually of the "U" type, but most modern coolers have straight tubes, which are easier to clean. The flow of oil and water through the cooler should always be in opposite directions, so that the oil in passing through meets colder and colder water; in this way the best cooling effect is obtained. In most coolers the oil is inside the tubes.

It is highly desirable that the pressure of the oil in passing through the cooler should at all points be higher than the water pressure, so that should any leakage occur it will be of oil into water; otherwise it will mean water leaking into the oil, which must be avoided for reasons given later on.

The capacity which hot oil in particular possesses of percolating through the most minute pores or leaks is remarkable, and leakage may occur under running conditions, even if the cooler has been tested cold and found perfectly tight under great pressure. When testing an oil cooler for leakage it should, therefore, always be tested "hot."

The cooling coils sometimes get badly corroded, when acidy water is used, and corrosion nearly always attacks certain "spots" in the tubes, particularly if they are made of brass. It looks as if local galvanic currents may often have something to do with heavy corrosion, caused by inequalities in the composition of the tube metal and due to the presence of small grains of different metals close together—copper, zinc, etc. To prevent corrosion in oil coolers employing sea water an iron rod fixed from end to end of the cooler has proved effective; the rod is often eaten away by galvanic action in a single voyage.

The cooling water should preferably be circulated through the cooler by means of a circulating pump and at a low pressure, which falls to nil when the turbine stops running. If the cooling water is led to the cooler by gravitation alone, trouble may arise from one of the pipes or passages being choked up, the ordinary flow and pressure of the water being unable to clear away the obstruction. Cases have been known where turbine bearings have seized because of such obstructions in the cooling water inlet pipe, the oil temperature rising rapidly, and the oil consequently losing its lubricating power. Had a circulating pump been used the obstruction in the pipe would probably not have formed at all or would, at any rate, have been cleared away in time, as because of the extra resistance the pump would automatically deliver the cooling water at an increased pressure. The cooling water outlet from the cooler should have a free overflow, which will ensure a low water pressure. The efficiency of the oil cooler is greatly affected by dirty cooling water; cases have been known where greasy, muddy river water—caused by dirty discharges from works higher up the river or due to heavy rainfall—used as cooling water has deposited sufficient slime and dirt to increase the turbine oil temperature at the rate of 1°F. per day.

The oil cooler has its best place in the circulation system after the oil pump, not before, as in the latter case the oil is sucked through the cooler, and any leakage would be of water into oil.

Thermometer pockets should be fitted in the inlet and outlet oil pipes, also in the water inlet and outlet to the oil cooler, as by temperature records taken, say, every hour it will at once be discovered if there is anything wrong with the cooler or with the oil in circulation. The water, if not clean, may have thrown down muddy deposits on the tubes, or the tubes may have been coated on the "oil" side with deposits from the oil system. In any case, the temperature records will at once indicate whether trouble is approaching, and a close investigation in good time will locate the cause and point out the remedy.

Shutting off the cooling water supply is the last operation when stopping a turbine, but the oiling should be continued until the turbine has come to a standstill.

In order to calculate the amount of heat carried away by the cooling water, it is necessary to know the quantity of cooling water going through the cooler per minute. This weight in pounds multiplied by the difference in temperature between the inlet and outlet water gives the total number of British Thermal Units per minute. Where it is not possible to measure the quantity of cooling water, and where the quantity of oil passing through the cooler per minute is known, the following calculation can be made, to get at the heat loss of the oil in going through the cooler. Multiplying the weight of oil in pounds per minute by the fall in temperature in going through the cooler and by 0.5—

which is approximately the specific heat of turbine oil—gives the number of B.Th.U.'s carried away per minute.

The tubes used in oil coolers vary from 3/8 inch to 5/8 inch in diameter internally. As to the desirable size of the cooler tubes, the cooling capacity per square foot of surface is greater for the smaller tubes, as the volume of oil in the tubes decreases with the square of the bore, while the cooling surface only decreases in direct proportion to the outside diameter. If an oil cooler is found to be too small in capacity, it is not of much use to increase the flow of cooling water through the cooler; it will, of course, make some difference, but if the cooling water is taken from the coldest available supply, and if the oil does not get cooled sufficiently, the only remedy is to increase the capacity of the cooler by adding more "surface."

In some installations where the oil is inside the tubes an improvement has been made by fitting twisted strips—of the same material as the tubes—inside the tubes in order to disturb the oil as much as possible; it is obvious that as long as the flow of oil is only 1.0 ft. to 2.0 ft. per second, which represents normal practice, the oil ordinarily shoots through the tubes without being "broken up," and a layer of cold oil on the inside of the tubes makes the cooling of the oil in the centre rather inefficient. The value of inserting the twisted strips—retarders—will easily be understood. The total cooling surface of the oil cooler in square feet may be taken as two to three times the quantity of oil in gallons circulated per minute; the lower figure must only be used with very small bore tubes or where the tubes are fitted with retarders.

Experiments carried out by Mr. Boella ("Engineering," March 2d, 1917) indicate that the heat transmission per hour through ordinary cooler tubes ranges from 70–200 B.Th.U.'s per sq. ft. per °F. or from 25–73 calories per sq. m. per °C. difference in temperature, whereas with flattened cooler tubes, the flow of oil is laminated, giving an increased heat transmission of 370–490 B.Th.U.'s per sq. ft. per °F. or 136–180 calories per sq. m. per °C. These results indicate great possibilities for improving existing types of oil coolers.

The Oil Pump.—In some of the earlier turbines a reciprocating pump was employed, but very soon the change was made to valveless designs. Later the development has been in the direction of rotary, toothed wheel pumps driven by worm or skew gearing off the main turbine shafts. The toothed wheel pump is more positive in action than the valveless "sliding vane" type of pump; also there is less chance of the toothed wheel pump being accidentally choked with rusty scale, dirt, etc., as the oil has a more effective washing action in passing through the pump. On the other hand, the toothed wheel pump has the disadvantage that the oil is "churned" more vigorously and may consequently suffer more when water happens to be present.

The oil strainer consists of copper or brass gauze, supported by a perforated cylinder, which it covers. This cylinder should be of the same metal as the gauze, as otherwise galvanic action comes into force and destroys the strainer by pitting and corrosion. The oil strainer should be situated in a position well clear of the bottom of the oil tank, say 4 in. to 6 in., to allow the water that almost invariably leaks into the oil to separate out, so that it can be drained away through a drain or sludge-cock of ample dimensions, not less than 1½ in. bore. The need for such a big bore is on account of the sludge, which may be formed in the oil, and which will not drain out through a small opening. If the strainer is placed close to the bottom of the tank, water is sucked into the pump first of all and is not given a chance to separate out from the oil. Care should be taken to have sufficient oil above the top of the strainer so that no air can be drawn in with the oil, as "aeration" of the hot oil has an oxidizing effect and may cause decomposition of the oil, if the temperature is high.

In large installations the oil pumps are nearly always operated separately from the turbine, either electrically or by steam; the pumps are started up before the turbine and kept in operation until the turbine has come to a standstill. In smaller installations, where the oil pump is an integral part of the turbine, the pump will not supply a sufficient quantity of oil until a certain speed has been reached; it therefore becomes necessary to have an auxiliary oil supply that works independently of the turbine-driven oil pump. This auxiliary supply is usually a hand pump, with which the bearings can be flushed before and during the starting up of the turbine; in larger installations a hand-operated pump becomes inadequate, and the auxiliary oil pump is driven by an electric motor or by steam. It cannot be too strongly emphasized that the bearings should be continuously flushed until the speed of the turbine is about 20 to 25 per cent. of the normal, this should also be done when in stopping the turbine the speed has fallen to the speed just mentioned. By watching the pressure gauge attached to the main circulating system, the attendant can always be guided as to the time when it will be safe to discontinue the auxiliary oil supply.

The oil pump should be designed to give a supply of oil at the pressure required, equalling 0.05 to 0.15 gallon per minute per square inch of total projected bearing surface.

The strainer on the suction side of the oil pump should have an area in square inches equalling from four to six times the number of gallons of oil circulated per minute.

The quantity of oil present in the circulation system should be from 0.15 gallon per kilowatt for smaller turbines to 0.10 gallon per kilowatt for the largest units, but the minimum amount of oil in any turbine should preferably be 120 gallons.

Oil Pressure and Circulation Systems.—On leaving the oil cooler the oil goes generally to the main oil distributing pipe, which runs along the turbine bed and from which branch pipes lead it into the various bearings. It is forced into the main oil pipe under a certain pressure which is regulated by means of a spring-loaded relief valve; this valve can be regulated to give any desired pressure within certain limits, and the surplus oil is allowed to discharge back into the suction oil tank.

Another way of maintaining a certain oil pressure is to force the oil up into an elevated tank, from which it is led through a main pipe down to the turbine and then distributed in the ordinary way. This system has the advantage that, should the oil pump fail for some reason or other, the top tank will continue the supply for a sufficient length of time to allow the turbine to be shut down before any damage is done. Unless the top tank is hermetically closed, this system does not allow of any alteration in the oil pressure, as the pressure will be dependent entirely upon the height of the oil level in the top tank above the level of the turbine bearings. The top tank should be fitted with an overflow pipe to carry surplus oil down into the return oil tank. It should also have a drain or sludge cock of at least 1½-inch bore and a drain pipe.

The return oil tank must be of sufficient capacity to take the whole of the oil in the system, in case during a standstill the whole of the oil in the top tank should be allowed to run down into the bottom tank.

"Sight feeds" are sometimes fitted in the inlet branch pipes to the bearings, their position being between the bearings and regulating cocks fitted in the inlet pipes. It is, however, difficult to keep them clean. If the oil drops through the sight feeds it has a tendency to take the air away, and the sight feeds fill up with oil. The same unsatisfactory results is generally experienced where the sight feeds are filled with water and the stream of oil is made to rise through the water; the oil carries the water away, and the glasses fill up with oil.

It is, of course, very desirable to have efficient sight feeds, but it is preferable to fit them in the return oil pipes from each bearing. Care should be taken that the outlets have ample openings to allow of the oil running through freely, otherwise it cannot escape from the bearings quickly enough, and overflows through the bearing ends. Some makers just fit a small test cock on each bearing; which if opened shows whether the inlet pipe is supplied with pressure oil or otherwise, but, of course, this does not give any idea as to how much oil goes through each bearing.

In plants with a top oil tank, distributing the oil by gravity, the oil pressure is a fixed figure, but where the oil is distributed direct from the oil pump, the maximum oil pressure that can be obtained depends upon the capacity of the pump and the resistance offered to the oil in its passage through the oil pipes and the bearings. The warmer the oil—or the thinner the oil in use—the lower will be the maximum oil pressure obtainable, as the thinner oil passes more easily through the bearings, and leaks more freely in the case of a rotary oil pump, *i.e.*, the pump discharges less oil per revolution.

A lowering of the oil pressure of a dangerous nature may take place when unsuitable oil gets very thick and sludgy, due to emulsification with water, particularly if the pump strainers are covered with sludge. Under these conditions a vacuum is formed in the pump, it "slips" and does not operate with its full capacity; hence the oil pressure falls, sometimes with only short warning, and may cause disastrous results. When a turbine starts up "cold," the oil pressure is usually high, even if the relief valve is fully open; as the oil warms up, the pressure falls, but should not fall more than can be met by partly closing the relief valve when the running temperature has been reached, thus leaving a margin over and above the minimum pressure required to operate the governor gear.

The cooling water service should not be put on until the oil in circulation has warmed up to within 20°F. of its normal temperature.

As regards the oil pressure required for distributing the oil with certainty to the bearings, a few pounds per square inch will be found adequate to give a satisfactory supply, say from 5 lb. to 15 lb. per square inch.

In many modern designs of turbines the oil is made use of in several other ways, the principal one being in connection with the operation of the governor gear. It is beyond the scope of this book to go into the various designs of oil-worked governor gears, but the author would like to emphasize the necessity of using good quality oil and keeping it in first-class condition; otherwise the result may easily be sluggish and unsatisfactory governing, as some of the clearances are exceedingly fine. One point worth mentioning is that, where a vertical spindle operates the steam throttle valve below, the oil-worked piston being above (see Fig. 73), the stuffing box of the oil cylinder invariably leaks slightly. If this oil is allowed to trickle down on top of the throttle valve cover it will smoke and "bake on" in the form of a carbon deposit, particularly when superheated steam is used; this is rather objectionable and may easily be prevented by fixing a cup on the spindle and a drain to carry oil away outside the throttle valve, as shown.

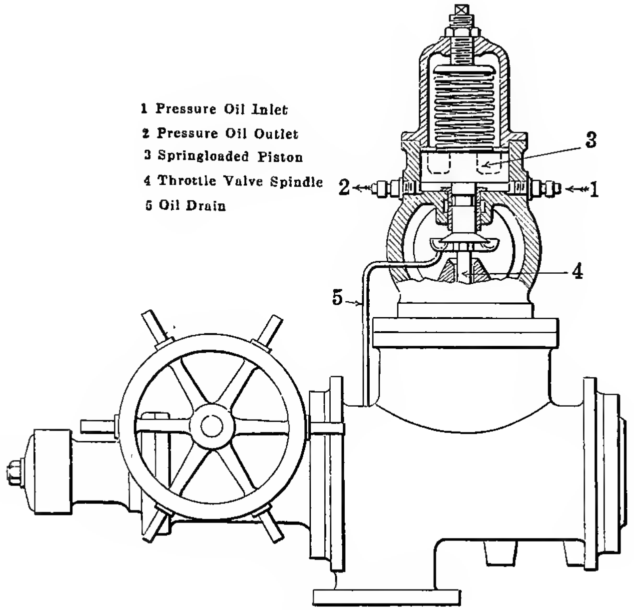

Fig. 73.—Turbine throttle valve.

The principle of operation of oil-worked governors embodies a pilot valve, which is moved by the governor, and which when moved allows pressure oil to flow into an oil relay cylinder, thereby causing a spring-loaded piston to rise or fall in this cylinder, according to whether the oil is introduced above or below the piston, or, if only acting on the underside, according to whether the oil is admitted or not. The piston, moving with great force, acts directly on the main steam valve. When the oil supply to the governor is taken from the main oil circulation system, a failure of this oil supply will cause the relay piston to descend and shut off the steam supply operating the turbine. The turbine cannot start until a sufficient oil pressure has been obtained in the oil supply system, and consequently any damage to the bearings due to insufficient pump pressure is thus obviated.

The oil pressure required by the governor gear is high, from 25 lb. to 60 lb. per square inch, in accordance with the requirements of the various designs.

Several makers fit two oil pumps, one pump delivering small quantities of oil under great pressure for the governor gear, the other pump delivering large quantities of oil at low pressure for lubricating the bearings.

Oil Pipes.—The distributing oil pipes should be of ample proportions, with as few bends as possible. The branch pipes leading to the bearings should not join the main oil pipe at right angles, but preferably at an angle not more than 30°, with a view to decreasing the loss in oil pressure due to fluid friction and resistance.

As regards the return oil pipes from the different bearings, these should be of ample proportions, so that the maximum quantity of oil from each bearing may return comfortably; otherwise the oil may overflow through the bearing ends and cause unsightly waste of oil, with a possibility in the case of turbo-generators of the oil being drawn over into the generator and spoiling the insulation. The branch pipes should meet the main return pipe at an angle of not more than 30°, and in case of "sight feeds" in the branch pipes, these should be designed so that air does not get churned with the oil causing aeration. At no place must the flow of oil be broken up or violently disturbed.

During late years most turbine makers have made the oil pipes of steel or wrought iron instead of copper, which originally was used exclusively. This has been done largely in view of lower first costs, but it is very questionable whether this step is an altogether wise one. The oil is nearly always charged with finely divided globules of air and water, and through the continued use the oil always becomes slightly acidy. These features combined cause corrosion of the iron or steel pipes in a much higher degree than when the pipes are made of copper—in fact, copper is hardly affected. (See page 221 and Example, page 226.)

Bearings.—The load on the main bearings of a turbine is mainly due to the weights of the rotor, shaft and generator, if any. The pressure is therefore the same, whether the turbine is under load or otherwise, and is never relieved, as is the case with the principal bearings of reciprocating engines. It is consequently of the very greatest importance to design the bearings with a view to quick distribution of the oil, particularly in the case of marine turbines, where greater pressures per square inch are carried in connection with lower surface speed. A high surface speed draws the oil in between shaft and bearing and makes it possible, and desirable, to use free flowing oils. On the other hand, the lower surface speed and higher bearing pressures met with in marine practice necessitate the use of heavier bodied oils and may even make careful oil grooving desirable.

With high surface speed, oil grooves should be dispensed with altogether, being distinctly detrimental, as they reduce the area of the bearing surface.

The following figures represent current turbine practice: Bearing pressures 40 lb. to 85 lb. per square inch; surface speed 25 ft. to 80 ft. per second; product of pressure per square inch by speed per second, 1500 to 5000, the higher figures being for high speed land turbines, while the lower figures represent marine practice. As an example, the following particulars, having reference to the turbine ship "Lusitania," which has two high-pressure and two low-pressure ahead turbines and two astern turbines, are given:

	Effective projected area, in.	P Bearing pressure, lb. per sq. in.	V Surface speed, ft. per sec.	$P \times V$	R.P.M.
H.P. bearings. . .	$27\frac{1}{2} \times 44\frac{3}{4}$	80	$22\frac{1}{2}$	1800	190
L.P. bearings. . .	$33\frac{1}{8} \times 56\frac{1}{2}$	72	$27\frac{1}{2}$	1980	190
"Astern" bearings.	$24\frac{1}{8} \times 34\frac{3}{4}$	83	20	1660	190

The bearings are of cast iron, lined with white metal on their running surfaces. At the centre of each bearing is fitted a safety strip of "Ajax" bronze $\frac{3}{100}$ in. below the surface of the white metal. Should the white metal accidentally get heated so that it runs, the rotor will be supported by the bronze strip and thus be prevented from dropping sufficiently to injure the blading by rubbing against the interior of the rotor casing. The bottom halves of the bearings are cooled by water circulation. Fig. 74 illustrates one of the main bearings of a large slow speed marine turbine. Note the oil drains at both ends and the oil throwers which prevent the oil that creeps beyond the drains from getting outside the bearings. The outer wall of the bearing is spherical, working in a dished pedestal in order to ensure equal pressure over the entire bearing surface, notwithstanding any slight deflection in the shaft.

The oil enters the bearing recesses (straight grooves) which distribute the oil assisted by the curved oil grooves; the oil grooves are not extended to the edge of the bearing, but leave a strip of white metal intact in order to keep up the oil pressure and prevent the oil from getting away before it has done its duty.

As all the pressure is downward, the top halves of the main bearings carry no load, but they must nevertheless be a good fit in relation to the lower halves, and in relation to the shaft at both ends, in order to prevent the oil from escaping too freely. Apart from the outer ends—where the clearance may be made 0.01 in.—the top halves do not need to touch the shaft in the centre portion of the bearing, so that a greater clearance is here allowed. Where the oil enters the bearing, the bottom half should always have a recess with the distributing edge well rounded or "chamfered," so that the oil may quickly, and as easily as possible, wedge itself in between the shaft and the bearing.

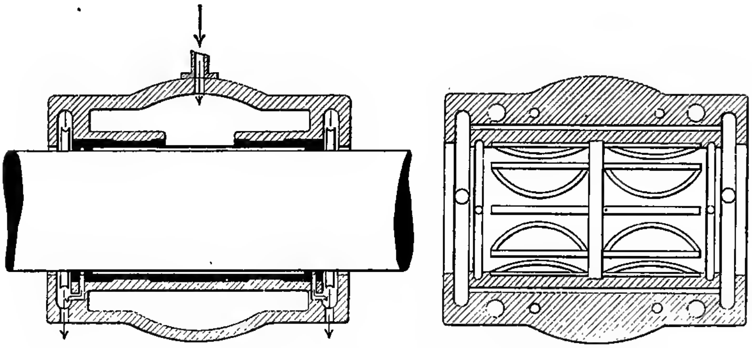

Fig. 74.—Marine turbine bearing.

In the case of bearings with water cooling of the top halves as well as the bottom halves, it is better to make the water connection between the two halves outside the bearings rather than risk leakage of water into the oil, which easily happens when the joint is inside the bearing, out of sight. Water cooling the top halves is, however, rarely used, and owing to possible annoyance with water cooled bearings caused by leaky joints or porous bearing metal, the tendency is nowadays to go away from water-cooled bearings and depend entirely upon a well-designed cooler of ample capacity.

In some cases turbine bearings have been designed as oil-cooled bearings, the oil before entering the frictional surfaces first passing round the outer surfaces of the bearing shells. The result is that the bearings are kept at a uniform temperature throughout, and that the oil removes a little more heat than it would have done had it been passed direct into the frictional surfaces.

Should a bearing give trouble it generally gives no warning; the oil evaporates and white fumes ooze out from one or both ends. The turbine should be stopped at once, as the white metal with all certainty has commenced to run and will want renewing before the turbine can be put under load again. Grit or dirt may have been the cause. Failure of the oil supply, if due to the oil pump pumping an insufficient amount of oil, will show up in decreased oil pressure and should be noticed by the attendant. Choking up of one of the oil distributing pipes to a particular bearing might be noticed in time, if the bearings are fitted with sight feed attachments.

Whenever a bearing cap has been adjusted, the turbine should not be put on full speed until one is fully assured that the bearing does not pinch the shaft.

The amount of oil circulated per minute varies according to the oil pressure required and to the size of the bearings. Current practice is to circulate the oil at the rate of 0.05 to 0.15 gallon per minute per square inch of total bearing surface, as mentioned under the heading "Oil Pump." In the case of slow speed marine turbines, a supply of 0.02 gallons per minute per square inch will be found adequate. This lower rate of feed emphasizes, however, the desirability in the case of marine turbines of having oil sight feeds in the return pipes from each individual bearing to make sure that each bearing gets its proper share.

Turbine Thrust Bearings.—Where greater or smaller end pressure has to be taken up, due either to the design of the turbine itself or to propeller thrust, the thrust bearing becomes an important feature of the turbine.

Thrust blocks for marine turbines are usually of cast iron, with a steel bush for holding the thrust rings. The top portion of the thrust block generally takes the steam thrust and the lower portion the propeller thrust. The block is fitted on a sole plate of its own and can be moved in a fore-and-aft direction; also the upper portion can be moved relatively to the lower portion in order to adjust the clearances of fore-and-aft play, which may be made about 0.01 of an inch. The thrust rings may be made of gun-metal with white metal facings on the rubbing surface.

It is evident that when the thrust block is supplied with oil under pressure from the outer edges of the thrust rings, the oil has to go against the action of the centrifugal force, and when it is between the rubbing surfaces the tendency is to squeeze it out all the time; whereas in the main bearings of the turbine the revolving shaft draws the oil in between the rubbing surfaces, feeding the oil towards the place where it is needed. An increased oil pressure does not help the oil in the case of a thrust block; the oil has only its natural clinging property—oiliness—to depend upon for getting to the place where it is required.

Thrust blocks in steam engine propelled ships are lubricated by means of oils heavily compounded with vegetable oils. The reason is that such oils, properly manufactured, have very great clinging properties, so that they are able to get in between the rubbing surfaces better and more easily than pure mineral oils.

In forced lubricated thrust blocks in connection with marine turbines the oil is taken from the main circulation system, as it would be cumbersome to make a separate oiling system for the thrust blocks. But oils used for forced lubrication must be pure mineral in character, and in view of what is said above, it is obvious that a heavy bodied oil will be needed for the thrust blocks, as light bodied pure mineral oils would cause the thrust bearings to run hot.

Another condition in connection with marine turbines that calls for more viscous oil than similar size land turbines is the vibration, which is set up partly by the turbines themselves and partly by the reaction of the water on the propellers. Heavier vibration calls for better cushioning in the bearings, and this can only be given by employing a more viscous oil.

Thrust bearings of the ordinary type carry a maximum bearing pressure of 15 lb. to 20 lb. per square inch in the case of land turbines, and 30 lb. to 50 lb. in the case of marine turbines.

Attempts have been made to introduce actual forced lubrication conditions in the thrust bearings, by making the oil pass through the hollow shaft and thence forcing it out between the revolving thrust rings and the stationary thrust block. Such a system has been designed by Ferranti, and is said to have given excellent results, making it possible to carry great pressures without any fear of the bearing seizing.

An ingenious method of getting over the difficulty with the thrust bearing has been designed by Franco Tosi. He balances the difference between the propeller thrust and the steam thrust by means of oil pressure exerted on the two sides of a piston which revolves with the shaft and is fitted with a labyrinth packing. Oil under pressure is constantly being forced into the chambers on both sides of the piston,and can escape only between the collars of the thrust blocks at either side. If the thrust is from right to left, the clearances on the left-hand side are diminished, so that it is easier for the oil to escape between the right-hand thrust collars; consequently, the oil pressure becomes lower in the right-hand chamber and the difference in oil pressure forces the piston to the right, or *vice versa,* thus automatically balancing the axial thrust and preventing metallic contact between the rings and the blocks. At high speed fluid friction developed between the piston and its casing, etc. would be very considerable, but as marine turbines are slow speed, this loss is only small.

With Parsons steam turbines the axial thrust on the rotor is more or less balanced by the propeller thrust, and the thrust bearing embodied in the turbine itself gives no great difficulty, but with geared turbines with the reintroduction of a main thrust block on the propeller shaft the multi-collar marine type of thrust bearing has failed to give satisfaction.

The even turning moment of the turbine transmitted through the gearing never pulsates or fluctuates, thus not giving the thrust collars that relief which in the case of a steam engine in some measure helps the oil to creep in between the rubbing surfaces.

For geared turbines the thrust problem has been solved by the Michell single collar thrust bearing, described page 170, which will carry a bearing pressure of 400 to 500 lb. per square inch with the greatest of ease and with a surface speed ranging from 60 ft. to 100 ft. per second.

The Hon. Sir C. A. Parsons has designed a similar type of bearing, but with centrally pivoted segmental blocks, allowing the turbine shaft to revolve in either direction. The frictional losses in these types of bearings are considerably less than in the ordinary plain type of thrust bearing; the coefficient of friction may be taken as 0.002 as against 0.03 to 0.04 for ordinary thrust bearings.

Wear.—As turbine bearings are virtually flooded with oil, it is probable that the shaft never comes into actual rubbing contact with the bearings except at the moment of starting. When the turbine is standing, the oil film is pressed out and actual contact between journal and bearing probably takes place, but as soon as the turbine starts running the first few revolutions will build up the oil film, which, if the oil is satisfactory, will support the shaft; *i.e.*, it "floats" on the oil film.

Turbine bearings, speaking about the vast majority, practically never wear. It sometimes happens that what may appear to be wear takes place for a certain length of time, after which it ceases; this is in reailty due to compression of the white metal, which has been rather soft.

After many years' working the tool marks should still be visible if the turbine has had proper care and attention.

Temperature Records.—When a turbine starts from cold the oil will gradually rise in temperature, rapidly at first, slowly later on, and if the conditions remain fairly uniform—uniform load, uniform temperature of cooling water and engine-room—the maximum temperature will be reached after a certain number of hours, varying from four hours in the case of small turbines to eight hours or even longer in the case of large units. This final temperature is not much affected by changes in the engine-room temperature or even by change in load, but is, of course, slightly higher with higher engine-room temperature and higher load.

The temperature of the cooling water, however, and the state of cleanness of the oil cooler have a marked influence on the oil temperature, and naturally so, because it is in the oil cooler that the bulk of the heat is removed from the oil, a minor portion only being radiated into the engine-room from the bearings, pedestals, oil pipes, oil tanks, etc.

The temperature of the oil in the main return pipe ranges from 100°F. to 140°F., seldom below 100°F. and not often above 140°F. But bearings have run without trouble for long periods at temperatures as high as 160°F. However, it is desirable that the oil temperature should be about 120°F. to 130°F.

In the case of marine turbines, the oil temperature rises in the Tropics as compared with conditions in temperate climates, due to the higher temperature of the cooling water, being 70°F. to 85°F. as compared with 50°F. to 70°F. for temperate climates. The oil must of necessity rise in temperature in order that the difference in temperature between itself and the cooling water may enable the water to take away the heat from the oil.

It would be useless to quote actual temperature records from turbines in operation, as they vary exceedingly; for instance, in some turbines the fall in temperature between the return oil and the oil leaving the cooler is as low as 4°F., due to the amount of oil delivered by the oil pump to the bearings being high per square inch of bearing surface, and to the bearings being water cooled.

In a good many turbines the difference in temperature between the outgoing and returning oil is from 15°F. to 20°F., and in some extreme cases this difference has been as high as 50°F. where the bearings have not been water cooled and the oil delivery per square inch of bearing surface has been low. The temperature rise of the oil going through the worm wheel casing (the worm wheel shaft operating the oil pump, governor, and sometimes the circulating pump for the condensing plant), or the thrust bearing is usually considerably higher than the temperature rise of the oil going through the other bearings.

For each particular turbine the temperatures of the oil and water inlet and outlet to the cooler, and of the oil inlet and outlet to the various bearings—or, as an alternative, the bearing temperatures at both ends of each bearing—indicate whether normal condition of lubrication and cooling prevail.

Thermometer pockets filled with oil should be fitted in the positions mentioned above. In case of the return oil temperatures taken in the bearing outlets, care should be taken that the flow of oil shall wash over the thermometer bulb or the pocket. Occasionally, the thermometers should be compared with a standard thermometer, say once a year. A temperature log should be kept in the engine-room, taking the temperatures every hour.

The turbine attendants will very soon get to know by heart the normal running temperatures at the various points, and they will learn to interpret the correct causes of any deviations from the normal temperatures, or at any rate to look in the right direction for the cause of irregularities, indicated by abnormal temperatures.

The Turbine Glands.—The most frequent cause of water getting mixed with the oil in circulation is leakage of steam past the glands, the steam condensing on the shaft and bearings, gradually working its way into the main bearings and mixing with the oil. It will, therefore, be useful to look for a moment on the various designs of glands.

There are three types:

(1) The labyrinth packing gland.
(2) The carbon packing gland.
(3) The water-sealed gland.

The function of the gland is either to keep high-pressure steam from leaking outward, or, in the case of the "vacuum end" of the turbine, to prevent air from being drawn in, which would adversely affect the vacuum produced by the condensing plant.

1. The *labyrinth packing* (Fig. 75) consists of a series of rings on the shaft which alternate with stationary rings in the surrounding casing; there is only a very slight clearance between the shaft and the stationary rings.

The steam—in the case of a high-pressure gland—must pass the rings in a zig-zag way, so that only a slight amount of steam escapes at the vent (1), which may be connected with an intermediary stage of the turbine or simply allows the steam to escape into the open. Any steam or water leaking outside the gland is deflected by suitable throwers fixed on the shaft in order to prevent the water as much as possible from getting into the adjacent bearing.

In the case of a low-pressure gland, steam at a reduced pressure-either from an intermediary stage or high-pressure steam throttled down to the required pressure—is introduced at (1) and leaks inward into the low-pressure turbine casing.

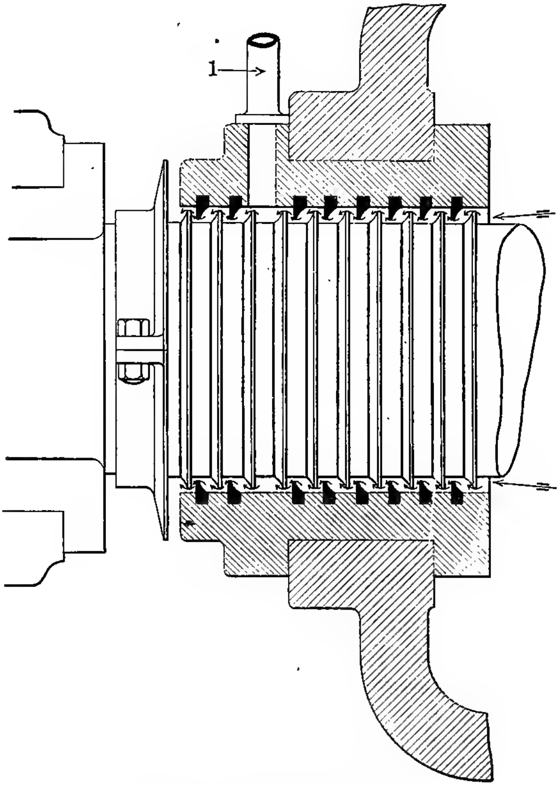

Fig. 75.—Labyrinth packing.

The pressure should be sufficient to prevent air from leaking in, that is to say, sufficient pressure should be applied so that a puff of steam is just visible oozing out of the gland. Excessive pressure should be avoided, as it means not only waste of steam, but also excessive condensation of steam on the shaft with a certainty of some of this getting into the bearings. Avoiding excessive condensation is particularly difficult in the case of the low-pressure glands of exhaust steam turbines with labyrinth packing glands. Owing to the variation in steam pressure it becomes necessary for the attendant constantly to readjust the gland pressure; otherwise either air will occasionally leak inward or excessive leakage of steam will take place outward. Occasionally the glands are water cooled, as the steam then condenses on its way through the gland and consequently the thrower outside the gland has to deal only with water, which can be much more effectively thrown away from the shaft than steam.

2. The *carbon packing* (Fig. 76) consists of a series of carbon rings, each made up of several sections and held in their places around the shaft by means of springs. The carbon rings should preferably not bear right against the shaft, but on a special sleeve fixed on the turbine rotor and slightly larger in bore than the turbine shaft, so that should heavy wear take place the shaft will remain unhurt and only the sleeve or the packing itself will get worn. No lubrication is needed of the carbon rings, but care should be taken that they be a loose fit on the cold shaft, as carbon *contracts* when heated. If grit and dirt get in, cutting and wear may occur owing to the absence of lubricant, and then leakage through the packing will take place. Sometimes the carbon packing glands are surrounded with a water jacket,

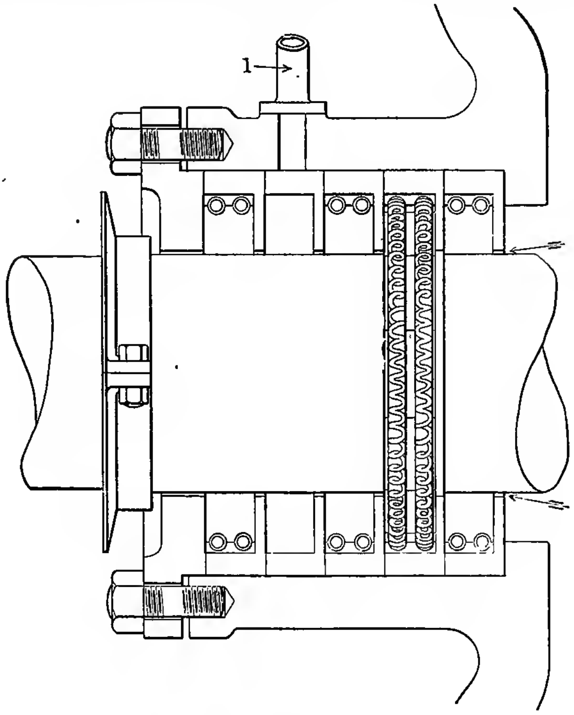

Fig. 76.—Carbon packing.

which causes a certain amount of steam to condense in the packing; this helps to seal the gland and "lubricate" the carbons. The vent (1) serves the same purpose as in Fig. 75.

3. The *water-sealed gland* (see Fig. 77) consists of a revolving wheel (1) formed with vanes on both sides and acting like a centrifugal pump. The water admitted at (2) (or sometimes at the circumference at (3) under a few pounds pressure), is thrown by centrifugal action to the outer edge of (1) and thus establishes a perfect seal, it being impossible for steam to escape round the outer edge, the clearance being about 0.01 in. to 0.02 in. The water should be clean and preferably soft, as otherwise dirt or scale will be deposited in the gland and may even get inside and coat some of the turbine blades. The water supply should be kept as low as possible by regulating the quantity admitted. The second disc (4) revolving in the groove (5) acts as another seal in series with (1); but the chief object in fitting it is to prevent water escaping from the gland past the groove (5). The water coming into this groove will be drained back into the main gland through drain holes (6) indicated at the bottom.

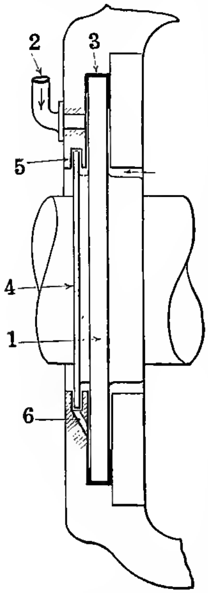

FIG. 77.—Water sealed gland.

During the time the turbine is being warmed up prior to starting, and where water-sealed packings are employed, the vacuum cannot be created until the turbine has attained a certain speed, as the glands do not provide a perfect seal until the centrifugal force is sufficient to prevent the air from going straight into the turbine. In case of high-pressure water-sealed glands, it is frequently desirable or necessary to watercool the gland casing, as it otherwise becomes so warm that the water evaporates too readily and gets into the turbine in the form of steam, and also, should the water not be very soft a certain amount of scale will be deposited, which is objectionable. It is only at low speeds—starting and stopping—that the high-pressure water-sealed glands allow steam to escape, thus making it possible for condensed steam to enter the bearing nearest the gland and mix with the oil in circulation.

GEARED TURBINES

The geared turbine of large horse power has only recently been developed, the idea being to run the turbine at high speed, transmitting the power through double helical gearing to a low speed propeller shaft—or generator shaft—thereby getting a very high overall efficiency. The gears, when not very accurately made, are noisy and inclined to wear, but the latest developments seem to be overcoming all obstacles in this direction.

If the gears are perfect, and as long as they remain so, the oil used in the turbine can also be used for the gears, being constantly supplied in streams at the points of contact between the teeth. But if the gears are inclined to be noisy, a heavier oil will be preferable in order to deaden the noise. Such a heavy oil will not be satisfactory in the turbine system, as it will separate only slowly from water and dirt and cause high temperatures all around.

If one oil system only is used for turbine bearings and gearing, and if the oil gets mixed with water—from the glands or the cooler—the oil will suffer in the turbine system to some extent; but when this same oil, mixed with minute particles of water and dirt, gets through the gearing exposed to many times the ordinary bearing pressure, it is sure to suffer very quickly indeed, and the result will be wear of the gearing. For these reasons, the author strongly recommends that the oiling system for the gearing should be made *distinct* and *separate* from the oiling system supplying the turbine bearings, quite apart from the question of whether the same oil or two different oils are used in the two systems. With separate oiling systems, the oil for the gears will remain dry and pure for a much longer time, and will thus have a much better chance of keeping the teeth of the gears in good condition and preventing wear.

Treatment of the Oil.—Before starting a new turbine, it should be carefully cleaned all through the oil tanks, oil pipes, etc., in order to remove as much grit and dirt, moulders' sand, rusty scale, cotton waste, etc., as possible. Cotton waste must never be used for cleaning purposes, as it leaves behind small fluffy pieces, which will tend to clog up the oil pipes and particularly the fine clearance spaces in the oil-worked governor.

Mutton cloths or sponges should be used for cleaning, and it is preferable to use a cleaning oil—light petroleum distillate with a higher flash point than paraffin—rather than paraffin, as some of the oil remains and mixes with the lubricating oil. Paraffin will commence to evaporate when the turbine starts running and may cause an explosion. The air should be driven out of the oil piping by means of the auxiliary oil pump, and when the pump is being filled with oil it should be put through the sieve and not direct into the tank, although the latter may be the quickest method.

After a new turbine has been run a month, during which time frequent examinations of the oil strainer will prove of interest, the whole charge of oil should be removed, and the oil tank, oil pipes, as well as the bearings, again thoroughly cleaned. The oil taken out, in which will be found impurities of many kinds, such as cotton waste, rust, sand, dirt, little pieces of iron, copper, red lead, packing material, etc., should be treated in a steam-heated separating tank, and afterward in a good steam-heated filter. It can then, if it was originally of good quality, be used as "make up" in the circulation system, which in the meantime has been filled with a fresh charge of oil. This first change of oil may seem an unnecessary precaution to take, but it is the author's strong recommendation, based on long experience, that it should always be made and that it pays in the long run.

It is during the early life of a turbine that it needs the greatest amount of care and attention; later on troubles are or ought to be rare if the oil is well looked after, frequently filtered, and the strainers kept clean. As regards the inside of the turbine oil chambers, etc., the surfaces have by some makers been painted; this has sometimes been done in order to save the labor of cleaning and scraping the surfaces. In nine out of ten cases the paint itself has been by no means oil proof, and the result has been that the warm oil quickly dissolved it, causing long protracted troubles with the oil breaking down and carrying sticky brownish black deposits everywhere throughout the oil system. The writer recommends leaving the tanks, etc., unpainted, but that the surfaces should be very carefully scraped and cleaned. Sandblasting appears to be too "searching," small grains of sand being embedded in the cast-iron surfaces and involving a possibility of trouble later on. Steelshot-blasting is a very efficient method of cleaning the surface.

Oil Filters and Settling Tanks.—When a turbine is in normal operation and has been thoroughly cleaned, the amount of impurities that gets mixed with the oil is usually small, and as far as the oil circulation system itself is concerned, the only precautions as regards filtering may be confined to a good sieve in the oil return tank, a cylindrical strainer on the pump suction pipe, or a set of gauze strainers. Ample capacity of the oil tanks is always a desirable feature leading to longer life of the oil and also giving the impurities and water a chance to separate out.

A special design of separating tanks was referred to by Mr. A. H. Mather in a paper read before the Institute of Marine Engineers, October 14th, 1907, and under the name of the "Two Tank System," is used in a great many turbine ships. See Fig. 78.

The two tanks (1) shown are not intended to be used concurrently. The oil is allowed to rest in one of the tanks for a certain period, while the oil circulation takes place through the other. When the oil has "rested" a sufficient length of time to ensure complete separation from water and other impurities, the large drain cock (2) placed at the lowest part of the tank is opened, and the water, dirt and sludge are drained away until pure oil appears. Means should be provided to show clearly the amount of water in the oil, and for this purpose a glass-sided box (3) is placed at one end of the tank in preference to the ordinary gauge glass; a strip of ⅛-in. steel plate should be placed at the ends of the box to slide in a groove, the idea being to prevent breakages of the glass, and by lifting the steel sheet to enable one to see the amount of water separated out. An air pipe (4), as shown in the drawing, should be fitted to the highest point of the tank and led to the necessary height. The oil passes a filter (5) on its way to the oil pump.

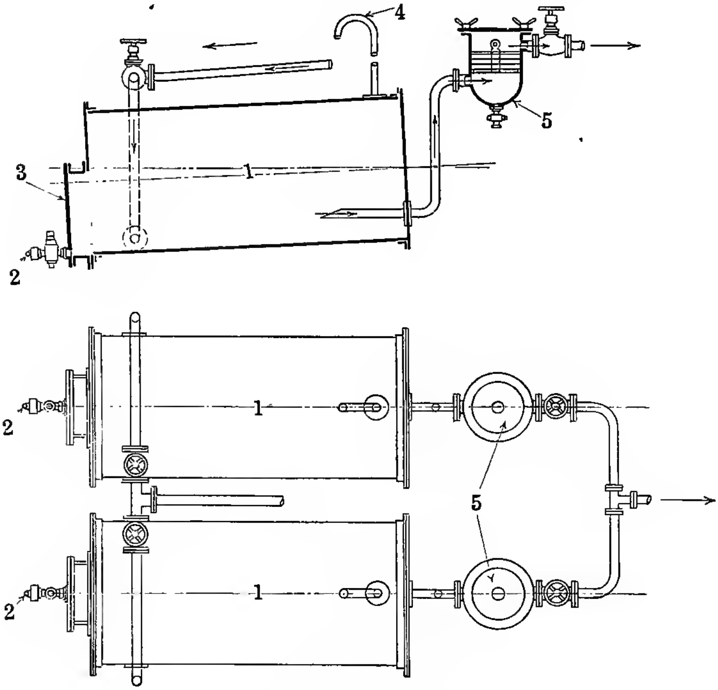

Fig. 78.—Two tank system.

In cases where a large proportion of water finds its way into the oil, a heater might be fitted in the return pipe to raise the temperature of the oil to about 150°F. This will result in immediate separation of all water and foreign matter as soon as the oil enters the suction tank, the oil rising quickly to the top and the separated matter remaining at the bottom. To facilitate separation, the return pipe should go almost to the bottom of the tank and deliver the oil in a downward direction. The tanks should be tilted; the suction of the pump should be placed as high as possible, the opening of the pipe to be directed upward if possible. The net storage capacity of the tank is, of course, the capacity above this level. On leaving the tank the oil is sucked through a filter consisting of three or four separate layers of gauze of, say, 24 mesh to the inch, the uppermost layer consisting of two sheets of gauze with a sheet of cheese cloth between them. The bottom of the filter forms a convenient receptacle for any dirt that may have been carried as far as this point, the dirt dropping downward from the filter gauze.

In small and medium size turbine plants ashore, where, as a rule, each turbine has its own separate oiling system, the two-tank system has only rarely been employed. The oil circulates continuously and gets little rest when the turbine is in operation. In such plants it is good practice to remove daily from 3 to 6 gallons of oil from each turbine unit, treating this oil in a steam-heated separating tank and filter. The purified oil should be returned to the circulation system at the same time that a corresponding quantity is drawn off for treatment. In this way the vitality of the oil can be maintained at a high standard. If the oil tank capacity is small, it is particularly desirable to follow this practice.

In large turbine power stations consisting of several units it is often desirable to have a separate plant for supplying the oil to the various turbines and for cooling and purifying the return oil. There are several designs of such plants, but common to them all is the feature that a portion of the oil is by-passed through a filter, while the main flow of oil is only strained and cooled, not filtered. The oil coolers, oil filters and oil tanks are all made up from several identical units, so that the necessary cleaning and inspection can be made while the plant is in operation, and without disturbing the normal operation of the oil plant.

Oil Consumption.—The "make up" for lost oil due to leakage and atomization—there is very little evaporation—amounts to from 1 pint to 4 gallons per week per turbine unit, depending upon the size and operating conditions. The average "make up" for a 1000-kilowatt turbine is about 1 to 1½ gallons per week.

Acquired Impurities.—During the passage of the oil through the entire circulation system it picks up more or less water, air, iron oxides and other impurities, and when passing through the main bearings the oil gets intimately churned together with these foreign matters; the result is that, owing to the high temperature and the great surface speed of the revolving shaft, the oil gradually breaks down.

When ordinary oils, not specially manufactured for turbine use, are employed they may not have a life of more than a few months, whereas high quality turbine oil may last under normal conditions 10,000 working hours or more, and 3,000 working hours under very unfavorable conditions; also, the margin of safety will be considerably greater when using the best possible oils. Whereas all oils, even the best, are affected in time, unsuitable oils will sooner show the signs of breaking down, which are (1) darkening in color; (2) increased specific gravity; (3) increased viscosity; (4) increased acidity; and (5) the throwing down of various kinds of deposits.

The first three effects cannot be said to be detrimental except that they are the "signs of warning" that the oil is breaking down. As regards the acidity, the acid produced in the oil is the result of oxidation, and is a petroleum acid which must not be confused with sulphuric acid, which is sometimes found in mineral oils that have been treated with this acid during their manufacture. Petroleum acids do not attack the metals ordinarily used in the construction of the circulation system, but they do slowly dissolve zinc or alloys consisting largely of that metal. Increased acidity can always be taken as a guide to judge how far the oil has suffered, and when it gets in the neighborhood of 0.3 per cent. in terms of SO_3, steps should be taken to prevent this limit being exceeded, by renewing either part of the oil, or all of it, as the circumstances may seem to justify. When the acidity of an oil is below 0.03 per cent. it is generally considered by chemists to be "free from acid;" good turbine oils often contain less than 0.008 per cent. of acidity, when new.

DEPOSITS

Deposits may form even where the best oils are in use, although always in very much smaller quantities than where unsuitable oils are employed. Naturally, it is the constant aim and endeavor of the oil manufacturer to produce oils which possess as great a resistance as possible against the oxidizing and emulsifying effect of the impurities, etc.

The principal causes of deposit, apart from the quality of the oil, are: (1) water; (2) solid impurities; (3) air; (4) electric action; (5) adding new oil.

1. *Water.*—Water has an emulsifying effect on the oil, particularly if it contains impurities, whether in solution or suspension. Where considerable quantities of water leak into the system and emulsification takes place, the oil becomes yellow or brownish yellow in color, and if a sample is taken out and heated it will separate into clean oil at the top, more or less milky water at the bottom, and a spongy sludge separating the oil and water. If the oil and the water are removed, the spongy emulsion, which varies in color from gray to brown, will be found to contain from 15 per cent. to 35 per cent. of oil and to consist of numerous exceedingly thin films of oxidized matter surrounding small drops of water; in fact, the sludge when freed from oil consists of about 99 per cent. water by weight, and 1 per cent. of exceedingly thin films. On analysis these films have been found to be composed of a chemical combination of petroleum acids produced by decomposition of the oil, and rust (iron oxides) which is found throughout the system.

The nature of the sludge in the oil produced by the water is most objectionable, as it tends to clog the oil strainers, oil inlets to the bearings, and oil inlet to the governor. Furthermore, the oil pressure may be reduced, due to the oil pump not delivering the requisite quantity of oil because of the partial choking of the pump strainers. The chief source of water getting into the oil is usually the gland packings; water may also leak into the oil in the oil cooler or in the bearings (when water cooled). On seagoing ships a leakage of cooling water into the oil can be detected at once by taste, the cooling water being salt. If one could always be sure of the steam passing the glands producing an absolute soft water of condensation free from boiler salts, it would be an easy matter by analysis to determine whether the water leaking into the oil was from the glands or from the cooler, or partly from one, partly from the other source. But when the boilers prime, such analysis becomes almost useless, for obvious reasons. Determining the degree of hardness of the water drawn away from the oil in the system is quite misleading, as the acidity of the water—washed out of the oil—upsets the titration test. Evaporating the water to dryness and ignoring the percentage of metallic salts—iron, copper, etc.—which the water has dissolved from the oil pipes, and comparing the grains of salts remaining with the results when evaporating a similar volume of cooling water, is about the only reasonably accurate chemical method of forming an idea as to where the leakage occurs.

Mechanically, it is often possible, sometimes even quite easy to locate the leakage.

Where leakage of water into the oil system cannot very well be avoided, a "water leg" consisting of at least 4 feet of vertical pipe—2½ inches to 4 inches in diameter—fitted to the bottom of one of the oil tanks may do great service, as it will catch the fine drops or particles of water circulating with the oil, and once a particle is caught in the "leg" it cannot again rise and mix with the oil; it goes to the bottom of the leg, which should be drained twice every 24 hours. Strict instructions should be given that the drain cocks in the oil tank or tanks should be opened twice every 24 hours, and every time the turbine is about to start up after a rest; the drains should be kept open until clean oil appears.

Turbine oils are affected by water if it contains boiler salts in solution, more than by clean water, and certain boiler compounds have a strong emulsifying effect, but the greatest effect seems to be produced by iron salts in solution. The water cannot help dissolving some of the iron during its rapid flow through the oil pipes, hence the desirability of using copper oil pipes in preference to iron pipes; copper is little attacked by water, and a copper solution has only a slight emulsifying effect on the oil as compared with the effect of an iron solution.

2. *Solid Impurities.*—The disintegrating effect on the oil caused by finely suspended solid impurities, such as fine rust, moulders' sand, etc., is very marked. The oil darkens considerably in color, the acidity increases rapidly; the oil assumes a "burnt" odor, a slimy dark colored deposit develops and lodges, particularly in the oil cooler. If, furthermore, there is a leakage, however slight, of water into the oil system, the oil may get badly emulsified, much more than would be the case with water alone, as the oil is in a weakened condition due to the oxidizing effect of the solid impurities. This will explain why, when a new turbine is being started up for the first time, emulsification of the oil may occur even if the oil is of good quality.

Where the inside of the oil tank is painted, emulsification and breakdown of the oil usually occurs, as there exist hardly any paints that are "oil-proof" under the exacting conditions prevailing in turbine practice. The advisability of changing the initial charge of oil will, in view of what is said above, now be fully understood, the effect being that the entire system gets thoroughly cleaned, and that the fresh charge of oil will have very much better conditions to work under.

3. *Air.* The circulating oil always contains more or less air, and when the temperature is above normal, say more than 140°F., this air has a tendency to oxidize the oil, a tendency that increases rapidly with increasing temperatures. This effect will

be better realized when considering that the oil film in the bearings is very thin and that the air is present in exceedingly fine bubbles, which are intimately mixed with the oil. The result is that the oil darkens in color, increases in acidity, and in extreme cases a black, carbonaceous deposit develops, which is exceedingly dangerous, as it may choke the oil inlets to the bearings and cause sluggish working of the governor gear, or may even cause it to stick, putting the governor out of action.

Another effect of air in the oil shows itself only when an abnormal amount is present; the effect is known as "fuming." Fumes issue from the main bearings and oil tank, notwithstanding that the bearing temperatures are quite normal; the fumes may be drawn into the generator windings and cause disastrous results. The cause of the "fumes" is that the fine air bubbles, with which the oil is heavily charged, burst in the bearing cavities and in the oil tank, producing a very fine spray of oil that oozes out in the form of a mist—the oil "fumes." The oil will be found creeping all over the outside of the bearings and turbine bed-plate, forming a very thin film, and the loss of oil may be quite considerable, several gallons per 24 hours. The remedy is to prevent, as far as possible, the oil from getting churned together with the air. Perhaps the churning takes place between oil throwers and baffle plates inside the bearings, or the oil gets violently disturbed in the sight-feed arrangements in the return pipes, or where the return branch pipes join the main return pipe, etc. If the spray is formed inside the bearings these should be ventilated, a large pipe connection being taken from the air space in the bearing cavities to the oil return tank. The "fumes" will then go through these pipes instead of oozing out of the bearing ends; sometimes enlarging the oil return pipes will overcome the trouble. The main return oil tank should always have a vent pipe, at least 1 inch in diameter, to prevent accumulation of oil "fumes" in this tank and in the return oil pipes. Frothing may also occur temporarily when a considerable percentage of the oil in circulation is renewed at one time, say, 50 per cent. New oil should always be added in small quantities at a time.

4. *Electric Action.*—If in the case of the electric generator there is a slight leakage of electric current from the generator (direct-current generator) or if the magnetic field is out of balance (alternating-current generator), and produces induced currents in the turbine shaft, the result is that an electric current passes through the shaft down through one of the main bearings, through the bed-plate and up through another main bearing back into the shaft. The effect on the oil is that it quickly

darkens in color, increases in acidity, and throws down a deposit which coats all parts of the turbine with which it comes in contact, lodging particularly in the oil cooler. The deposit is of a fairly hard, brittle nature, and of dark chocolate color; it is exceedingly difficult to remove, and therefore very objectionable. The remedy is completely to insulate electrically one of the main bearings from the turbine bed-plate, including the connections between the oil pipes and that particular bearing. This insulation will prevent the formation of an electrical current, and consequently the formation of deposits will cease.

On rare occasions local galvanic currents may cause corrosion of the oil tubes in the oil cooler, or of the turbine shaft and bearings, and even in the governor, causing the oil-operated piston to stick, or may eat away the sharp edges of the pilot valve.

5. *Adding New Oil.*—Where practically no water enters the circulation system and where practically no waste or leakage of oil occurs, so that the amount of new oil added to the system per week is only very small, the oil in time becomes very dark in color, and the acidity increases considerably. In such cases it has been found that when new oil is added a dark deposit is thrown down throughout the system, owing to the action of the old oil on the new, and this is particularly the case with heavy viscosity oils rather than with light oils.

Speaking generally, deposits are always inclined to accumulate in the most dangerous places, such as the oil pipes leading from the main oil pipe into the main bearings. A partial choking of the oil inlet would reduce the oil feed, the bearing would heat up quickly, and if not observed in time the bearing surfaces would with all certainty be destroyed, which might have very serious consequences, owing to the high speed at which all turbines operate, and particularly so on account of the time it takes—half an hour or more—for the turbine to come to rest from full speed. If deposits get into the oil pipe feeding the governor gear, the governor may fail to act, and consequently the turbine would either gradually slow down or increase in speed much above the normal speed. The parts inside the governor gear in contact with the oil are very sensitive—with small clearances—and the oil must be absolutely clean and good in order to make the parts work smoothly.

TYPICAL EXAMPLES OF TURBINE TROUBLES

Example No. 1.—1000-*K.W. Turbine,* 3000 *R.P.M.*

Temperature of oil leaving bearings............	120°F.
Temperature of oil leaving cooler..............	110°F.
Quantity of oil in circulation..................	60 gallons.

The oil cooler contained 100 copper pipes 21 mm. diameter and 1 meter long, the oil being sucked from the cooler, with the result that a slight amount of water was always leaking into the oil in the cooler owing to the thin copper tubes not keeping quite watertight in the endplates. The cooling water was taken from a brook; it was practically soft water and for several years no trouble had been experienced. The oil in use was similar to Circulation Oil No. 1 (page 236) and gave complete satisfaction. Suddenly trouble commenced. An emulsified sludge was formed throughout the oil system and the bearing temperatures increased. It was found necessary to change the oil every three or four weeks, whereas previously the oil (without any daily treatment) was renewed only every six months.

A thorough examination revealed the fact that the oil cooler was leaking and furthermore that the water supply had been changed. The water instead of being taken from the brook was taken from the coal washing plant, after indifferent filtration; it contained coal dust and was exceptionally hard. An emulsification test with fresh oil, using this water, showed unsatisfactory separation and explained the cause of the trouble.

As a result of the higher bearing temperatures which had prevailed for several months a large amount of sludge had settled in the oil cooler and gradually baked into a fairly hard deposit which almost choked the cooler.

Example No. 2.—3000-K.W. Turbo-generator.

Oil temperature of bearings..........	120–130°F.
Quantity of oil in circulation.........	120 gallons.
Rate of circulation..................	Exceptionally rapid.

A certain amount of sludge was continuously developed in the oil system and settled at the bottom of the turbine bed chamber. Two samples were drawn at an interval of seven weeks and were analyzed as follows:

	Sample No. 1, per cent.	Sample No. 2, per cent.
Oil....................................	12	17
Water..................................	22	36
Sludge.................................	66	47
Sludge.		
Water..................................	45.1	43.0
Oil....................................	34.2	34.2
Volatile matter insoluble in petroleum spirit..	18.5	20.0
Ash (containing oxides of iron, silica and lead)..	2.2	2.8
Petroleum acids........................	1.389 as SO_3	1.598 as SO_3
Oil.		
Acidity................................	0.154	0.218
Color, Lovibond ¼" cell..................	125	179

It will be seen that the color of the oil, which when the oil is new is about 35 has darkened considerably, also that the acidity of the oil and sludge has increased between the dates of taking the two samples. The cause of the deposit is emulsification and oxidation of the oil, brought about by the rapid circulation (aeration of the oil), and also the very small volume of oil in circulation. Only a small amount of water was leaking into the system, but owing to the very rapid circulation of the oil the water was never given a chance to separate out.

Example No. 3.—Four large turbines were using an exceptionally heavy turbine oil similar to Circulation Oil No. 3. The bearing temperatures were high, from 150–165°F. and the oil coolers were constantly filling up with a thick sludge. An investigation proved that the boilers were priming. The boiler salts carried over with the steam found their way through the turbine glands into the bearings, contaminating the oil and causing the sludge. Owing to the fact that the oil was far too viscous for the conditions the accumulative effect of the water charged with boiler salts was very troublesome.

A change in grade of oil to a light viscosity oil similar to Circulation Oil No. 1 was made with the result that the bearing temperatures were reduced to 120–130°F. and at the same time an efficient system of daily treatment of the oil in the turbine was instituted. It was then found that very little sludge formed in the system and the little which did form was largely removed from the oil by the process of daily treatment.

Example No. 4.—That an admixture of fixed oil, whether vegetable or animal, quickly causes trouble when water is present is obvious, and usually very soon detected. The following example is of interest in this connection.

A new grade of turbine oil was tried on board a large turbine steamer, the entire system being cleaned out and filled with the new oil. On the first trip of the boat the oil got badly emulsified and the Chief Engineer, complaining bitterly, insisted upon reverting to the old oil. Careful examination proved, however, that there was a small percentage of saponifiable matter present in the turbine system and in the turbine oil supply tanks on board the boat; and strangely enough the percentage of saponifiable matter, althouuh very small, was greater in the oil circulating in the turbine than in the oil in the supply tanks. It was evident that some compounded marine engine oil had been "accidentally" added to the system and evidently a slightly greater proportion had been added into the turbine system than into the supply tanks.

In connection with marine steam turbines great care must be exercised to prevent contamination with marine engine oils, which are always compounded with vegetable or animal oils. This point must be particularly watched in case of large warships where oil is pumped on board through a flexible hose; a separate line must be used for turbine oil.

Example No. 5.—In a large turbine shortly after erection the bearing temperatures commenced to rise and a tenacious emulsified sludge developed throughout the system. It was found that the water softening plant for treating the boiler water had not been properly looked after, excess soda getting into the boilers. Priming of the boilers carried soda into the turbine, and through the glands it finally reached the oiling system. The turbine bed chamber was painted with "oil-proof" paint, but the soda very soon dissolved or destroyed it and mixing with the water brought about the emulsification.

Example No. 6.—*3,000-K.W. Turbine.* An oil similar to Circulation Oil No. 1 and of good quality was in use. Oil temperatures were normal, being approximately 120°F. The quantity of oil in circulation was 60 gallons; the oil was drawn through the cooler by the oil pump, so that the oil was always under suction. Very little water leaked into the oil system, being approximately one pint per 24 hours; the oil gave excellent results and was renewed only once a year. A thin deposit developed in the oil cooler having the following composition:

Oil with a trace of moisture	46.4 per cent.
Volatile matter insoluble in petroleum spirit	48.9 per cent.
Fixed carbon and oxides of silica	0.1 per cent.
Iron oxides	2.2 per cent.
Copper oxides	2.0 per cent.
Balance undetermined	0.4 per cent.

A sample of the water leaking into the oil system was analyzed and found to be very hard, similar to the cooling water. Obviously what had happened was that the cooling water had constantly leaked into the oil system; owing to the small volume of oil in rapid circulation considerable aeration took place and the combined effect of the air and water was to produce slowly the deposit which was found in the oil cooler.

This and Example No. 1 point to the desirability of always having the oil under a pressure in the oil cooler higher than the pressure of the cooling water.

Example No. 7.—A 1,500-K.W. turbine had for several years been using an oil similar to Circulation Oil No. 1 with every satisfaction.

Quantity of oil in circulation	80 gallons.
Bearing temperatures	Quite normal.

Suddenly the bearing temperature rose within one week from about 110°F. to 140°F. On examination it was found that a thick deposit had developed and nearly choked the oil coolers. The deposit on analysis gave the following composition:-

Oil and water	42.8 per cent.
Volatile matter insoluble in petroleum spirit	17.8 per cent.
Fixed carbon and oxides of silica	1.6 per cent.
Oxides of iron	36.4 per cent.
Balance undetermined, containing copper oxides, etc	1.4 per cent.

Analysis of the oil showed that it was in very good condition, the percentage of petroleum acids being only 0.05 per cent. It was somewhat dark in color and heavier in viscosity than the fresh oil, but nothing to be alarmed about.

On the oil pipes being taken apart it was found that during five years' operation the pipes had rusted on the inside, and a portion of the rust had been either absorbed by the water circulating with the oil or circulated in the form of a fine powder.

As mentioned elsewhere finely divided iron and iron salts have a very powerful effect on turbine oils. This explains the formation of the sludge which almost put the oil coolers out of action and brought about the high bearing temperatures.

Example No. 8.—1700-K.W. TURBOGENERATOR, 3000 R.P.M.

Quantity of oil in circulation	60 gallons.
Temperature of oil leaving bearings	Approximately 150°F.
Temperature of oil leaving cooler	140°F.

Great trouble was experienced in this turbine with oxidation. A black brittle deposit developed throughout the system, settling particularly in the oil cooler and in the oil inlets to the bearings, also in the governor gear, preventing the governor from functioning properly.

	Unused	Used
Oil.		
Specific gravity Open flash point Fire point } Unaltered.		
Saybolt viscosity at 104°F.	135″	153″
Color	40	400
Petroleum acids as SO_3	0.006%	0.08%
Deposit.		
Volatile matter insoluble in petroleum spirit		95.2%
Ash, chiefly iron oxides		4.8%

The analysis given in the preceeding table compares the unused oil and the oil after four months use:

It is obvious that the temperature of the oil in circulation was too high and the amount of oil in circulation too small, with the result that the oil was quickly oxidized.

Example No. 9.—A large turbine suddenly developed high bearing temperatures, and an investigation proved that the vertical oil cooler had become air locked, the upper part of the oil cooler thus being put out of action. The obvious remedy was to fit an air vent pipe, leading the air from the uppermost part of the oil cooler up to the main oil return tank.

Example No. 10.—A 1000-K.W. steam turbine immediately after erection was greatly troubled with oil vapors oozing out of the turbine bedplate (used as the oil reservoir), which meant not only a large waste of oil but also a considerable danger to the generator.

An investigation proved that the oil return pipes from the bearings, instead of sloping gradually into the bedplate, were vertical; the return oil falling into the reservoir caused the oil to splash about and form a great deal of oil spray. The return oil pipes were then altered and the trouble ceased.

Example No. 11.—A 1500-K.W. steam turbine was greatly troubled with oil vapors which evidently emanated from the main bearings, and the presence of oil in the generator was clearly visible. Everything possible had been tried to stop the vapors emanating from the bearings, when on an investigation by an oil expert it was found that the return oil tank had no vent pipe, and that the fine oil spray developed in the bearings could not pass back into the oil tank, but simply filled up the oil return pipes and then had to find its way out through the bearing ends. The obvious remedy was applied and the trouble thus overcome.

Example No. 12.—A 1500-K.W. Howden turbine, 3,000 R.P.M. was using an oil similar to Circulation Oil No. 2 and of good quality. Difficulties were experienced with the oil "creeping" along the turbine shaft and getting into the generator.

An investigation proved that the oil was unnecessarily viscous for the conditions and an oil similar to Circulation Oil No. 1 was installed to see whether the change in oil would make any difference. Curiously enough the "creeping" of the oil entirely disappeared without the Engineer being able to offer any definite explanation as to the reason why it ceased. At the same time a remarkable difference in the bearing temperatures took place as shown in the following table:

	Old oil, °F.	New oil, °F.
No. 1 bearing	130	116
No. 2 bearing	124	110
No. 3 bearing	122	108
No. 4 bearing	123	108
No. 5 bearing	134	122
No. 6 bearing	116	106
Temp. of inlet oil	110	98
Temp. of outlet oil	130	114
Temp. inlet cooling water	48	48
Temp. outlet cooling water	78	68
Temp. engine room	80	79

The above figures show clearly the lower bearing temperatures obtained by using the low viscosity oil, notwithstanding that the supply of town water through the oil cooler was greatly decreased when the new oil had been installed; as town water had to be paid for the change in oil brought about quite a considerable saving in the water bill.

Note: Where oxidation takes place due to oil temperatures being too high, a change to lighter viscosity oil has often reduced temperatures and stopped the oxidation.

Example No. 13.—350-*K.W. Mixed Pressure Turbine,* 3,000 *R.P.M.*

Temperature of oil leaving bearings	120°F.
Temperature of oil leaving cooler	105°F.
Quantity of oil in circulation	60 gallons.
Oil consumption	1 gallon per week added to the system.

The turbine was in operation day and night continuously until it had to be stopped owing to the armature of the generator breaking down. Before the turbine was stopped the oil temperatures had for several weeks been gradually creeping up, for some unknown reason. When the turbine was opened up for inspection the flexible coupling between the turbine and the generator was found to be absolutely solid with a black brittle carbonaceous deposit, which was also found throughout the entire oil system.

Strangely enough there was no perceptible wear of any of the bearings; the surfaces of the brasses were black and dull, covered with a very slight deposit. The oil from the turbine had a charred odor and a dark brown bloom, whereas the bloom of the fresh oil was green. It was apparent that a radical change had taken place in the oil. The deposit consisted of:

	Per cent.
Oil and volatile matter insoluble in petroleum spirit, with a slight percentage of water	77.4
Fixed carbon	2.4
Iron oxides	10.5
Copper oxides	8.4
Undetermined, containing carbonate of magnesia, traces of lead, etc.	1.3

The total amount of the deposit was about 25 lb. and a large portion of this had undoubtedly been in constant circulation with the oil in the form of very fine powder which settled when the turbine was stopped. Owing to a fault in the rotor and armature, stray currents had passed down through the bearings, oil pipes, oil cooler, etc., and had caused the oil to break down, developing the deposit.

The remedy, apart from putting the rotor in order, was to entirely insulate the end bearing of the turbine from the bed plate. This practice is now followed by a good many turbine builders

Example No. 14.—A 1000-K.W. exhaust steam turbo-generator had an electric breakdown similar to the turbine mentioned in Example No. 13. The oil used underwent a remarkable change in the course of one week, becoming changed in color from 35 to 180 and the acidity increasing from 0.002 per cent. to 0.298 per cent.; simultaneously, the viscosity increased about 20 per cent. A brownish brittle deposit with a lustrous fracture developed throughout this system having the following composition:

	Per cent.
Water	24.2
Oil	17.2
Volatile matter insoluble in petroleum spirit	52.0
Ash, chiefly iron oxides	4.3
Petroleum acids	2.3 as SO_3.

CURTISS VERTICAL TURBINES

These turbines are chiefly found in the United States, only a few having been installed in England. They operate electric generators and are made in sizes from 500 K.W. to 20,000 K.W., the corresponding speeds ranging from 800 R.P.M. down to 720 R.P.M. The revolving parts are supported by a combined step-and-guide bearing and by upper and middle guide bearings. The middle bearing may be left out with smaller machines where the turbine shaft is in one piece.

The step bearing is shown in Fig. 79 and consists of two cast-iron blocks, one carried by the end of the shaft and the other held firmly in a horizontal position, and so arranged that it can be adjusted up and down by a powerful screw. The lower block is recessed to about half its diameter, and into this recess oil is forced with sufficient pressure to balance the weight of the whole revolving element; there are of course no oil grooves. The amount of oil required is small, from 1½ gallons per minute for a 500-K.W. machine to about 6 gallons per minute for an 8000-K.W. machine. The oil, after passing between the blocks of the step bearing, wells upwards, lubricates a guide bearing supported by the same casting and leaves through oil drain (1).

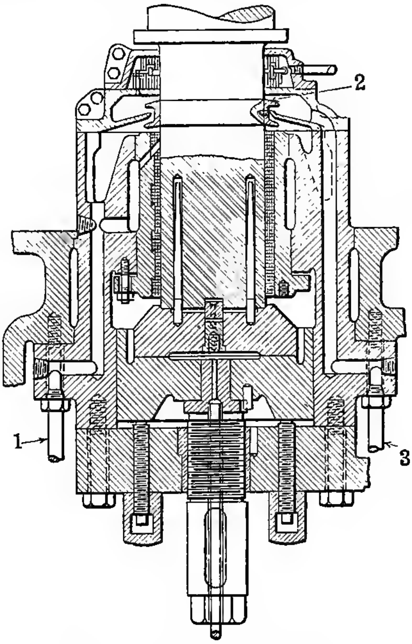

Fig. 79.—Curtiss step bearing.

A carbon packing, prevented from rotation, and consisting of two sections of rings, each section comprising two rings made up from three segments, is fitted above the oil thrower (2), and, in order that no oil or air shall enter the turbine chamber above the packing, a low steam pressure is maintained between the two sections of the packing, just sufficient so that vapor is visible at the outlet of drain pipe (3). If the flow of oil into the bearing is too great, the oil overflows into drain (3) mixing with the steam; the mixture should be drained into a separate tank with baffle plates, in which the water is held back; the recovered oil may be allowed to enter the main oil system when entirely freed from water.

The oil pressure required for the step bearing is slightly higher than the bearing pressure, ranging from 300 to 800 lb. per square inch, thus producing perfect oil film lubrication. To start lubrication a pressure 25 per cent. greater than the normal running pressure is needed. The film thickness depends upon the flow of oil, ranging usually from 0.003 inch to 0.006 inch.

In some designs a powerful brake bearing is provided which can be operated from the outside, and can be used to take the whole weight of the revolving part in case the step bearing support should fail. In ordinary operation the shoes of this brake will be set about 0.01 inch below the brake ring. It is thus in a position to receive the revolving part in case the step bearing support should fail. Another and more important feature of this brake is to stop the machine when it is desired to do so. A 5,000-K.W. machine will run for four or five hours after the steam has been shut off, unless a brake is applied.

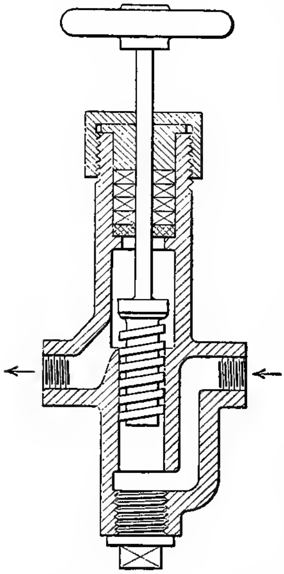
FIG. 80.—Oil pressure baffler.

In some cases the step bearings have been operated with water instead of oil, in which case no packing is necessary, the water being allowed to pass up into the turbine. The trouble with water is that it causes rusting of parts. When accidentally the step bearing oil pressure has dropped below the pressure required, the bearing surface immediately cuts; but the metal is removed very slowly and lubrication is easily re-established when the pressure oil flow is restored. Precautions are, however, taken in the shape of accumulators and other auxiliaries necessary for the maintenance of a flow of pressure oil to the step bearing.

The guide bearings are babbit lined sleeves, with a clearance of 0.0005 inch per inch shaft diameter for the lower guide bearing, and twice this clearance in the upper and middle bearing. They have suitable oil grooves to ensure good oil distribution; the oil is fed at the rate of 0.5 to 1.5 gallons per minute per bearing according to size, and is distributed by gravity from an elevated oil tank, or from branch pipes from the main pressure system.

In the latter case bafflers, as illustrated in Fig. 80 are fitted to reduce the oil pressure. The oil is forced to pass through the narrow spiral passage formed by the thread and the longer the passage the more is the pressure reduced. These bafflers are also placed in the delivery line to the step bearing to reduce the pressure and also to reduce the intensity of the pulsations caused

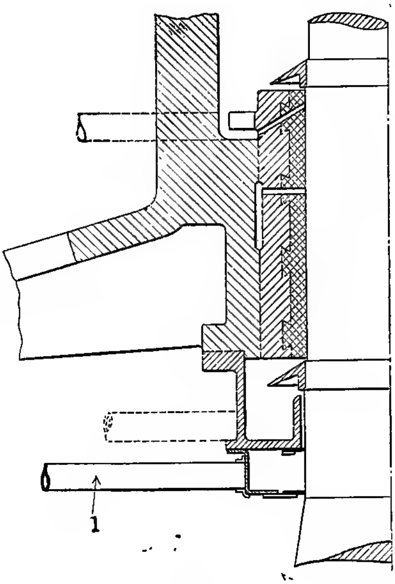

FIG. 81.

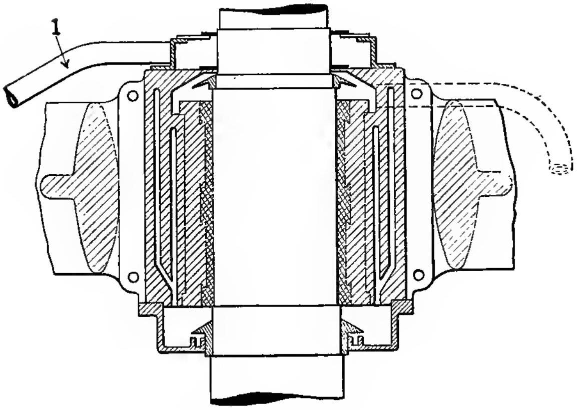

FIG. 82.

FIGS. 81, 82.—Preventing oil spray from guide bearings.

by the reciprocating main oil pump. When the oil leaves the guide bearings it is thrown off into oil troughs, large drain pipes guiding the oil back into the oil reservoir.

A carbon packing is also fitted between the middle guide bearing and the turbine; excessive steam admitted to this packing will get up and mix with the return oil from the middle guide bearing and should be avoided.

The guide bearings may cause trouble by oil throwing, caused by leaky joints (which is easily remedied) or by oil spray sucked out from the bearings by the draught created by the rotating parts. Deflectors, as shown page 164 may also be adapted for vertical turbines, but the disease is a troublesome one to cure. Possibly the oil supply is too great, particularly when the oil is introduced under great pressure, or the oil troughs may have become obstructed by dirt, which may account for the oil getting into the generator; they should therefore be kept clean, as well as the oil return pipes. If oil leaks through a porous casting, a mixture of litharge and glycerin applied to the points of leakage is said to be a remedy.

To stop the fine oil spray being carried out from the bearings, it is necessary to equalize the air pressure outside and within, as shown in Figs. 81 and 82 for an upper and middle guide bearing respectively. The pipes (1) are pressure equalizing pipes, taken outside to a point where there is no suction, and in addition felt rings are fitted, as shown, and prove very effective as long as they are not worn too much. The arrangements in Figs. 81 and 82 were designed by E. D. Dickinson of the General Electric Company. The casings are made of sheet iron with rivetted joints; the felts are fastened by means of metal rings. Where bolts are used they should be locked, so that the nuts cannot come undone through vibration.

Oil Distribution.—The oil is distributed under pressure to the step bearings and guide bearings as described, but the latter are sometimes fed from an elevated tank, with an overflow pipe back to the oil reservoir. On its way to the bearings the oil pressure is reduced by one or more bafflers, so that each bearing gets the right amount of oil. The oil is returned by gravity from the bearings and passes a filtration and cooling system, in which it is freed from water, dirt and other impurities, before it is circulated afresh.

The oil reservoirs should preferably be in duplicate and operated alternate days, similar to the "two tank" system (page 217).

When water is used for the step bearing, the oil pumps have to supply oil only for the upper and middle bearings, usually by way of an elevated tank. The amount of oil going to each bearing is regulated by small control valves and sight feeds in each line.

In an installation of one or two units of the same capacity, two high-pressure steam-driven pumps supply oil to the step bearings and two low-pressure pumps supply the upper and middle guide bearings and an accumulator gear, for equalizing variations in pressure caused by fluctuations in the speed of the pumps. These accumulators in case of failure of pump will keep the turbines running for some time and automatically cause reserve oil pumps to come into action. The accumulators may be on the principle of a heavy weight which is raised or lowered according to the amount of oil "stored" in the accumulator. Air chambers have also been used as pressure accumulators and must be absolutely air tight. In installations of three units of the same capacity three high- and three low-pressure pumps are fitted, two sets being sufficient to supply all units.

In a plant comprising two or more units the starting or stopping of a unit means that the amount of oil required is altered; the alteration in oil supply is automatically brought about by influencing the speed of the oil pumps. The latter should run at no greater speed than that required to give the necessary oil supply plus a margin. If the speed is greater, power is wasted, and an excessive oil supply may cause various kinds of trouble, such as oil throwing, oil overflow into packing drain pipe, excessive churning of the oil in the pumps (causing emulsification when water is present), etc.

The number of gallons of oil in circulation is about 10 per cent. of the rated K.W. capacity for turbines of 4000 K.W. or over, 20 per cent. for turbines between 2000 K.W. and 4000 K.W. and a still higher percentage for smaller turbines, being 200 gal. for a 500-K.W. unit.

Oil.—The step bearing lubrication is not dependent upon the viscosity of the oil; the shaft floats on the oil film, whether the oil is thick or thin, simply because the oil is introduced at a sufficiently high pressure. Some "body" is however, required for lubricating the guide bearings, particularly when there is a tendency to vibration. Very low viscosity oils were at one time used for Curtiss turbines, but any leakage is accentuated by their use, and more oil spray may be formed in the bearings. The oil must, of course, be a circulation oil in order to separate well from water and withstand oxidation. Unless the conditions specially call for a more viscous oil, Circulation Oil No. 1 should be recommended in all cases.

SELECTION OF TURBINE OILS

For satisfactory lubrication of steam turbines only three oils are required having approximately the following specifications:

Circulation Oil No. 1.[1]—*Neutral Filtered Oil.*

Specific gravity	.870
Flash point open	395°F.
Saybolt viscosity at 104°F.	135″
Saybolt viscosity at 140°F.	70″
Setting point	20–25°F.

Circulation Oil No. 2.[1]—*Mixture of a Neutral Filtered Oil and Filtered Cylinder Stock.*

Specific gravity	.900
Flash point open	410°F.
Saybolt viscosity at 104°F.	265″
Saybolt viscosity at 140°F.	120″
Setting point	35°–40°F.

Circulation Oil No. 3 [1]—*Mixture of a Neutral Filtered Oil and Filtered Cylinder Stock.*

Specific gravity	.900
Flash point open	425°F.
Saybolt viscosity at 104°F.	500″
Saybolt viscosity at 140°F.	200″
Setting point	35–40°F.

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[1] All circulation oils must separate rapidly from water, and only a trace of sludge must be produced in the emulsification test.

LUBRICATION CHART NO. 4

FOR STEAM TURBINES

Land Turbines.—Circulation Oil No. 1 is suitable for the great majority of land turbines, including the vertical type of Curtiss turbines.

During the last ten years or so, turbine builders have gradually realized the importance of using a light viscosity oil for high speed turbines and have designed the lubricating system in such a manner that the pump pressure required to operate the governor gear can be obtained, notwithstanding the use of a low viscosity oil.

The advantages of such an oil as compared with a heavy viscosity oil are:

Lower frictional losses (*i.e.*, low bearing temperature).
Rapid removal of heat from the turbine bearings.
Rapid cooling of the oil in the coolers.
Quick separation from water, dirt and other impurities.
Longer life of the oil.
Greater freedom from trouble.

When Circulation Oil No. 1 is not viscous enough to give the pump pressure required for the governor gear, Circulation Oil No. 2 or even No. 3 (in very special cases) must be used.

Marine Turbines.—Marine turbines operate at lower speeds than land turbines and with higher bearing pressures. A heavier viscosity oil is therefore required and Circulation Oil No. 2 will generally be found to be the correct grade.

Geared Turbines (Land and Marine).—The lubricating system for the gears should preferably be separate and distinct from the lubricating system serving the turbine bearings, as the conditions of service are entirely different, and frequently Circulation Oil No. 3 will be found best for the turbine gears. Only in rare cases will this oil be the most suitable oil for the turbine bearings, as its use frequently will mean:

High frictional losses (*i.e.*, high bearing temperatures).

Slow separation from water, dirt and other impurities.

Rapid oxidation of the oil and the development of objectionable deposits in the circulation system.

For turbine bearings in geared turbines, when the lubricating system is separate from that serving the gears, a lighter viscosity oil, either Circulation Oil No. 1 or No. 2 should preferably be used, as recommended under *Land* and *Marine Turbines.*

CHAPTER XIV

BEARING LUBRICATION OF STATIONARY, OPEN TYPE STEAM ENGINES

The parts to lubricate are the main bearings, the crank pin, the crosshead and guide, the eccentric straps and sheaves, the valve motion and the governor.

Main Bearings.—In small engines these bearings are syphon oiled; in larger engines they are ring oiled or are oiled from a circulation oiling system.

Crank Pin.—The crank pin in most engines is oiled by the banjo system, the oil being delivered into the banjo either by a sight feed drop oiler or by a pipe from the circulation oiling system.

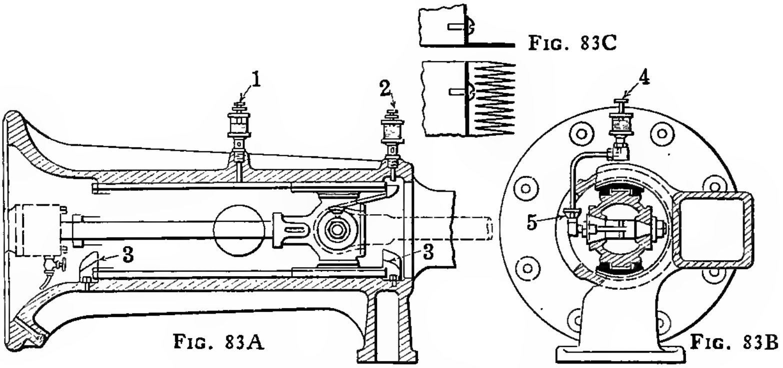

FIG. 83C

FIG. 83A

FIG. 83B

FIG. 83.—Crosshead and guide lubrication.

Crosshead and Guide.—Lubrication of the crosshead and guide may be accomplished as shown in Fig. 83*A*. Oiler (1) lubricates the top slipper; oiler (2) supplies the crosshead, and the oil leaving these points finally reaches the bottom guide, being retained by the splash guards (3). The crosshead pin may also be lubricated through holes drilled as shown in Fig. 83*B*; the oiler (4) feeds oil to the wiper (5) which is fixed on the crosshead and delivers the oil to the crosshead pin.

The lower crosshead slipper is preferably fitted with a comb shown in detail in Fig. 83*C*, which touches the guide with a slight pressure and assists in spreading the oil all over the guide; this arrangement is also used to advantage on vertical engines.

Fig. 83 shows a bored guide, which is now commonly used for stationary steam engines and which gives greater satisfaction than flat guides. Great accuracy is more easily obtained when the surfaces can be bored and turned than when they have to be planed.

In the best constructions the lower guide is drilled so that oil from the end wells continuously flows along the horizontal passages and up through these holes, being distributed by means of short transversal oil grooves. In the absence of this arrangement Fig. 84 shows suitable grooving of the bottom guide shoe and chamfered edges at either end instead of combs.

There is a growing tendency to construct stationary steam engines, whether vertical or horizontal, with a gravity circulation oiling system, consisting of a pump, top and bottom tank, distributing pipes, return pipes, and a strainer or filter in the circuit as for example, the filter (Fig. 215, page 552). This system entails many advantages over the ordinary method of distribution, such as greater certainty of the oil reaching every part and greater ease in controlling the oil supply, greater margin of safety in operation, lower friction brought about by an abundant supply of lower viscosity oil, and an appreciable reduction in oil consumption, when care is taken to avoid leakage throughout the system. The oil wastage in gallons per month will with a good system range between 1 per cent. and 2 per cent. of the engine horsepower.

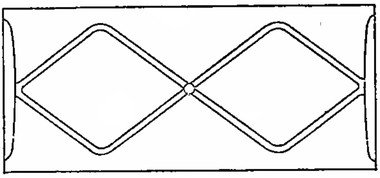
FIG. 84.—Oil grooving of bottom guide shoe.

The *governor*, *valve motion*, etc., are usually hand oiled, but in large engines small sight-feed drop oilers are employed for the most important parts.

Bearing Oils.—The bearing oils used for external lubrication of stationary steam engines are usually straight mineral oils, as they come in contact with more or less water of condensation from the glands, which would emulsify compounded oils.

For the crank pins and main bearings, when they do not form part of a circulation system, and when they are heavily loaded or in bad mechanical condition, compounded engine oils are sometimes required to keep them "cool," such as one of the marine engine oils (page 258). In extreme cases castor oil has been used with great success, but its use should be discouraged on account of its tendency to gum. Castor oil is often resorted to in case of trouble and is allowed to remain in use instead of correcting the mechanical defect and introducing a proper grade of engine oil, which will on an average reduce the frictional temperature 50 per cent., as shown in the following example, which is typical.

On the main bearings of a steam engine where castor oil was fed through an oil circulation system, the rise in temperature of the bearings above room was 17°F. By gradually introducing an oil like marine engine oil No. 1 (called X) the frictional temperature was reduced as follows:

	Bearing temperature, °F.	Room temperature, °F.	Frictional temperature, °F.
Pure castor oil	88	71	17
90% castor + 10% X	86	71	15
80% castor + 20% X	82	69	13
60% castor + 40% X	86	75	11
Pure X oil	90	82	8

This shows a decrease in the frictional temperature of 53 per cent. In changing over from castor oil, or any other vegetable or animal oil, to an oil largely mineral in character, it is necessary to exercise great care and make the change gradually, as the deposits which have accumulated from such oils are loosened, and if loosened too quickly, cause trouble. The deposits when loosened gradually are caught in the strainers of the oil pump and should be removed as they appear.

It is not unusual to find steam cylinder oil in use on guides or mixed with the engine oil. This is bad practice as the great viscosity of the cylinder oil causes great friction and high temperatures; it would be better to introduce a marine engine oil on guides, inclined to be troublesome, assuming that they cannot be made to run cool on the ordinary engine oil.

On very large, long stroke engines with open guides and tail rod supports, the engine oil may be so wasteful in splashing away that the use of cylinder oil may be justified. The difficulty with splashing from crank pins in long-stroke engines and providing proper splash guards has in some cases prompted the use of crank pin grease, usually a white grease, in place of oil.

In large crank-pin bearings or main bearings on slow-speed engines, whether grease or oil is employed, oil grooves are sometimes an advantage when the engine always runs in one direction. Fig. 85 shows the proper way of making the oil grooves in the four parts of a main bearing; the straight oil grooves and chamfered edges collect and feed the oil along their entire length. The bearing pressure is constantly squeezing the oil from the centre toward the edges of the brasses, but the curved grooves help to conduct the oil back towards the centre of the bearing.

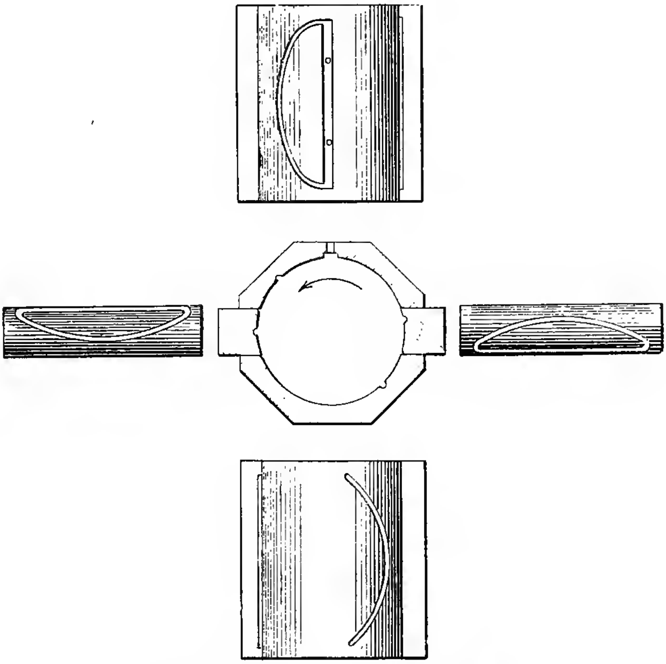

Fig. 85.—Oil grooving a main bearing.

When grooving bearings, an important rule is to groove only one, not both, of the surfaces, and the grooving should preferably be done in the female or enveloping surface; for example, the bearing surfaces of the connecting rod brasses are grooved, not the crank pin itself. (See Fig. 22, page 115.)

As exceptions to this rule note the grooves in Fig. 84 and the distributing oil grooves in long spindle bearings for machine tools (Fig. 122, page 292).

LUBRICATION CHART NO. 5
FOR STATIONARY OPEN TYPE STEAM ENGINES

	Circulation oiling systems, H.P.	Drop feed systems, H.P.
Bearing oil No. 2[1]	Below 250	Below 100
Bearing oil No. 3	250 to 400	100 to 250
Bearing oil No. 4	Above 400	250 to 500
Bearing oil No. 5, 6	For special cases only.	Above 500
Marine engine oil Nos. 1 and 2	Only to be used where bearings are subjected to abnormal pressures or are in bad condition mechanically.	

[1] For Bearing oils, see page 127.

CHAPTER XV

BEARING LUBRICATION OF HIGH-SPEED ENCLOSED-TYPE STEAM ENGINES

The vertical, high-speed, enclosed type of steam engine has been much developed in England, the engines ranging in size from 10 H.P. to 2,500 H.P. with corresponding speeds of from 800 r.p.m. down to 250 r.p.m.

The horizontal, high-speed, enclosed-type steam engine has come into favor in America for small powers. Both the vertical and horizontal types may be lubricated by the force feed circulation system or the splash oiling system.

Force-feed Circulation.—Fig. 86 illustrates a typical force-feed circulation system. The oil pump (1) sucks the oil from the oil reservoir and delivers it at from 5 to 15 lb. pressure per square inch through pipes (2) into the main bearings. The crank shaft is hollow and the oil is forced from the main bearings into the shaft, and through oil passages into the eccentric sheave and crank pins, whence it reaches the crosshead bearings through passages in the connecting rods or tubes attached thereto. The oil leaving the crossheads splashes on the crosshead guides and drops back into the crank chamber. The oil then flows to the oil reservoir and re-enters the oil pump through a strainer, thus completing the circuit. In large engines the guides are fed with a direct supply of oil from the main distributing pipe.

An adjustable oil relief valve (not shown) is fitted, which allows a portion of the oil to overflow back into the oil reservoir. In this way the oil pressure may be adjusted within certain limits. The oil pump should be of ample capacity, so that the pump pressure, by means of the adjustable relief valve, can be kept at any desired point. Too small an oil pump or slack bearings decrease the oil pressure, or make it necessary to use exceedingly viscous oils, which result in unnecessarily high friction losses.

The oil pump should be placed with its suction strainer elevated to leave room below for water to accumulate. Otherwise water is drawn with the oil into the pump and forced through the bearings, tending to emulsify the oil. Water gets into the crank chamber, owing to the presence of ill-fitting glands or "scored" rods. Where the rods enter the crank chamber top, scrapers are preferable to glands with soft packing. The oil which is carried up from the crank chamber and scraped off, together with the water, should be drained to an oil separator outside the crank chamber or treated in a steam heated settling tank to recover as much oil as possible.

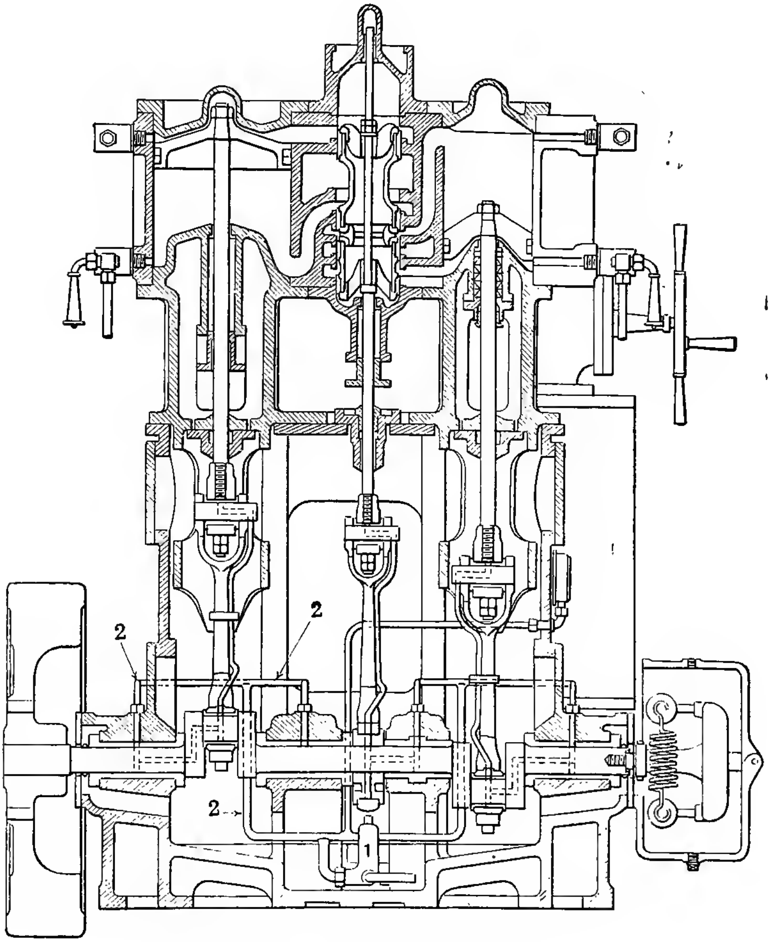

FIG. 86.—Force-feed-circulation.

Metallic packings are preferable to soft packing in these engines, as there is less danger of "scoring" the rods than with soft packing, which is easily screwed up too tight. Once a rod is scored, it is impossible to prevent water travelling through the "ridges" down into the crank chamber.

Slightly superheated steam is an advantage, as less condensation occurs in the cylinders, therefore less water finds its way through the glands.

The crank chamber should be systematically drained at suitable intervals.

A drain cock of preferably not less than 1½ inch bore should be fitted at the lowest point in the crank chamber, and if the water can be drained off while the engine is running, this should be done at frequent intervals. Where the draining cannot be accomplished while the engine is running, it should be done before starting up, every time the engine has had a rest.

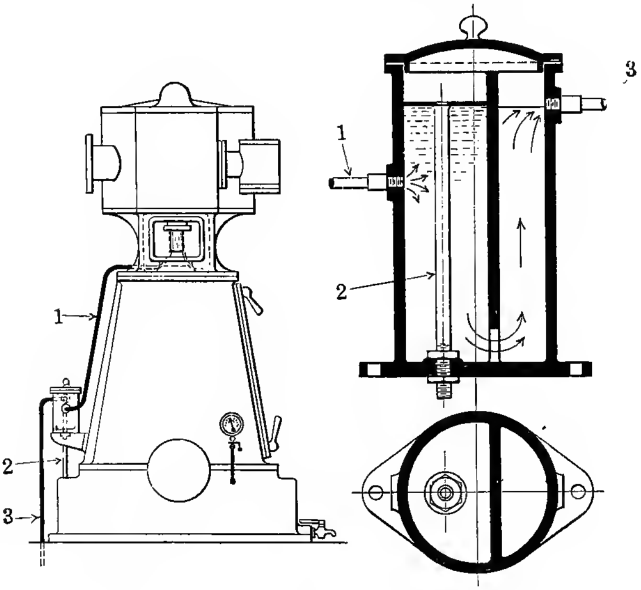

FIG. 87. FIG. 88.
Oil and water separator.

When the engine is supplied with wet steam, it is difficult to prevent an excessive amount of water getting into the crank chamber, unless the rods and oil scrapers are in perfect condition. When this is not the case the piston and valve rods are constantly splashed with oil which is carried up through the scrapers. Accordingly, a large amount of a mixture of oil and water is constantly scraped off.

Some engines have holes in the crank chamber top which allow the water and oil to drain straight into the crank chamber; obviously this is bad practice. Other engines have an automatic separator, as shown, mounted on the engine in Fig. 87 and in detail in Fig. 88. The drain pipe (1) from the crank chamber top enters the separator at the side, the oil rises to the surface and overflows through the adjustable pipe (2) back into the crank chamber; the water flows below a baffle and leaves the separator through the drain pipe (3).

As to the water which drains into the crank chamber, Fig. 89 shows a useful arrangement. From the lowest point in the crank chamber, whether this be at the end or in the middle, a pipe (1) is connected to a tank (2) which acts in very much the same way as the "water leg" for turbines. Once water gets into the tank, it cannot re-enter the crank chamber. Accumulation of water should be drained out periodically.

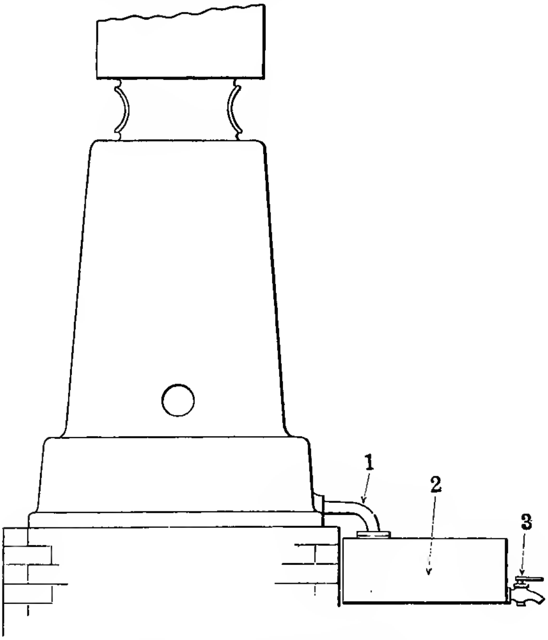

Fig. 89.—Water drainage tank.

Every plant should have arrangements for treating daily a portion of the oil in circulation, to free it from water, sludge and impurities, and so maintain its vitality. This system of daily treatment is mentioned, page 114 and page 218 under *Steam Turbines.*

In large engines it may be necessary to cool the oil to keep its temperature below 140°F.; a cooling coil made of seamless tube immersed in the oil reservoir is usually all that is required. Practically all that is said regarding oil in connection with steam turbines, applies also to force lubrication steam engines and will therefore not be repeated here.

The oil pressure gauge should be watched regularly. If the oil pressure gradually declines, the cause may be: bearings requiring adjustment, emulsification of the oil, or choking of the filter.

Some engines have double strainers so arranged that either can be removed for cleaning without disturbing the action of the oil pump. It is of great importance that the strainers be kept clean and free from sludge or dirt.

In horizontal engines it is difficult to prevent oil from splashing onto the piston rod and getting into the piston rod packing; with saturated steam this is not a serious matter, but with superheated steam the oil carbonizes in the packing. Fig. 90 shows a special scraper gland fitted round the piston rod and fixed in a partition. This arrangement is used in some large Uniflow engines and has proved very effective.

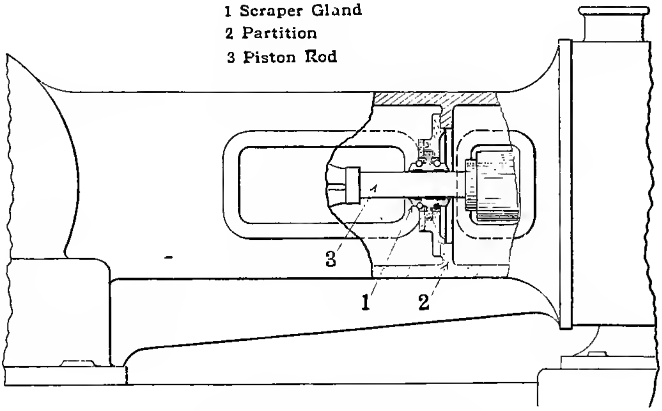

FIG. 90.—Piston rod scraper gland.

Mutton cloths should be used for wiping the crank chamber when cleaning, not cotton waste, which often will cause trouble, as the fluffy fibres stick to the surfaces, are afterwards carried with the oil to the pump, and may choke the strainers.

The advantages of forced lubrication over the ordinary methods are many. The lubrication is entirely self-contained. The engines, with correct bearing adjustment and oil pressure, operate noiselessly and will run for years, practically without wear, due to the perfect film formation. As the engines are double-acting the relaxation of pressure on the upstroke of the pistons gives the oil a chance to force itself thoroughly in between the rubbing surfaces, forming an excellent cushion for the next stroke. In fact, engines may be run with the bearings rather slack and yet without noise; there is not sufficient time during a single stroke to squeeze the oil film out, particularly if the oil has a high viscosity. If an engine uses an oil too low in viscosity it is inclined to run noisily and the oil in circulation becomes very warm; the introduction of the correct viscosity oil will reduce the temperature and give a sweeter running engine.

It is in the author's opinion good practice to run with rather small bearing clearances and low viscosity oils; such oils give less friction, lower temperatures, separate more easily from water, etc., and last longer than viscous oils.

Force feed circulation, when properly arranged, is a very economic oiling system; the consumption of crank chamber oil ranges from .05 to 3.0 grams per B.H.P. hour, the normal average being 1.0 gr. per B.H.P. hour. The consumption is highest for smaller engines and when a great deal of water gets into the oil.

Grades of Oil.—The same oils as are used for steam turbines should also be used for forced lubrication steam engines, and for normal conditions the oils may be recommended as follows:

LUBRICATION CHART NO. 6
FOR FORCED LUBRICATION STEAM ENGINES

Circulation Oil No. 1[1]	For engines below 150 H.P.
Circulation Oil No. 2	For engines from 150 H.P. to 400 H.P.
Circulation Oil No. 3	For engines above 400 H.P.

NOTE.—Certain makes of engines operate with unusually large bearing clearances; others have unusually stout connections between the cylinders and the crank chamber, so that a large amount of heat is carried down from the cylinders into the crank chamber. In either case Circulation Oil No. 2 must be used for engines below 250 H.P. and Circulation Oil No. 3 for engines above 250 H.P.

Splash Oiling.—On account of its simplicity and low cost this system is used to some extent on small horizontal engines of American make, but it is chiefly used for vertical single-acting engines, like the Westinghouse Engine (U. S. A.) and the Willans Central Valve Engine (England), the former being made in all sizes up to 200 H.P., the latter in sizes up to 1,500 H.P. Splash oiling is rarely used for vertical double-acting engines.

The crank chamber is filled with water and oil to a level about ¾ inch below the underside of the crank shaft. The cranks dip into the bath and splash the oil to the crank shaft bearings, crank pins, eccentrics and pistons. When the engine is to be started with a new "bath" after the chamber is thoroughly cleaned, the water for the bath must be rain-water or condensed water. On no account should hard water be used or water from a

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[1] For Circulation oils, see page 236.

source suspected of containing acid, chemicals or other oils. When the water has been poured in warm (130°F.) the right quantity of oil can be added, usually a layer from ⅛ inch to ¼ inch thick which equals from 3 per cent. to 6 per cent. of the volume of water in the bath.

The engine is now run slowly at light or no load, until the bath gets well emulsified; first then should the full load be put on, and only after examining the bath. For this purpose the engine is stopped and one of the doors removed; the oil will now be seen covering the surface, and after the surface is stirred with a stick, the water underneath must appear milky, yellowish white. If after being stirred the oil flows quickly together in a thick film, there is too much oil in the bath; if it only closes over the water with difficulty, more oil must be added.

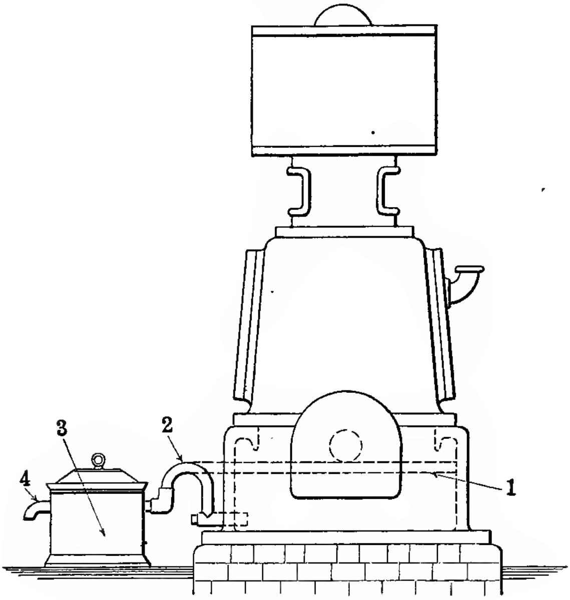

Fig. 91.—Water overflow arrangement.

During operation of the engine more or less water from the cylinders (condensation), particularly with wet steam conditions, finds its way into the crank chamber and the level of the bath rises. An automatic overflow should therefore be fitted, otherwise the oil overflows through the end bearings, and the engine may run short of oil. Fig. 91 shows such an overflow arrangement, which will be readily understood. When the level (1) rises, water from a quiet corner in the bath enters the inlet to the overflow pipe (2), and only the small amount of emulsified oil carried away with the water is lost. Any oil carried in suspension will be retained by the oil separator (3) and can be returned to the bath through the vent pipe fitted higher up on the crank chamber, together with the daily or weekly "make up" for loss in oil.

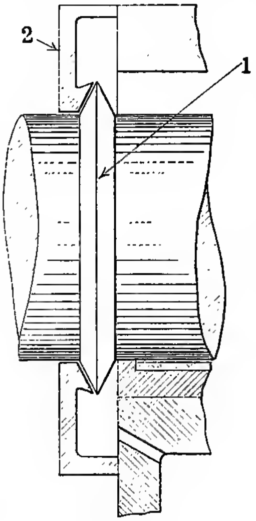

FIG. 92.—Willans oil thrower.

In the Westinghouse engines the "make up" oil is fed through oil cups to the main bearings, and leaving these reaches the bath.

When superheated steam is used, and no condensation reaches the bath, some water will evaporate and it may be necessary to add condensed water to the bath to keep up the level. In such cases the crank case oil consumption with a good quality oil becomes exceedingly low. Consumptions as low as 1 pint per 24 hours for a 1000 H.P. Willans engine are on record.

The greater the stream of water leaving the overflow (4), the greater the oil consumption, but under reasonably good conditions, a consumption of 0.5–3.0 pints per 24 hours, according to the size of engine, will prove ample.

There are, however, special sources of oil loss, such as loss through end bearings or past the pistons. Fig. 92 shows the oil thrower arrangement of a Willans engine. Any lubricant reaching the oil thrower (1) is returned to the bath through the passage shown. Leakage may occur if the thrower is too far away from the cover (2); drops of oil are ordinarily caught between the edge of the thrower and the bevelled edge on the cover, but if the space is too great oil may get past, without touching the thrower. When the oil has got past this point it may either leak down the outside of the cover or pass along the shaft. To prevent the latter trouble, the clearance between the shaft and the cover must be sufficient so that drops of oil may exist on one surface without touching the other.

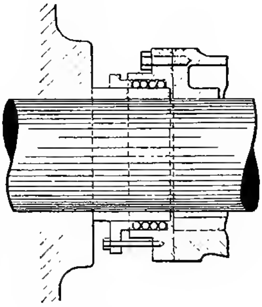

FIG. 93.—Willans stuffing box.

Leakage of oil may also be due to the overflow being choked with emulsified clots of oil, cotton waste, etc. In that case the bath level rises, the oil finally overflows through the bearings, and getting caught by the rim of the flywheel is thrown into the engine room in the vicinity of the flywheel.

With large shaft diameters the arrangement shown in Fig. 92 is not always satisfactory and a proper gland may be provided, with very soft packing, which must be tightened up very gently to prevent "grooving" of the shaft. To avoid such wear taking place on the shaft itself, a bushing is provided as shown in Fig. 93.

When the piston rings in a Westinghouse engine are in bad condition, the oil splash from the crank chamber will get drawn past the low-pressure pistons in particular, and is exhausted with the steam. The quality of the oil has nothing to do with this trouble, and the only remedy is to put the rings in order; rounding the *upper edges* of the rings is always a good precaution, as on the up-stroke the rings will ride on the oil film, and on the down-stroke scrape off excess oil.

Temperature.—The presence of water in the bath ensures that the bearings shall not reach a temperature higher than 212°F., but for normal running it is preferable to keep the temperature much lower, say 120°F. to 140°F., after two or three hours' run.

With condensing engines this temperature is rarely exceeded, but with non-condensing engines the greater amount of heat from the cylinders often makes the bath uncomfortably hot; a simple arrangement of cooling pipes should then be fitted, and the boiler feed water may be used as cooling water on its way to the feed pump. Approximately 25 per cent. of the feed water will suffice to keep the bath reasonably cool.

There should preferably be no joints in the cooling coils inside the crank chamber to avoid leakage, as if the water is hard or contains acid, chemicals or other impurities, a leakage into the bath may destroy the oil. For similar reason cooling waters should be avoided which are liable to attack the cooling coils, as even pin holes will allow a great deal of water to leak in.

Oils.—If the bath were made with oil only the bath temperature would quickly rise, owing to the large amount of heat developed by fluid friction in the bearings and by the splashing of the cranks through the viscous oil. When the bath contains only a few per cent. of oil, the viscosity of the emulsion is practically the same as for water alone. This was shown by K. Beck of Leipzig, and reported in *Zeitschrift für Physikalische Chemie*, Vol. LVIII; the viscosity, taken by an Ostwald viscometer, of a 10 per cent. mixture of castor oil and water was only a little over 1 per cent.

greater than the viscosity of pure water. It is rather curious that even with fairly high bearing pressures the water emulsion is capable of furnishing adequate lubrication. The explanation is probably that little particles of emulsified oil, or of oil in suspension, attach themselves to the rubbing surfaces and form a coating which prevents metallic contact; and the friction is very low because of the low viscosity of the emulsion, which forms the lubricating film.

In the early days castor oil was the favorite lubricant, but it has several drawbacks; it becomes acid and gummy, due to oxidation, as it is intimately mixed with the hot air in the crank chamber. While therefore castor oil produces excellent lubrication and a rich emulsion it often leads to corrosion of the surfaces and a sticky deposit accumulates on the connecting rods, etc. The consumption of castor oil is comparatively large, as the water leaving through the overflow is heavily charged with emulsified castor oil. Castor oil is now seldom used; the same oil is used in the bath as in the steam cylinders and valves.

In America straight mineral dark cylinder oils are generally used and while they give a moderate degree of satisfaction under the best conditions, the results are not at all good when the engines employ wet steam or when certain hard limy boiler feed waters are used. The emulsion, which is always poor with a straight mineral oil, breaks down under these latter conditions, resulting in high friction and wear. If the American users of the Westinghouse type of engine knew the results which are obtained by the use of lightly compounded filtered cylinder oils, the dark "Virginia" and similar oils now used straight would soon be displaced by better oils.

Dark cylinder oils, whether straight mineral or compounded, are inclined to become thick and livery, particularly if there is too much oil in the bath. In large engines, where the conditions are usually less trying than in small engines, dark compounded cylinder oils may, however, give good results, but in smaller engines, filtered cylinder oils suitably compounded with fixed oil are much to be preferred. When the steam is wet (boilers priming) and boiler impurities are carried into the engine, some will reach the bath and will tend to thicken the oil. It is under these conditions that dark cylinder oils get "livery," whereas filtered cylinder oils are very little affected, even if there is rather too much oil in the bath. Filtered cylinder oils thus give a much greater margin of safety and prove more economical and more efficient than dark oils. It is a mistake to use a large percentage of fixed oil; 4 per cent. to 6 per cent. is all that is required. With more fixed oil the emulsion becomes unnecessarily rich and more oil is lost through the overflow.

Small engines are sometimes lubricated with a bath of circulation oil, but 15 per cent. to 20 per cent. of oil is then required as compared with 3 per cent. to 6 per cent. when cylinder oil is employed. Certain small engines have the bearings more or less enclosed, and the oil holes are rather small. If cylinder oil were used in the bath, small clots of emulsified oil would choke these small openings, and circulation oils must therefore be used for such engines.

Sticky deposits may develop on the rods, etc., as already mentioned, in reference to castor oil; similar black deposits may be produced with cylinder oils, particularly so with dark oils, and they will appear on the rods in peculiar patterns or streaks caused by the motion of the rods, and consist of water, oil, oxidized oil (insoluble in petroleum spirit) and a few per cent. of iron and iron oxides (wear). The cause of the deposits may be inferior mineral base in the oil (presence of too much coloring and bituminous matter), or inferior fixed oil (too much free fatty acid); or again, the quality of the oil may not be at fault, but the temperature of the bath is above 140°F. which is a critical temperature as far as oxidation of the oil is concerned. Shortage of oil in the bath will also bring about deposits, but they will then be found rather rich in metallic contents, indicating excessive wear.

LUBRICATION CHART NO. 7

FOR HIGH SPEED, ENCLOSED TYPE ENGINES, EMPLOYING THE SPLASH OILING SYSTEM

Engine description	Grade of oil	Percentage of oil used in bath
Small, horizontal engines, operating in ordinary engine rooms	Circulation oil No. 1 or No 2[1]	100
Small, horizontal engines, as employed in steam motor wagons	Circulation oil No. 3 or similar oil of even higher viscosity.	100
Vertical engines, up to 50 H.P.	Circulation oil No. 2 or Cylinder oil No. 2 F.L.C.[2]	15 4 to 6
Vertical engines, up to 300 H.P.	Cylinder oil No. 2 F.L.C.	4 to 6
Vertical engines, above 300 H.P.	Cylinder oil No. 3 F.M.C. or Cylinder oil No. 3 D.M.C.	3 to 4 3 to 4

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[1] For Circulation oils, see page 236.

[2] For Cylinder oils, see Table No. 19, page 389.

CHAPTER XVI

CRANK CHAMBER EXPLOSIONS

In many modern high speed engines, whether they be steam, gas, petrol or Diesel engines, the crank chamber is filled with oil spray, a more or less dense mist of fine oil particles. These engines are acknowledged to be safe and reliable in operation, as far as lubrication is concerned, notwithstanding what is probably a fact, that most of them when running would explode were a spark to be formed inside the crank chamber.

It is a well known fact that to make an explosive mixture with air, an inflammable *gas* of some kind is not essential. Any sufficiently inflammable substance in the form of *fine dust* will produce this effect if present in the requisite proportion, as for example in the case of many explosions in coal mines. A mixture of air and coal dust can be made to explode when the coal dust reaches a certain percentage; and as soon as a spark or a naked flame is formed or brought within the danger zone an explosion will occur. An explosion of this character occurred in an oil cake mill, the air being heavily laden with fine seed dust; the mixture was fired by a spark from a dynamo and many lives were lost. Another explosion occurred in a flour mill, sparks from a hot bearing firing the mixture of air and flour dust.

Coming back to the enclosed high speed engines, it is obvious that from the time of starting, an increasing amount of oil spray is formed due to the smashing action of the moving parts on the stream of oil escaping from gudgeon pins or crossheads and crank pins. When the engine has been running for some time, the air will contain a certain constant amount of "oil mist" in accordance with the conditions of speed, ventilation, etc., of that particular engine. In very large engines, as for example large enclosed type marine Diesel engines, it is doubtful whether they ever contain sufficient oil mist to be capable of exploding; but in smaller and much higher speed engines, the danger of explosion is ever present.

In 1911 an enclosed steam engine, 300 H.P. with force feed circulation, exploded in a large hosiery factory. On a Monday morning the engineer went to the engine room, started the engine and left the power house; a few minutes later the engine exploded. This is what happened:

During the week-end the engineer had tightened up the brasses on the low pressure crosshead, and on Monday morning the engine was started up without examination as to whether this bearing had been tightened up too much, which unfortunately was the case. After a few minutes the crosshead got hot; the heat spread to the cast-iron slippers, which work vertically in circular guides about 8 inches diameter. The clearance was only about 0.01 inch when cold and 0.002 or 0.003 inch with the engine warm; consequently, the excessive heat conducted from the crosshead pin caused the slippers to expand and seize. The circular guides broke and flying sparks from the slippers fired the mixture of air and atomized oil in the crank chamber. The governor casing blew off, the opposite wall of the engine room fell out, while one of the other walls was moved 4½ inches and the roof of the engine room was blown away. The engineer having left the engine room, nobody was killed.

Another disaster took place on a British battleship. An enclosed steam engine exploded and killed a number of men. The papers reported that the explosion was due to carelessness on the part of one of the men, who approached the engine with a naked light just after it had been opened and the inspection doors removed, so that the crank chamber was still full of the mixture of atomized oil and air.

Similar explosions have been reported in connection with Diesel engines installed in submarines belonging to one of the large Continental powers, and in several cases the explosion was due to sparks in the crank chamber owing to one of the pistons seizing. This would seem to indicate that as far as cylinder lubrication is concerned, the greatest care should be taken in designing the lubricating system, and in using such oils as will ensure as safe and clean lubrication as possible of the pistons, particularly so in the case of Diesel engines for naval purposes, where high speed and short connecting rods are the characteristic features, owing to the cramped space available for the engines.

Several explosions have happened in the past with enclosed high speed gas engines, due to exactly similar conditions, namely, a mixture of air and atomized oil. It is a fact worthy of note that at least one firm of engine builders in England now ventilate their enclosed gas engines and Diesel engines by fitting a small fan that removes from the crank chamber any gases that may pass the pistons, as well as the finest oil vapor, thus making the possibility of an explosion very remote indeed.

This system appears to be particularly desirable for high speed naval Diesel engines and has been used in Continental submarines; to avoid excessive loss of oil, the fan discharges through a separating tank, in which baffle plates cause a portion of the oil to "condense" and settle out.

CHAPTER XVII

BEARING LUBRICATION OF MARINE STEAM ENGINES

Hand oiling is still used, the practice being to pour oil from an oil feeder into oil cups, say during four to eight revolutions of the engine every half hour. The bearings get flooded with oil after each oiling and thereafter the oil film is gradually squeezed out and lubrication becomes less and less efficient until such time as the bearings are oiled again. Obviously this method is both wasteful and inefficient.

The better method now most frequently employed is to have oil cups fitted with syphon wicks which syphon the oil from the cups and deliver it into oil pipes leading to the various bearings. Syphon oil boxes are fitted near the tops of each cylinder and distribute the oil through feed pipes ending in "wipers," which are touched by oil receiving boxes fixed on the moving parts, at the moment these boxes reach their highest positions; the oil is finally guided to the various points through pipes fixed to the moving parts.

A syphon box is fitted over each main bearing with two or more oil feeds according to the size of the shaft; from these boxes may also be taken oil feeds for the crank pins, when the latter are arranged for "banjo" oiling. An oil box is fitted for each crosshead guide, and a comb fitted to the bottom end of the slipper dips into the oil well and carries the oil well up on the guide which is usually water cooled.

The oil feeds vary with changes in temperature, the oil feeding more quickly when warm, due to its lower viscosity. The oil feed is much dependent on the oil level in the cups. The syphons feed more slowly when the oil level is low; it is therefore necessary to keep the oil level as uniform as possible by frequently replenishing the oil cups.

A better system is to replenish the various syphon oil cups not by hand but from a centrally-placed oil tank, feeding adjustable quantities of oil through the feed pipes, each of these having a sight feed arrangement by which the oil feed can be ascertained going to the corresponding oil cup. If, for example, one feed pipe is feeding 60 drops per minute to one of the oil cups, the latter distributing by syphons the oil to several points, then the oil level in this cup will quickly adjust itself automatically to such a level that the oil syphons all told will syphon out 60 drops per minute. If they feed more, the oil level will gradually decrease until a point is reached when the oil feeds all told amount to 60 drops per minute. The control of the oil feeds from the central oil tank can best be done by mechanically operated lubricators, which start and stop feeding with the engine.

Experience has proved that the installation of such a central distributing oil tank, preferably in connection with mechanically operated lubricator pumps, will save from 40 per cent. to 60 per cent. of the total amount of oil consumed for external lubrication.

There is always a greater or less amount of condensed steam finding its way down the piston and valve rods and dropping all over the external moving parts, and in case of a hot bearing the cold water hose is frequently applied. Sometimes a small trickle of water is allowed to run into or on to those bearings which are inclined to run rather warm. When oils pure mineral in character are used the water will displace the mineral oil and the bearings will heat and may seize.

Marine engine oils should therefore be compounded with a suitable percentage of good quality fixed oil, so that they will saponify freely with water and form a rich and creamy lather. Good quality marine oils, while they combine satisfactorily with water, will give more efficient and more economical lubrication if they are used without water. The oil when leaving the bearings, usually in a more or less emulsified condition, is run to waste into the bilges, it being impossible to recover the oil from the emulsified waste oil.

Marine engine oils should contain only a small percentage of fatty acid, say less than 0.4 per cent. in terms of SO_3, so as not to cause corrosion or pitting. The fixed oil should not produce a disagreeable odor exposed to the heat in the engine room, nor should the fixed oil used for compounding be of a drying nature, but semi-drying oils like rape oil will give good service. Castor oil was at one time much used and is still used largely in the East, but is expensive when used alone. It can, however, be mixed with mineral oil in the presence of an animal oil, say, 20 per cent. castor, 6 per cent. lard oil and 74 per cent. heavy viscosity mineral oil, preferably Texas, Russian or other asphaltic base oil to get a low setting point. The lower the setting point and the greater the percentage of good quality fixed oil of reasonably low cold test, the less will the oil be affected by climatic changes.

The bearings of large marine steam engines require oils of great oiliness to give the necessary margin of safety under the severe operating conditions. Pure mineral oils of the requisite oiliness do exist, but they are so viscous that they will not syphon properly and feed irregularly owing to poor cold tests. The admixture of fixed oils having great oiliness is therefore dictated not only by the presence of water, but also by the necessity of keeping the cold test and viscosity of the finished oil reasonably low. Blown rape oil, blown cod oil or blown whale oil, preferably the first mentioned, are used to the extent of 10 per cent. to 25 per cent., the fixed oils being usually blown until they have a viscosity of 720″ to 1400″ Saybolt at 210°F. Such very viscous fixed oils raise the oiliness and the viscosity of the mineral base appreciably without unduly raising the setting point.

In Table No. 9 are given typical readings of three marine engine oils which will serve for all marine purposes where compounded oils are needed. The important figures are those for viscosities, cold tests and compound; the figures for specific gravity and flash point are of little consequence.

Large engines and vessels navigating in hot climates need higher viscosity oils than smaller engines or vessels operating in colder climates, but only practical tests extending over a period of say three months can decide which of the three grades should be preferred and what percentage of compound it should contain. The higher viscosity oils are usually the more economical, but they may be unnecessarily viscous and thus waste power in creating too much "oil drag" in the bearings.

TABLE No. 9

	Specific gravity	Saybolt viscosities at			Open flash point	Cold test	Per cent. of compound
		104°F.	140°F.	212°F.			
Marine engine oil No. 1..	.920	450	190	65	400	25	10–20
Marine engine oil No. 2..	.930	750	270	75	405	$^{25}/_{30}$	10–20
Marine engine oil No. 3..	.940	1400	340	85	410	$^{30}/_{35}$	15–25

Forced circulation has during recent years made great progress in naval ships both in Europe and the United States, not only for steam turbines and auxiliary high speed enclosed type steam engines, but also for the large reciprocating type main engines in destroyers and other craft.

The working parts including the crossheads are enclosed in an oil tight casing, packed glands being provided for the piston and valve rods to prevent too much water getting down into the oil in circulation. Observation windows and electric lights may be fitted to watch the moving parts. The oil is supplied by reciprocating pumps operated by the engine itself or independent thereof. The oil may be forced into the hollow crankshaft, holes being drilled radially at each main bearing, crank pin and eccentric, the oil from the crank pin continuing its way through a tube fitted to the connecting rod into the crosshead bearing, finally reaching the crosshead guides.

The oil delivery pipes may also deliver the oil into the main bearings first of all, the oil thence reaching the hollow crank shaft, etc., as is customary on land engines.

The oil supply system is frequently made in duplicate.

The oil collecting in the oil wells is pumped away by independently operated pumps, fitted with suction strainers, the oil being delivered through a filter to a "settling tank," finally reaching the storage tanks ready to be circulated afresh.

Main engines fitted with forced oil circulation have been inspected after the vessel has done 20,000 miles, and the tool marks in the white metal bearings were found to be still visible and no measurable wear had taken place.

The risks of accidents due to hot bearings caused by insufficient oil supply are practically eliminated by this system; there is a great saving in the time and expense which was required with syphon lubrication in rebabbitting, adjusting and examining bearings after each voyage. The cost of lubrication is also much reduced by forced oil circulation and the engines operate much more quietly.

Auxiliary engines which are now frequently fitted with a full force feed circulation system should preferably have the cylinders raised so high above the crank chamber top that no part of the piston and valve rods entering the cylinder or valve glands will enter the scraper glands fitted in the crank chamber top. If this be arranged, no oil from the crank chamber can possibly enter the steam cylinders, which is important with a view to preventing oil from reaching the boilers.

The *oils used for force feed circulation systems* must be similar to those used for steam turbines, *i.e.*, they are circulation oils. *Circulation Oil No.* 2 is used on most small auxiliary high speed engines, *Circulation Oil No.* 3 on large slower speed engines, and larger auxiliary high speed engines.

One might ask why these oils, pure mineral in character and lower in viscosity than the compounded marine engines oils, can replace the latter and with such great success. The answer is simply that the oil is supplied to all bearings *in abundance*, not only supplying a complete lubricating film, but also continuously *removing frictional heat* from the bearings, which therefore run *much cooler.* The bearings do not get contaminated with water, and as the revolving parts practically "float" on a complete oil film, wear is practically eliminated and the results are excellent from every point of view.

It is to be hoped that the merchant marine will take advantage of the experience gained by the various navies with force feed circulation, which undoubtedly is very superior to the systems now generally employed.

Thrust Bearings.—Fig. 94 illustrates the horseshoe type of thrust bearing still almost universally used for marine steam engines. The collars on the shaft press against the horseshoes, which are adjustable in a fore and aft direction so as to distribute the load more or less evenly between them. Changes in temperature difference between shaft and horseshoes alter the distribution of load and cause heating of certain collars and shoes, so that a hot thrust is by no means uncommon, in fact, the thrust bearing often gives the engineers more trouble than any other bearings or part of the engine room machinery. The oil is fed by syphons from the top and led into oil grooves of various "fancy" patterns. The collars are often arranged to dip into the oil and carry the oil up with them. The oil bath is sometimes fitted with a cooling coil, but it is more effective to cool the horseshoes themselves, which is often done in large and important thrust bearings. (See Fig. 95.)

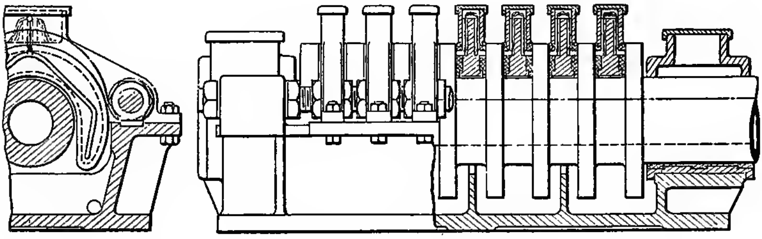

Fig. 94.—Horse shoe thrust bearing.

The lubrication is, however, always poor, as the centrifugal force throws the oil away from the points where it is most needed; the bearing pressures allowed are therefore low, usually 50–70 lbs. per square inch, with a mean surface speed of 500 ft. per minute, but with the best cooling arrangements and perfect workmanship a bearing pressure of 100 lbs. per square inch and a mean surface speed of 600 ft. per minute has been accomplished; and in other cases a pressure of 60 lbs. per square inch with a surface speed of 800 ft. per minute. The friction is high, often consuming 5 per cent. of the shaft horsepower; the rubbing surfaces are in only a semi-lubricated condition, the coefficient of friction being approximately .03.

The Michell single collar thrust bearing (see page 170) will no doubt come more and more into general use, not only for marine turbines but also for marine steam engines, as with a little intelligent attention it gives no trouble whatsoever and consumes less than one-tenth of the friction ordinarily wasted in the horseshoe type of thrust bearing.

Stern Tube Lubrication.—A large majority of ships are fitted with Lignum Vitæ stern tube bearings, the propeller shaft being fitted with a bronze liner, and the lignum vitæ being placed as strips 2 inches to 3 inches wide with 2 inch spaces between the strips. Salt water is usually the only lubricant used in these bearings, but occasionally the stern tube gland is fed with a Stauffer grease cup through which a suitable grease can be fed into the gland with a view to reducing the considerable amount of friction which is generated here.

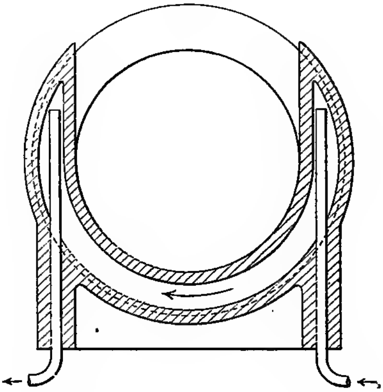

FIG. 95.—Cooling the thrust.

Unquestionably there is a very great frictional loss in the lignum vitæ stern tube bearings, and the only way to reduce this frictional loss is to fit the bearing with an outer gland as in the case of the Cederwall, Vickers, or similar type of packing. Thus enclosed the lignum vitæ can, if desired, be replaced by proper bearing metal and in any case the stern tube bearing can be efficiently lubricated by means of oil or thin grease. This means a great saving in power and also entails the advantage that where the vessel gets into shallow waters, as is the case with a number of river boats or coasting steamers, the entrance of mud, sand or other impurities is entirely obviated, thus preventing trouble and giving much longer life to the stern tube bearing, the wear being practically eliminated.

Another advantage is that galvanic corrosion, rusting and pitting of the shaft cannot take place, assuming of course that the lubricant employed is of reasonably good quality.

An arrangement patented by Vickers and Sons, Leeds, is illustrated in Fig. 96 and was referred to in "Engineering." They write as follows:

> "This appliance was fitted to two twin-screw hopper-barges constructed for the Clyde Navigation Trustees by Messrs. Fleming and Ferguson, Limited, of Paisley, in 1896. After running two years the shafts were examined, and were found to be in very good condition. They were again examined quite recently after three years' continuous work, and the wear was found to be less than $\frac{1}{32}$ in. of the total diameter of the shaft in the bush, so that it was not considered necessary to true up the bushes. When one remembers the peculiar gritty nature of the Clyde water, and that the barges are often in close proximity to dredges which are disturbing the bed of the river, this result will be accepted as very satisfactory. The section is almost self-explanatory. It will be seen that on each side of the floating packing there are two packings; and next the guard-ring there are elastic discs which grasp the shaft like the sleeve of a diver's jacket. The inner one is a fine elastic woollen felt, and the outer of a special composition of a slightly elastic nature which is unaffected by either sea water or oil. Incidentally, the application of oil here reduces the friction, and as the friction resistance within the stern tube is a large proportion of the total friction of the engine and shaft, the advantage is very considerable."

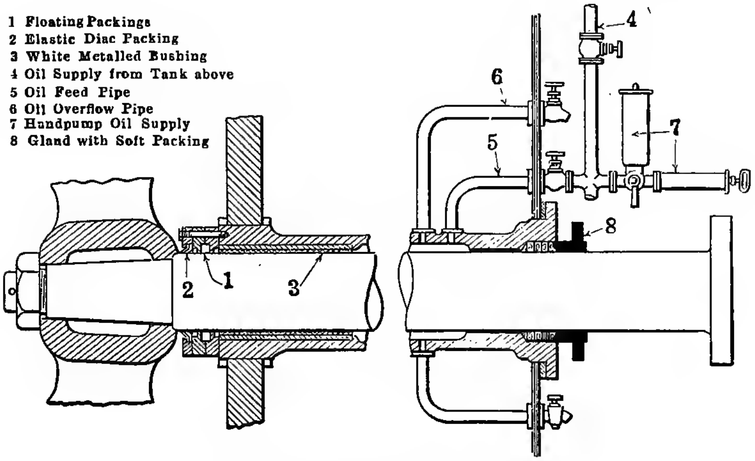

FIG. 96.—Vickers' stern tube packing.

The continuous bronze liners now often fitted, which are carried right into the propeller boss, protect the shaft from galvanic corrosion, but do not prevent the entry of sand, so that whatever system of lining or bushing (cast iron, white metal or lignum vitæ) is employed, many advantages are always obtained by enclosing the stern tube and having a proper oiling arrangement fitted.

CHAPTER XVIII

RAILWAY ROLLING STOCK

BEARING LUBRICATION OF LOCOMOTIVES, TENDERS AND CARS

Axle boxes.—Axle boxes are termed inside or outside according to whether they are inside or outside the wheels. Generally speaking, tenders and cars have outside axle boxes and locomotives inside boxes; some locomotives, however, have the wheels inside the frames and the axleboxes outside.

Fig. 97 shows an *outside axle box.* A door is formed in the front portion of the box. To prevent rain water from entering the box through the joint, the box may project above the door, as shown; another solution is to have attached to the door a sheet metal rain-guard which projects over the top of the box (Fig. 98). For the same reason the door should be so designed as to prevent water getting in at the sides and bottom. At the wheelside of the box is a dust guard, usually made of wood, in two halves, which are forced gently against the shaft by springs. One type of dust guard has oil pads fitted in little recesses in both halves which are made of lignum vitæ; the bottom pad has two syphons, the ends of which are immersed in the oil reservoir and thus lubricate the dust guard and prevent wear.

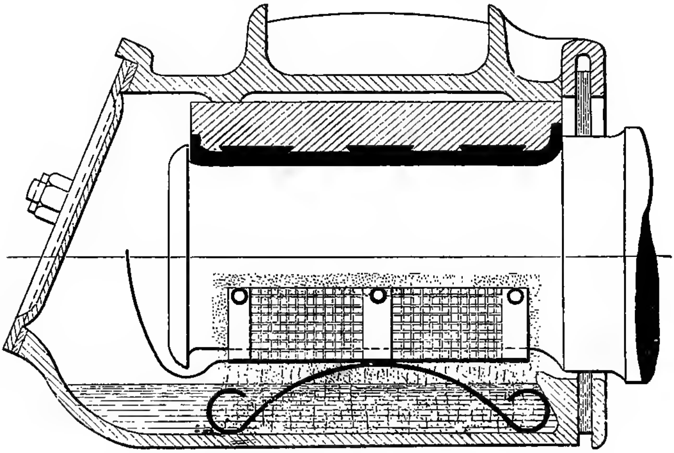

Fig. 97.—Outside axle box.

Most dust guards get little or no lubrication, and when they are worn they no longer keep the dust out as efficiently as one might desire.

Between the top of the "brass" and the cover of the axle box, to which the weight is transmitted through the springs, is placed a hardened cast steel liner or wedge piece, which serves to distribute the load uniformly over the whole of the brass.

Inside axle boxes consist of two almost semi-circular castings with vertical side plates which fit the horn plates; the lower half is suspended from the upper half by bolts and the springs rest upon the upper half.

Journals and Bearings.—It has become a general practice to roll the journals of crank pins and axle journals with a hard steel roller, in order to compress the surface and make it very tough, and capable of resisting wear. The roller is held in the tool post of the lathe after the finishing cut has been taken and is forced against the journal. This same method is also frequently used for rolling the white metal in babbitted bearings.

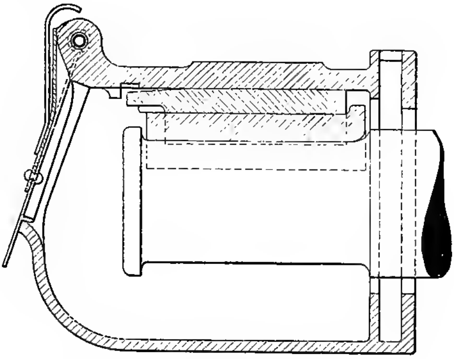

FIG. 98.—Axle box with rain guard.

As regards bearing metals, locomotive driving and trailing bearings are usually bronze lined with white metal, and the tendency is to extend the use of white metal as a lining for bearings. The reason for this tendency is that a good white metal combines the necessary strength with plasticity. It contains hard grains which transmit the pressure to a plastic matrix. The hard grains prevent excessive wear, and as they are embedded in a yielding matrix the load is evenly distributed over the entire surface.

With phosphor bronze, unless the bearings are very carefully scraped together, the load is not so evenly distributed, and in the case of shocks and vibration, local heating may easily occur, causing a hot bearing.

It is a well-known fact that in running down a long gradient, crank pins with bronze bearings are liable to heat, due to excessive shocks in the bearings caused by the absence of steam in the cylinders, which otherwise would "cushion" the blow at either end. Strips of white metal embedded in the crank pin bearings help to prevent such heating.

Another reason for the wider adoption of white metal is, that should the bearing seize, the shaft is only little affected, and the bearing can be rebabbitted at a small cost.

A large proportion of lead in white metal is not desirable, as it causes increased friction, and, being a bad conductor of heat, does not allow the heat to be dissipated so readily; consequently the bearings run warmer. Furthermore, lead is more easily attacked by acids which may be present in the oil.

It is necessary for the white metal to be supported by brass or cast-iron of sufficient thickness to avoid distortion under running conditions. If the brasses are too light, they may crack, or at least run exceedingly warm. This action causes the edges of the brass to pinch the journal and makes it very difficult for the oil to do its work properly.

As mentioned above, phosphor bronze can be used as a bearing metal only when the faces are very accurately scraped together. In the case of white metals, however, such careful fitting is not necessary, as the bearing surfaces will bed themselves together more readily.

Of recent years bronzes of a new type called "plastic bronzes" have been used, particularly in the United States. The difference between them and the white metals is that they are made up of plastic substances embedded in a hard matrix, whereas the white metals are made up of hard substances embedded in a soft matrix. There seems to be a divergence of opinion as to the utility of these plastic bronzes.

THE PROPORTIONS OF ROLLING STOCK JOURNALS

It is very important that the load on journals shall not be transmitted eccentrically. Take a journal with a diameter D and length L, the load being not in the centre, but transmitted at a point x inches away from the centre (Fig. 99); then the bearing pressure at the extreme ends of the bearing will be

$$\frac{P}{D \times L}\left(1 \pm \frac{6x}{L}\right)$$

To take an example: Let P be 16,000 lbs., the diameter 8 in., and the length 10 in. If the load be central the pressure per square inch will be 200 lbs. uniformly distributed. If 2 in. are added to the inside of the box, making the length 12 in. and x equal to 1 in., then the maximum and minimum pressure per square inch will be 249 lbs. and 83 lbs. respectively at the outside and inside edges, while the average pressure is only 166 lbs. per square inch. This will indicate that it is often preferable to accept an increased pressure per square inch rather than create an eccentric loading.

On locomotive driving journals the brass covers half the journal and the pressures per square inch are usually somewhere about 200 lbs.

In the case of car and tender bearings the arc over which the brass touches the journal is usually 90 degrees, occasionally 120 degrees, and the pressure per square inch of projected area is usually from 300–325 lbs.

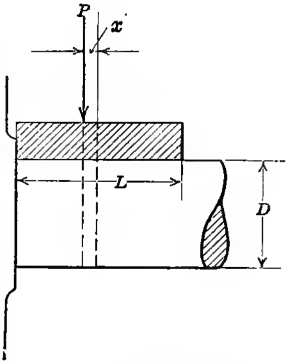

Fig. 99.—Eccentric loading.

The small space available, particularly on narrow gage railways, often makes it difficult to give locomotive bearings the dimensions required for cool running. The journals can always be made strong enough, but the difficulty is to make them long enough. When a bearing runs consistently hot, an increase in journal diameter is no remedy, as, although the bearing pressure per square inch is reduced, the surface area and surface speed of the journal are both increased, so that notwthstanding the larger radiating surface, no advantage is obtained. With greater length of the journal, the surface area is increased, but not the surface speed, and the result is a cooler running bearing.

Some interesting information was given by Mr. T. Robson in an article in "Engineering" for November 25, 1910, in which he gives an empirical formula for judging whether a bearing will be inclined to overheat or not.

Let S = the maximum continuous speed of the vehicle in miles per hour.

D = the diameter of the wheel in inches.

W = the weight on journal in tons.

L = the effective length of the journal in inches.

Then,

$$K = \frac{W \times S}{L \times D};$$ K being a constant, which is determined by actual experience.

The article gives values for this constant for different bearings, all of which are white metalled and, except in the case of crank pins, lubricated by means of a pad or oil saturated waste below the journal.

Mr. Robson gives his experience with various bearings, inclined to heat, and others, which owing to longer journals, ran reasonably cool.

A summary of Mr. Robson's recommendations is given in Table No. 10.

Table No. 10

Type of bearings	Maximum speed in miles per hour	Value for K
Inside locomotive journals on carrying axles and bogies	70	0.8
Outside journals on locomotives and tenders	70	0.9
Crank pin journals	70	4.0 to 4.5
(For some inside crank pins *K* was 5.6 which was too high, but could not be reduced on account of the narrow track)		
Carriage journals	70	0.7
Goods and mineral wagon journals	25	0.5

METHODS OF LUBRICATION

Locomotive Axle Boxes.—The usual practice is by means of syphon oil feeds (tail trimmings) from auxiliary oil boxes, the oil being led through tubes to the top of the bearings, entering the bearing through either a central oil hole into one longitudinal oil channel at the top of the brass, or through two oil holes leading into two oil grooves forming a slight angle with the journal. By this system the oil enters the bearing only with difficulty, except at the two bearing ends, and once it has left the bearing the oil is lost.

In modern systems the boxes are fitted with oiling pads underneath the journals, or they are filled with waste, preferably woollen waste thoroughly saturated with oil. The oil that enters the bearing is caught by the pad or the waste, and distributed over the entire underside of the journal. The lower edges of the brass are eased away, so as to facilitate the entrance of the oil film between the journal and the brass.

The most recent practice is to instal mechanically operated forced-feed lubricators on the frame or in the cab, from which the oil is automatically distributed to the axle boxes under pressure. Test-cocks are provided in suitable positions, so as to regulate and test the oil feed. This method is an ideal one, as it ensures a feed of oil to the bearings in direct proportion to the revolutions of the journal; also this method is unquestionably the most economical, and the oil reaches the bearings with absolute certainty, the distribution being entirely automatic.

Where mechanical lubricators are used for feeding oil both to the cylinders and to the axle boxes, such lubricators should have two compartments, so that a bearing oil may be used for the axles, and cylinder oil for the cylinders. Obviously, it is ordinarily not desirable to use cylinder oil for the axle boxes, as it is far too viscous and causes unnecessarily high temperatures of the journals and boxes.

In the case of bogey boxes, oiled through syphons from the top, they are exposed to rain, or to the spray of water from the cylinder waste-water cocks. If sufficient water enters the oil well on top of the box, it will dislodge the oil, and thus cause a heated journal. There is a general tendency among engine drivers to fill up the oil wells too high, and during running the vibration and oscillation causes the oil to splash over the edge of the box, causing unnecessary waste. To overcome this the best method is to fill the oil well with saturated waste, interlacing the oil syphons into same, and oil can then be added to the waste as required. This will prevent the entrance of water, and will also prevent waste of oil.

Axle Boxes for Tenders and Cars.—In many cases pads are used for the underside of the journal, plus an additional oil feed by means of syphons arranged in the top of the boxes. The best practice is to use a pad or waste in the boxes, and rely on these for the lubrication without any additional oiling from above; this permits doing away entirely with oil grooves in the bearings, so that the whole bearing surface is available to carry the load.

Pad Oilers.—The best known make of these oilers is the Armstrong oiler, Figs. 97 and 100, which has given general satisfaction and is extensively used. The Armstrong oiler consists of a pad on a light frame, supported by resilient steel springs. The pad is so woven that the points of the pile only lightly touch the journal. This pile is made of a special mixture of cotton and wool in order to retain the oil drawn up from the well of the box by the feeders, which should have high capillary powers. The buttons, which are made of lignum vitæ, act as buffers and prevent the pile of the pad from being flattened out and glazed; in this way the capacity of the pad for supplying oil to the face of the journal remains unimpaired for a long period. New oilers should be dried and soaked in oil for about twelve hours before being placed in the axle boxes. About one pint of oil should be supplied to each axle box, or sufficient to cover the bottom of the well to the depth of ½ inch, and a similar quantity about every 3,000 miles. If the axle boxes are dust-proof and the oilers are kept free from grit and properly fitted, the makers claim that they will last 250,000 miles without repair or removal, and guarantee that they will last for 100,000 miles.

Pad oilers like the Armstrong oiler will lubricate the journal however high the journal speed may be, and the action is unaffected by frequent changes in the direction of rotation.

The use of such oilers results in:

Ample and uniform oil distribution.

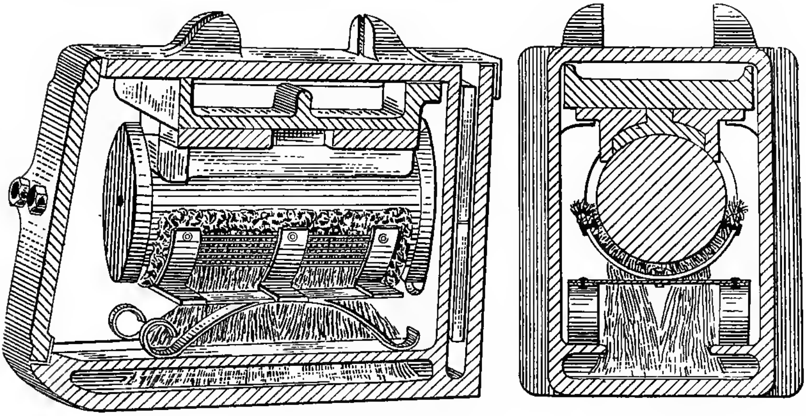

Fig. 100.—Pad oilers.

Freedom from "hot boxes" under most conditions.

Less necessity for frequent periodical inspection of axle boxes.

Reduction in oil consumption and other general lubricating charges.

Waste Oiling.—Good wool waste should be soaked with the proper seasonable kind of oil for at least 48 hours before being used. The surplus oil should be drained off, allowing sufficient oil in the waste so that it will show under slight pressure. If there is too much oil in the waste, the waste becomes too heavy, and will fall away from the journal, thus depriving the bearing of lubrication altogether. Well soaked waste will have absorbed approximately five times its own weight of oil.

The first waste (Fig. 101*A*) should be moderately dry and packed tightly around the back end of the box, so as to make a guard for the purpose, not only of retaining the oil, but of excluding the dust. Then the box should be packed with the drained waste, made into balls, firmly enough so that it will not fall away from the journal when the car runs over crossings, etc., but not so tightly as to squeeze out the oil. The waste should be kept even with the journal, an inch below the edges of the brass. This is most important, as waste packed too high will be caught and carried round, causing a hot box.

At high journal speeds, say above 300 ft. per minute, the waste is inclined to be pushed over to one side of the box by the friction between the journal and the waste, and there compressed so tightly that lubrication becomes deficient. There is one type of box which has three compartments divided by longitudinal ribs, thus effectively preventing the waste from moving and ensuring uniform saturation of the waste all through.

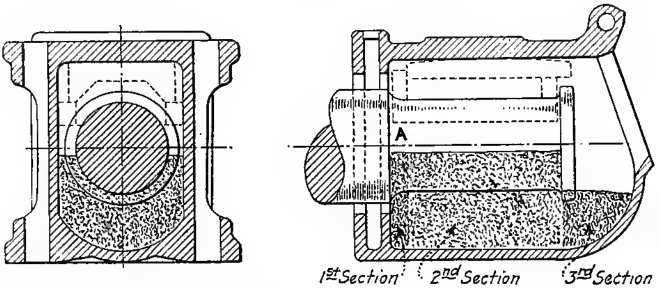

FIG. 101.—Waste oiling.

The waste in the front end of the box should be as high as the opening, and have no thread connection with the waste underneath the journal. This waste should be placed in the box by hand after the box has been packed. It performs no service other than to act as a stopper to prevent the waste that is doing the work of lubrication from working forward.

It is important to give some intelligent attention to the waste in the boxes during service, the chief requirement apart from oiling being to lightly loosen the waste packing on either side of the journal for about every 1000 miles' run, to bring it into good contact with the journal and avoid the hardened and glazed condition which is gradually brought about by contact with the revolving journal. Suitable tools for this purpose and also for packing the boxes are shown in Figs. 102 *A*, *B*, and *C* showing a packing knife, hook, and loosening tool respectively.[1]

Dust Guards.—Efficient dust guards to prevent the entrance of dust are of the very greatest importance. Too much attention

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[1] Copied from American Locomotive Dictionary.

cannot be paid to this matter, as, if dust and grit are allowed to enter, the lubrication can never be perfect, and pad oilers and waste are liable to be choked. The dust trouble is particularly prominent in countries like the South of England, due to the lime dust.

In the case of newly-laid roads, it frequently happens that fine granite dust causes trouble, being very hard and very fine it enters the boxes, and may cause a great deal of wear.

Inspection and Oiling of Axle Boxes.—Although as a general rule it is true that regular and careful inspection of axle boxes is desirable, yet it is also true that there can be too much inspection. As a matter of fact, pad oilers (and this also refers to woollen waste), once they are well fitted and work well, should not be disturbed in any way. An examination every three months will, as a rule, be quite sufficient, and at the same time a small quantity of oil may be introduced in the box, assuming that there is no additional oil supply from the top.

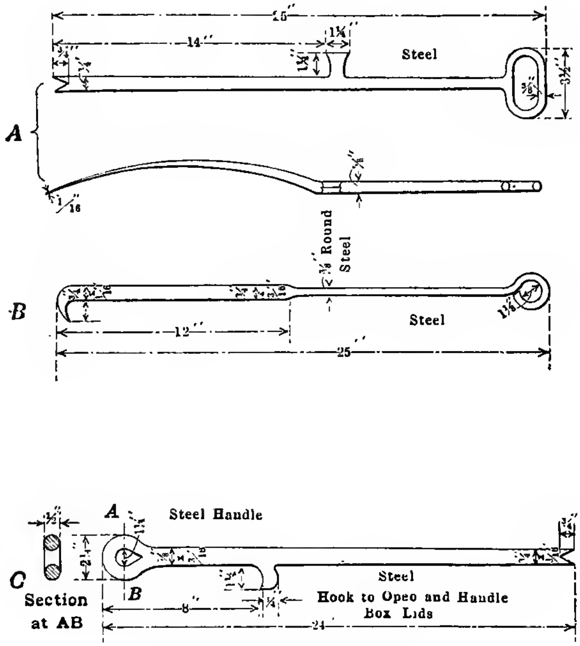

FIG. 102.—Packing tools.

The *oil consumption* with waste packing ranges from 500 miles to 4,000 miles per pint of oil, a good average being 3,000 miles per pint of car oil.

Special Oiling Systems.—Lubrication of axle boxes by means of a circulation system has attracted considerable attention. Several systems have been tried, including a force-feed circulation system by means of a rotary oil pump, and also a system consisting of a round disc fixed to the front end of the journal, dipping in the oil in the bottom of the box, and lifting the oil to the top of the box, from which it flows into the bearing in liberal quantities.

It is obviously desirable (particularly in railway practice) to give the journals as liberal a supply of oil as possible. The difficulties are, that it is not easy to prevent excessive leakage of oil through the ends of the box; and that the entrance of dust and dirt makes the oil dirty, and may cause clogging of oil pipes where such exist. Other mechanical appliances have been tried, such as rollers against the under side of the journals, but have not been successful.

It must be kept in mind that whatever appliance is used, it should be so designed that it is not liable to get out of order; for instance, the clogging of an oil pipe, or the breakage of an oil pipe due to vibration, will cause stoppage of the oil supply altogether, with disastrous results.

Connecting Rods and other Parts.—The brasses in connecting rod bearings must be let completely together so as to cover the entire surface of the journals and minimize the entrance of dust and grit.

Syphon lubrication is extensively used. For those parts which require only a small amount of oil, trimming-pins, or trimming-plates are used, being a piece of 1/8-in. wire or 1/16-in. plate, which has a hole at the bottom and also at the top, through which are threaded one or two strands of wool, just sufficient for proper lubrication of the motion bars or other parts, where such a small amount of oil is found ample.

It is safer to use syphons than to feed the oil through oil cups where the oil feed is adjusted by means of a needle valve, as a needle valve is more easily choked than a syphon. Figs. 103, 104 and 105 show various designs of such oilers.

For reciprocating parts, such as connecting rod ends, choke or plug trimmings are frequently used; see Fig. 106. This trimming is pushed well into the syphon tube, and prevented from dropping right into the tube by a big loop, which rests on the top of the syphon tube. When the engine is running, the oil is thrown up into the syphon tube, and the trimming being, say, 3/16 in. below the top, a well or reservoir of oil is always maintained, the oil soaking through the plug trimming and entering the bearing.

The plug trimming should preferably end close to the journal, as this largely prevents the oil being wasted by escaping between the brass and the strap. Sometimes a little tube is screwed in here, so as to positively prevent escape of oil. Plug trimmings may be made of copper trimming wire, the wire being wound in the same manner as the yarn in the usual plug trimming. The advantage is said to be that a much heavier oil can be used than could possibly syphon through the ordinary worsted trimming. Sometimes (in Continental practice) oil is allowed to go direct into the syphon tube through holes at the bottom; this, of course, means waste of oil while the engine is standing. In America and on the Continent, plug trimmings are frequently discarded in favor

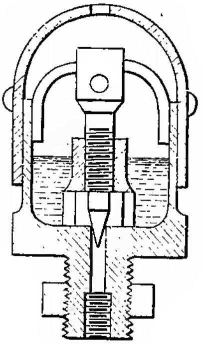

FIG. 103.

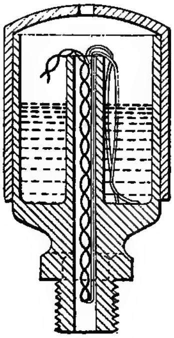

FIG. 104.

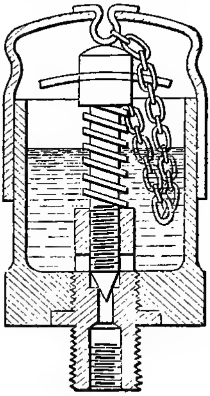

FIG. 105.

Locomotive stationary oilers.

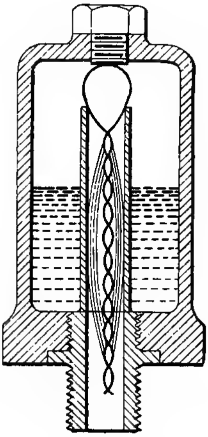

FIG. 106.—Plug (choke) trimming.

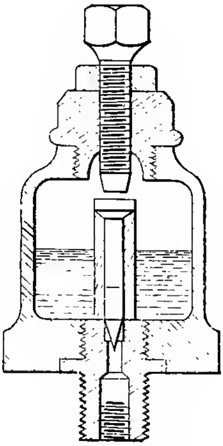

FIG. 107.—Rod needle oiler.

small needle valves, consisting of a loose fitting pin with a head at the top, Fig. 107, the upward and downward motion of the pin being regulated by an adjustable stop in the oil cup cover.

Another method is to have simply a long thin piece of wire bent over at the top, fitted in the syphon tube, passing through a small fitting screwed into the top of the syphon tube, and having a central opening through which the wire or needle passes down. The difference in diameter between the needle and the opening determines the oil feed.

In oil cups that are entirely enclosed, the cover should have a tiny hole to allow the air to get in as the oil leaves the cup, or the hole in the cover should be plugged up with a piece of cane (which is porous), or a piece of cork with a V-groove at the side.

When changing over from an oil largely vegetable or animal in character, it nearly always happens that the syphons and trimmings get more or less choked with deposit due to the change. It is therefore to be recommended, wherever any drastic change in oils is to be carried out, that new trimmings be made for all the oil cups and lubricators.

The consumption of engine oil for the various external parts of a locomotive, including axle boxes, varies considerably according to the size and the method of lubrication. The consumption may be as low as 2 pints per 100 miles and as high as 8 pints per 100 miles, the average being about 3½ pints per 100 miles.

When sharp curves are frequent it is desirable to oil the wheel flanges by means of a jet of oily steam. Various forms of lubricators are employed for this purpose; they all endeavor to atomize the oil with a jet of steam, which is then directed on to the wheel flange.

Methodical Oiling.—It is very important that the oiling of the locomotive be carried out in a methodical manner, the oiler going round from one part of the engine to another, oiling always in the same manner of rotation. This is the only way in which he can be reasonably sure of not forgetting some of the parts As a matter of fact, lack of attention to this point may be said to be very largely responsible for bearing troubles. This also applies to the attention that should always be given to taking out syphons or trimmings wherever possible when the locomotive has finished the journey. Overfilling of oil holes or oil cups should be avoided as it is wasteful and does not improve lubrication.

GREASE LUBRICATION FOR LOCOMOTIVES AND CARS

In the United States the use of grease on locomotives has during recent years been given some considerable attention, not only for the connecting rods and coupling rods, but also for the axle boxes.

Fig. 108 shows the grease cup arrangement for one of the rods; when the lock nut (1) is loosened the threaded plug (2) can be given a turn and again locked; the grease gets squeezed into the bearing and is gradually consumed, until the plug is given another turn, and so on.

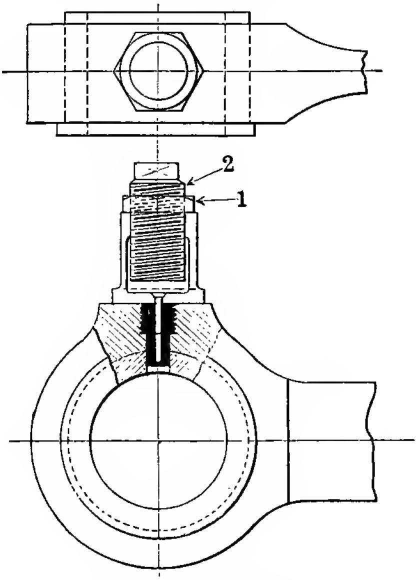

Fig. 108.—Rod grease cup.

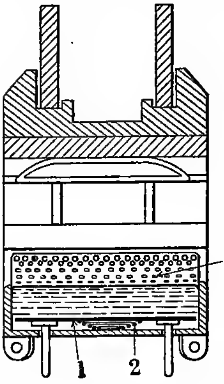

Fig. 109.—Driving box grease lubrication.

Fig. 109 shows the application of grease to a driving box; the grease is moulded to the shape of the cellar and placed on the follower plate (1); the spring (2) pushes the follower plate upward, thus squeezing the grease through the perforated plate (3) shaped to the contour of the journal and kept at a distance of about ⅛ inch.

Oil grooves are cut to distribute the grease as shown; the vertical grooves are cut only on the "off side" of the brass, presumably to act as drainage grooves. Through a hole shown on the left some grease reaches the hub face of the wheel; a similar hole, not shown, is arranged for lubricating the hornplates.

It is stated by the makers of these grease appliances that the grease recommended for the axle boxes must not get sticky when worked between the fingers, and when smeared with a penknife on a piece of white paper small bubbles of water must appear on the surface. The author has no personal experience with these greases; they are probably rather soft low melting point greases somewhat similar to the English railway wagon greases mentioned below, and containing a certain amount of water, to bring about emulsification, so that the journal when revolving may continue to abrade or melt the grease.

It is obvious that whatever claims may be substantiated in the way of "economy" and ability to stand up to severe conditions, the amount of power lost in friction is considerably increased with grease lubrication, and also the wear.

An advantage with grease lubrication is that the starting friction is lower than with oil on account of the thicker film between the surfaces.

Some tests were carried out in 1904 at the St. Louis Exhibition on locomotives, using grease and oil. A consolidated type locomotive, 22″ × 28″, 8-wheel coupled, 2 wheels in front (2–8), developing a maximum power of 1,000–1,100 H.P. showed a frictional loss as follows:

Oil: at 15 miles per hr. : 61 H.P.
at 30 miles per hr. : 107 H.P.
Grease: at 26.6. miles per hr. :224 H.P.

A Pennsylvania consolidated type locomotive, developing a maximum power of 1,000–1,100 H.P. consumed in friction alone when using grease throughout:

With Grease: at 15 miles per hr. : 132 H.P.
at 30 miles per hr. : 224 H.P.

It was demonstrated that wear of axles and crank pins was greater with grease than with oil, and that there was not much difference in the cost of lubrication, the consumption with grease being approximately 450 miles per pound of lubricant.

Outside the United States grease has not been favored for locomotive lubrication; in Europe oil is used everywhere in preference to grease.

In Great Britain grease is, however, still used for lubricating colliery trucks and goods wagons, but this practice is rapidly dying out in favor of oil.

The grease is placed in a cavity formed in the top of the axle box. Large openings in the bottom of this cavity communicate with similar openings in the brass, and under the influence of frictional heat the grease gradually melts and lubricates. The friction is high; the boxes are often neglected, lids are torn off, and the grease cavities contaminated with dirt, water, etc. Altogether the results are such that the sooner this form of lubrication is done away with in favor of oil lubrication the better.

On page 27 will be found some information about the manufacture and constituents of such railway wagon greases.

Railway Oils.—The character of railway oils is governed to a large extent by the climatic conditions. In the Tropics the oil is exposed to very high temperatures during the day and quite low temperatures during the night. Long distance trains going from a warm low-lying country into a cold mountainous district will find themselves exposed to widely varying temperature conditions during their journey. In temperate climates the same conditions exist except that the differences between the day and night temperatures are smaller; still the variation in temperature may be quite considerable. For example, the Scottish express trains running between London and Scotland will meet temperatures in the North very appreciably lower than the temperatures in the South.

These conditions call for oils with low setting points in order that they may feed as uniformly as possible and with certainty through the oil syphons and other feeding appliances.

On the other hand, once the oil has entered the bearing surfaces it is exposed to considerable pressure and high temperature, so that it must possess great oiliness at the bearing temperature. In brief, railway oils must have viscosities which are not unduly influenced by great variations in temperature. The oils which best satisfy these requirements are mixtures of non-paraffinic base mineral oils with setting points in the neighborhood of zero °F. mixed with from 10 per cent. to 25 per cent. or even more of a suitable fixed oil. Mineral oil of the character described will give fluidity in the cold, and the admixture of fixed oil has the effect of maintaining great oiliness and viscosity at high temperatures.

The admixture of fixed oil serves another purpose in the case of locomotive engine oil, in that it prevents the oil from being washed away from the bearing surfaces by the steam which escapes from the piston rod and valve rod gland, the condensed steam producing a "lather" on the guides and other parts.

The setting points required for the blended oil can be determined only on the road, although syphoning tests may be carried out in the Laboratory indicating the syphoning and the capillary power of the oil at different temperatures, including the lowest temperatures to which the oil will be exposed during service.

Such syphoning tests are not much used by railways, and yet they are of the very greatest importance.

Oils differ very considerably in their ability to syphon, and furthermore, the quality of wool on the market varies very considerably in its syphoning qualities. In the case of syphon oilers, the wool which will give the greatest syphoning effect for the class of oil in use is the most desirable to use. In the case of pad oilers, which are fixed below the axles and lift the oil from the bottom of the box, the ability of the pad and its feeders to draw the oil and hold it is most important. It will be found that the quality of wool required for the two purposes is different. Wool or cotton which will lift the oil a considerable distance and hold it there will not easily deliver the oil to the journal, nor will it have good syphoning qualities when used in a syphon oil cup.

As regards the viscosity of railway oils, it is always desirable that the viscosity should alter as little as possible per degree Fahrenheit. As a rule, the more fluid the oil, the quicker will it feed through the lubricating appliances, and consequently if the oil varies greatly in viscosity with a varying temperature, the feed will be irregular and wasteful. When comparing oils for change in viscosity due to increase in temperature, the oils least affected at the bearing temperatures are the free-flowing vegetable or animal oils, while mineral lubricating oils made from either paraffin base crudes or asphaltic crudes are distinctly inferior in this respect. When the running temperatures are low, approaching freezing point, the comparison may fall out differently as most vegetable and animal oils (as well as paraffin base lubricating oils) have a poor cold test, whereas asphaltic base oils still flow freely.

The selection of the right quality of vegetable or animal oil is very important, because unsuitable fixed oils usually become acid during use, and have a strong tendency to oxidize and produce gummy deposits. The acidity has an effect on the bearing metal, and that, in connection with the gumminess produced by the oil, attracts and fixes the dust and dirt which enter the bearing. As a result, the oiling pads or oiling waste, or the oil syphons, become choked and more or less inoperative, due to the deposit.

The fixed oils used for compounding locomotive engine oils may be rape oil, olive oil, or whale oil, or mixtures of these; rape oil and whale oil are usually used in the form of blown oils, blown to a viscosity of 400″ to 720″ Saybolt at 212°F. and the percentage ranges from 10 per cent. to 25 per cent., the same as for marine engine oils; in fact the character of the oils is very similar.

Car oils are usually dark lubricating oils, containing less than 3 per cent. of asphaltic matter, and preferably compounded, although not to the same extent as locomotive engine oils, as the bearing pressures which they have to withstand are much less.

Car oils are preferably compounded with 8 per cent. to 12 per cent. of animal oil (blown vegetable oils are apt to clog the pads). They are often used straight, *i.e.*, not compounded, on account of the lower price per gallon.

The following specifications are typical of locomotive engine oils and car oils:

TABLE No. 11

	Specific gravity	Saybolt viscosity at			Per cent. of compound	Setting point, °F.	Color
		104°F.	140°F.	212°F.			
Locomotive engine oil, summer grade	0.920	500	195	66	15–25	10	Dark red
Locomotive engine oil, winter grade	0.920	360	155	56	10–20	0	Dark red
Car oil, summer grade	0.930	600	235	65	8–12	10	Black
Car oil, winter grade	0.930	500	190	60	5–10	0	Black

In exceptionally cold climates lower setting points may be required, and when locomotive bearings are abnormally loaded, a greater percentage of compound than recommended above may be needed, even to the extent of using pure rape oil or pure castor oil. Pure castor has here the advantage over other fixed oils of possessing an excellent cold test, which under great variations in temperature is of great value.

CHAPTER XIX

ELECTRIC STREET AND RAIL CARS

Street cars are nearly always driven by electric motors, but are occasionally operated by cables, travelling below the streets, as for example, the cable trams in Edinburgh.

The important parts requiring lubrication are the axles, the motor and the gearing.

Axle Boxes.—The construction and lubrication are often very similar to railway practice. One meets all sorts of combinations of syphon oiling (from the top), pad oilers or oily waste packing (from below), the development being distinctly in favor of the latter oiling methods.

The Armstrong and other pad oilers are widely used, but unfortunately many oil wells are made too small, so that it is difficult to fit the pads, and the wells contain too little oil.

A very unsatisfactory combination of grease and oil lubrication is not infrequently used. The oil is fed from below, and the grease, filling a cavity in the brass, acts as reserve lubricant. The trouble is that the grease becomes softened by the oil film on the journal and in time gets worked into the pad oiler below the axle, choking the pad and making it inoperative.

With grease alone, the friction and wear are much greater than with oil, and the necessary period of oiling and inspection of the cars varies from once a day to twice per week, whereas with oil an inpsection once every two to six weeks represents current practice.

The axle boxes are usually fitted with dust-guards. This is important, to keep not only the dust out, but also water, as, on rainy days and when the tracks are not properly drained, the wheels throw the water about, and if it gets inside the bearings in any quantity trouble is sure to follow.

Motor Bearings.—Ring oiling is not uncommonly employed, and when suitable shapes of rings are employed (see ring oiling bearings page 160) the rings will run at such a speed that no oil spray is formed, and yet sufficient oil but not too much will be conveyed to the journal.

Much trouble has, however, been experienced with ring oiling on electric cars, the oil escaping from the bearings and getting on to the commutator and rotor.

Pad oilers are gaining in favor both for motor bearings and suspension bearings, as they are very reliable in feeding the oil and do not overlubricate the journal. The pad must be placed so that it rests on the journal in a position where the oil can easily wedge its way in between the bearing surfaces (Fig. 110). From the pad a number of woollen syphon strands reach down into the oil well, which may hold a large amount of oil, or if it is only small, the oil should be fed continuously to the well from an oil cup placed in a suitable position.

Oil-soaked waste is also used to some extent, feeding through an opening in the side of the brass, as shown in Fig. 111. The opening may be rectangular, with all sides well chamfered on the inside where the oil is to enter the bearing, and from each corner a shallow oil groove has been found advantageous to distribute the oil, on account of the rather sparing oil supply.

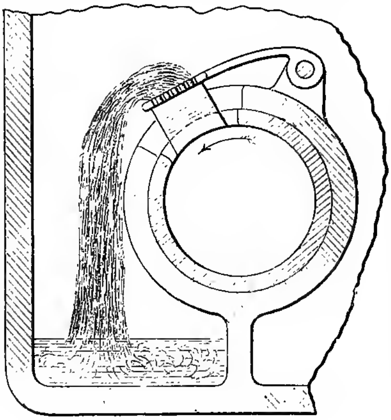
FIG. 110.—Pad oiler.

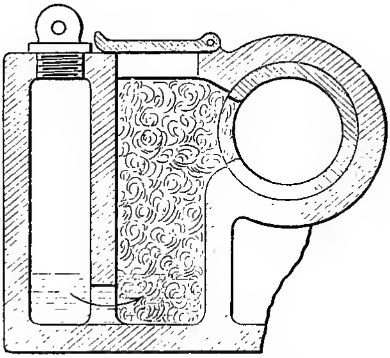
FIG. 111.—Waste oiling.

Oil is added at intervals to the oil-soaked waste in the way indicated; in one case one pint of oil had to be added every 120 to 160 miles for a 5¼ × 10 inch journal running 1,100–1,600 R. P. M., the weight of the rotor being 2 tons.

An interesting method of circulation oiling has been used for the motor bearings on a South of England electric railway, as shown in Fig. 112. The oil pump (1) pumps the oil in the same direction independent of the direction of its rotation, as will be seen from the detail drawing, Fig. 113. The oil is forced to the diaphragm plate (2) which has one, two or three one-mm. holes, through which a small amount of oil is constantly delivered to the bearing, the greater portion continuing its way to the suction joint box (3), where it joins the return oil from the bearing and finally re-enters the oil pump. Each motor bearing has its own independent pump supply, delivery and return pipes.

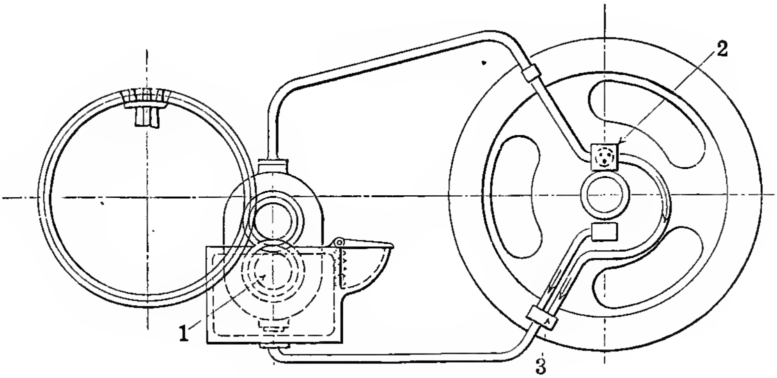

Fig. 112.—Diaphragm-circulation oiling.

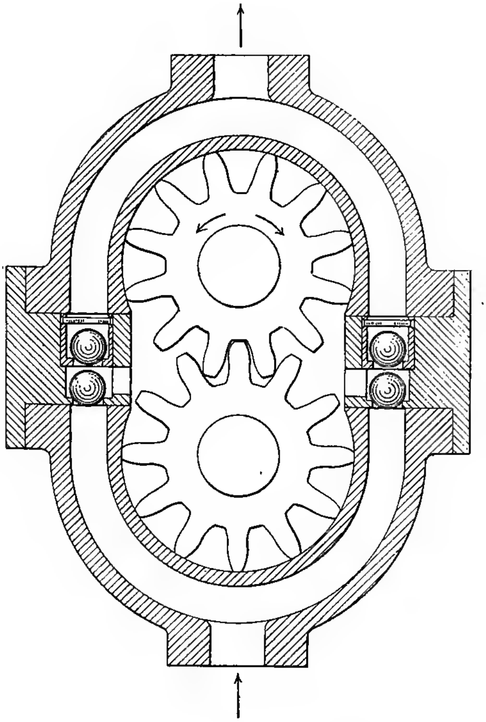

Fig. 113.—Reversible rotary pump.

The wear of motor armature bearings on British street cars ranges from 5,000 to 50,000 miles per 1/16 inch vertical wear, the wear of the suspension bearings being rather less; the average life of motor bearings appears to be 10,000 to 12,000 miles.

The reason for such large wear as compared with stationary motors is the effect of fine hard grit and dust (wear from pavement, etc.) which are whirled up by the wheels and enter the bearings.

Gear Wheels.—Most gear wheels are enclosed in a casing and use some kind of a thin gear grease. The results are always inferior to those obtained with gear oil, but of course the gear case, if oil is to be used, must be as oil tight as possible.

With grease or grease and oil the life of the gear wheels may be from 50,000 to 200,000, whereas with oil the gears last considerably longer.

The pinion wheels do not last as long as the gear wheels, but also here the use of oil is conducive to longer life.

Oils.—The oils used for lubricating the axle boxes of electric street and railway cars are usually lower in viscosity than the oils used in railway practice, because the bearing pressures and conditions generally are not nearly so severe. Bearing oils Nos. 3 and 4 represent oils which may be recommended for electric street cars, and bearing oils Nos. 4 and 5 are recommended for electric railway cars. All of these oils should preferably be compounded with not more than 10 per cent. of a non-gumming animal oil and in cold climates a low setting point would be required.

The oils for motor and suspension bearings should be of a rather higher viscosity as they are exposed to high temperatures (commutator heat) or pressure (from pinion wheel).

Bearings oils Nos. 5 or 6 may be recommended and may with advantage be compounded when the conditions are severe.

As to gear lubricants, the same oils as are used for the motor and suspension bearings can be used when the gear case is reasonably oil tight. When a more viscous lubricant is required, mixtures of oil and gear grease in suitable proportions, so that the mixture is not unnecessarily heavy, will form the best solution.

Wheel Flange Lubrication.—For electric locomotives which have to negotiate many curves, as for example the electric locomotive service through the St. Clair Tunnel, wheel flange lubricators have given excellent service. The oil is contained in an airtight receptacle of one-quart capacity, whence it is led to the wheel flanges by pipes and sprayed upon the flanges by jets of air. The air is supplied through a ¼-in. pipe, which is connected to the oil receptacle above the surface of the oil. A branch of this pipe is connected to the oil delivery pipe which leads to the flanges. The air is controlled by an electric push button, so that the lubricant is applied only when needed, as on curves. This apparatus has been in successful operation since July 10, 1910. The six electric locomotives to which it has been applied haul 1,000-ton trains up and down 2-per cent. gradients on which flange wear had been rather heavy, owing to the many curves and the rather low centre of gravity of the locomotives. Lubrication of the flanges has so improved conditions that 50,000 miles and more are now run between wheel tyre turnings. This means that the wheels can be removed for turning at the same time that the armature is removed for commutator dressing. The former mileage made between tyre turnings was from 12,000 to 25,000 miles. Filtered reclaimed armature bearing oil is the lubricant used.

CHAPTER XX

TRANSMISSION SHAFTING

The long main lines of shafting used for power transmission are called line shafting. Countershafting is driven from the line shafting and operates the various machines by fast and loose pulleys or by clutches.

The speed of shafting ranges from 120–450 R.P.M.; the diameter of line shafting usually ranges from 2½ in. to 6 in., of countershafting from 1 in. to 2½ in.

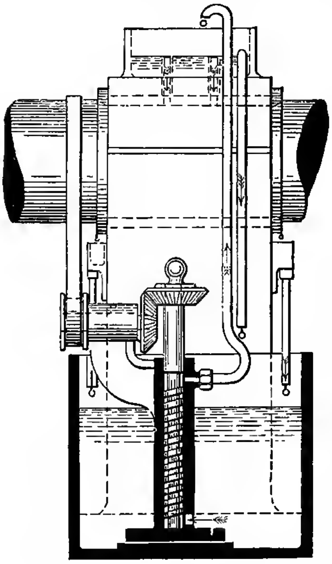

Fig. 114.—Screw-circulation oiling.

Many bearings on countershafting and small diameter line shafting are hand oiled or oiled by glass bottle oilers. Line shafting bearings are seldom hand oiled; they are usually bottle oiled and modern shafting is frequently ring oiled. Ball and roller bearings are also coming into prominence for quick speed line shafting.

Heavy large diameter shafting bearings, as for example many second motion shaft (jack shaft) bearings, develop so much heat that they can be kept cool only by a circulation oiling system.

Fig. 114 shows a simple form. The screw can be lifted right out for examination by taking hold of the knob.

Fig. 115 shows a more elaborate system with three oil feeds from the oil box. The drawing will need no explanation.

The power required to drive the line and countershafting in a mill or shop is always a considerable percentage of the total load. In textile mills it ranges from 20 per cent. to 60 per cent.; in engineering workshops it ranges from 20 per cent. to 75 per cent. Whether more or less machines are in operation, the shafting load is always of the same magnitude, and it is not too much to say that in most existing factories or works an average of 10 per cent. could be saved in the shafting load by introducing better lubricants, and another 10 per cent. by regular attention to keeping the shafting in perfect alignment. Losses from poor alignment and from unsuitable oils frequently occur simultaneously. Poor alignment often means that certain bearings heat due to the extra load; instead of the bearings being adjusted, the oil gets the blame and a more viscous shafting oil is introduced, which "cools" the bearings inclined to heat and at the same time adds 10 per cent. to 25 per cent. of extra fluid friction to all the other bearings. If bearings are kept in good alignment, low viscosity shafting oils can be used and a considerable saving in power obtained (see remarks, page 312, regarding shafting in textile mills).

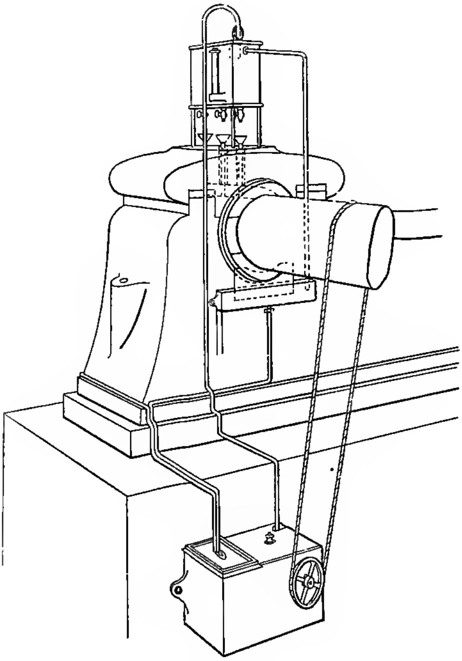

FIG. 115.—Pump circulation oiling.

Where electric driving is employed, it is a simple matter to take the shafting load every 3 or 6 months, as a check on the efficiency. With steam plants, the I.H.P. may be recorded, or the number of revolutions of the flywheel and the time taken before it comes to rest from full normal speed, after steam has been shut off.

Shafting bearings should be provided with savealls to prevent dripping of lubricant. Oil creeping along the shaft, when it does occur, is usually only toward one side of the bearing, and may be overcome, as shown in Fig. 116 by an oil thrower (1) and splashguard (2). The oil drops from the splashguard into the saveall (3). As regards ring oiling bearings see pp. 158.

Ball and roller bearings save a great deal of power; a type of roller bearing very suitable for line shafting is the Hyatt flexible roller bearing (Fig. 53, page 177) which gives a coefficient of friction of .005 to .008, whereas ball shafting bearings give a coefficient of friction of .002 to .003. Good alignment is essential with ball and roller bearings, more so than with plain bearings, an exception being the Skefko Ball Bearing. The following figures indicate the coefficient of friction which may be expected for different methods of lubrication in connection with shafting bearings.

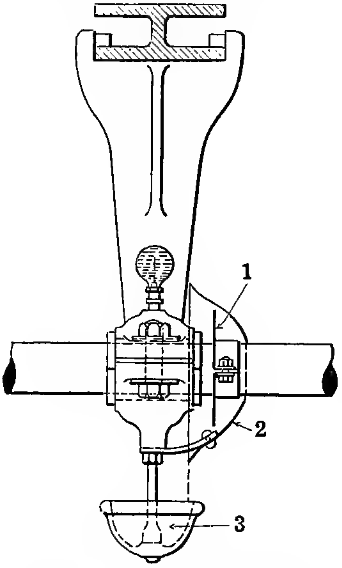

Fig. 116.—Shafting oil thrower.

	Coefficient of friction
Ball bearings	.002–.003
Roller bearings	.005–.008
Ring oiling bearings	.010–.015
Bottle oiling, syphon oiling	.02 –.04
Hand oiling	.04 –.15

The great savings in power which follow the introduction of high-class shafting bearings is better realized on the Continent of Europe than elsewhere; in Great Britain and the United States conditions of shafting are much behind Continental practice.

Lubrication.—Most shafting bearings are lubricated by oil; as mentioned elsewhere shafting in weaving sheds is frequently lubricated by grease applied through gravity grease cups, spring grease cups, or applied direct to the shaft. Stauffer cups are not used because they require to be given a turn every day or two, while the other methods are more or less automatic in action and require attention only at long intervals.

The waste in power by applying grease, as compared with oil, ranges from 5 per cent. to 20 per cent. of the shafting load, according to the fluidity and quality of the grease and the speed of the shafting.

The better the lubricating system the lower viscosity oil can be used, and the lower the friction.

For hand oiling, oils compounded with, say, 5 per cent. of a non-gumming fatty oil will last longer and give better results than straight mineral oils. For bottle oilers straight mineral oils should be used to ensure the needles keeping clean and in working order. Oils for ring oiling bearings and ball bearings should also be straight mineral.

The following chart is a rough guide for selecting the correct grade of shafting oil·

LUBRICATING CHART NO. 8

FOR SHAFTING BEARINGS

Bearing Oil No. 2......	For most moderate and high speed shafting and countershafting in good alignment and condition and with reasonably good lubricating appliances. This oil is usually too thin for hand oiled bearings.
Bearing Oil No. 3......	For slow or moderate speed light and medium shafting and countershafting in good or moderate condition and with good or moderate lubricating appliances. Also for hand-oiled bearings on countershafting.
Bearing Oil No. 4......	For slow or moderate speed, heavy shafting.

NOTE.—Lubricants for Ball and Roller Bearings (see page 190).

Shafting Greases.......	Grease should be of as light a consistency and as low a melting point as practicable, without incurring undue waste of lubricant. The mineral oil used in the grease should be of similar viscosity to the oil which would prove suitable if the bearings were arranged to use oil instead of grease.

For Bearing oils, see page 127.

CHAPTER XXI

MACHINE TOOLS

Machine tools are machines such as lathes, shapers, boring, drilling, milling, planing and grinding machines, etc., the speeds ranging from quite low on large lathes and planers to very high, up to 10,000 to 30,000 r.p.m., for modern grinders.

There are a great many bearings on most machine tools which are hand oiled, the speeds or pressures being low. The oil holes should preferably be protected by a cover. Fig. 117 shows a typical oil hole cover; the lid (1) is turned, disclosing the oiling hole (2); the lid by means of an internal spring may be made to turn back automatically and cover the hole after the oiling operation. Fig. 118 shows a hand oiling arrangement with ball valve (1) and felt chamber (2). Felt, wool, or worsted yarn may be used in the chamber, and serves to feed the oil more uniformly to the bearing in between oilings. With a rise in temperature more oil is liberated, so that such an arrangement is a great improvement over the ordinary oil hole without felt.

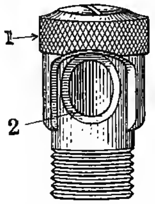

Fig. 117.—Oil hole cover.

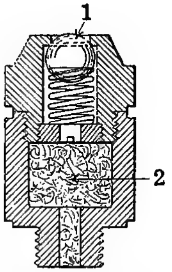

Fig. 118.—Ball valve and felt chamber.

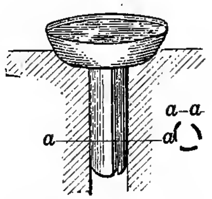

Fig. 119.—Oil hole protector.

Hand oiling arrangements.

Fig. 119 shows a simple oil hole protector, consisting of a cup, the shank of which is split in three parts which grip the oil hole, as the cup is pressed into position. The cup and shank are filled with felt, which acts in the same way as the felt in Fig. 118.

In many modern machine tools felt pad arrangements are made use of to a considerable extent. Fig. 120 shows an arrangement used by Brown and Sharpe for the bearings of internal grinding spindles. The oil soaks through the felt and enters the bearing through the passage shown.

In many bearings large recesses are cored out around the spindle boxes in the middle and fitted with felt pads which are pressed gently against the revolving spindle by means of light feather or spiral springs.

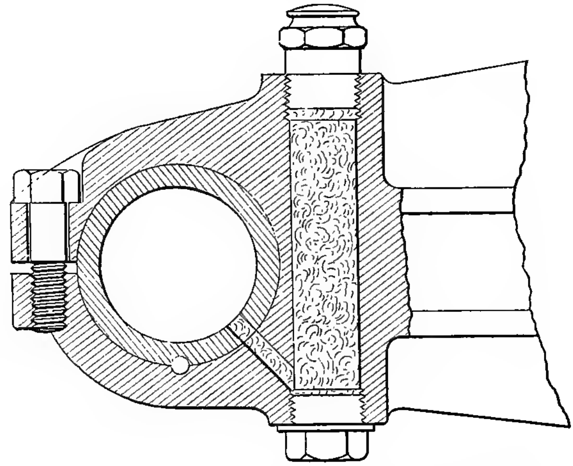

FIG. 120.—Felt oiling arrangement for grinder spindle.

Fig. 121 shows two types of pads; when in use they are both placed below the spindles in a well partly filled with oil, which is replenished from time to time through an oil filling hole at the top communicating with the oil well. Right- and left-hand spiral grooves, as shown in Fig. 122 are excellent for distributing the oil toward the bearing ends, where fine V threads on the spindle cut in the opposite direction tend to prevent leakage and have proved very efficient in this respect.

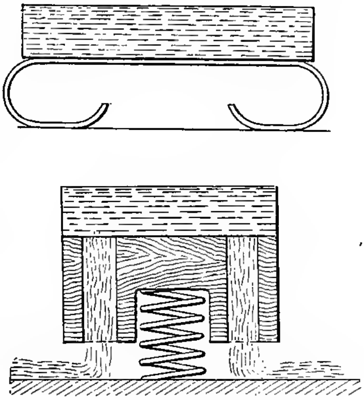

FIG. 121.—Spring felt pads.

Bearings which require a fair amount of oil may be supplied by small syphon oil cups or drop feed oilers; occasionally ring oiling bearings are employed. In some recent designs a circulation oiling system is employed, a pump delivering the oil to a distributing box whence oil is guided to the various bearings and gears and finally returns to the pump reservoir. Grease is seldom used for machine tools, except in ball bearings, which are now widely used, especially as vertical thrust bearings for drill spindles, heavy revolving tables, etc.

The lubrication of lathe saddles, ram slides of shaping machines, flat or V-shaped slides of planing machines, is receiving more attention nowadays. Instead of the surfaces merely being flooded by an oil can, most of the oil being wasted to no good purpose, some modern machines have felt pad insertions in the sliding member. The felt pads are kept soaked with oil, being hand oiled through oil passages from above, and keep the large surfaces economically and fairly well lubricated. In some V-grooved slides, V-shaped wheels are placed in the stationary slides; the wheels are partly immersed in oil, and are forced gently against the moving slide which they lubricate. The felt pad arrangement is probably equal to if not more efficient than the revolving wheels.

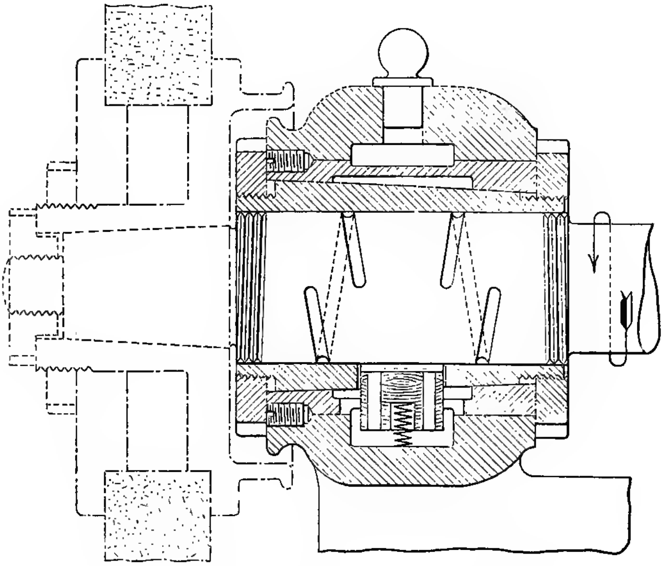

FIG. 122.—Spiral oil grooves for grinder spindle.

Apart from high speed machine tools, the majority of bearings in machine tools are only poorly lubricated at the best of times and the coefficient of friction is high. Slightly compounded oils are therefore preferable to straight mineral oils, as they have greater oiliness. The low-viscosity oils, which are (or ought to be) used for high speed tools like grinders, need not be compounded, as the friction depends upon the viscosity of the oil and not on its oiliness.

Exposed in thin films to the oxidizing influence of air and fine metallic dust, the oil which invariably creeps all over the machine tools in time oxidizes and stains or tarnishes the bright surfaces, particularly in machine shops exposed to bright light or sunlight.

In all mineral oil there are certain complex unsaturated hydrocarbons, coloring matter, etc., which are easily oxidized and which are the cause of the brown, thin, tenacious films just referred to.

Pale mineral oils are less apt to cause tarnishing than dark colored oils, and it is a great help to have a few per cent. of animal oil, say 6 per cent. of lard oil, mixed with the mineral oil. The admixture of animal oil has a marked effect in preventing the oxidized matter from forming a film, and makes it quite easy to wipe the surfaces clean.

An admixture of a vegetable oil will have the opposite effect; it helps to cement the oxidized matter together and makes it more difficult to keep the bright surfaces on the machines clean.

LUBRICATION CHART NO 9

FOR MACHINE TOOLS

Oils of three viscosities are required as follows:

Bearing Oil No. 1[1]..... (Straight mineral.)	For very high speed machines, as grinders.
Bearing Oil No. 2...... (Preferably pale and compounded with 6 per cent. of lard oil.)	For all moderate or high speed machine tools of every description, except grinders.
Bearing Oil No. 4...... (Preferably pale and compounded with 6 per cent. of lard oil.)	For all slow or moderate speed, heavy machine tools, for gear chambers, etc.

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[1] For Bearing oils, see page 127.

CHAPTER XXII

TEXTILE MACHINERY

The textile industries, comprising the cotton, woollen, worsted, silk, flax, hemp and jute industries, are all highly specialized and employ such a variety of machinery that it is impossible inside a few pages to give even an outline of the principal types and their uses.

Characteristic of most of the machines is that the amount of power actually used in doing useful work, that is in handling the fibres or material itelf, is small and that by far the greater portion of power is consumed by the friction of numerous spindles or shafts often revolving at high speeds and usually only lightly loaded.

Great improvements have taken place so far as the mechanical construction and lubricating arrangements are concerned, and the author will endeavor in the following pages to point out some of the important features. While some considerable attention has been paid to the selection of suitable oils, yet very great power reductions can be accomplished in practically all existing mills by the introduction of such oils as will be mentioned later on.

The subject will be divided into four sections, namely:

1. Preparing.
2. Spinning.
3. Weaving.
4. Bleaching, Dyeing, Printing and Finishing.

PREPARING MACHINERY

Openers and Scutchers. (Used for Cotton Only).—Openers and scutchers are very similar in action; they open and loosen the fibres of cotton by quickly revolving beaters; the cotton fluff thus formed is blown a certain distance and again gathered together, forming a soft thick sheet of cotton called a lap. In this process the cotton fibres are cleaned from dirt and grit, passing first through the openers and next through the scutchers. There are quickly revolving spindles in these machines, the lubrication of which is important. By feeling these bearings an expert can always get an idea of the quality of the spindle oil used in a mill; if they run excessively warm, the oil in use is probably too viscous, assuming of course that the bearings are in good condition mechanically.

The high speed bearings are either oiled by bottle oilers or they are preferably ring oiled.

The room in which the openers and scutchers are placed is called the Blowing Room or Scutching Room.

Washing and Drying Machines.—(Used only for wool and worsted.) Wool-washing and drying machines do not present any lubrication features of interest, except that in some mills hydroextractors are used for "whizzing" the wool before it passes into the drying machines for the final drying.

These hydroextractors are of the same type as those used for recovering oil from waste (Fig. 220, page 566), and unless they have ball bearings or Michell bearings they require oils of great oiliness, much more viscous than the spindle oils used in the mill. Hydroextractors are usually driven direct by a small steam engine or steam turbine.

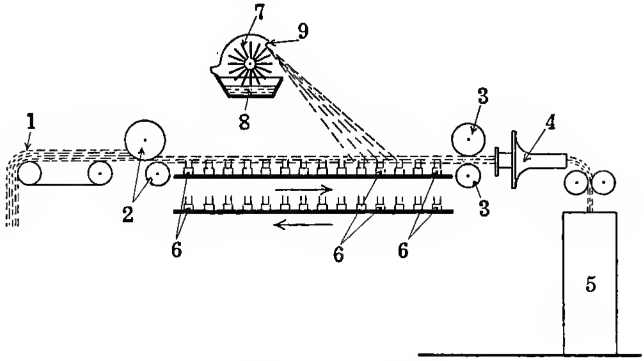

Fig. 123.—Preparer gill box.

Preparer Gill Boxes.—(Used for wool, worsted, flax, hemp, jute and waste silk.) These machines comb open the fibres, lay them parallel and deliver them in the form of a continuous "end" or "lap." There are always several sets of gill boxes through which the material has to pass.

The last preparer gill box in the series is called the can gill box and is shown in Fig. 123. The lap (1) enters the back rollers (2), is drawn between the front rollers (3) and delivered through the slowly revolving funnel (4) as a continuous sliver into the can (5). Between the front and back rollers the fibres are combed by the fast moving fallers (6) which rest with their ends on slides and are pushed to the right by means of square threaded screws; they fall at the end and are returned quickly by bottom screws (revolving in the opposite direction) to be raised again into position just behind the front rollers.

The fallers, slides, screws, etc., wear rather quickly, and good lubrication is therefore extremely important, particularly when working with dusty fibres, such as jute and hemp. The dust, which is composed of earthy particles, also small pieces of woody and fibrous matter, contaminates the oil on all rubbing surfaces.

If when leaving the gill boxes the fibres (such as wool) go to the carding machines, they must be oiled. The oiling should not be done in the first, second, or third gill boxes, but preferably in the can gill box. One method of oiling is shown in Fig. 123. A circular brush (7) revolves in the oil trough (8). When the bristles of the brush pass the blade (9) they shower or spray the hot oil onto the fibres of the wool as they pass through the machine.

Carding Machines.—(Used for all short fibres, not for long worsted and long silk). The carding operations remove all impurities and arrange the fibres parallel, delivering the material in the form of sliver.

The soft laps coming from the blowing room enter the carding machine and are broken up by the revolving cards, being delivered from a large carding drum to smaller carding drums which return the fibres to the main drum; finally the fibres are removed in the form of a thin veil from the last drum by means of a quickly oscillating stripping comb. The veil is gathered together through a trumpet, passes a pair of rollers and is delivered as sliver into a card can.

The bearings for the stripping comb are placed in so-called stripping comb boxes, which contain a bath of oil, and in which cams operate and give motion to the stripping comb. These stripping comb boxes are always rather warm and indicate the quality of the spindle oil. The numerous bearings on the carding machines require to be well oiled. Several of the spindles supporting the smaller carding drums have an endwise oscillating motion, tending to scrape off the oil film.

There are usually two or more sets of cards before the sliver is passed on to the Drawing Department.

Short wool does not leave the cards as sliver, but before going to the drawing frames, it is passed fom the cards straight into so-called condensers; the wool enters these as a thin soft sheet and is divided into a number of strips, which are rolled into coarse threads, suitable for coarse spinning, which is the next operation.

Combers.—(Used for all long fibres, only rarely for cotton.) Long wool, worsted, flax and other long fibres are not carded, but pass through combers. There are many types of combers, but the object in them all is the same, *i.e.,* to straighten the fibres and separate the short fibres from the long ones.

Most parts of these machines revolve slowly, such as revolving tables, drawing off rollers, etc., and require a rather viscous oil, but the "dabbing brushes" have a quick motion and should preferably use thin spindle oil. Modern dabbing motions are enclosed in a chamber containing oil to ensure continuous lubrication and a speed of 800–1200 dabs per minute can be obtained without unreasonable vibration.

The slowly revolving tables—called circles—are often supported by balls placed in ball races. These races get very hot, when the circles are steam heated, and the oil will carbonize and gum unless the oil manufacturer has kept this condition in mind and selected a "non-carbonizing" oil. Some circles are supported by large rollers, which revolve and dip into oil reservoirs and are thus kept continuously oiled.

Drawing Frames.—The drawing frame receives thick "slivers" of fibres and attenuates them by the so-called drawing operation.

The frame consists essentially of several sets of rollers, each successive pair revolving at a greater speed than the previous pair. The top rollers are weighted and the bottom rollers fluted to grip the fibres tightly.

When drawing material like wool or worsted the rollers are heavily pressed together, and a specially viscous oil is required; with cotton the rollers are not so heavily loaded and they are easier to lubricate. Care must be taken not to overlubricate, as if the oil gets on the rollers it will produce oil stains on the yarn. The bearing keeps for the roller bearings should preferably be fitted with flannel layers inside, which have the effect of holding and distributing the oil all over the bearing surfaces and keeping the dust out.

Slubbing, Intermediate and Roving Frames.—Slubbing, intermediate, and roving frames are used for producing coarse thread from the sliver coming from the drawing frames, the sliver passing through several of these frames in the order indicated. Slubbing and intermediate frames are used only in cotton mills; for other fibres only roving frames are used.

All of these frames are flyer frames and very similar in construction.

Fig. 124 shows a slubbing frame. The sliver passes from the can (1) through draft rollers (2) through the hollow arm of the flyer (3) and is wound on to the bobbin (4) driven by skew wheels (5) at a slightly lower speed than the flyer, which is driven by skew wheels (6). The bobbin together with its wheel drive is continuously lifted and lowered during the operation.

The spindle has a footstep-bearing and a neck bearing, both usually oiled by hand.

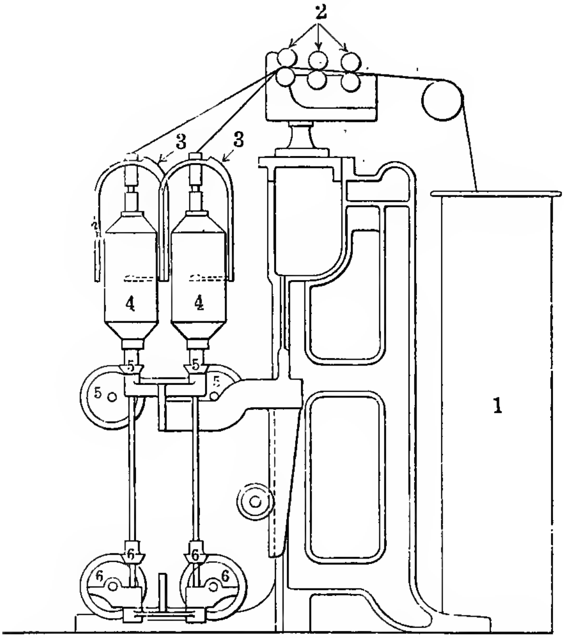

FIG. 124.—Slubbing frame.

SPINNING

The object of spinning is to draw out and twist the coarse thread received from the Preparing Department and produce a more or less finely spun yarn. There are four main types of frames, namely, Ring Frames, Flyer Frames, Cap Frames, and Mule Frames.

Ring Frames.—Figs. 125 and 126 show this type of frame and spindle. The thread is drawn by the draft rollers (2) from the bobbins (1) and delivered through the eye (3) to the bobbin (4). The bobbin (4) is driven from the tin roller (5), pulls the thread through the "traveller" (6), and continuously winds up the yarn. The traveller revolves on the ring (7) fixed on the lifter (8).

The bobbin is fixed on the spindle (9) which is surrounded by a sleeve and immersed in an oil bath. There are several holes provided in the sleeve which allow the oil to enter freely at the bottom and the side. Some of the oil rises along the spindle, overflows at the top and returns through a vertical passage to the oil reservoir at the bottom.

The casing and oil reservoir in which the spindle revolves is called the bolster. It will be noticed that the spindle sleeve is provided with a spring which will allow slight lateral movements of the sleeve in relation to the bolster.

"Make up" oil is added at intervals through the oil well (10) which communicates with the bottom oil reservoir and is protected from dust due to the shape of the driving whorl (11).

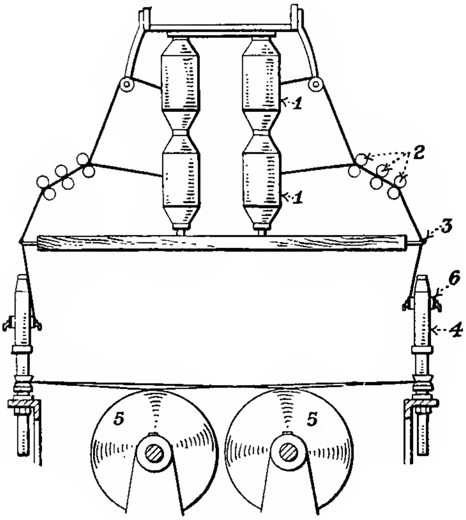

Fig. 125.—Ring frame.

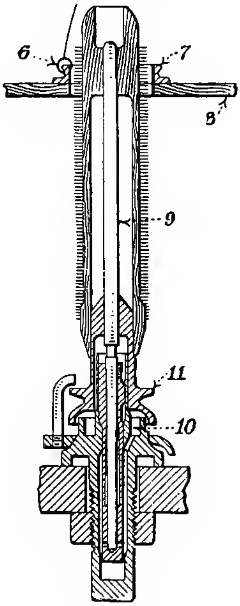

Fig. 126.—Flexible ring spindle.

The so-called Rabbeth spindles are now going out of use; they are similar to Fig. 126 except that the spindle sleeve is rigidly fixed in the bolster. They cannot be operated at higher speeds than 6,000 r.p.m. as they are then inclined to throw off the bobbins. The flexible type ring spindles are operated smoothly at speeds ranging from 6,000 to 11,000 R.P.M. notwithstanding slight unevenness in the driving bands.

When a new frame is being started the oil should be pumped out after two days' working and fresh oil introduced. The oil should be renewed after a week's run and again after four weeks' further running. Current practice for oiling frames afterward is to add a little fresh oil every three months to the oil wells and to empty them for cleaning and recharging once every twelve months.

Fig. 127 shows an oil can for refilling spindle baths. The measure (1) is lowered in the tube shown, filled with oil, and when lifted, tips over its contents into the spout (2) which pours the oil into the spindle bolster.

Another type of oil can is also used for this purpose, in which there is a plunger pump which is pressed down by the thumb. An adjusting screw is fixed below the thumb-piece by means of which the amount of each discharge can be adjusted. The delivery spout may have a sight feed arrangement to indicate that the pump is in working order.

By connecting all the bolsters to a horizontal oil pipe (Fig. 128) and having an oil filling vessel (1) at the end, the oil level is correctly maintained for all spindles. The oil level cannot become too high, because of the overflow (2) which discharges excess oil into the small oil receiver (3). The system can be drained by removing drain plug (4).

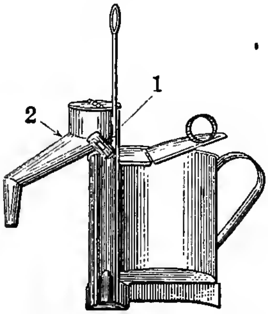

Fig. 127.—Ring spindle oil can.

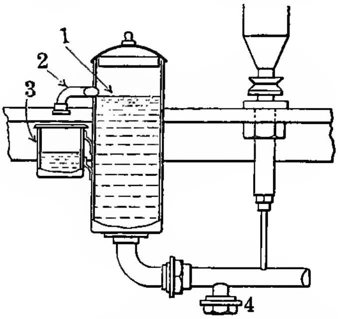

Fig. 128.—Ring spindle oiling arrangement.

While this system is excellent for preventing shortage of oil in the bearings, it carries with it the danger of forgetting to overhaul and clean the spindles, which is important and ought to be done at least once per annum.

Flyer Frames.—(Used for all fibres.) Fig. 129 illustrates a typical Flyer Spindle. The Flyer (1) revolves and lays the yarn on the bobbin (2) which is lifted and lowered by the lifter (3). The spindle is supported by a neck bearing (4) in the rail (5), and a footstep bearing (6).

The small recess shown in the centre is not often found in spindle footstep bearings, but is a great advantage; it prevents heating of the spindle tip and serves to collect dirt which otherwise would cause friction and wear. On very heavy spindles it would probably be beneficial to let the oil circulate, as indicated in Fig. 129, the action being the same as in ring spindle footsteps.

Flyers used for wet spinning (flax mills) should have their tops enclosed, as shown in Fig. 130, to prevent entrance of moisture, which causes rusting and makes it difficult to unscrew the flyers, unless a heavily compounded oil is used for oiling the spindle tops.

Fig. 130 shows a patent flyer spindle (the Bergmann Spindle) used for spinning flax, hemp, and jute. The spindle is driven in the usual manner but the whorl is in line with the footstep, so that the principal object of the neck bearing is to steady the spindle. The neck bearing is made very flexible by means of feather springs (1) and is covered with a lid to keep out dirt and fluff from the felt oil pad which keeps the spindle well oiled. The whorl protects the footstep from dirt, and in this type of footstep the oil may be arranged to circulate in the same way as in the footsteps of ring spindles. If the spindle is lifted by means of the whorl, the footstep bearing is disclosed for examination and oiling.

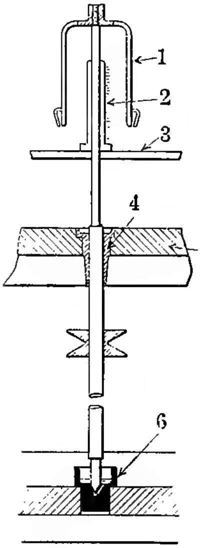

Fig. 129.—Flyer spindle.

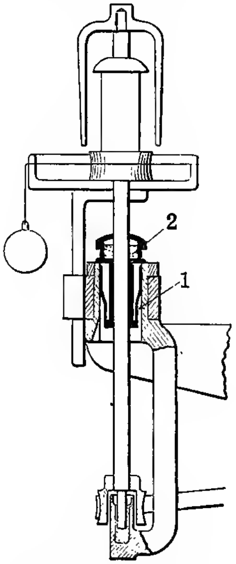

Fig. 130.—Bergmann spindle.

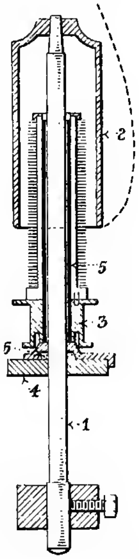

Fig. 131.—Cap spindle with felt pad oiling.

The felt pad arrangement here shown (2) and also used for many cap spindles (Fig. 131) ought to be much more widely used for neck bearings of flyer spindles; it is simple, efficient and economical.

An attempt has been made to introduce oil circulation for the neck bearings. The rail is hollowed out and forms an oil reservoir; the oil passes slowly through tiny openings in the neck collars into the neck bearings; by means of collars on the spindles below the rail the oil is thrown off into dishes surrounding the spindle, returning through pipes to an oil reservoir, whence a pump takes the oil and delivers it into the rail. The oil thus circulates continuously. It should be drawn off every three months and filtered, and can be used again, if of good quality. This arrangement is, however, rather complicated and not so foolproof as the felt pad arrangement.

One type of flyer frame, the "Arnold Forster" frame, has the spindles fitted with ball bearings and a self-lubricating felt pad to ensure smooth and easy running.

Cap Frames.—(Used for wool, worsted and waste silk.) A typical cap spindle is illustrated in Fig. 131. The spindle (1) is stationary and the cap (2) rests on its top. The bobbin is revolved by means of the whorl (3) operated by a driving band from the tin roller. The bobbin continuously winds up the yarn and pulls it over the bottom edge of the cap. The lifter (4) raises and lowers the bobbin, which slides with a long brass tube (5) on the spindle.

Obviously, it is very important to oil this tube well; the felt pad arrangement (6) is very efficient and economical, it being sufficient to oil the felt pad once every week or fortnight. In many cap spindles there is no felt pad, and the spindle is dabbed once or twice per day with an oily brush; this old fashioned method means a higher oil consumption, more wear and about 10 per cent. higher power consumption.

Mule Frames.—(Used for cotton, wool and waste silk). Fig. 132. The mule spindles (1) are placed on a movable carriage (2) which during the spinning period moves to the left, while the draft rollers (3) draw the thread from the bobbins (4). When the carriage moves to the right the yarn is wound on the spindles, the fallers (5) moving down into such positions as to guide the yarn correctly on to the spindles.

Mule spindles have a neck bearing and a step bearing, the same as the flyer spindles, the only difference being that they are placed at an angle; the oil is therefore inclined to be thrown out of the footsteps. One method to minimize waste of oil due to this cause is to protect the footsteps, as for example with Jagger's Footstep Protector shown in Fig. 133 which has proved very useful. It also protects the bearing from dirt and fluff, and during oiling all oil is caught by the protector; without protectors much oil often runs down the rail and is wasted.

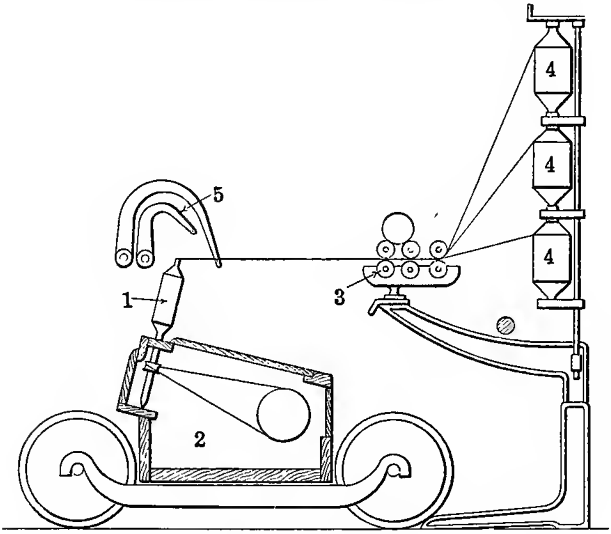

FIG. 132.—Mule frame.

The neck bearings are oiled once, twice, or three times per day according to operating conditions and the class of oil in use. The footsteps are usually oiled the same number of times per week, as the neck bearings are oiled per day.

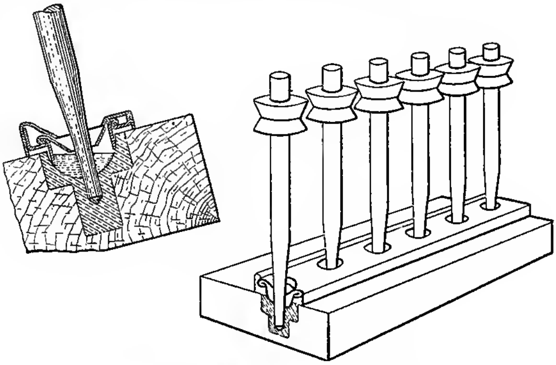

FIG. 133.—Jagger's footstep protector.

In the centre of the mule is situated the headstock, from which all parts of the frame receive their motion, and it is regarded as one of the most ingenious and complicated machines in the textile trade.

Driving bands are usually made of cotton and are affected by the moisture in the air. With most spinning frames the consumption of power varies approximately 1 per cent. for every 6 per cent. variation in the relative humidity of the atmosphere in the spinning room. The higher the relative humidity the more the bands contract, and the higher the power consumption.

With some modern frames, notably cap frames and jute spinning frames, the driving bands have their tension maintained uniform by means of weighted tension pulleys, as shown for a cap frame in Fig. 134.

The tension need therefore never be any more than that required for driving the spindles at their correct speeds, and humidity has no influence on the power consumption. A higher spindle speed can obviously be obtained with this type of drive, and as the spindles are never subjected to excessive strains from the band pulls their lubrication is easier; lower viscosity spindle oils can be employed with confidence and the power consumption can then be considerably reduced as compared with frames employing the ordinary type of band drive.

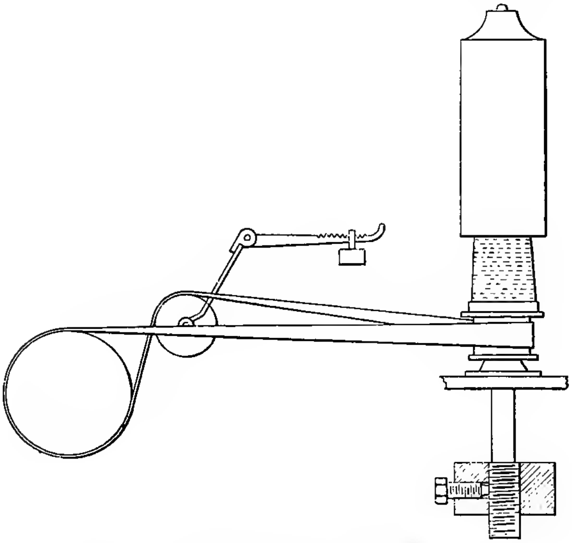

Fig. 134.—Uniform belt tension arrangement.

Thread, Twine and Cord.—In the treatment and manufacture of thread, twine and cord a variety of light machines are employed, such as doubling, winding and gassing frames, reeling machines, twisting, twine and cord machines, thread polishing machines, balling and spooling machines, the lubrication of which presents no striking features.

Doubling frames have either flyer spindles or ring spindles. There are some self-acting doubling frames (Twiners) very similar to mule frames. Some winding frames employ ring spindles.

Rope making machines are either vertical or horizontal machines, the former being used chiefly for large cables.

From the lubrication point of view these machines, which often look ponderous and complicated, consist essentially of revolving bobbins and are not difficult to lubricate.

Wool Oils and Batching Oils.—*Wool oils* are used for lubricating the fibres preparatory to the carding operation.

With all high class wool the oil must at a later stage be *completely removed,* as otherwise the yarn will not take the dye properly. Olive oil is undoubtedly the best grade of wool oil. It is easily removed, but is expensive, therefore only used for the highest class of material. Other fixed oils, such as nut oil, lard oil, etc., are almost as good as olive oil, but are also expensive. Wool oleins (produced from wool grease) and various fatty acids (oleic acids) are much used mixed either with a percentage of other fixed oil or with mineral oil, even up to 80 per cent. of the latter. The lower the class of material and the more intense the scouring methods, the more mineral oil can be used in the mixture, without running undue risk of having trouble in the dyeing of the yarn. The wool oil must never contain more than 6 per cent. of fatty acid, or 12 per cent. of wool olein (which normally contains 50 per cent. of free fatty acid), as more acid weakens the fibres and destroys the wires on the carding machines as well as the pins of the preparing and combing machines.

Rape oil, cottonseed oil, and the like are not so suitable, as they oxidize and produce gumminess and deposits in the machines.

Some mineral oil, 20 per cent. to 30 per cent., should always be present in the wool oil, wherever permissible, as its presence greatly reduces the well-known tendency which all fixed oils, particularly vegetable oils, have for spontaneous heating, which has been the cause of many outbreaks of fire.

Batching oils are used for softening the fibres of flax, hemp and jute. Low viscosity mineral oils are generally used, and occasionally mixtures of whale oil and mineral oils.

WEAVING

Winding, warping and sizing machines prepare the yarn for the weaving process. The lubrication of these machines calls for no comment.

Looms.—There is an immense variety of looms, from small, quick-speed cotton or silk looms to large, slow-speed carpet looms.

The function of all looms is to form a fabric by interlacing warp and weft threads; there are three essential movements in a loom: Shedding, Picking, and Beating Up.

Shedding is the operation of dividing the warp into two portions for insertion of the weft.

Picking is the operation of passing the shuttle containing the weft through the opening formed in the warp.

Beating up is performed by the reed and sley, which, through the action of cranks and connecting rods, advance and recede from the cloth after each "pick" in order to place the weft threads parallel with one another.

Picking motions are called Overpicks or Underpicks, according to whether the shuttle receives its motion from an arm placed above or below the sley. Overpick is generally used for fast running looms, and most heavy slow-speed looms have the underpicking motion. This motion is cleaner, as oil is not required about its parts near the cloth, and is therefore preferable for white and light colored goods, on which oil stains show up more than on dark colored fabrics.

The shuttle at the end of each journey is arrested by running into an "eye" made of buffalo hide and fixed in the shuttle box; the buffalo hide is steeped in neatsfoot oil to preserve it and to minimize wear of the shuttlenose.

The shuttle gets its motion from a buffalo hide "picker" sliding on the picker spindle and connected with the driving arm by means of a leather strap. The driving arm has a jerky motion which causes the picker to hit the shuttle hard and send it across the loom to the shuttle box on the other side. The driving arm may also be arranged in the form of a lever, which acts on the picker direct.

The picker spindle is lubricated by dabbing it at intervals with an oily brush. There is a patent automatic picker spindle lubricator in use on overpick looms, consisting of a small pad saturated with oil and carried by an arm which brings the pad into contact with the picker spindle at each forward movement of the sley, and on the return movement again makes the pad recede, to give room for the passage of the picker.

The danger of oil getting onto the cloth increases with the speed of the loom. The speed is given in number of "picks" per minute and ranges from 240 picks per minute for narrow looms and fine material down to 20 picks per minute for very coarse goods; for most woolen or worsted cloths the picks number from 60 to 70 per minute.

With quick speed looms the cranks operating the reed and sley are apt to throw oil onto the fabric, particularly so when the bearings are overlubricated.

In velvet looms the fabric is woven over a number of long "needles," which are continuously withdrawn from the finished portion and inserted again; in large velvet looms it is an advantage to oil these needles sparingly with "stainless" oil.

BLEACHING, DYEING, PRINTING, FINISHING

Bleaching and dyeing departments employ comparatively little machinery requiring lubrication. The most important machines from our point of view are probably the hydroextractors.

Printing machines (calico, thin woolen, linen, jute) are usually hand oiled, the same as other printing machines.

The *Finishing* processes are very varied.

For *cotton goods* the main operations are: Singeing, raising, shearing, brushing, steaming, starching, calendering, impregnating, breaking down, damping, mangling, moireing, embossing, tentering and stretching, doubling, measuring and plaiting, marking, and pressing.

For *woollen and worsted cloth* the main finishing operations are: crabbing, scouring, milling, singeing, dyeing, raising, wet rolling, tentering, cutting, brushing, shrinking, pressing.

Again here *hydroextractors* are used after the dyeing process, and most of the machines used up to this point are fairly heavy, slow-speed machines, requiring a viscous oil for lubrication. In the scouring process any oil stains received during manufacture must be scoured out; in the subsequent operations extreme care must therefore be taken to avoid oil stains and "stainless" oil should be used for lubrication in the last few stages, *i.e.*, cutting, brushing and shrinking. The pressing is generally done in a hydraulic press.

For *linen cloth* the following finishing operations are used; cropping, washing, tentering, beetling, calendering, pressing.

For *jute cloth* the finishing processes are as follows: damping, cropping, calendering, folding.

The only machines calling for comment are the *calenders* of which there are several forms, all consisting of several heavy rollers called press bowls placed horizontally in a strong frame and pressed against one another with more or less pressure either mechanically or hydraulically.

The bearing brasses, top and bottom, should preferably only touch the journals over an arc of 90° to 120° and the edges should be well chamfered to facilitate the entrance of the oil; when there are a number of bearings one above the other, the waste oil from one bearing should be guided into the bearing just below, and so on. Some of the bowls are heated by steam or gas, and their journals become very hot, so much so that oil cannot be used and high melting point greases have to be employed. The wear of calender bearings is often very considerable.

OIL CANS AND CABINETS

As most oiling in textile mills is hand oiling, it is extremely important to have the oil cans in good condition and see that they are maintained with small spout openings. Some oilers are inclined to cut off the ends of the spouts to make the oil flow more readily and the result is a great waste of oil, as when a row of spindles is oiled the spaces between the spindles are oiled as well as the spindles. The oil cans should be so adjusted that as the oiler goes along the frame at a regular speed a drop of oil falls into each bearing.

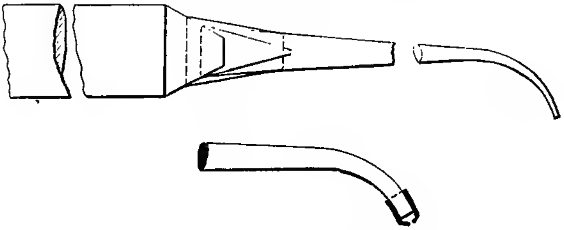

Fig. 135.—Oil saving devices.

Fig. 135 illustrates two methods of regulating the oil flow from the oil can. The top illustration has an inside cone with a tiny opening, so that it is impossible to get a rapid feed of oil from the end of the oil can spout. The cone cannot be interfered with by the operatives and can be made of any size according to the requirements. The bottom illustration shows the orifice of the spout itself, soldering a strong cap on to the end with an opening of say $\frac{1}{32}$ inch. The drawback to this arrangement is that the operatives can easily cut off the cap, whereas they cannot interefere with the cone arrangement shown in the other drawing.

It is a great advantage to have in each of the spinning rooms a small cabinet holding a few gallons of oil sufficient, say, for one week's consumption. The cabinets should be arranged with lids that can be padlocked. A small oil can can be filled from the cabinet without waste and the oil is always kept clean. Such small cabinets can be used for conveying the oil from the store room into the various departments.

STAINLESS OILS

So-called "stainless" oils have several times been referred to. Really stainless oils do not exist; any oil, whether pale or dark in color, whether mineral, vegetable or animal, will in time produce a visible stain, but the term stainless as applied to textile practice usually means that during the scouring or washing process which most fabrics undergo, oil stains will disappear.

Oil stains take the form of drops, splashes, or streaks. They may be due to oil dropping from overhead shafting, or oil may have got on to the yarn due to over-oiling the top roller bearings in the spinning frames. Weavers sometimes cover up defects by smearing with dirty oil to escape detection. Oil stains have been caused by greasing the reed, but the most frequent cause of oil stains is oil throwing from the cranks operating the sley and from the cams actuating the pickers; such splashes show up chiefly on the warp. Stains are also caused by oil splashes from the picker spindle in the shuttle box. Hence the reason why a stainless picker spindle oil is nearly always used, even if the loom oil employed for other parts of the loom is not stainless.

As to oil dropping from overhead shafting, the oil stains produced are often difficult or impossible to remove, owing to the presence of fine metallic wearings in the oil, chiefly iron. Iron stains become red; copper or brass stains may become black, gray or greenish.

Mineral oils give a permanent stain on fabrics and the darker the oil, the more objectionable are the stains. Even bloomless oil or oils so pale as to be almost water white will in time become yellow, due to oxidation, and the color will continue to deepen with time. The longer the interval between producing the stain and the attempt to remove it (scouring) and the less severe the scouring process, the less oil will be removed. If only a short time has passed, stains may be removed by dabbing with lard oil, olive oil or other fixed oil, which by blending with the mineral oil makes it stainless, *i.e.*, it can be removed by scouring with soda lye in the ordinary way.

Cotton cloths are bleached, and mineral oil stains are decomposed in this process, by the successive attacks of alkali and chlorine. For a time after bleaching the oil stains will not appear, but after several months, the stains begin to show up yellow.

The best remedy for oil stains is to take such precautions that no oil stains are formed. In many weaving mills, shafting is grease lubricated for this reason, or if oil is used for the bearings, they are well fitted up with splashguards and savealls, which prevent the oil dripping from bearings or creeping along the shafting and then dropping.

Where it is considered necessary to have a stainless oil, the degree of stainless properties required depends upon the length of time the goods are stored before scouring and upon the severity of the scouring operation. Speaking generally, an admixture of 15 per cent. of good quality animal oil or equivalent non-drying fixed oil will impart to the spindle or loom oil sufficient stainless properties for the majority of conditions.

In *cotton mills* many looms require stainless oils only for the picker spindle.

In *woollen and worsted mills* stainless loom oil should be used for lubrication throughout for all looms weaving high class cloth, as dress cloth, or such cloth as is used for naval uniforms, etc.

For low woollen goods, blankets, etc., stainless oils are never required.

In *linen mills* stainless oils are not infrequently used for high quality goods, but in *jute mills* stainless oils are rarely if ever called for, as the material is not of sufficient high quality to justify the extra cost of stainless oils above the cost of ordinary loom oils.

In *hosiery factories* for material such as woollen underwear, light colored stockings, etc., stainless oils must be used as the fabric invariably gets more or less soiled with oil during manufacture. This point is so important that many hosiery factories when testing the oil for stainless properties soak a piece of fabric with the oil, keep it in stock for a certain time and then scour it to see whether the oil can be entirely removed.

In *lace and curtain factories* pure neatsfoot oil is often used as the fabrics receive only a gentle washing and the oil must scour out very easily. Not infrequently the fabrics are not washed at all and it is then absolutely necessary to have an oil as pale and as stainless as possible.

Neatsfoot oil meets the requirements. It is almost colorless and even if there are oil stains on the lace or curtains they will be removed the first time they are washed.

In many *special industries* such as corset manufacturing, the thread used for stitching is oiled occasionally in order to lubricate the needles in the machines. As the corsets are not washed the oil must be as pale and as stainless as possible. Again here, neatsfoot oil or a mixture of neatsfoot oil with water-white mineral oil is required. If there is a considerable percentage of mineral oil in the mixture the oil stains will in time become yellow, so that for white goods which are kept in stock a long time this is an important point to keep in mind.

Table No. 12 gives the author's specifications for spindle and loom oils.

Table No. 12.—Grades of Spindle and Loom Oils

	Saybolt viscosity at 104°F., secs.	Per cent. of compound
Spindle oil No. 1	55	Nil
Spindle or loom oil No. 2	95	5–6
Spindle or loom oil No. 2S	95	15–20
Spindle or loom oil No. 3	125	5–6
Spindle or loom oil No. 3S	125	15–20
Spindle or loom oil No. 4	150	5–6
Spindle or loom oil No. 4S	150	15–20
Lather oil	75–100	30–35

As to the *nature of the compound*, rape oil has been used with success but the oil is inclined to gum and tarnish, particularly where frames or machinery are exposed to sunlight. With blown rape the tendency to gum is still greater; animal oils have a much less tendency to oxidize and should be preferred; sperm oil is excellent, but very expensive; lard oil or pale whale oil will give good results; if desired they may both be used together in the same spindle or loom oil. When stainless properties are required (Nos. 2S., 3S., and 4S.) a small percentage of olein, say not exceeding 3 per cent., is an advantage, as it has good emulsifying properties.

The mineral base of the oil should be pale in color, but it does not matter whether it is an acid treated or a neutral filtered oil.

Lather oil (see page 315) must possess exceptionally good stainless properties; it must therefore be made from pale colored, preferably water-white mineral oil and a large percentage of fixed oil, say 30 per cent. to 35 per cent., and its free fatty acid contents must not exceed 5 per cent.; more acid will cause trouble with rusting of the needles and other parts. A suitable lather oil may be made from 24 per cent. rape, 6 per cent. pale whale, 3 per cent. olein and 67 per cent. water white mineral oil of low viscosity, say 75″ to 100″ Saybolt at 104°F.

Each factory has its own formula for lather oil mixture. The following is typical:

Lather oil	3 gal.
Hard household soap	7 lb.
Water	18 gal.

LUBRICATION OF TEXTILE MILLS

Engine Room.—Steam engines, chiefly of horizontal construction, are largely used for driving textile mills; generally they drive the various mill floors by rope-drives from the flywheel. In modern mills electric driving is not infrequently used, the generators being operated either by steam engines or turbines, only rarely by gas engines.

As to the lubrication of these engines the reader is referred to the information given under the respective headings. The author would only mention the desirability of using compounded steam cylinder oils, and using a lower viscosity, preferably filtered cylinder oil in the large low pressure cylinders.

The practice of using very viscous oil, even cylinder oil, on the guides is not a desirable one; an engine oil like Bearing Oil No. 4[1] will generally be found suitable for external lubrication throughout, as well as for the second motion shaft bearings (rope race). When main bearings or crank pins are difficult to keep cool with this oil, Marine Engine Oil No. 1 or 2 may be recommended, even with a gravity circulation system, which is frequently employed in textile mills.

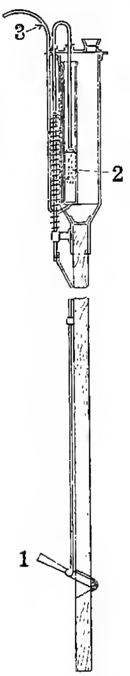

Fig. 136.—Overhead shafting oiler.

Mill Shafting.—The shafting generally operates at rather high speeds, from 160 to 350 R.P.M. and the bearings are either bottle oiled or ring oiled. The countershafting, gallow-pulleys, etc., are often hand oiled. As such hand oiling is a tedious occupation, it not being easy to reach the bearings, a shafting oiler is often used, as illustrated in Fig. 136. By pulling the trigger (1) the piston (2) is depressed against the action of a spring and discharges a small amount of oil through the feeding tube (3).

In many mills the engine oil used in the engine room is also used for the mill shafting, and the waste in power caused hereby is on the average 4 per cent. of the full mill load. The engine and shafting load (transmission load) is approximately 25 per cent. to 30 per cent. of the full mill load and the saving in power by introducing Bearing Oil No. 2 which the author recommends generally for mill shafting, is roughly 15 per cent. of the transmis-

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[1] See page 127.

sion load. It is a rare thing to find shafting oils in use lower in viscosity than Bearing Oil No. 3 and against this oil Bearing Oil No. 2 will save about 10 per cent. on the transmission load.

Mill Lubrication.—(*Spinning Mills*). Frequently one oil is used throughout, except for ring spindles, which are always given a separate oil, similar in viscosity to Spindle Oil No. 2. The mill oils used are generally similar in viscosity to Bearing Oil No. 3 and occasionally slightly lower in viscosity, but seldom below 150″ Saybolt at 104°F. The oils are often straight mineral, but sometimes compounded with from 5 per cent. to 10 per cent. of fixed oil.

The author, however, recommends Spindle Oil No. 3 for general mill lubrication of preparing and spinning departments as well as for countershafting and gallow pulleys.

For ring spindles, Spindle Oil No. 1 is recommended: For high speed mules, flyers, and for all cap spindles, Spindle Oil No. 2 is recommended in preference to Spindle Oil No. 3 as it gives an even greater reduction in power [compared with the oils generally employed.

When the spindle bearings begin to get dry, the spindles "whistle," vibrate ("dance"), and frequent breakages of the yarn occur. With compounded oils the tendency to run dry will always be found to be much reduced, as compared with straight mineral oils.

Compounded oil must not be used for ring spindles as in time it will produce a gummy deposit which will interfere with lubrication, choking the vertical passage in the bearing. If the oil is of too low viscosity or badly refined it will cause continuous wear on the step bearing, so that notwithstanding repeated cleaning the oil will always become discolored.

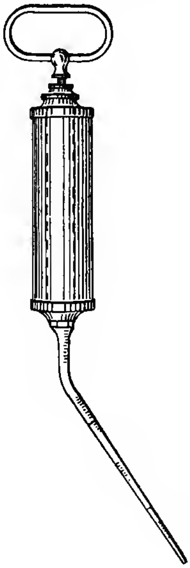


Fig. 137.

The pump illustrated in Fig. 137 is used for the purpose of extracting old oil from bath spindle bearings before they are cleaned and re-oiled. The pipe is inserted in the spindle bearing; the piston is operated up and down by the handle, drawing the dirty oil out from the bearings and discharging it into the main barrel of the pump which can afterward be emptied.

In wet flax spinning, a special oil must be used for oiling the flyer spindle tops, when they are of the open type, say spindle oil No. 4S. Many mills use lard oil or olive oil, but these oils are unnecessarily expensive and no better than the oil just mentioned. The advantage of compounded oils over straight mineral spindle oils are that lower viscosity oils can be used and yet they will be found to be more "oily" than the more viscous straight mineral oils; therefore they reduce friction and last longer. They seem to form a very tenacious oil film in the spindle bearings and are displaced only with difficulty. This is no doubt due to the presence of the fixed oil which we know excels over mineral oil in the property of oiliness.

The best practice is to oil the neck bearings of flyer spindles and mule spindles while the frames are running. This is Continental practice and means that thinner oils can be used efficiently, as one is always certain of the necks being thoroughly oiled. Oiling when the spindles are standing, as is the practice in England, may mean that in some necks, particularly when they are worn, the oil runs straight through the clearance between neck and collar. When neck bearings are fitted with felt pads for lubrication, it is immaterial whether they are oiled while the spindles are running or when standing.

As to typical savings in power accomplished on spinning frames, see pages 315 to 319. In most mills the oils recommended above will save over 8 per cent. of the departmental loads, equivalent to 6 per cent. of the full mill load.

Top Rollers.—In some cotton mills Spindle Oil. No 3 is often sufficiently viscous for the top rollers, but in others, as well as in most other spinning mills, woollen and worsted mills in particular, a more viscous oil is required; and speaking generally, the engine oil used in the power house will prove very suitable as a top roller oil. In flax mills a special preparing room oil is often used for the preparing room and for the press rollers in particular. This is found necessary when the roller covers are not fitted with flannels; but if they are so fitted, an oil like Bearing Oil No. 3 can be used satisfactorily. Tallow or white tallow greases are often used for top rollers, especially when they are badly worn and therefore difficult to lubricate; bad lubrication of the top rollers causes a jerky motion and unevenness in the yarn.

Traveller.—The ring upon which the traveller moves in a ring spinning frame should be sparingly greased with clean tallow.

Combers.—For combers a viscous oil like the engine oil used in the engine room must be used for lubrication of the slow moving parts, whereas the spindle oil should preferably be used for the dabbing motions. When the circles are highly steam heated, anon-carbonizing, very viscous mineral oil is required, having a Saybolt viscosity of say 75″at 212°F. and made from a pale, non-paraffinic base, distilled oil mixed with good quality filtered cylinder stock.

Weaving Mills.—Loom oils should preferably be compounded for the same reasons as given for spindle oils.

The percentage of compound need not be more than 6 per cent. unless particular stainless properties are required. For high speed light looms, Loom Oil No. 2 or 3 is recommended and for slow speed heavy looms, Loom Oil No. 4. The oils must of course be sold as loom oils; if branded spindle oils they would almost certainly be condemned by the mill people. As stainless loom oils or as stainless picker spindle oils (particularly when overpick motion is employed) Loom oils No. 2S, 3S and 4S are recommended.

Bleaching, Dyeing, Printing and Finishing.—Bearing Oils Nos. 3 and 4 are generally used. The calenders, however, require a very viscous oil, such as Bearing Oil No. 5 or oil even more viscous.

High melting point greases, with melting points suitable for the temperature of the bearing journals, are also used.

HOSIERY MACHINES, POWER SEWING MACHINES, ETC.

Hosiery machines are chiefly knitting machines, and either *straight bar machines*, knitting flat pieces of material, or *circular machines*, knitting tubular pieces. Bar machines have several hundreds of needles and the largest circular machines many thousands of needles. The needles require some slight lubrication so that the yarn may pass easily through them. The lubrication is done by the yarn, which before entering the machines is passed through a trough containing emulsified lather oil; as the yarn leaves the trough, surplus lather is squeezed out by rollers.

For general lubrication of most circular machines and power sewing machines Loom Oil No. 2S will be found suitable. Bar machines require a somewhat heavier oil, such as Loom Oil No. 3S and this oil may also be recommended for circular machines which have become worn.

Stainless properties are practically always required, and the oil ought to be thoroughly tested in this respect as mentioned, page 310.

POWER REDUCTION IN TEXTILE MILLS

Very great reductions in power can be accomplished by paying careful attention to the selection of suitable oils for each department in the mill, as well as for the mill shafting and the power house.

In a ring spindle frame, for example, about 80 per cent. of the power is required for driving the frame empty, only 20 per cent.

being consumed in handling the yarn. In the case of preparing machinery an even greater percentage of the full load power is required to run the machines or frames empty.

In a jute spinning frame of the ordinary type the power consumed usefully is very much the same as in a ring spindle frame, but in the modern spinning frames, in which the tension of the driving bands is kept uniform, there is a great reduction in the power consumed by the frame, and only 65 per cent. of the full load power is required for running empty.

In mules or looms a great portion of the power is used in overcoming the inertia of the moving parts which have to be accelerated, stopped, and, in the case of the loom, quickly changed. In the loom, for example, the sley moves backward and forward quickly, the picker motion just as quickly, and the shuttle is thrown quickly to and fro, all of which requires a geat deal of power, so that the percentage of power influenced by lubrication in a mule or loom is less than in ring spinning frames.

In the average steam-engine driven textile spinning mill, 1½ to 2 lb. of coal are consumed per indicated horsepower per hour, and the heat value actually converted into useful work in the form of preparing or spinning the yarn, etc., will not be more than 1½ per cent. to 2 per cent. of the heat value of the coal used under the boilers.

The possible saving in power by introducing correct grades of spindle and loom oils is nearly always considerable. To take an example: On a ring spinning frame using an oil having a Saybolt viscosity of 95″ at 104°F., another oil with a Saybolt viscosity of 55″ at 104°F. was introduced; both were straight mineral oils. The results were as in table on p. 317:

The saving in power in this case amounted to 8.8 per cent. and indicates the results which can be obtained in most textile mills, as the first oil used is typical of the ring spindle oils now in general use and is quite unnecessarily viscous, except perhaps for frames with old and worn Rabbeth spindles. Whenever a change from a viscous oil to one less viscous is carried out, the low viscosity oil will turn black, the discoloration being due to extremely fine metallic particles from the rubbing surface. In other words, very slight wear takes place, the surfaces adapting themselves to the new oil. After the pumping out and recharging process, the fresh oil should work perfectly clean.

Such a saving in power is worth many times the value of the oil itself, and in addition the yarn produced by the frame will be found more uniform, due to the smoother running of the spindles.

Particulars of Ring Frame

Number of spindles	300
Diameter line shaft pulley	40 inches.
Diameter frame pulley	15 inches.
Diameter tin roller	10 inches
Diameter whorl	1 inch.

	Viscous oil	Low viscosity oil
(1) *Influencing Conditions.*		
Counts spun	10½	10½
Weight of yard per doff	14.0 lbs.	14.6 lb.
Room temperature	89°F.	90°F.
Relative humidity	62%	62%
(2) *Power (measured by Emersons Dynamometer).*		
Brakehorse power	3.64	3.32
(3) *Temperatures.*		
Temperature of spindle rail	98°F.	97°F.
Frictional heat	9°F.	7°F.
(4) *Loss due to Belt and Band Slip.*		
Speed of line shaft, r.p.m	281	281
Theoretical speed of tin roller	749	749
Registered speed of tin roller	740	745
Belt Slip	1.2%	0.7%
Theoretical speed of spindles	7400	7450
Registered speed of spindles	7010	7085
Driving band slip	5.3%	4.9%

Improved lubrication means lower frictional heat, which is evidenced by a lower rise in temperature of the spindle rail above the room temperature.

The driving bands which run over the tin roller and drive the spindle always slip slightly; when they are in proper condition the slip should not be more than a few per cent. The lower friction of the spindles will reduce the band slip and thus slightly increase the spindle speed, as shown by the test. Less band slip also means less wear of the driving bands and the annual consumption of driving bands is quite a good indication of the quality of ring spindle oil used. The reduced power consumption of the frame will tend to decrease the belt slip in the driving belt, and this effect is also shown in the test figures.

In a worsted spinning mill a test was carried out on a spinning frame having 216 open type flyer spindles. The oils in use on the two tests were Oil No. 1 and Oil No. 2. Oil No. 1 was a straight mineral oil having a Saybolt viscosity of 165″ at 104°F. Oil No. 2 is spindle oil No. 2 specified on page 311. The power measurements were recorded by an Emerson Dynamometer, and besides particulars of the horsepower readings were obtained of the rail temperature, room temperature, relative humidity, tin roller speeds and spindle speeds, every 10 minutes for two hours in the forenoon and two hours in the afternoon. Before testing, the frame was cleaned and well oiled with Oil No. 1 and after the first test was completed the footsteps were again wiped out and Oil No. 2 was put into use. The frame was then allowed to run for a full day before the second test took place.

Oil in use	H.P. required to drive frame	Rise in temperature of spindle rail
Oil No. 1	2.39	10.3
Oil No. 2	2.15	5.4

Reduction in H.P. required to drive frame. . .0.24 or 10.0 per cent.
Reduction in temperature of spindle frame. . . .4.9°F. or 47.6 per cent.

	Tin roller speeds per minute			Spindle speeds per minute		
	Calculated	Actual	Per cent. slip	Calculated	Actual	Per cent. slip
With Oil No. 1	231	225.3	2.47	2,054	1,893	7.8
With Oil No. 2	231	225.4	2.42	2,054	1,900	7.5

The temperature of the atmosphere and the relative humidity were the same on both tests.

In one mill the introduction of Spindle Oil No. 2 for cap spindles reduced the wear of the driving bands very considerably. It was brought to the Overlooker's notice that the band boy had very little work to do, and when asked why he did not attend to the bands he replied that as soon as the new oil was put into use the bands very seldom broke and he had none to repair.

In another case the power consumption of the frames with oil No. 1 was so great that the belts were always slipping on the pulleys. It was not possible to get all the spinning frames running until 7 o'clock, as it took some considerable time before the oil became warm and fluid enough to reduce the power consumption of the frames. The steam engine driving the mill was hardly powerful enough to cope with the load.

Comparative power tests in textile mills should therefore never be carried out on Mondays when the mills have been shut down for the week-end. The oil cools down in the bearings and the starting load on the Monday morning is always considerably higher than later on during the week.

When engines are overloaded, it is often difficult to start the mill on full load, on Monday mornings in particular, and it may even be necessary to leave out one or two departments until the engine eventually is able to cope with the load. The introduction of more suitable grades of oil reduces the horsepower required and particularly the starting horsepower in the early part of the week, so that the engines are able to get up their normal speed much more rapidly and maintain their speed more uniformly during the day. There have been many cases of overloaded engines which after a change in lubrication have been found quite powerful enough to drive the mills, so that a study of the lubricating conditions has saved such mills the heavy expense of putting in a new engine or introducing electric motors to take care of part of the load. When better lubricants are introduced the improved working of the machines is soon observed by the easier starting of the machines or by their running for a longer time after the driving belt has been moved on to the loose pulley.

Quite a simple test for the engine and shafting load is to run the engine and shafting at the dinner hour when all the machinery in the mill is stopped; then shut off steam and observe the number of revolutions made by the engine before it comes to a standstill, and the time taken. An improvement in lubrication is immediately shown by the greater number of revolutions and the longer time that passes before the engine comes to rest.

When an appreciable reduction in power has been accomplished in a textile mill by introduction of better lubricants, the main effects are the following:

(1) A reduction in the total horsepower of the mill as well as in the engine and shafting load and the power consumed by each department in the mill.

(2) A reduction in the amount of coal required for power purposes. When the reduction in power is appreciable it should always be possible to find a corresponding reduction in the coal consumption, particularly when the amount of coal used for heating and power are kept separate.

(3) A reduction in the temperature of all bearings and spindle bases.

(4) An increase in the speed of countershafting, machines and spindles due to reduced slipping of driving belts and driving bands. If the engine has been overloaded the reduction in power will bring about an increase in the engine speed and the engine will reach its normal speed more quickly after starting.

(5) A slight increase in production, chiefly due to fewer stoppages, as many stoppages are caused through defective lubrication.

(6) There will be a decrease in the wear and tear of the machines as well as of belts and driving bands. The decrease in the wear of the driving bands may often be quite considerable.

CHAPTER XXIII

MINE CAR LUBRICATION

The tubs in collieries are known by many names, such as trams. hutches (Scotland), mine cars (U. S. A), etc. The following remarks chiefly apply to mine cars in collieries.

Their lubrication consumes on an average 50 per cent. of the oil used in a colliery and is of great importance, as trouble with the tub lubrication may easily cause reduced output. The tubs are preferably made of steel; with wooden tubs dust shakes through the floors, contaminates the axles, and interferes with lubrication. Their carrying capacity is from 4 cwt. to 2 tons. Tubs have two axles usually of rolled steel ranging in diameter from 1¼ inches to 2 inches, wheels ranging from 7 inches to 16 inches in diameter, and bearings of a length preferably not less than twice the diameter of the axle.

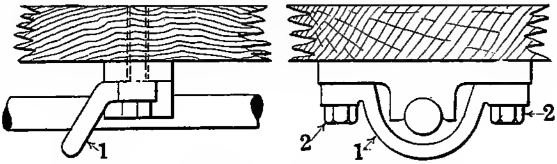


Fig. 138.—Open type bearing.

Wheels and Axles.—With *fast wheels* the wheels are riveted to the axle which revolves in the cod bearings.

With *loose wheels* both wheels are loose on the axle, which does not revolve.

With *loose wheels and axles* the wheels as well as the axles, are free to rotate. Where the track has many curves this system, or a combination of one fast and one loose wheel is often used.

Cod Bearings.—These may be either outside or inside bearings and either open or enclosed. Fig. 138 shows a typical open type bearing. The spectacle plate (1) should be bent well to one side, so that it does not foul the automatic oilers, when the tub passes over them. The bolts (2) should preferably be put in from the bottom and must not project below the axle, as in Fig. 139 when they will foul the oilers. Fig. 140 also shows an undesirable condition from the oiling point of view, and it may be produced by excessive wear of the bearing shown in Fig. 138.

Cod bearings may be of cast iron but are usually of cast steel, and where there is no dust or the dust is not of a gritty nature they are preferably lined with white metal. The question of grit is of importance only when the speed of the tubs is sufficiently great to raise the dust to any extent.

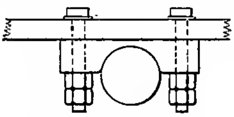


FIG. 139.

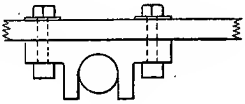


FIG. 140.

Cod bearings.

When, as is sometimes the case, the bearing entirely encloses the axle, or the spectacle plate is in the centre, the axles cannot be oiled automatically, except by squirt oilers, as for example the Abbott oiler which will be referred to later. Fig. 141 illustrates the Rowbotham wheel, much used in South Wales on account of the fine dust existing in the mines. The wheel is loose on the axle and the hub serves as an oil reservoir; the oil is injected by a syringe against a self-closing ball valve, as shown. Enclosed wheels of similar types are much used in the United States frequently employing oil soaked waste, and on the Continent there are several types of roller or plain bearings so arranged that the bearing housings at either end of the axle are combined and form a sleeve surrounding the axle, as shown in Fig. 142. The space between the axle and the sleeve is filled with oil through

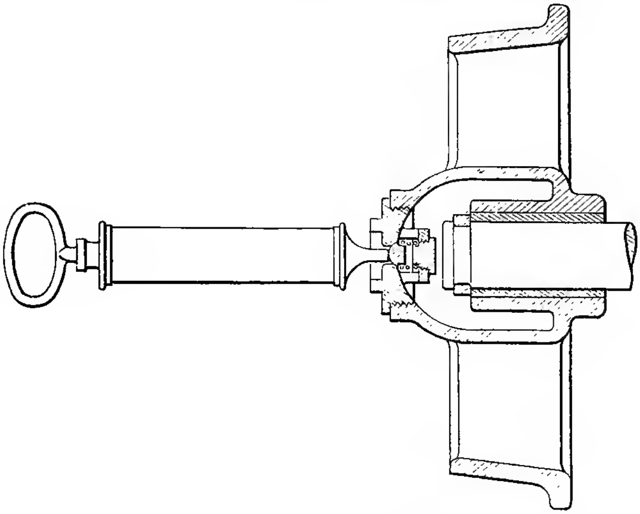


FIG. 141.—Rowbotham wheel.

a filling hole in the centre. The lubrication is very economical; one filling may last a month or more. The oil works its way out through the ends and keeps the bearings clean. The bearings should have good felt packings when using oil, as otherwise it works out too freely and is wasted. With roller bearings a very soft grease is better than oil and more economical.

OILERS AND GREASES

Hand Oiling.—The tubs are still in some mines oiled by hand, although this practice is fast disappearing. The tubs are turned over first on one side then on the other; the oil is applied through "coffee pots"; loose wheels are given a "spin" when being oiled to get the oil well worked into the bearing. By flattening the end of the oil can spout it is possible to reduce the waste of oil to some extent. It is good practice to use thick oil and heat it in a steam heated tank; cold oil will not run through a flattened spout, and if an ordinary wide spout is used most of the oil will be wasted.

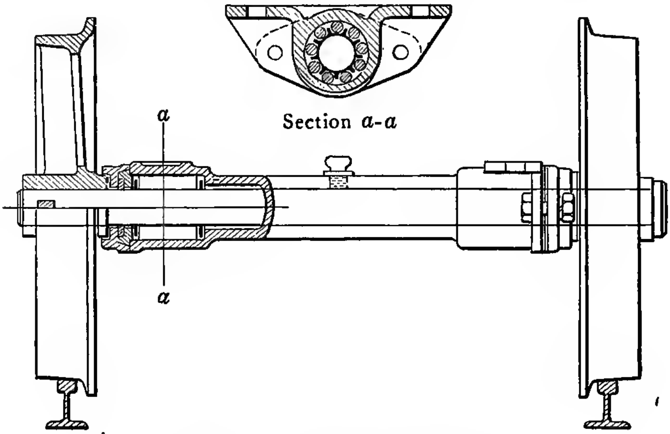


Fig. 142.—Roller bearings for mine cars.

With fast wheels, the axles may be oiled by hand by means of a brush; to avoid undue waste, the brush should not be dipped in the oil, but into cotton or wool waste kept well soaked with oil.

Hand greasing may be done by a stick or a brush but is always very wasteful; the surplus grease drops on to the track and makes it greasy and dirty.

Mechanical Oilers.—Fig. 143 shows an early type of greaser, a scalloped wheel connected to the axle by a spiral spring, which allows the wheel to be depressed when the axle passes over it and gets smeared with grease. Coal dust gets into the trough and gives trouble. When the grease is thick or becomes thick, due to cold, the wheel cuts a track in it and revolves without lifting the grease. Revolving brushes have been used instead of the wheel but are very wasteful indeed.

The "knock out" greaser, Fig. 144, is a better form of greaser; it is simple and accessible; the wheel can be lifted right out. This greaser is also used for oil but should then have a brake fitted so that it soon stops after the axles have passed, otherwise it causes waste by throwing the oil.

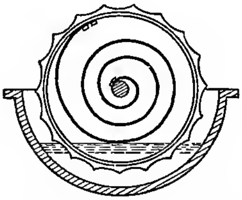


FIG. 143.—Scalloped wheel greaser.

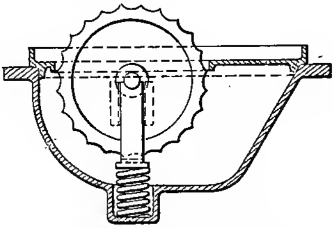


FIG. 144.—"Knock out" greaser.

The disadvantage of this and similar greasers when using oil is that the oil drains off during an interval, so that when the next set of tubs comes over, the first few tubs do not get properly oiled.

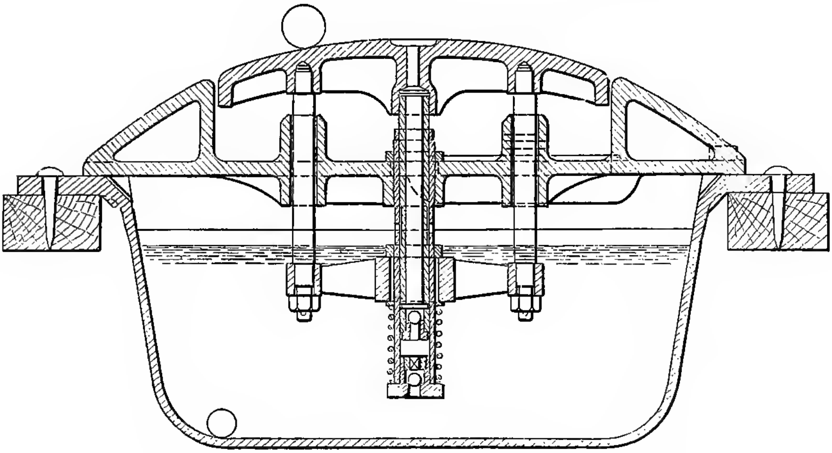


FIG. 145.—Automatic pump oiler. (*Woodman & Thomsen.*)

All tub oilers should be so designed that none of the axles can pass over without being oiled. Most types have some form of pump actuated by the tub axles; the wheels of the tubs passing over an oiler should therefore be of the same size and as uniform as possible. When the wheels are much worn the axles of those particular tubs are nearer the ground, depress the pump plunger too much, and cause waste of oil.

The oiler or its foundation should be secured firmly to the rails; otherwise it may be pushed into the ground with the result that the axles no longer depress the plungers sufficiently.

Fig. 145 illustrates an oiler designed by W. A. E. Woodman and the author. It is suitable only for open type bearings (Fig. 138) and fast wheels. It has a large container; the lid carries the pump barrel with its suction valve. The bow is guided by two vertical guide bars and carries the pump plunger with a delivery valve at the bottom. The guide bars are connected by a cross piece, which is forced upward by a spring against a stop; the stop is adjusted vertically by a single outside adjustment, thus determining the depression of the plunger when the axles pass over the bow, and wipes the oil from the oil delivery well in the centre of the bow. The lid entirely covers the container and is provided with a large filling hole; the edges of the hole are raised above the level of the lid, to prevent dust and dirt getting in when the container is being filled. This is a very important point, and for the same reason the filling lid is so designed that it cannot be left open, but automatically falls and closes the opening.

In many types of oilers for open type bearings, the haulage ropes and coupling chains are liable to get underneath the bow and bodily pull the oiler out of the track. This has been provided against by placing at either end of the bow a fin, which is cast on to the lid and gives an inclined plane for the rope or chain to run up and slide clear over the bow. These fins also act as buffers against severe end shocks.

The oiler has to be well made, but in the author's experience tub oilers cannot be too well made. The oiler shown has worked under very severe conditions in South Wales (very heavy tubs) where no other oiler has been able to stand up to the conditions. After many months' working no perceptible wear had taken place, no dirt had got into the container (only a coarse sieve is provided), and the adjustments had never been touched. Equally good results have been obtained in Lancashire and other collieries, where the conditions are much less severe.

The oilers are usually placed on the same foundation, but sometimes it is best to "stagger" them. This gives more room for the ponies (where ponies are used) and is also advantageous where the spectacle-plates are inclined to foul the oilers. The rail at the first of a pair of oilers and a little before is raised say 1½ inches above the other rail. This makes the tub body slide over toward the lower rail and gives more clearance to oil the underside of the axle in the cod bearing. The same performance is reversed at the next oiler which is placed, say, 10 to 15 yards farther along the track.

On the surface the oilers should not be exposed to rain, but placed under a roof or shelter. Down pit the oilers should be laid down in a dry place and not where surface or roof water is likely to come in contact with them. On entering a wet district the tubs should be oiled so that the oil film will last until the tubs reach the next oiler, which should be placed immediately after the wet district. It is much easier to renew and maintain the oil film if it is never allowed to be completely washed away; the oil does not adhere well to a wet axle.

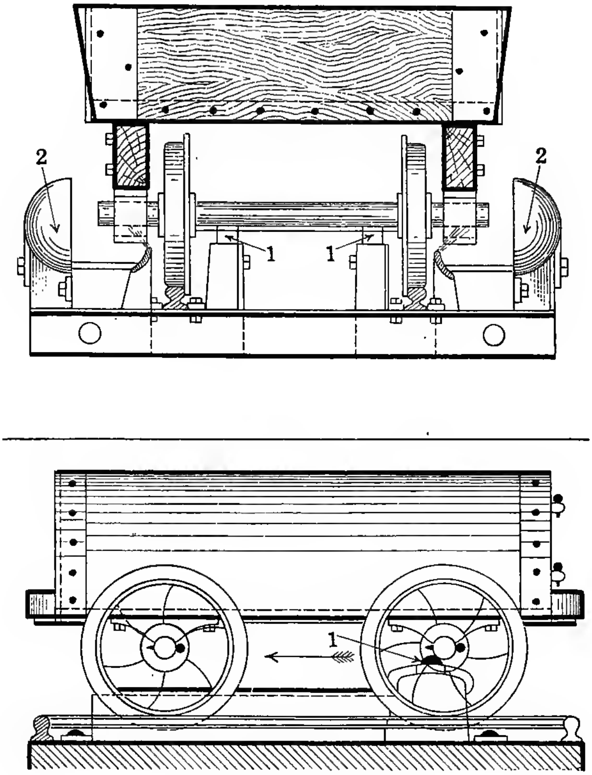


Fig. 146.—Abbott oiler.

Fig. 146 shows one form of the Abbott oiler oiling outside axle bearings of the type shown in Fig. 140, which can obviously not be oiled by the oiler shown in Fig. 145. The plungers (1) are depressed quickly and so timed that they squirt oil on to the underside of the axles; surplus oil is caught by the saveall (2).

The oil in Abbott oilers must be steam heated to give a good and uniform squirt; for this reason they cannot be used down pit, where there is no steam.

Distance Between Oilings.—Apart from wet districts it may be said that the larger the wheels and the cooler the pit, the longer distances can be allowed between the oilers, other things being equal. The axles should never be allowed to run dry; it is better to space the oilers closer together and give them less oil per oiler, than to space the oilers so far apart that there is a risk of under-lubricating the axles. Efficient oiling, saves wear and tear and means less power required for hauling the tubs. It is good practice not to exceed 1½ miles between oilings, and with small wheels and narrow bearings oiling every mile will be required.

In some mines, using a very viscous oil, tubs have run as much as four miles on one oiling, but the lubrication has not been all that could be desired.

Before grades of tub oils and greases are described, it is necessary to refer to the various systems of haulage.

SYSTEMS OF HAULAGE

With *endless rope haulage* the empty tubs are continuously and slowly hauled into the mine, and return loaded, the speed of haulage being from 2 to 4 miles per hour.

With *main haulage* the shaft is inclined toward the workings, the incline exceeding 1 : 24. The empty tubs run into the shaft by gravity and are hauled out loaded; only one rope and one haulage drum are employed.

With *main and tail haulage* two ropes are used; the main rope hauls the loaded tubs out and the tail rope pulls the empty tubs in. The haulage drums are both operated by the same engine. The speed for main and tail haulage may be as high as 20 miles per hour.

The haulage ropes are driven either by a steam haulage engine or by an electric haulage engine. In the United States ropes are discarded in many mines and the mine cars pulled out or in by electric or compressed air locomotives.

LUBRICANTS

Grease can be used only for slow speed conditions; if used on main and tail haulage it gives a great deal of trouble and wastes much power in hauling the tubs; also the wear is very excessive. Good tub oil as compared with grease gives cleaner and better lubrication and not only does it save a great deal of power, but rightly applied it also saves in cost. In most cases where a change has been made from grease to oil, the saving in consumption is 50 per cent. or over. With electrically operated haulage the difference between grease and oil or even different qualities of oil is readily observed.

With ball or roller bearings there is very little difference in friction between oil and grease. Very little lubricant is required but it must be of good quality (see under *Ball and Roller Bearings*).

The lubricant must be selected according to the temperature of the mine, whether it is dry or wet, the amount and nature of the dust, the type of oiler employed, and the distances between oilings.

Temperature.—In deep, badly ventilated pits the temperature is higher than in shallow well ventilated pits. The higher the temperature the more viscous the oils required. In cold pits a good cold test will be required, so that the oil will not be too sluggish in the automatic oilers.

Wet Pits.—In very wet pits good quality grease may have to be used, if the tubs must run long distances between oilings. It is not so easily washed off the axles as is oil. Tub oils for wet pits should have a tendency to emulsify with water.

Dust.—*Fire clay dust* and *coal dust* have a drying effect on the oil film. Free flowing oils and frequent oilings are desirable with these kinds of dust.

Stone or flint dust will cause heavy wear; the wear can be minimized only by using viscous oils of good quality and by frequent oilings. If a sticky oil is used, the dust forms a grinding paste with the oil and causes heavy friction and wear.

Type of Oiler.—*Wheel greasers* (Figs. 143 and 144) can use oil of almost any description, and also grease as long as it is not too thick.

Abbott oilers can use oils with a poor cold test, as they are usually steam heated. Such oils solidify on the cold axles and form a film with good lasting properties if the oil is of good quality.

Pump oilers like Figs. 145 and 146 when not steam heated cannot use oils which are so sluggish at the working temperature that the pump fails to act.

Hand Oiling.—When the oil is heated it need not have a good cold test, but this may be necessary when it is not heated.

Distance Between Oilings.—With long distances between oiling more viscous oils are required than when the oilers are closer together.

GRADES OF OILS AND GREASES

It is customary to use black oils, one for summer use with a cold test of 25°F. to 30°F. and a winter oil with a cold test of 5°F. to 15°F. These oils are dark residual oils from distilling lubricating crudes, or from redistillation of lubricating oil distillates, or they are mixtures of such oils with low viscosity, low cold test oils, so as to produce oils of the right viscosity and cold test.

The asphalt contents should preferably not exceed 3 per cent. in the better quality oils, but for rough service, oils with much higher asphalt contents have been used. Typical viscosity figures for black oils are given in Table No. 13.

Table No. 13

	Saybolt viscosity, in secs.		Cold test, in °F
	104°F.	140°F.	
Winter black oil	500	200	5/15
Summer black oil	600	280	25/30
Heavy black oil	1200	380	50/60

Black Tub Greases are usually rosin greases. Sometimes so called Floating Greases, containing talc, are used.

There are various formulæ and the better qualities contain no filler. A rough test for the presence of filling material is to burn a sample and examine the residue (lime, talc, etc.)

CHAPTER XXIV

STEAM ENGINES

Lubrication of Cylinders and Valves

Stationary and Marine Engines.

With special chapters on:
Corliss Valve Engines.
Colliery Winding Engines.
Uniflow Engines (Stumpf Engines).
Marine Engines.

Locomotives.

STEAM ENGINES, STATIONARY AND MARINE

Steam engines are the most reliable and most highly developed and specialized of all power producers.

Most land steam engines are horizontal and practically all marine engines are vertical, except a few "inclined" engines employed in paddle-steamers.

They can be classified according to:

1. Arrangement and number of cylinders.
2. Type of valves employed.

1. *Arrangement and Number of Cylinders.* Steam engines may have one, two, or three cylinders side by side, all using *high pressure steam.*

Two-cylinder engines—twin engines, mostly horizontal—are used as colliery winding and haulage engines or steelworks rolling mill engines.

Three-cylinder engines—triple engines, mostly horizontal—are used as steelworks rolling mill engines.

Engines in which the steam expands in two, three or four consecutive stages are called compound engines, triple-expansion engines and quadruple-expansion engines respectively. Some triple-expansion engines have two low-pressure cylinders and are therefore four-cylinder, triple-expansion engines.

The two cylinders of a compound steam engine may be arranged one behind the other—a tandem engine, or side by side—a cross compound engine, or with horizontal, high-pressure and vertical, low-pressure cylinders—an angle compound engine.

2. *Types of Valves.* Many types of valves are in use, but they may be divided into four main groups, as follows:

1. Slide Valves.
2. Corliss Valves.
3. Piston Valves.
4. Drop Valves or Poppet Valves.

Slide valves are not used in single-cylinder engines of over 125 horsepower, because they are inefficient.

In compound and triple-expansion engines slide valves may be used for the intermediate and low-pressure cylinders in sizes from 50 to 750 horsepower per cylinder.

Slide valves can only be used for *low superheat,* as their unsymmetrical shape causes warping. They can, however, be used at *high speed,* as they are positively operated.

Corliss valves are rarely used in engines below 125 horsepower in size, as they are not so adaptable to the high speeds at which small engines operate. They can be employed with *moderate* superheat.

Piston valves, notwithstanding their rather low efficiency, are used even for very large power units, as they can be operated at high speed, with high steam pressure, and high steam temperature, and are very reliable for severe service, as in colliery winding engines and steel works rolling mill engines. They are largely used in marine engines and for locomotives.

Drop valves are used for the highest powers, on account of their great efficiency; they are not used for power units below 125 horsepower, for the same reason as given under *Corliss Valves.* Drop valves can be operated with high steam pressure and high steam temperature, at higher speeds than the Corliss valve, but not at such high speeds as the piston valve.

Land Engines.—In Table No. 14 is shown for the different types of valves: the normal range of steam pressure, maximum

TABLE No. 14

Valves	Steam pressure	Max. steam temp.	R.P.M.	H.P. per cylinder	No. of cylinders	
					Horizontal	Vertical
Slide......	60 to 120	450	350 to 60	Up to 125	1	1
Corliss....	80 to 160	525	150 to 60	125 to 2000	1, 2 or 4	1, 2 or 3
Piston.....	90 to 200	600	500 to 90	Up to 3000	1, 2 or 3	1, 2 or 3
Drop or poppet...	120 to 200	600	180 to 90	125 to 3000	1 or 2	

steam temperature permissible revolutions per minute, horsepower per cylinder, number of cylinders employed in horizontal as well as vertical land engines.

In Table No. 15 is shown the most frequent combinations of valves employed in single-cylinder engines, twin engines, triple engines, compound engines and triple-expansion engines as used for land purposes.

TABLE NO. 15

	High-pressure cylinder	Intermediate-pressure cylinder	One low-pressure cylinder	Two low-pressure cylinders
Single-cylinder engines.	Slide			
	Corliss			
	Piston			
	Drop			
Twin engines. Two high-pressure cyls. side by side.........	Slide			
	Corliss	(Colliery winding and haulage engines, steel works rolling mill engines)		
	Piston			
	Drop			
Triple engines. Three high-pressure cyls. side by side.	Slide	(Steel works rolling mill engines)		
	Piston			
Compound engines......	Corliss		Corliss	
	Piston		Piston	
	Drop		Drop	
	Corliss		Slide	
	Piston		Slide	
	Piston		Corliss	
Triple-expansion engines...............				
Three cylinders........	Corliss	Corliss	Corliss	
	Corliss	Corliss	Slide	
	Corliss	Slide	Slide	
	Piston	Piston	Piston	
	Piston	Piston	Slide	
Four cylinders.........	Corliss	Corliss	Corliss	Corliss
	Corliss	Corliss	Slide	Slide
	Corliss	Slide	Slide	Slide
	Piston	Piston	Slide	Slide

Marine Engines.—Small marine engines are compound engines, say below 100 H.P. for single units. The vast majority are, however, triple-expansion engines. Single units above 3,000 I.H.P. are frequently triple expansion, four crank engines, with one high pressure, one intermediate pressure and two low pressure cylinders.

Single units above 4,000 I.H.P. are frequently quadruple expansion engines, with one high pressure, one first intermediate, one second intermediate, and one low pressure cylinder.

The valves belonging to the high pressure cylinder are practically always piston valves. Piston valves are also generally used for the intermediate pressure cylinder, but sometimes slide valves are used. Slide valves are generally used for the low pressure cylinder.

Practically all marine steam engines are of the inverted vertical type; only a few have the cylinders and valves lying at an angle, as is the case with some paddle steamers.

Steam Pressure. In modern marine steam engines high steam pressures are employed, being usually from 180 lb. to 200 lb. per square inch.

In the vast majority of cases saturated steam is employed, but during recent years superheated steam has come into use very largely on the Continent, the maximum steam temperature at the engine stop valve being 650°F.

The ***Revolutions per Minute*** of marine steam engines are largely governed by considerations affecting the propeller efficiency, and, therefore, do not vary much for engines above, say, 1,000 H.P., being generally between 80 and 90 R.P.M.

In the case of launches, higher speeds are frequently used and with consequent lower propeller efficiency. Some large naval ships have been constructed with high speed, short stroke engines, the maximum speed however seldom exceeding 130 R.P.M.

Having now classified the various types of steam engines, the subject will be treated under the following headings:

STEAM
OIL IN EXHAUST STEAM AND FEED WATER
OIL IN BOILERS
METHODS OF LUBRICATION
LUBRICATORS
LUBRICATION
DEPOSITS
CORLISS VALVE ENGINES
COLLIERY WINDING ENGINES
UNIFLOW ENGINES
MARINE ENGINES
CYLINDER OIL CONSUMPTION
SELECTION OF OIL
TESTING CYLINDER OIL
PHYSICAL AND CHEMICAL TESTS
TALLOW MIXTURES AND SEMI-SOLID GREASES
LUBRICATION CHART

STEAM

The range of steam pressure employed for different engines is given in Table 14, page 330. Table 16 shows temperatures of saturated steam corresponding to various pressures:

TABLE 16.—PRESSURES AND CORRESPONDING TEMPERATURES OF SATURATED STEAM

Gauge pressure, lb. per sq. in.	Temperature, °F.
60	307
80	324
100	338
120	350
140	360
160	370
180	379
200	388
220	396

Dry or Wet Saturated Steam.—When the steam leaves the boiler in a dry condition, it is called dry saturated steam, but under certain conditions, for instance, when the boiler is forced above its normal capacity or if the water level in the boiler is too high, the water boils violently; priming takes place, and the spray or foam from the water surface goes out with the steam, which in this condition is called wet saturated steam.

It is in order to prevent the bulk of this water from being carried over with the steam, that various so-called anti-priming devices are frequently employed. If the steam pipe is long or not properly covered, a fair amount of steam will be cooled and condensed into water which is carried along with the steam toward the steam engine, together with any water that may have been carried over from the boiler. Therefore, the steam pipe should be covered with insulating material, to minimize condensation. Water in the steam should be taken out, as far as possible, by a steam separator. But where the steam is very wet, it is difficult even with a good separator to prevent some of the water from entering the steam engine.

Superheated Steam.—Saturated steam, in passing through the heated superheater tubes, is heated above its saturated steam temperature and becomes superheated steam.

The water which has been carried over from the boiler during periods of priming, contains impurities, either solid impurities or salts in solution. When priming ceases this water evaporates in the superheater and the impurities will accumulate in the superheater tubes, in the form of a dry dust, which gets blown over with the steam into the engine and interferes with lubrication.

The *steam separator* tends to remove not only water but also rusty scale and impurities which are carried over from the boiler or which break loose from the inside of the steam pipes, also fine oxidized scale from the inside of the superheater tubes which gets carried over in the form of a fine black dust.

Cutting and scoring of cylinders, valves, and valve faces is sometimes experienced shortly after starting up a new engine. It is seldom due to lack of lubrication or to the quality of the cylinder oil used, but in most cases it can be accounted for by the steam line not being properly blown through and cleansed from scale, foundry sand, rust, and the like. It is obvious that the entrance of such impurities into the steam engine will cause trouble, and the utmost care should be taken, when starting new steam engines, that the pipe-lines from the boilers to the engines, as well as the internal spaces in the valve chests, cylinders, and steam connections between the cylinders, shall be thoroughly cleansed.

The importance of having a steam trap just before the inlet for the steam into the engine is not sufficiently appreciated by most steam users. If no steam separator be fitted, it is obvious that solid matters from the steam line or the boilers will have free access to the engine, which often results in the necessity for early repairing of cylinders and refacing of valves, etc.

OIL IN EXHAUST STEAM AND FEED WATER

A portion of the oil used for lubricating the steam engine cylinders and valves will pass out through the valve rod and piston rod glands, but the greatest portion will leave the engine with the exhaust steam and will be present in the form of *oil in suspension* or *oil in emulsion*.

Oil in suspension consists of oil globules that are fairly easily removed from the steam by the exhaust steam oil separator. The globules of oil which are not extracted from the steam in the separator will, in the case of condensing engines, mix with the condensed steam and reach the hot well, where the greater portion will rise to the surface in the form of "float" oil which can be skimmed off.

A final safeguard may be provided in the form of a feed water filter, the filter medium being cloth, sand, wood-wool, etc., which will retain the globules of oil in suspension. The filter gradually becomes fouled with the oil and the difference in pressure of the feed water on either side becomes greater and greater. If the fouling of the filter be allowed to proceed too far, the danger arises that the collected matter may be swept through and carried into the boilers. If a pressure gauge be fitted, it shows the difference in pressure before and after the filter; and the engineer will, from experience, soon become acquainted with the maximum difference in pressure permissible.

In marine practice the danger of the pressure becoming too high is particularly great where the feed water pump is directly driven by the main engines, as in event of the engines racing, the increased speed of the feed water will certainly tend to clear out the oil from the filter and carry it straight into the boilers.

Asbestos fibre is said to be capable of almost entirely breaking up the emulsified particles of oil and water, and of thus extracting the greater portion of even emulsified oil, but, so far, experiments with such filtering material have not led to any practical solution of this question, as asbestos fibre is both costly to renew and costly to clean.

Oil in emulsion consists of minute particles of water (less than 1⁄50,000 inch in diameter), coated with an oil film. They are so fine that they float in the steam and consequently the exhaust steam oil separator will only remove a portion of the emulsified oil. The greater portion of the oil in emulsion, therefore, mixes with the condensed steam, which assumes a milky appearance. The greater the amount of oil the more milky will the water be.

Whereas oil in suspension, as above mentioned, is fairly easily removed in the hot well or in the feed water filters, not so with the oil in emulsion. The particles are so small that they will not rise to the surface in the hot well, and the filtering medium in the feed water filter will not be able to retain them.

EXHAUST STEAM

In *non-condensing* steam engines the steam passes out into the atmosphere, or it may be used for the purpose of heating the premises, for drying purposes, or for heating the feed water in feed water heaters. The presence of oil in the heating or drying apparatus reduces its heating capacity very considerably.

In condensing engines the steam, when leaving the engine, is condensed either by the jet condensing or the surface condensing system.

Jet Condensing System.—The exhaust steam on entering the jet condenser meets numerous jets of cold water. The cold water condenses the steam into warm water which by means of a pump is taken from the condensing chamber and delivered into the hot well, from which a small portion of the water is taken away by the boiler feed pump for boiler feed purposes. The bulk of the water, however, is either allowed to waste, or, where only a limited supply of cooling water is available, it is passed through a cooling tower, where it is cooled, so that it can be used over and over again. A large portion of the cylinder oil will separate out and present itself as float oil on the surface, which can be skimmed off from time to time. There is generally very little chance of any cylinder oil reaching the boilers where the jet condensing system is employed.

Feed Water Heaters.—Such heaters are installed in numerous plants ashore and generally they are what are termed "contact feed water heaters" in which the steam comes in direct contact with the feed water.

Some oils form an emulsion with the water and do not separate out in the heater. The greater the quantity of water contained in the heater the easier it will be for the oil in suspension to separate; but to get the separation anywhere near satisfactory, it is necessary to use a pure mineral cylinder oil. Under no conditions should the oil be allowed to accumulate in large quantities in the heater, but it should be drained or skimmed off at suitable intervals.

It is also good practice to take the suction of the feed pump from a point as far below the surface as possible, as near the bottom the water is generally most free from oil. Limy deposits which accumulate in the bottom of the heater should never be allowed to reach the level of the suction pipe.

Surface Condensing Plant.—The exhaust steam is here not cooled by direct contact with the cooling water, but simply passes through the condenser chamber, in which are a great number of tubes through which cold water is forced. The steam is cooled, condensed, and pumped into the hot well, whence the boiler feed pump takes the *whole of this water* and delivers it back into the boiler, where it is converted into steam and starts the circuit afresh.

All the oil contained in the exhaust steam will accumulate in the hot well, and the same remarks which were made in reference to contact feed water heaters apply here as to skimming off the float oil and taking the feed water from a low level in the well. Also here oil in emulsion will be carried through with the feed water, and will enter the boiler unless eliminated by special means. Surface condensing engines in land service are comparatively few in number, but are used to some extent for electric power installations and the like, and more especially where town water is expensive; also for ice-manufacturing plants, when the condensed water is afterward used for ice production and where any trace of oil would make the ice cloudy.

If a feed water filter could be invented in which some special form of filtering material, such as asbestos fibre or some other substitute, was employed, capable of extracting oil in emulsion, such a filter would be welcomed by many engineers, as it would be the simplest way of preventing oil being carried into the boilers, of course operated in connection with an exhaust steam oil extractor which would extract the bulk of the oil.

Example 15.—A horizontal, 200-horsepower, cross compound, condensing Robey engine was using a common black cylinder oil. The engine was surface condensing, and the feed pump discharged the water through a filter which was supposed to clear the feed water from oil. After passing this filter the feed water went direct to the boilers. The consumption of cylinder oil was found to be 4 or 5 drops per minute, and if the feed was reduced, the engine started groaning and grinding. In spite of all that the makers of the filter claimed, oil was found in quantities in the boilers, and was the cause of a most serious complaint from the insurance companies.

An examination of the boiler deposit showed that it was composed of black greasy matters and boiler scale. The boiler scale was partly carbonates, sulphates, and hydrates of lime and magnesia. After introducing a pure, mineral, *filtered* cylinder oil it was found possible to reduce the oil consumption to one drop in 70 seconds, and it was reported that a marked improvement in the boiler conditions took place at once, practically all the oil separating out in the hot well.

Extracting the Oil.—The oil may be separated from the exhaust steam by oil separators or extracted from the feed water, by chemical or electrical treatment.

Exhaust Steam Oil Separators.—Some exhaust steam oil separators are very large reservoirs fitted with baffle plates, in which the exhaust steam loses its velocity, the oil and moisture separating out, mainly by gravitation, as in the Baker separator, Fig. 147.

The exhaust steam enters the separator through branch (1 , and is immediately caught and deflected to the lower part of the separator body by the baffle (2). This baffle besides deflecting the steam also tends to retain such globules of oil and water as adhere to it due to the impinging of the steam against its surface. These globules eventually collect and roll down baffle (2), finding their way into the well in the separator bottom. A large free passage is provided under the baffle (2), which allows of a decrease in the speed of the steam so that, by the time the steam is passing through the cleansing angles (3), it is well expanded and the temperature lowered, allowing an appreciable condensation to take place. This will be deposited on the angle bafflers in chamber (4), whence the globules trickle down on to the surface of the water in the separator well (5), which is maintained at a constant level determined by the position of the oil pipe (6), through which the caught oil is discharged by gravitation if the steam engine is non-condensing. If it is a condensing engine, the oil must be pumped out by a small pump which should always be placed at least 24 inches below bottom of separator.

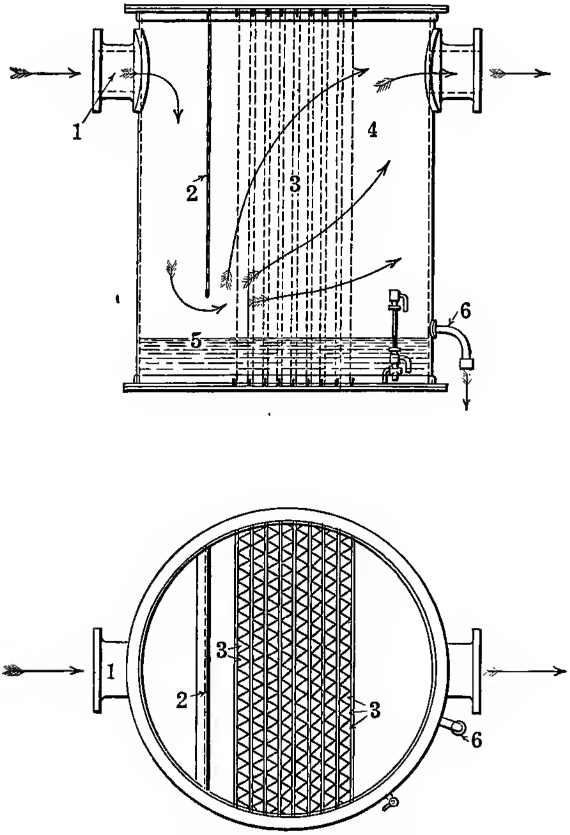


FIG. 147.—Baker oil separator.

It has been found sometimes that, when *very high vacua* are carried in steam condensing plants, the exhaust steam is not freed from the oil and water contained. The cause of the trouble needs little seeking, as the air which is always contained in the condensing plant, and which constantly leaks into the system, expands rapidly with the higher vacua. Accordingly, the velocity of the vapor containing the air is so great through the oil extractor that any oil or water present will be swept out from the separator. Where means are provided so that oil and water once taken out of the steam cannot again enter the flow, this effect of high vacua is greatly minimized. This point has been kept in mind in other separators which are more compact and operate on the principle of splitting up the steam in many little steam flows, frequently changing their direction and trapping the oil by baffle plates which are so designed that once the oil has been removed from the steam, it cannot be picked up again by the steam

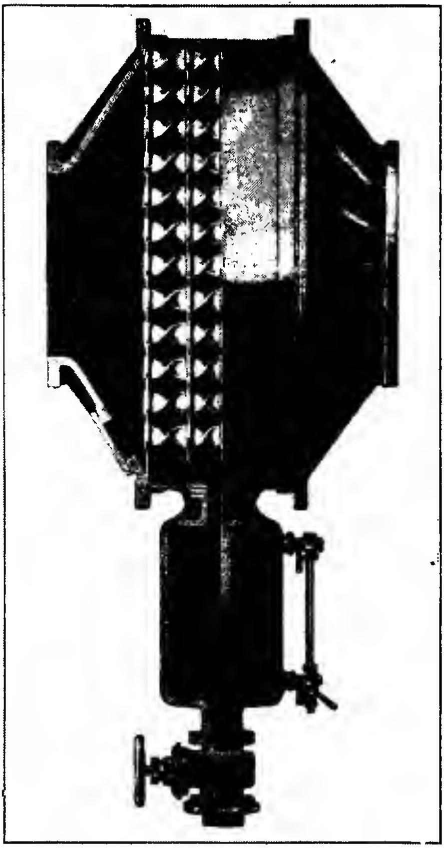


Fig. 148.—Princep's oil separator.

but gravitates to a reservoir in the bottom, whence the oil can be removed at intervals.

The *Princep's oil separator* (Fig. 148) is a good example, illustrating these principles. The steam is allowed to expand and reduce its velocity, so as to allow the solid and liquid particles to free themselves from the steam. A series of plates is suspended from the top. These plates are provided with a number of holes. In each hole is inserted a ferrule projecting from ¼ inch to ⅝ inch on each side of the plate. Through these ferrules are passed plates, twisted to a pitch equal to the distance between each plate. The steam on entering the separator and passing through the holes strikes the twisted blade, which, being at an angle of 45°, deflects the oil and water on to the face of the plate. The continual action of the steam forces the deposit on the plate into the bottom chamber. It is impossible for any oil collected on the first plate to go forward to the second, because it is prevented from doing so by the ferrule which surrounds the hole. If the first deflecting action has not abstracted all the oil and sediment from the steam, the next or third deflection in the next chamber will nearly always do so, but for safety's sake a few more plates are fitted.

The makers *guarantee that there shall be not more than ⅛ of a grain of oil* per gallon of water (condensed steam).

FEED WATER .

Chemical Treatment.—Oil in emulsion can be removed from the feed water by adding certain chemicals (alumina-soda process) which produce a flocculent precipitate. The large precipitated particles take hold of and absorb the minute particles of emulsified oil, so that subsequent filtration easily clarifies the water.

Feed water softening and purifying plants are frequently in use where the greater portion of the feed water is taken from the town main or other source of fresh supply, yet in a great many large installations where surface condensing is resorted to, and where, therefore, only a small percentage of feed make-up is required, feed water purifying plants may be installed with the main object of entirely freeing the water from cylinder oil. It becomes necessary in such cases to add a certain amount of water containing lime, so that, by virtue of the chemical processes, the oil may be thoroughly eliminated. This treatment has the disadvantage that certain chemicals are added to the feed water which are objectionable, as they may increase the tendency of the boilers to prime.

Electrical Treatment.—Another method is the electrical treatment in which the milky feed water containing the emulsified oil is passed through a tank containing two rows of iron plates; an electrical current is passed through the water, from one set of plates to the other. The result is that the minute particles of emulsified oil coagulate and combine with iron oxide (rust), produced from the plates, forming a heavy deposit which can be easily removed by subsequent filtration through a sand filter.

By this method it is possible to remove practically every trace of oil from the feed water. The makers (Davis Perrett, Ltd.) guarantee that the contents of oil shall be less than 0.1 grain per gallon, the consumption of electric energy being 1 B.T.U. per 1000 gal. of water treated.

FEED WATER SOFTENING.—If certain chemicals are added to *hard* feed water containing salts of lime, magnesia, etc., some of the lime and other ingredients are precipitated and are taken out in the form of sludge, whereas the remainder are transformed into such salts in solution that will not produce scale inside the boiler. In small plants a frequent practice is to add the chemicals to the hot well or directly into the feed water on its way to the boiler, or even into the boiler itself. In this case a great deal of sludge is produced which necessitates frequent "blowing down" of the boiler.

The best method of adding the chemicals is to have an independent feed water softening plant, so that the water after treatment is pumped into the boiler in as purified a condition as possible, the sludge precipitated in the softening plant being removed by filtration.

Even if the feed water has been so treated that no scale is being formed in the boiler, it is obvious that, as only clean steam evaporates away from the boiler, the water will become more and more concentrated with salts in solution and inclined to cause priming, so that a certain amount of water should be blown out and replaced with fresh feed water, in order to keep the boiler water in good condition.

Feed water when treated is slightly alkaline; if it is excessively alkaline, the boilers prime and the degree of alkalinity should therefore be kept as low as possible.

OIL IN BOILERS

As has been explained, oil may be introduced in the feed water either in the form of minute particles of oil kept in suspension, or as minute particles of water coated with a thin film of oil (oil in emulsion).

When entering the boiler, the oil in suspension will rise to the surface more or less rapidly; and even if hardly appreciable quantities of such oil are introduced, it will almost invariably be noticed on the plates in the neighborhood of the water level. Much of this surface oil on the boiler water level can be disposed of by judicious use of the scum cocks.

The presence of oil in emulsion is, however, much more dangerous as the small particles of emulsified oil have only a very slight tendency to rise. They combine with the solid matters in the boiler water, such as carbonate of lime, carbonate of magnesia, rust (which is always introduced with the feed water or comes from the boiler plates), etc. Through this combination with these heavier solids, the state of affairs soon becomes this: that the combined particles have the same gravity as the water, and accordingly rise and fall with the eddy currents set up by circulation. They coat the under side as well as the upper side of tubes and flues and cling to the hot plates. The emulsified particles of oil which combine with the iron rust generally become so heavy that they sink to the bottom.

The greasy deposit on tubes and flues has the effect of immediately retarding the flow of heat through the plate. If the deposit contains a sufficient percentage of oil, the flow of heat may be retarded to such an extent that the plate becomes overheated and the deposit begins to decompose, the layer in contact with the hot plate giving off various gases which blow the outer part up to a spongy, leathery mass, which by reason of its porosity retards the flow of heat even more than the thin greasy deposit. *The plate subsequently becomes heated to redness, and being unable to withstand the pressure of the steam collapses.* At the same time the temperature has increased to such an extent that the oil is burned away from the deposit, leaving behind an apparently harmless deposit, containing the solid particles with which the oil originally became combined.

It has been found that new boilers with clean flues are more affected by oil than are boilers in which a certain amount of scale is present. Many cases have been known where *new* boiler furnaces have come down when the thickness of the coating of grease has probably been less than one-thousandth of an inch. A coating of oil of this thickness will increase the temperature of the boiler plates several hundreds of degrees F. even with a moderate rate of evaporation.

A series of experiments was carried out by the late Mr. Wm. Parker, Engineer in Chief to the Lloyd's Registry, with a view to determining how far the conductivity of steel and iron plates is affected by oil films. His experiments proved that if an open steel dish was painted with three or four coats of greasy deposit taken from the bottom of a boiler in which a furnace collapse had occurred, mixed with a little cylinder oil, it was possible to burn the bottom of the dish before the water in it boiled.

Example 16.—The following interesting example is an excerpt from a paper read before the North East Coast Institution of Engineers and Shipbuilders, 1904–5, by Mr. D. B. Morison, and speaks for itself.

A disastrous accident came under my notice some time ago in which the furnaces of a passenger steamer collapsed in mid-ocean.

The boilers were apparently clean, with no appreciable scale on any part. The principal cause of the accident was the use of a very inferior oil for swabbing the rods and lubricating the auxiliary engines. The oil became emulsified with the feed water and being therefore unfilterable passed directly into the boilers. The deposit scraped from the furnaces and other parts of the boiler was analyzed by Mr. J. B. Dodds of Newcastle-on-Tyne, who reports as follows:

Deposit from Furnace below Level of Fire

Calcic sulphate	2.51	per cent.
Calcic oxide	0.852	per cent.
Magnesic oxide	7.33	per cent.
Ferric oxide	10.11	per cent.
Zinc oxide	7.102	per cent.
Insoluble matter, chiefly sand, dirt, etc.	2.55	per cent.
Free oil, only mechanically held by above constituents	66.76	per cent.
Oily matter, combined with oxides of magnesia, iron and zinc	2.95	per cent.
Total	100.164	per cent.

"*Remarks.*—The very dark color of this sample is due to the abnormal quantity of oil present. This quantity is so great that it must have materially affected the transmission of heat to the water."

Deposit from Shell at Water Level

Calcic sulphate	0.788	per cent.
Calcic oxide	1.816	per cent.
Magnesic oxide	9.62	per cent.
Ferric and ferrous oxide	11.04	per cent.
Zinc oxide	16.87	per cent.
Insoluble matter, chiefly sand, dirt, etc.	4.34	per cent.
Free oil, only mechanically held by above constituents	41.04	per cent.
Oily matter, chemically combined with above oxides	14.49	per cent.
Total	100.004	per cent.

Deposit Scraped from Furnace Crowns

Calcic sulphate	69.9 per cent.
Magnesic oxide	8.55 per cent.
Ferric oxide	3.55 per cent.
Zinc oxide	4.5 per cent.
Insoluble matter, which consists largely of more calcic sulphate, with sand, dirt, etc.	8.15 per cent.
Free oil,* only mechanically held by above constituents	0.77 per cent.
Oily matter, chemically combined with above oxides	4.6 per cent.
Total	100.02 per cent.

* On furnace crowns which have been overheated there are generally only evidences of oil having been there.

Deposit from Under Side of Tubes

Calcic sulphate	3.93 per cent.
Calcic oxide	1.1 per cent.
Magnesic oxide	5.78 per cent.
Ferric oxide	11.04 per cent.
Zinc oxide	15.31 per cent.
Insoluble matter, sand and dirt	8.38 per cent.
Free oil, only mechanically held by above oxides	20.23 per cent.
Oily matter, chemically combined with above oxides	34.104 per cent.
Total	99.874 per cent.

"*Report.*—My examination of the sample of cylinder oil would lead me to infer that any injury found was due to the presence of a large quantity of oil in the boiler, and that this quantity may have been increased by the use of an oil deficient in lubricating power, necessitating its use in large quantities.

"The comparatively small percentage of ferric oxide (peroxide of iron) in these samples would show that the iron surfaces had been only very slightly affected as far as corrosion or oxidation is concerned. The presence of zinc oxide in decided quantity would indicate that zinc had been the medium used to protect the boiler against corrosion or oxidation, and that it had successfully effected its purpose.

(Signed) JOHN BRADBURN DODDS."

When a boiler has become contaminated with oil, it should be washed out in the usual manner, then filled with water containing 0.5 lb. of soda ash per boiler horse power. The water should be kept boiling at atmospheric pressure for 24 hours, then drawn off, and a thorough washing of the boiler should follow.

METHODS OF LUBRICATION

Points of Application.—In order to lubricate the internal parts of steam cylinders and valves, cylinder oil is introduced at one or several of the following points:

1. Direct to the steam chest.
2. Direct to the valves.
3. Direct to the cylinders.
4. Direct to the piston rod.
5. Into the steam line.

1. *Direct to the Steam Chest.*—This is one of the earliest methods of application. In the case of slide valves oil is usually introduced so that it drops directly over the valve face. In the case of Corliss valves or drop valves (Fig. 154*A*), oil is usually introduced at two points halfway between valves and steam pipe (4). The flow of steam going to the right carries along with it the oil to the right-hand valve (6*b*), and the flow of steam going to the left carries the oil to the left-hand valve (6*a*). The oil, after passing the valves enters the cylinder and provides lubrication for the piston (1); finally the oil reaches and lubricates the exhaust valves.

2. *Direct to the Valves.*—Oil is delivered at one point at the centre of the Corliss valve, or at two points, one at either end of the Corliss valve. It is the ends of the valve that require most lubrication, and feeding to the ends direct is therefore preferable to feeding at the centre, in which case the flow of steam sweeps the oil right through the valve without any lubrication reaching the valve ends. Piston valves are sometimes lubricated by two oil feeds in this manner, one feed to each end of the valve.

3. *Direct to the Cylinders.*—Sometimes in the case of large engines, oil is introduced, either at the centre of the cylinder, or at the top, or bottom; the oil thus introduced is gradually spread by the piston over the cylinder walls.

4. *Direct to the Piston Rod.*—Oil is introduced direct to the piston rod externally, that is, outside of the piston rod gland, either by oil dropped from a lubricator on to the piston rod, or by an oil swab resting on the rod. The oil may also be introduced, particularly under conditions of high temperature and pressure, directly into the piston rod gland itself, which gives a greater certainty of the oil being properly distributed, as, when the oil is applied externally, the greater portion is scraped off by the gland and runs to waste.

The four points of application so far mentioned are direct, that is, the oil is delivered as direct as possible to the moving parts requiring lubrication, and speaking generally, the more "direct" the oil is fed, the less satisfactory is its distribution.

There is this disadvantage that as cylinder oil is very heavy in viscosity, it spreads only with difficulty; it is apt to overlubricate some parts and not reach other parts. For this reason a great deal of oil is required in order to insure that a complete lubricating film is maintained everywhere.

Feeding Oil into the Steam Line.—Thi is the best method of application and embodies an entirely different principle, as, instead of lubricating the various parts direct, the steam itself is lubricated.

By the introduction of the oil into the main flow of steam, it is possible to make the steam carry the oil to all parts requiring lubrication, in fact, the steam itself is made a lubricant. The oil is introduced preferably on the boiler side of the engine stop valve, and in the case of saturated steam, should be introduced at least 18 inches away from the stop valve.

In the case of superheated steam, which does not carry the oil so well as saturated steam, it should be introduced not more than 18 inches before the engine stop valve. In cases where the superheat is very high and where the steam is carried around the steam cylinder before it enters the valves (usually drop valves) on the top of the cylinder, it is not practical to introduce the oil before the engine stop valve, as it would be precipitated on the way; the oil is then introduced directly into the drop valves at a point where the flow of steam will break up the oil and distribute it in the steam passing through the valves every time they open.

Atomizing the Oil.—It is, however, not sufficient to merely introduce the oil into the steam pipe or flow of steam, as the oil then is merely pushed along in the form of drops.

The best method, insuring perfect distribution, is the atomizing method by which the oil is introduced through an atomizer (Fig. 150) into the centre of the flow of steam. The steam impinging with great velocity (from, say, 60 feet to 150 feet per second) against the spoon shaped end of the atomizer will squeeze the oil through the slits in the atomizer, so that the oil gets thoroughly broken up, and in the form of an exceedingly fine spray mixes with the steam.

Various atomizers have been made for the purpose of splitting up the oil into minor particles, for example the oil was made to ooze out from the perforated end of a tube, but the small holes (see Fig. 149) only divided the oil into drops sufficiently small to pass through these holes. Other forms allowed the oil to be broken up over sharp edges.

After many trials, the author evolved the sawslit type of atomizer illustrated in Fig. 150 (not patented). Its introduction has saved many thousands of barrels of oil and many thousands of horse power that previously were wasted. When passing the slits, which should not be more than 1/32 inch wide, the oil is well atomized, and entering the engine it lubricates the spindle of the engine stop valve, making this valve easy to operate. It lubricates the steam valves and their spindles, the steam throwing down a slight portion of the oil on these points. The oil is thoroughly distributed in the form of a uniform coating over the piston, piston rings, and cylinder walls. The piston rod receives its proper share of the oil, and accordingly

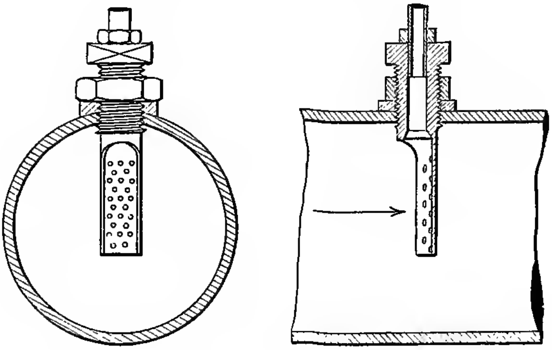


FIG. 149.—Atomizer.

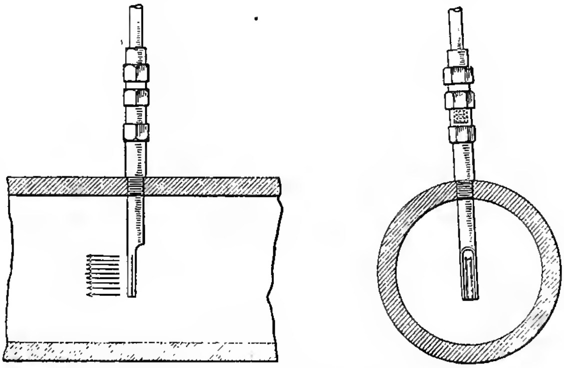


FIG. 150.—Thomsen's atomizer.

lubricates the piston rod gland packing from the inside, which is much more economical and efficient than lubricating the piston rod from the outside.

The exhaust valves receive their share of lubrication, and the exhaust steam, if it be carried over to the low pressure cylinder (in the case of a compound engine), or to the intermediate pressure and low pressure cylinders (in the case of a triple expansion engine), will carry over finely atomized oil, so as to assist in lubricating these cylinders. Speaking generally it will be found that when the feed of cylinder oil is ample for the satisfactory lubrication of the high pressure cylinder, sufficient oil will be carried through to lubricate successfully the remaining cylinders.

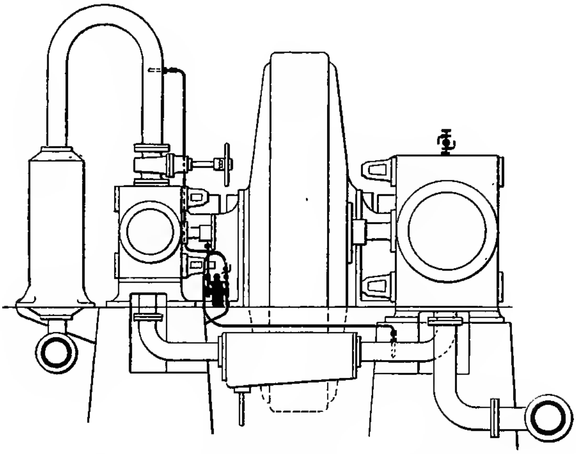


FIG. 151.—Two oil feeds for a compound engine.

If between cylinders of a compound or triple expansion engine there are large receivers which may perhaps be utilized for reheating the steam, these receivers will act as oil separators, in which case it frequently becomes necessary to feed oil direct to the intermediate and low pressure engines; but this should be done by introducing the oil into the steam inlet pipes leading to these cylinders, in preference to feeding the oil direct into the valves or cylinders.

Ordinarily, the oil feeds to the intermediate and low pressure steam pipes need be only from 5 to 25 per cent. of the feed into the high pressure steam main.

Fig. 151 shows how the two feeds from a mechanically operated lubricator mounted on a compound steam engine introduce oil to the high pressure steam pipe and low pressure inlet pipe through atomizers carrying the oil into the centre flow of steam.

Where a number of engines or pumps, or a row of steam hammers, each separately lubricated, take their steam from the same main, admirable results may be accomplished, in the way of saving in oil consumption combined with better lubrication, through the employment of *one lubricator* mounted on the steam line a good distance away from the first unit (sometimes exceeding 20 feet), and feeding the cylinder oil through an atomizer into the central flow of steam.

The steam, as previously explained, acts as a carrying medium for the lubricant, and each unit gets a share of the oil in proportion to the quantity of steam passing through. Atomizing the oil and using the steam as the oil spreading medium, results in the most efficient distribution of the oil, so that not only is the friction reduced, but also the quantity of oil required for full lubrication. As this method relies upon the velocity of the steam to atomize the oil, it will be understood that only in very exceptional cases where the velocity of the steam is too low will it fail. This will be the case where the engines, for some reason or other are operated at considerably less than half load.

When the oil is supplied *direct* to the various parts, it is very frequently found that the piston rod, particularly under high pressure conditions, is poorly lubricated. The rod shows evidence of uneven distribution of oil; it looks scratched all over, and has that peculiar raw-polished surface, which indicates wear. Where in such cases the atomization method is introduced, the oil cups furnishing lubrication to the outside of the piston rod can usually be dispensed with, and, due to the better lubrication of the piston rod from the inside, the surface of the rod will soon assume a glossy oily appearance, indicating that the wear has ceased and that the piston rod is getting a hard polished skin.

When stopping for week-ends or for longer periods, it is good practice to give an extra large quantity of oil for the last five minutes the engines are running. This will give a nice coating of oil to all the internal surfaces and prevent the formation of rust, which otherwise might occur.

Where the atomization method is introduced, it is not unusual to find that some of the joints between the point of entrance of the oil and the valve chest commence to leak, as some of the oil may dissolve deposits and dirt in the joints, which will therefore need to be tightened or repacked to keep steam tight.

Typical Results of Using the Atomization Method.—The cylinder oil should be introduced on a length of steam pipe with as few bends as possible before it enters the valve chest, and there must be no drains which might trap the oil. The importance of this point is illustrated in Example No. 17.

Example 17.—Four steam hammers were supplied with steam from the same main, and a sight-feed lubricator was mounted a good distance before the first steam hammer, while a drain pipe was fixed between this hammer and the lubricator. As long as all hammers were in full swing everything went well, but when only one hammer was working the flow of steam was so small that some of the oil was not properly atomized, but dropped to the bottom of the pipe and was urged along the steam pipe, and, reaching the drain, dropped down.

After the position of the lubricator was changed to a place between the drain and the first steam hammer, no further trouble was experienced.

Example 18.—On a colliery winding engine a good grade of cylinder oil was used, the consumption being 1⅛ gallons per 24 hours. The oil was introduced into the steam pipe, *but not through an atomizer.* The Corliss valves were grinding slightly. After fitting an atomizer, the grinding immediately stopped, and the consumption was reduced to ¾ gallon per 24 hours' work.

After twenty months' working under these conditions the tool-marks on the high pressure cylinder were not worn away and the colliery manager was satisfied that no other method of lubrication would have kept the cylinders in such remarkably fine order.

Example 19.—A cylinder oil of good quality had been in use for some time with only fairly good results on a "Robey" compound horizontal engine, the oil being introduced direct into the steam chest by a sight-feed lubricator. When the oil was introduced 4 feet away from the cylinder into the steam pipe from a mechanically operated lubricator, an inspection a few weeks later showed that great improvement had taken place. The internal wearing surfaces had a nice oily appearance and no wear was noticeable. It was observed, when taking out the piston, that the thread of nut and piston rod end were well lubricated, whereas before they used to be dry, and difficulty was experienced in getting the nut off.

Example 20.—Two "Ruston Proctor," horizontal, cross compound engines were lubricated with sight-feed, hydrostatic lubricators, feeding cylinder oil into the valve chest of high pressure cylinder. It was necessary to resort to "flushing" of the low pressure cylinders through tallow cups which were placed on the centre of the low pressure cylinder barrels. After altering the feed to the steam pipe and employing an atomizer (in this case only 4 inches from the valve chest, owing to a drain in the steam line), the consumption of the same cylinder oil was reduced 25 per cent. and the "flushing" of the low pressure cylinders was found to be unnecessary as the oil, atomized, was carried over with the steam.

Example 21.—Some blowing engines on an ironworks had large D slide valves (42 in. by 48 in. outside dimensions) with 8 in. travel. Revolutions per minute of the engine, 40; steam pressure, 60 lb. per sq. in.; the steam superheated to 450°F. This engine was using half-a-gallon of a *very viscous mineral cylinder oil* per 24 hours' run and the slide valve at times jarred very badly. A compounded cylinder oil was then introduced, but although the valve worked better, yet it jarred badly at times, and the defect could be stopped only by a copious supply of oil.

After this *an atomizer was fitted*, and the working of the engine changed at once. The valves subsequently worked very smoothly, the engine giving no trouble, and the consumption of the same cylinder oil was reduced 30 per cent.

Example 22.—A colliery fan engine (large slide valve with expansion valve) used 8 gallons of cylinder oil per week through sight-feed hydrostatic lubricators and tallow cups.

These appliances were replaced by a mechanical lubricator, the feed entering flush with the inside of the steam pipe. This alteration made it possible to reduce the consumption of cylinder oil to 4 gallons per week. A further reduction was tried, but the amount of oil had to be increased owing to the vibration of the eccentric rods, which indicated that the valves were insufficiently lubricated.

Another mechanical lubricator of an improved type was then fitted introducing the oil *through an atomizer* into the same place as before, the result being that the engines ran smoother than ever, and the oil consumption was reduced to only 1⅝ gallons per week.

Example 23.—On a large steam engine driving an air compressor it was found necessary to tighten the glands two or three times a week, when the oil was introduced direct into the valve chests. After the lubricator was altered to feed into the main steam pipe through an atomizer, *the glands required to be tightened only once in three weeks.*

Example 24.—A 350-horsepower fan engine in a colliery consumed 3 gallons per day of common cylinder oil fed through three mechanically operated lubricators, having a total of eight oil feeds, feeding direct to the Corliss valves. In addition, it was found necessary to feed extra oil to the ends of two of the Corliss valves, in order to keep them silent.

A change was made, feeding a good quality compounded oil into the high pressure steam pipe through an atomizer, and the improvement in lubrication was immediately noticed. The two lubricators were discontinued; the consumption was gradually reduced to two pints per day, and it was never found necessary to feed extra oil to the Corliss valves.

Example 25.—A 2-cylinder, horizontal rolling mill engine was lubricated with a common straight mineral grade of cylinder oil internally and for the piston rod guides. Grease was used on the crank pins, eccentrics and main bearings. By the substitution of a good grade compounded cylinder oil for the internal lubrication introduced through atomizers, and an engine oil, specially suited to the work, on slides, eccentrics, crank pin and main bearings, a great reduction in the power required to overcome the friction in the engine was made.

With previous oils in use, the engine, with all load off, took 94.2 I.H.P. Five weeks after, with the new oils in use, and under exactly similar conditions, the engine consumed only 41.4 I.H.P. showing a reduction of 56 per cent. in the power necessary to drive the engine with the rolls uncoupled. The average temperature of slides above room was reduced from 33°F. with the old oil in use to 12.5°F. with the new oil, showing a reduction in rise in temperature, due to friction, of 20.5°F. or 63 per cent.

The cost of lubrication was reduced by 19 per cent. with the better grade oils in use, the actual quantity of oil required being only one-third of that required with the previous oil.

The total number of indicator cards taken during both tests was 160, every set of cards being taken simultaneously, as all pencil motions were operated electrically.

Example 26.—Striking differences caused by lubrication may often be noticed on long-stroke, slow-speed reciprocating pumps, for example, Weir's or Woodeson's type. If a change in the cylinder oil be made to a better grade, or if the method of lubrication be improved, the change will immediately result in a greater number of strokes per minute, and a smoother and more gliding motion of the rods, the reason being that from 25 per cent.–50 per cent. of the indicated horsepower is consumed by friction.

These examples show that a decided success has followed the combination of mechanical lubricators with atomizers and suitable grades of oil. The arrangement must, however, in each case be given due thought and consideration to ensure good results.

LUBRICATORS

The Tallow Cup.—The earliest form of lubricator is the tallow cup, consisting of an oil reservoir with a filling plug at the top and a cock at the bottom for emptying the oil from the reservoir into the cylinder, or valve chest, etc. When the tallow cup is filled with oil and the charge flushed into the engine, most of it will immediately drop to the bottom of the cylinder and be swept out with the exhaust steam, within the next few strokes of the engine. Then the engine runs on what little oil there may be left, and within a short time will be running with no oil at all, until such time as the engine attendant considers it necessary to repeat the operation.

When the tallow cup is fixed on the valve chest, most of the oil never reaches the cylinder. It finds its way to the lower regions of the valve chest, mixes with any condensation which may be present, and is drained out.

The tallow cup still survives as an emergency lubricator for flushing purposes, when extra oil is required in places where no oil feed is ordinarily provided for, such as top of cylinders or valve chests, etc. Tallow cups are also still used for feeding oil to small steam pumps and the like.

As regards proper lubricators for feeding cylinder oil, there are two main types in use: the Hydrostatic Lubricator and the Mechanically Operated Lubricator.

Hydrostatic Lubricator (Fig. 152).—The lubricator is usually attached to the steam pipe and sometimes to the steam chest. Steam through pipe (1) enters the condenser (2) at the top of the lubricator. In this condenser the steam is cooled and condensed into water; when the valve (3) is open, the water is allowed to flow down through pipe (4) into the bottom of the oil reservoir (5). The incoming water displaces the oil and compels it to flow down through the pipe (6), through the adjusting valve (7) fitted for the purpose of regulating the feed; then the oil rises through the water in the sight-feed glass (8) and enters the steam pipe (10) through the delivery pipe (9).

The gauge glass (11) shows the level of the oil inside the container. The drain cock (12) is fitted for drawing off the water before the lubricator is refilled with oil through filling plug (13).

The distance from the steam inlet at the top of the pipe (1) to the top of condenser (2) should be at least 18 inches in order to get sufficient height of water to force the oil through the lubricator. Sometimes when a large oil feed is demanded the pipe (1) is made in the form of a coil, so as to provide increased cooling surface for condensation.

When the lubricator is exposed to draft or to low temperature, which makes the oil sluggish, it is necessary to provide additional water pressure by means of longer piping above the condenser.

The lubricator must be started every time the engine starts, and it must be stopped each time the engine stops or it keeps on feeding and oil is wasted. In draining off the condensed water and in refilling the lubricator, a certain amount of oil is usually wasted.

The oil feed is affected by change in viscosity of the oil. It will therefore vary with the engine room temperature, and also every time the lubricator is filled with fresh oil. The oil passes through small passages, which are liable to be partially choked with dirt, thus reducing the oil feed. For these reasons it is difficult to maintain a uniform feed with a hydrostatic lubricator, more especially where a very small feed is desired. A uniform feed of oil, however, is of great importance, as otherwise the

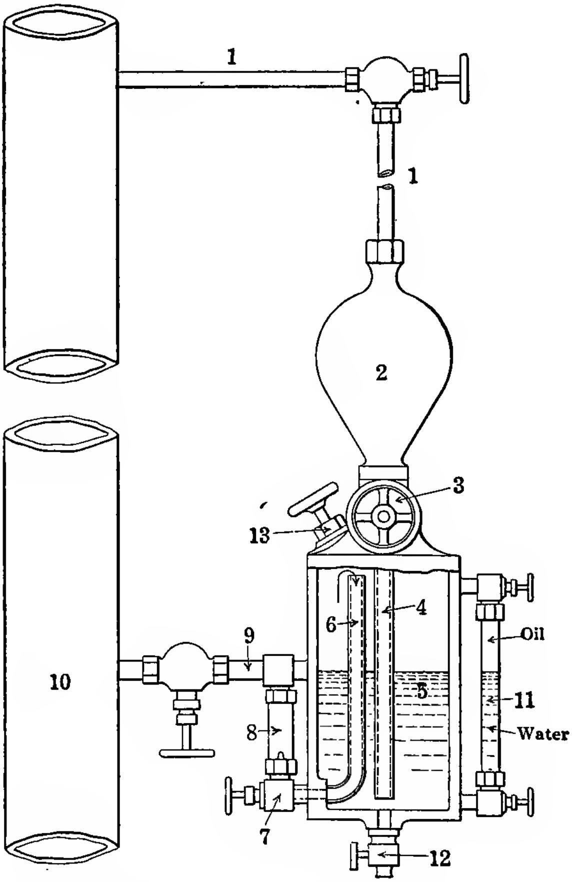


FIG. 152.—Hydrostatic lubricator.

steam is either charged with a large amount of oil—too much, or with a small amount of oil—too little.

In connection with hydrostatic lubricators the following points must be kept in mind.

When the sight-feed glass is inclined to get smeared with oil, this may be caused by the oil drops being very large or the sight-feed glass having too small a bore. The remedy is to fit a wider glass, or solder a wire on to the feed nipple, so as to guide the oil drops centrally, or to fill the glass with salt water or glycerine. The heavier specific gravity of these liquids causes the oil drops to rise earlier, *i.e.*, the drops are smaller and do not touch the glass.

Leakages of joints and packings must be avoided, as they interfere with the operation of the lubricator, which is very sensitive.

The lubricator must be filled completely with oil and the condenser must be given time to fill up with water, otherwise steam will enter the oil reservoir and agitate the oil and what is known as "churning" occurs in the sight-feed glass. When churning takes place the lubricator must be emptied, cooled, filled afresh and time allowed for the condenser to fill with water.

The oil drops vary in size, according to the size of the nozzle, the gravity of the oil and the liquid in the sight-feed glass; ordinarily it will be found that one gallon of oil will feed in 10,000 to 24,000 drops.

If the oil is fed by an unreliable lubricator, or if the oil feeds do not introduce the oil in the best possible manner, more oil is required to provide lubrication, and the lubrication will not be so efficient as when the oil is properly fed and applied.

True economy in the lubrication of the valves and cylinders is obtained by feeding a minimum quantity of the correct grade of oil to the working parts with such regularity as will insure an unbroken oil film between the frictional surfaces. Such economy can never be secured by the use of a lubricator which feeds intermittently or irregularly.

The hydrostatic lubricator, which is still largely used in the United States has in other countries been practically superseded by the mechanically operated lubricator.

Mechanically Operated Lubricators.—Mechanically operated lubricators are operated from some moving part of the engine; they therefore start feeding as soon as the engine starts, and stop feeding when the engine stops, and they feed the oil in direct proportion to the speed of the engine.

Mechanically operated lubricators preferably have sight-feed arrangements for each oil feed, so that the exact quantity of oil passing through the various delivery pipes can be observed. These lubricators should be so constructed that each feed is independent, subject to separate adjustment and control. Also, the working parts should not be liable to wear, and what is especially important, all the working parts, valves, etc., should be easily accessible for inspection and cleaning.

In order to insure that the oil pipes, from the mechanically operated lubricator to the various parts of the engine where oil is introduced, shall be always completely filled with oil, spring loaded check valves should be fitted at their extreme ends. The pipes are thus always filled with oil and lubrication is insured instantly the engine, and therefore the lubricator, start to operate. This check valve should be of the combined check and vacuum valve pattern, in order to prevent the oil from being sucked out of the lubricator container when a vacuum is formed in the steam line during a standstill. If the oil is introduced into a steam connection where a partial vacuum exists (for instance before the low pressure cylinder of a triple-expansion engine) it is essential that a valve of this description be fitted.

Care should be taken that the valve does not leak, and that the spring is strong enough to keep the valve on its seat against the vacuum which tends to open it. The construction and operation of mechanically operated lubricators are treated in greater detail page 85.

LUBRICATION

The internal moving parts, comprising valves, valve rods, piston and piston rod, are exposed to the action of hot steam and with the exception of the valve rod and piston rod, none of the internal parts are exposed to view, so that the condition of lubrication cannot easily be ascertained. The internal lubrication of steam cylinders and valves is therefore of greater importance and more difficult than the lubrication of the external moving parts.

Slide Valve.—The flat surface of the slide valve rubbing against the valve face is difficult to lubricate, particularly in the case of large slide valves. In some cases, oil grooves are cut in the valve or in the valve face, in order to assist the oil in spreading all over the frictional surfaces.

The pressure between the valve and its face is great, particularly with "unbalanced" slide valves. Improper lubrication results in abrasion and cutting; excessive leakage of steam takes place and wipes away the lubrication film from the valve face, necessitating an increased consumption of oil. Excessive friction of the slide valve frequently makes the valve groan during operation, and the excessive resistance in moving the valve can usually be noticed by trembling of the eccentric rod.

When the cover from the slide valve chest is removed and the slide valve is examined, excessive friction is always indicated by a dryness of the rubbing surfaces, showing wear and streaks of cutting where the metallic surfaces have eaten into one another. It is important that the cast iron in the valve and in the valve face should be of slightly different quality or hardness, as, if the quality is practically the same, they do not work well together.

Efficient lubrication of the slide valve produces a polished, glossy surface on the valve face. The valve operates without noise; the eccentric rod works smoothly, and when opened up for inspection the frictional surfaces show a complete lubrication film.

Owing to the large flat frictional surfaces of slide valves and to the difficulty of getting the oil thoroughly introduced between them, and, furthermore, due to the great pressure between the valve and its face, it will now be understood why the use of slide valves is limited to steam pressures of, say, 125 lb. to the square inch, and a maximum steam temperature of, say, 450°F., and also why overloading always makes lubrication difficult. Experience has proved that when the oil is introduced into the steam and is thoroughly atomized, the oil gets much better distributed and has in many cases overcome groaning and trouble with slide valves where the direct methods of lubrication have failed to produce good results.

Corliss Valves.—The Corliss valve operates under conditions very similar to those of the slide valve, as it has a reciprocating sliding motion, only it oscillates over a cylindrical surface instead of moving over a flat surface.

Conditions of high temperature and high pressure, therefore, affect the lubrication of the Corliss valve in the same manner as they affect the slide valve. Bad lubrication is usually noticed when "feeling" the valve stems. As the admission Corliss valves are not positively operated during the closing period, bad lubrication may sometimes be indicated by the valves working sluggishly or even "sticking." Corliss valve engines are specially referred to page 368.

Piston Valves.—There is but little pressure between the piston valve and its cylindrical sleeve, the pressure being mainly that exerted by the piston rings. Exposed to high pressure or high temperature, the piston valve expands uniformly, and the pressure between the piston rings and the sleeve remains the same. High pressure and high temperature, therefore, have little effect on the piston valve, nor are they affected by overload, and consequently these valves can be operated under extreme conditions.

The signs of good or bad lubrication are similar to those indicated by slide valves, but, owing to its cylindrical, balanced construction, the piston valve is easier to lubricate. It is important, however, that the oil be well distributed, and again here experience has shown that this can best be done by the atomization method of lubrication.

Drop Valves.—The drop valve lifts from its seat and drops on its seat; consequently, no lubrication is required, except for the valve spindle, which usually is very long and has a very short motion in its guide. The clearance between the valve spindle and its guide is slight so that it is important to have perfect lubrication.

The oil on the valve spindle is stagnant and exposed for a long time to the high temperature. It should be of the highest quality, so as not to bake into a carbonaceous deposit, which might cause sticking of the valve.

The oil should preferably be sparingly used and introduced by means of the steam, so as to be uniformly distributed.

Piston and Piston Rings.—In vertical steam engines there is no pressure between the cylinder and the cylinder walls, except that exerted by the piston rings. For this reason the lubrication of the pistons and piston rings in vertical engines is easier, and less oil is required than in horizontal engines, in which, besides the pressure between the piston rings and the cylinder walls, is frequently added the pressure of the weight of the piston sliding over the bottom of the cylinder.

In the case of large horizontal steam engines, the extra friction due to the weight of the piston is frequently avoided by extending the piston rod out through the back cover and connecting it to a tail rod support. In this way, by making the piston rod sufficiently rigid, the whole or part of the weight of the piston will be supported by the crosshead and tail rod guides, so that the duty of the piston rings becomes only that of preventing leakage of steam from one side of the piston to the other.

In the case of horizontal steam engines employing highly superheated steam, this arrangement will always be found desirable and frequently necessary, as otherwise excessive friction and wear results.

The piston rings are always softer than the cylinder, so that if there is any wear, the greatest wear will be on the piston rings and not on the cylinder walls.

During recent years a number of piston rings have been introduced which exert pressure against the cylinder walls due to the action of internal springs. Where the conditions are ideal, these rings give good service, but they are somewhat rigid in their construction, so that where the movement of the piston from one end of the cylinder to the other is not absolutely central, experience has proved that these spring piston rings under extreme conditions have caused excessive friction and heavy wear.

It must be kept in mind that the temperature of the oil film is high and that excessive pressure or friction may easily destroy the oil film and produce bad results. For most conditions the old Ramsbottom type of split piston ring, which is very flexible, therefore still holds its own over a wide range of service.

It is always an advantage to have the corners of the piston rings rounded off, as, if they are sharp, they act like scrapers on the cylinder walls and destroy the oil film. When they are rounded, they do not dislodge the oil film, and better lubrication results.

The reason why modern piston-packings of rather complicated constructions are not so widely used as one might expect will perhaps be found in the fact that in event of the centre line of the piston and rod not being quite coincident with the centre line of the barrel, the flexibility of the piston-packing may not be great enough to allow for this difference. This has led to an endeavor on the part of piston-packing makers and designers to embody in their design the quality known as "floating," which means that the particular type of packing in use may exert as nearly as possible even pressure all round against the walls of the cylinder, quite independently and without affecting the piston body. This same experience has also led the makers of metallic packing for piston rods, etc., to allow the packing a little lateral movement from the rod, which prevents excessive friction and prevents distress of the packing and subsequent blowing.

Example 27.—The following is an interesting example illustrating how the various types of piston packing may have a bearing on the lubricating conditions. Complaints were made about a cylinder oil in use on an 8,000-horsepower, three-cylinder, horizontal rolling mill engine, the complaint being that excessive wear showed up in the cylinder, the cylinder walls appearing dry, no matter how much oil was used.

The engine had for several months been running on a very small consumption of cylinder oil and giving every satisfaction, the oil being fed into the three steam chests on the cylinders. The engine was hardly powerful enough to cope with the load.

As the chief engineer had a suspicion that some portion of the steam was leaking past the pistons, the cylinders were rebored and new pistons were put in fitted with a modern non-floating type of piston ring, instead of Ramsbottom rings which were employed previously. When the engine restarted it was found to be worse than ever, and the output of the steelworks largely decreased. At the same time the coal consumption went up, and it was quite apparent that more steam was leaking past the pistons than under the old conditions. The reason why the non-floating rings did not give satisfaction was that the axes of the cylinders were not coincident with the axes of the three piston rods and tail rods. Accordingly, the piston rings at a certain part of the stroke were bearing hard against the cylinder barrels, setting up heavy friction.

At the same time, as the rings were not moving freely enough, steam was leaking past the pistons in enormous quantities. This will also explain why the cylinder walls were dry, as the steam oozing past the pistons would tend to carry away the film of oil on the cylinder walls. After some experimenting, new sets of piston rings were put in. These were of a type which allowed sufficient come-and-go (floating) to meet the conditions of the engine. After this satisfactory results were again secured by the use of the same oil, a very marked improvement being shown while dealing with the maximum load, and in the coal bill falling to normal.

From the designer's point of view, there are several important things to consider in order to reduce the amount of power consumed by friction in steam engine cylinders.

Firstly.—The weight of the piston itself should preferably be taken by means other than the wearing surfaces; in other words, *the piston should not be allowed to wear on the bottom of the cylinder barrel.*

Secondly.—The duty of the piston rings should be only to attain steam-tight working. That construction would be the best which accomplished this with the smallest amount of pressure between the piston rings and the cylinder walls. Further, the construction should allow of a certain amount of come-and-go, as the coincidence of the centre line of the piston and that of the cylinder barrel can never be depended upon in actual practice.

On opening up steam cylinders for inspection, the surface should present a rather dull apearance, coated with a thin film of oil. The presence of oil can be ascertained by striking a piece of paper around the cylinder bore at various parts of the stroke. After the oil film has been wiped off, the surface underneath should appear bright and glossy. If any wear has taken place, the surface will also be bright, but in quite a different way, it will look silvery as if raw-polished with fine emery cloth, and although actual scoring may not have taken place, there will always be found fine streaks indicating wear. This may be due to a variety of causes, such as unsuitable or improperly selected oil; the lubricator may be unreliable, or the method of lubrication may not be satisfactory; or possibly, the oil feed has been cut too low.

Packing Glands.—The function of the packing glands used for piston and valve rods is to prevent steam leakage outward in high pressure cylinders, and air leakage inward in low pressure cylinders of condensing engines.

A perfect seal can be obtained only by the presence of a complete oil film on the rods, so that full and efficient lubrication of the packing glands is essential.

There are many types of piston rod glands in service, but they can be divided into two main groups, viz.: glands having soft packing and glands having metallic packing.

Soft Packing Glands.—These are used only under saturated steam conditions. The friction is always comparatively high, and if the packing is screwed up hard, undue pressure is produced between the packing and the piston rod which results in scoring of the latter, after which it becomes difficult to keep the gland tight.

In reversible engines such as colliery winding engines, steel works rolling mill engines, etc., the reversing of the engines takes place by changing the position of the slide valves or piston valves in relation to the position of the pistons. This movement of the valves is done by hand in the case of small engines and by a special reversing engine in the case of large engines. It is obvious that the pull required to reverse the engine is influenced by the frictional resistance offered by the valves moving on their seats, and the additional resistance of the valve rods moving in their glands.

Where the valve rods have been lubricated externally, which method is wasteful and inefficient, a change to the atomization method of lubrication brings about a marked improvement, particularly moticeable in reversible engines. The valve rods will receive internal lubrication when inside the valve chest, and accordingly will convey efficient lubrication to the packing, so that the external lubrication of the valve rods can be dispensed with altogether.

The reversing lever will be easier to operate, due to lower gland friction, and this is a point greatly appreciated by the engine drivers; in fact, every change in the grade of cylinder oil or in the method of application will be immediately noticed in the pull required to shift the reversing lever.

Metallic Packing Glands.—Fig. 153 shows a simple design. Metallic packing is superior to soft packing. The gland friction with metallic packing is appreciably less than with soft packing and there is much less danger of scoring taking place.

It is essential when using metallic packing that the deflection and movement of the piston rod can take place without setting up any undue pressures in the packing, which should exert only a slight pressure against the piston rod. This is accomplished by ball joints and annular "floating spaces" round the packing.

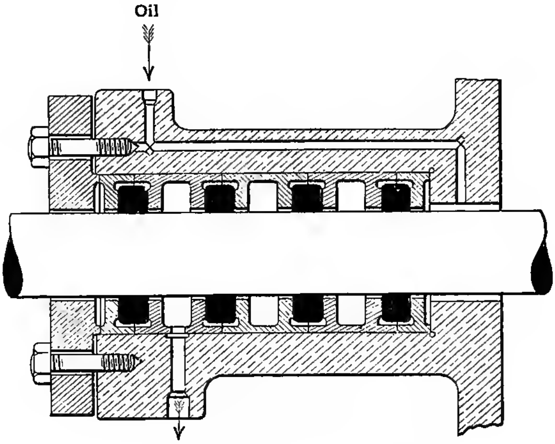


Fig. 153.—Metallic packing.

Metallic packing is always employed in the case of superheated steam and also in the case of high pressure saturated steam in large engines.

When the atomization method of lubrication is employed with saturated or moderately superheated steam, it is frequently unnecessary to lubricate the metallic packing direct. In the case of highly superheated steam, however, it is always necessary to have a direct feed of cylinder oil into the metallic packing. Only the highest grade of cylinder oil should be used for this purpose and should be fed uniformly and sparingly, as the excess oil remains stagnant in the casing, which holds the packing, and being exposed to high temperature the oil is inclined to bake into carbonaceous deposits.

DEPOSITS

Experience shows that in most cases where deposits develop in steam engines, the cause can be traced back to the boiler conditions. The deposit, if analyzed, will usually prove to be "boiler matters" amalgamated with a greater or less percentage of cylinder oil, decomposed oil, iron and oxides of iron.

Deposits Due to Dirty Feed Water.—Where the feed water is taken from rivers, it should be taken from as clean a place as possible and impurities should be prevented from entering the water supply. In rainy weather the rivers are swollen and muddy, and if dirty feed water is introduced into the boilers they are apt to prime, and the impurities will be carried over with the steam and cause deposits.

In India the river water contains some very fine suspended matter; this silt gets carried over with the steam when the boilers prime and causes deposits inside the engines. It will appear that heavily compounded oils have proved successful in preventing such deposit from caking and hardening, whereas with mineral or only slightly compounded oils the deposit becomes hard and very troublesome.

Example 28.—A 500-horsepower, horizontal, tandem, compound steam engine, using slightly superheated steam, had been lubricated satisfactorily with a good grade of dark cylinder oil. After an economizer breakdown, trouble immediately started and a black deposit developed in the cylinders. The analysis was as follows:

Water	6.0 per cent.
Oil and volatile matter	43.4 per cent.
Metallic iron, oxides of iron, lime and traces of copper	50.6 per cent.

It was found that the feed water was of very poor quality and contained a large quantity of impurities. However, as it passed the Green's economizer before it entered the boilers, the economizer pipes had the effect of precipitating the impurities in the lower bends and the feed water was pumped into the boilers almost clean. A sample of impurities taken from one of the lower bends of the economizer piping was analyzed and showed a composition of oxides of iron, with a large percentage of carbonate of lime, silicates, and also traces of coal ash.

When the economizer broke down, the impure feed water was pumped direct into the boilers, and on the boilers priming, the steam carried the impurities over into the steam engine, which explains the trouble.

While on the subject of superheated steam, it may not be out of place to mention the necessity for good control of the temperature of the steam.

Example 29.—In one case trouble was experienced in a steam engine employing superheated steam, although the temperature of superheat, as indicated by the thermometer placed just in front of the engine stop valve, only showed 530°F.

When another thermometer was brought along it recorded a temperature 120 degrees in excess of this, showing that the old thermometer, probably on account of the superheat on occasions exceeding the normal, had been overheated. Such overheating will always produce a weakening of the bulb which means a lowering of the mercury in the stem, and *the thermometer therefore reads too low.*

Where a steam trap is not fitted or is of insufficient capacity, the boiler sludge will deposit in the corners and cavities of the valve chest, in the clearance spaces of the cylinder, behind the piston rings, etc. Where the oil is introduced into the main steam pipe and finely atomized, the greater part of the boiler sludge will be swept through the engine and the valve chambers, cylinders, etc., will keep cleaner than where cylinder oil is applied direct.

The following example shows the importance of fitting a steam separator.

Example 30.—An oil of good quality had been used on a steam engine employing superheated steam and giving every satisfaction. Without warning, trouble began. The oil carbonized in the cylinders and heavy wear of the internal surfaces was noticed. A sample of the black deposit was analyzed, and contained the following constituents:

Traces of lime (carried over from the boilers.)
56.4 per cent. metallic iron and oxides of iron, principally metallic iron, produced by wear.
12.8 per cent. free oil.
30.8 per cent. volatile matter, chiefly carbonized oil.

It was found that through an alteration in the pipe line some borings had dropped into the steam line, and were urged along with the steam. The trouble continued for a considerable length of time, until the last boring had disappeared. Afterward no trouble was experienced, the same oil giving the satisfaction it gave before.

Deposits Due to Impurities in the Steam.—The solid impurities in the steam are mainly two kinds, namely:

1. Iron oxides (rust) from the boiler, the superheater tubes, or from the steam line.
2. Boiler salts and boiler impurities carried over with the steam during periods of priming.

Rusty scale may come from the superheater tubes and the steam pipe. The cast-iron or steel surfaces in the tubes or pipes will in time be covered by a rusty scale produced by oxidation, as there is always a slight percentage of air mixed with the steam. Owing to the vibration of the steam pipes and to the expansion and contraction due to the temperature variations, this rust in time breaks loose, and is carried into the engines. The iron oxides from the superheaters is often in the form of a very fine black dust whereas the rust from the steam pipe is more coarse. The impurities, whatever kind they may be, when entering the steam engine adhere and cling to the oil film all over the internal rubbing surfaces. The result is the formation of a dark colored sludge or paste, which accumulates in the valves, valve ports and passages, the spaces between and behind the piston rings and on the piston faces.

In extreme cases the piston rings will be completely choked with deposits; they become inflexible in their grooves; they no longer perform their duty of preventing leakage of steam from one side of the piston to the other, and the result is excessive wear of the piston rings and the cylinder, also heavy loss in power due to the increased friction and steam leakage past the piston. The valves and pistons groan, and the various indications of excessive friction characteristic of the different kinds of valve motion will become apparent.

When using saturated steam, and particularly wet saturated steam, the washing effect of the wet steam has a tendency to remove the deposits from the high pressure cylinder and valves, but they are then frequently found in the passages leading from the high pressure cylinder to the low pressure cylinder, or in the latter.

Sometimes a liberal supply of oil or the use of a light bodied compounded cylinder oil will temporarily relieve the distress of the engine.

In the case of superheated steam, the deposits formed in the high pressure valves, valve chambers and cylinders, particularly when very heavy viscosity dark cylinder oils are used, remain there and are baked into hard, carbonaceous deposits, which are most objectionable and cause heavy wear. A liberal oil feed will only accentuate this trouble, as the excess oil simply decomposes and forms more deposits. The use of a light bodied compounded filtered cylinder oil will frequently help to loosen the deposits and remove them from the high pressure valves and cylinders.

In many cases where heavy carbonization has been experienced, great improvements have been brought about by introducing the atomization method of lubrication. It is obvious that, where oil is introduced direct to the various frictional surfaces, it takes time for it to spread; therefore more oil is required and it is to this surplus oil that the impurities particularly adhere. Where the cylinder oil is thoroughly atomized with the steam, it is spread to the best advantage over the internal surfaces; it presents only a thin lubricating film, and there is no surplus oil to which the impurities can adhere. Better atomization and distribution of the cylinder oil results therefore not only in greater economy, but also means cleaner lubrication internally, that is, less formation of deposits.

Where the steam is very pure, carbonization seldom occurs when good quality oils are used, not even if the oils are fed *direct* and not atomized. If, however, the steam is dirty, the impurities adhere to the oil film, and, due to the high temperature, a layer of oil carbon will be formed by oxidation. Later, a new layer of impurites will cover the layer of oil carbon, and another layer of oil will produce more oil carbon, so that if a crust of carbonaceous matter is examined it will frequently be seen to consist of alternate layers of impurities and oil carbon.

Compounded filtered cylinder oils of good quality will produce practically clean lubrication, notwithstanding dirty steam; such oils prevent the impurities from caking together with the oil, so that they are swept out of the cylinder with the steam.

Where the feed water is treated chemically and where a surplus of soda reaches the boiler and priming occurs, even a small quantity of soda in the steam will have a very deleterious effect on lubrication. The soda dries up the oil film and a more liberal oil feed is required when using saturated steam, whereas in the case of superheated steam a greater feed of oil will usually mean more trouble and increased formation of carbonaceous deposits.

When reheaters are installed between the high pressure and lower stage cylinders, the oil may be carbonized in these reheaters and if some of it is carried over it will cause deposits in the intermediate or low pressure cylinders.

Example 31.—The following analysis of a deposit taken from the valve chest of a 1000-horsepower horizontal steam engine is typical of deposits due to priming of boilers.

Iron and iron oxides	2.3 per cent.
(This represents slight wear of the internal surfaces and rust carried to the engine from the steam line.)	
Carbonate of soda, caustic soda and carbonate of lime	44.2 per cent.
(This has come from the boiler.)	
Oil and volatile matter, chiefly oil	49.2 per cent
Water	4.3 per cent.

Example 32.—On a colliery where the water used for boiler purposes was hard, the practice was to introduce soda direct into the boilers. Owing to this, and also to the fact that the boilers were worked rather at overcapacity, priming frequently occurred. It was found that when the steam was very wet and carried water containing boiler solids in suspension and various soluble salts, all these solids deposited themselves in the bottom bends of the superheater tubes, the water evaporating. When priming of the boilers ceased, the steam going through the superheaters carried the dry dust in the bottom bends into the steam engines, where the deposits had the effect of "drying up" the oil film, so that the piston rods appeared dry; groaning of valves and pistons was noticed, and could be stopped only with a very copious supply of cylinder oil. The cylinder oil was introduced into the main steam pipe through atomizers. Due to this, quite a large percentage of the deposit was swept through the engine with the exhaust steam and into an exhaust steam turbine. The oil and the boiler solids deposited themselves on the turbine blades and necessitated frequent cleaning, at the same time decreasing the efficiency considerably.

When a feed water softening plant was installed the priming of the boilers was entirely overcome and the troubles ceased.

A *chemical analysis of deposits* developed in steam engines will, as indicated in the examples, always be of service in tracing their cause. A very simple test which can easily be carried out is to take a portion of the deposit and burn it on a hot plate. The oil will burn away, and the residue, if consisting mainly of iron and rust, will indicate that rusty matters have been carried over to the engine or that wear is taking place; if the residue consists of chalky matters of a light color, or of a yellowish reddish color, it indicates priming of the boilers, the boiler salts being carried over with the steam into the engine. If the whole of the deposit burns away, it shows that the oil in use has produced oil carbon, and that either it is an unsuitable quality of oil, or the oil is used in excess or is not distributed in the best possible manner.

To avoid priming it is important that the feed water softening plant shall be in good working order and that the tendency of the boiler to prime be overcome or minimized by keeping a proper water level, by keeping the water in the boiler in good condition, and having sufficient boiler capacity, so that the boilers are not overloaded.

LUBRICATION OF CORLISS VALVE ENGINES

In the following the lubrication of Corliss valves will be briefly analyzed.

Fig. 154*A* and *B* illustrate the high pressure cylinder of a steam engine having Corliss valves. The piston (1) is shown in Fig. 154*A* as moving toward the left, the steam being exhausted through the exhaust valve (2) to the exhaust pipe (3) leading to the low pressure cylinder (possibly through a receiver). The steam coming from the steam pipe (4) into the valve chest (5) enters the cylinder, alternately passing the admission valve 6*a* or 6*b*.

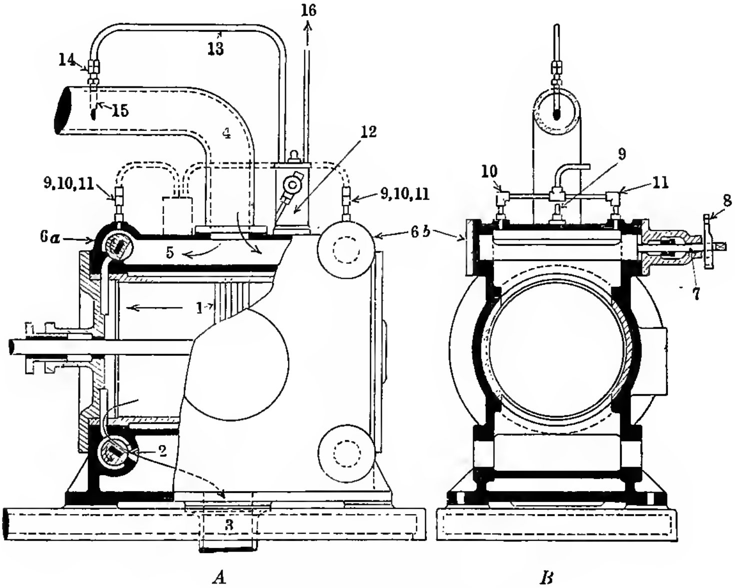


FIG. 154.—Corliss valve lubrication.

Fig. 154*B* shows a cross section of the cylinder and the valves. The admission valve (6*b*) is operated through the spindle (7) by means of the lever (8). The valve will require lubrication on the entire surface in contact with the valve face. How is this best accomplished?

The first attempt made to lubricate a valve of this description was by feeding the oil direct into the centre of the valve, as shown by (9) in Fig. 154*B*. What happened, however, was this: the oil which dropped on to the centre of the valve was immediately swept through the valve port opening. Although the valve needed to be lubricated along its entire length, the oil was not given a chance to do so, and only succeeded in lubricating a narrow strip of the valve and valve face just in the centre.

A slight improvement on this system is feeding the oil at the points 10 and 11 instead of feeding it at the centre. But in this case also the steam will sweep the drops of oil through the valve ports and prevent the oil from spreading over the entire valve face. The system is therefore not by a long way satisfactory, although it is advocated by the majority of engine builders.

Where, however, Corliss valves are very big, or where the steam is not very clean, or in cases of superheated steam, all sorts of difficulties and trouble may occur. The valves groan and wear. They may even stick, refusing to move, causing serious irregularities in the working of the engine. The cause of the trouble is bad lubrication, particularly of the two ends of the valves, the valve end rubbing hard against the end cover. It is quite evident that if it be difficult for the oil to remain on the middle part of the valve, it will be even more difficult for it to reach the two ends of the valves, where the oil is most needed.

Probably steam will constantly keep condensing and will reach the valve ends, but will tend only to wash away any oil that may be present, except when the steam itself has been thoroughly lubricated, and therefore practically becomes a lubricant. *In order to get the best results the steam must be lubricated.* In the illustration, a double feed mechanical lubricator (12) is mounted on the engine, actuated by some part of the valve mechanism, and discharging cylinder oil through pipe 13 leading to the check valve 14, the drops of oil trickling down inside the atomizer 15 being exposed to the central flow of steam.

In this way every drop of oil will be divided into thousands of the most minute particles, and will be intimately mixed with the steam, so that when the steam is admitted through the admission valve (6*a*) or (6*b*) it sweeps over the valve faces and seats and will deposit sufficient oil to lubricate thoroughly. Further, some of the oily steam will condense and carry oil to both ends of the valves and to the valve end rubbing against the valve cover. Oil pipe (16) carries oil to the low pressure cylinder.

Cases have been known where it was impossible to stop the groaning of a Corliss valve even with a feed of 120 drops per minute of good cylinder oil, and where the mere change of the oil feed from feeding "direct" on to the valve to feeding into the steam pipe had an almost immediate effect of silencing the valve, and doing this on a comsumption of between one and two drops per minute. It is the old story over again, that "a drop of oil in the right place is better than a gallon on the floor."

If the steam has free access to one end of the valve, and the access to the other end is restricted, wobbling of *exhaust valves* may occur at each stroke of the engine. The cause for this will be readily understood.

Knocking of the valve operating motions may be due to improper lubrication of the valves, but may also simply be produced by a loose joint somewhere. This can easily be detected by flooding one bearing after another of the external motion with oil. When the bearing which caused the knocking is excessively lubricated in this way, the knock, which ordinarily is sharp, will be deadened as the thicker oil film in the bearing will cushion the blow. Adjustment of the bearing in question should therefore generally overcome the trouble.

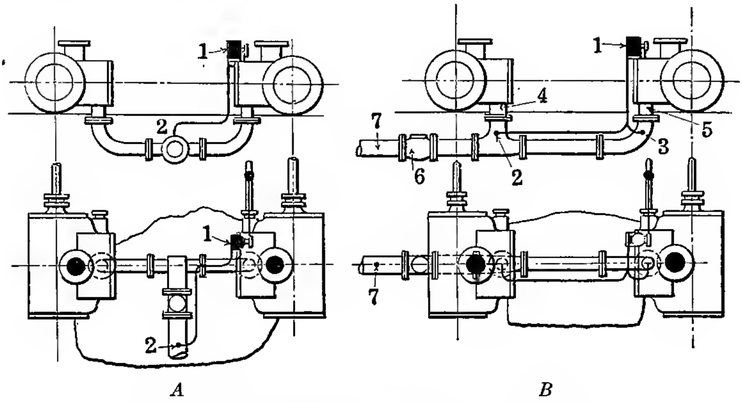
LUBRICATION OF COLLIERY WINDING ENGINES

The lubrication of colliery winding (hoisting) engines presents several interesting features. Many winding engines are internally lubricated by means of hydrostatic sight-feed lubricators feeding the cylinder oil either into the valve chest or valves, or into the main steam pipe. Winding engines are generally horizontal twin steam engines, the main steam pipe branching off to each engine, and usually a sight-feed lubricator is mounted on each branch pipe between the throttle valve and its respective engine. As winding engines work intermittently, it will be understood that when sight feed lubricators are in use *a good portion of the cylinder oil will be wasted,* as they continue to deliver oil during the periods when the engine is standing. As the sight-feed lubricators are generally mounted between the throttle valve and the engine, it will in such cases be found difficult to operate the throttle valve, and the *valve stem will be found subject to more or less wear owing to lack of lubrication.*

Hydrostatic lubricators are seldom equipped with atomizers, so that the drivers of winding engines generally complain of difficulty in operating the reversing lever, owing to heavy friction in the valves and glands.

It will also be found that in order to minimize wear on the valve stems and piston rods it becomes necessary to swab the rods or to lubricate them through a sight-feed drop oiler, dropping cylinder oil on the rods outside the glands. This is, of course, very wasteful, *as most of the oil is scraped off the glands and runs to waste.*

When a mechanical lubricator is used feeding the oil into the main steam pipe before the throttle valve, through an atomizer, one oil feed will do to supply all requirements for the internal lubrication of throttle valve, reversing engine and two cylinders, *if* the steam pipe comes to each cylinder by an equal branch as in Fig. 155*A*, in which (1) is the lubricator feeding cylinder oil into steam pipe at (2). But two feeds are necessary if the steam pipe is arranged as in Fig. 155*B*, for the greater inertia and density of the cylinder oil compared with that of the steam carries it past the branch pipe 4 of the near cylinder, most of the oil being carried to the right-hand engine.



A *B*

Fig. 155.—Lubrication of colliery hoisting engines.

Ordinarily, therefore, a two-feed lubricator should be fitted, feeding into the branches (4) and (5) respectively at the points (2) and (3).

If it be considered necessary to lubricate the throttle valve (6) automatically, an extra feed can, of course, be put in to deal with the throttle valve at (7); but if this valve is of the equilibrium type, a swab with cylinder oil on the valve rod at week-ends will suffice to keep gland and valve stem in good order.

The advantages resulting from this manner of applying the right grade of cylinder oil are many.

First.—There is no waste of oil, as it is fed into the main steam pipe in direct proportion to the number of revolutions made by the engine. The lubricator stops feeding when the engine comes to rest.

Second.—As the oil is properly atomized and distributed throughout the body of the steam, the main stop valve and the throttle valve will be lubricated, and therefore easier to handle, the wear will be overcome and the reversing engine will need no separate lubrication.

Third.—Each engine will receive its portion of the oil required for satisfactory lubrication and it will be found unnecessary to use the tallow cups which are often used to give an extra dose of cylinder oil direct into the cylinders when the oil is not properly atomized.

Fourth.—As the steam is thoroughly lubricated, the valve rods and piston rods when coming inside the steam chest or cylinder will be coated with a good film of oil, and thus receive their share of lubrication, which in turn will mean better lubrication of the gland packing, whether metallic or soft. Accordingly, less wear of the piston and valve rods will be apparent and the packing will have a longer life. It will generally be found unnecessary to apply cylinder oil externally to the rods.

Fifth.—Owing to the better lubrication of the valve glands and of the valves, the reversing lever will be easier to operate; and this is a point greatly appreciated by drivers of winding engines.

Sixth.—Owing to the better lubrication, which means less power consumed in overcoming the friction, the engine drivers find that they can shut off steam earlier when the cage is nearing the end of its journey, and they also find that they can accelerate the engines and the cage more quickly, or with less opening of the throttle valve.

Much the same remarks apply to steel-works rolling mill engines, which also work intermittently, and usually are reversing.

UNIFLOW STEAM ENGINES (STUMPF ENGINES)

The Stumpf engine has *one cylinder only;* steam of high pressure and high superheat expands right down to the condenser vacuum, the exhaust taking place through the piston uncovering exhaust port in the centre of the cylinder.

There are thus *no exhaust valves;* the piston is very long, so that the exhaust ports are uncovered only at the right moments. After the steam has been exhausted and the piston moves back it compresses the remaining steam and the clearance space when the piston is at the end of its stroke is very small, the intention being that the compression should rise quite up to the boiler pressure.

As the steam always exhausts through ports in the centre of the cylinder and always enters at each end alternatively of the cylinder, the temperature of the cylinder ends will be very high, and the temperature in the centre very low, the steam always flowing in the same direction; hence the name Uniflow Engines, as they are often called.

The Stumpf engine will give the same efficiency as an ordinary compound engine using superheated steam.

Owing to the small clearance great accuracy is necessary in manufacture and adjustment, and the valves must not leak.

The diagram Fig. 156 is taken from a uniflow engine suffering from two faults, namely, too small clearance (at that end of the cylinder) and leakage through the admission valve. It will be seen that the piston during the compression stroke compresses the steam that leaks in to a point far above the boiler pressure, partly due to the clearance space being smaller than intended. The effect of this high compression is that the steam in the compression space is heated far above the normal temperature; it may reach as high as 700°F. which has a very bad effect on the piston rod and the metallic packing. The piston rod may become so hot that the oil fumes and carbonizes badly.

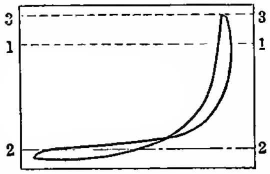


FIG. 156.—Faulty uniflow engine diagram. 1. Boiler pressure. 2. Atmospheric line. 3. Maximum compression pressure.

The best method to lubricate the Stumpf engine is by a six-feed mechanically operated lubricator, distributing the oil feeds as follows:

1. One feed into steam main before the stop valve, feeding through an atomizer.

2–3. Two feeds, one into each of the vertical steam pipes, also through atomizers.

4–5. Two feeds, one into each of the admission valves, as on light load the oil fed into the steam pipes will not be atomized and reach the cylinder in sufficient quantity.

6. One feed into the metallic packing of the piston rod.

As these engines run at a high speed the oil from the crosshead is likely to be splashed on the piston rod and get carried into the packing where it carbonizes. It is, therefore, always advisable to use cylinder oil for lubrication of the crosshead and sometimes also for the guides, unless special precautions are taken for preventing the bearing oil from getting on to the piston rod. (See Fig. 90, page 247.)

MARINE STEAM ENGINES

Marine steam engines are often poorly lubricated. This is because in times gone by disastrous accidents and troubles with boilers have occurred due to the cylinder oil used for internal lubrication being carried into the boilers. Instead of endeavoring to obtain full lubrication and yet avoid boiler troubles, marine engineers have gone to the other extreme and have, except in the case of engines employing superheated steam, confined themselves to swabbing the piston rods and valve rods only, with a liberal supply of cylinder oil through the tallow cups, when acute trouble made it necessary to apply this remedy.

By the well-known practice of "swabbing the rods" most of the cylinder oil is scraped off by the glands and runs to waste and only very little oil gets past the packings inside the engine, with the result that at best only the lower parts of valve chambers and cylinders are lubricated, and only very inefficiently.

Usually, the swab-pot has an open top and is exposed to coal dust, dirt and impurities, which may well give rise to trouble.

The virtue of well lubricated valves and pistons is not only that the frictional losses are reduced, but also that an oil seal is provided on the rubbing surfaces, which prevents or minimizes leakage of steam past the valves and pistons.

Marine engines employing superheated steam cannot operate without lubrication. Mechanically operated lubricators are provided, which feed the oil into the main steam pipe or direct to the valves, cylinders and packings, and if proper care be taken in selecting the correct quality of oil and in extracting the oil from the exhaust steam before it reaches the boilers, complete and efficient lubrication can be obtained without any danger of boiler troubles.

It would be desirable to employ this same system for marine engines using saturated steam. The quantity of oil required is very small indeed and the best results are certainly obtained by feeding a minimum quantity of the correct grade of oil into the main steam pipe before the engine stop valve, feeding the oil with such regularity as will ensure an unbroken oil film between the frictional surfaces.

Extraction of Oil. Exhaust Steam Oil Separator.—Whereas exhaust steam oil separators for a long time have been in very general use on steam engine plants ashore, they have not yet gained the same universal favor among marine engineers. Exhaust steam oil separators have, however, been designed which are compact and suitable for marine service.

If the bulk of the oil from the exhaust steam is removed by means of an oil separator, the result is that practically no oil is left in the steam to settle on the condenser tubes; this is a great advantage, as oily deposits in the condenser greatly impair its efficiency. It also means that the oil filters will more easily take care of the remainder of the oil and will not need cleaning so often.

Where the internal surfaces are well worn together and a good skin produced, it is sometimes possible, without any apparent inconvenience or trouble (owing to the wet steam generally carried) to operate marine steam engines for long periods without internal lubrication; but the internal friction is considerably higher than when proper lubrication is employed, and the wear produced on the piston rings often makes itself apparent by producing sharp edges, so that the rings act as scrapers on the cylinder walls, producing heavy wear all round. Further, *when no oil is used internally, the leakage of steam past the piston rings is often considerable.*

Example 33.—A remarkable instance was reported in "Power," for July 21, 1908. Four first-class armored cruisers of the United States Navy were put out of commission in a period of less than ten months by burnt-out boiler tubes. A thorough inspection of the main engines showed that only a very ordinary amount of oil was found in the exhaust steam. Examination of the auxiliaries, however, disclosed the trouble, which was located in the exhaust from six 100-kw. capacity lighting sets, which were in operation day and night. No lubrication was used in the cylinders, but a careful test showed the presence of 2.2 ounces of oil per hour in the exhaust from each engine. These engines were of the forced lubrication enclosed type, and the oil was drawn up from the crank chamber and crept along the piston rods into the cylinders. When this trouble was overcome by lengthening the distance pieces between the cylinders and the crank chamber top, and no oil was found any longer in the exhaust from these engines, *a great drop in the economy was at once noticed,* the steam consumption increasing to 36.3 lb. of steam per kw. hour, whereas under the old conditions the engines had passed the United States Navy requirements of "a steam consumption not exceeding 31 lb. per kw. hour," without lubrication of the cylinders.

However, as has been explained, the cylinders were really getting lubrication, although the oil was only a light-bodied oil from the crank chambers. A series of tests was then made on one of the redesigned engines, to determine the effect upon the economy of varying quantities of cylinder oil. The trials showed that when the oil feed was cut very fine the consumption of steam per kw. hour increased rapidly. The lowest steam consumption with ample internal lubrication was found to be 29.7 lb. per kw. hour, compared with 36.3 lb. per kw. hour when the engines were operating without internal lubrication. The difference in the steam consumption is partly due to increased consumption of power to overcome the internal friction, and partly to the heavy leakage of steam past the piston rings due to the absence of the oil film. Further, when the film of oil is not present on the cylinder walls of steam engines, radiation of the heat from the steam more easily takes place, the oil film being a bad conductor of heat.

These trials show very clearly that the economy of a reciprocating vertical engine is to a very great extent dependent upon proper lubrication of the cylinders.

When this is the case with vertical engines, it is obvious that proper cylinder lubrication is still more important with horizontal steam engines.

CYLINDER OIL CONSUMPTION

The oil consumption is dependent upon many conditions which will be briefly referred to in the following.

Large engines require less cylinder oil per B.H.P. hour than small engines.

Horizontal engines obviously need more cylinder oil than *vertical* engines, but care should be taken not to *underfeed* vertical engines, even if they do not "complain," as it means extra friction and loss of steam through leakage.

Large engines without tail rods require more oil than when tail rods are fitted, which relieve the pressure between the piston and the cylinder.

Steam Pressure and Temperature.—The greater the steam pressure, the higher the temperature, but when oils are chosen to suit the temperature, the oil consumption cannot be said to be influenced by the steam pressure or the steam temperature.

Superheated steam does not, as many appear to think, mean an increased oil consumption; speaking generally, it may be said that the consumption for engines employing superheated steam, other things being equal, need not be more, in fact may be slightly less than with dry saturated steam. Where the steam is dirty, the oil *must* be applied in the best possible manner and as *economically* as possible.

Saturated Steam.—Wet, saturated steam means an increased demand for cylinder oil, quite independent of whatever kind of impurities may enter with the wet steam.

The oil consumption figures in Table No. 17, given in grams per B.H.P. hour, may be considered approximately correct for average conditions. The higher figures in each case apply to smaller engines or wet steam conditions, while the lower figures apply to larger engines or engines employing dry or superheated steam, or vertical engines, marine engines in particular.

TABLE 17.—CYLINDER OIL CONSUMPTIONS IN GRAMS PER B.H.P. HOUR

Horsepower	Horizontal engines	Vertical engines
Steam engines below 400.........	1.0–0.3	0.6–0.15
Steam engines above 400........	0.6–0.15	0.4–0.05

SELECTION OF OIL

The object of internal lubrication in a steam engine is, firstly, to form a *lubricating film* between the rubbing surfaces and thus replace the metallic friction with fluid friction as far as possible; secondly, to form *an oil sealing film* in order to prevent leakage of steam past the valves, pistons and gland packings.

Only by feeding the *correct grade of high quality cylinder oil, specially selected to suit the operating conditions* of the engine, *applied in the correct manner*, to *the right place* and *in the right quantity*, will the steam engine continue to operate at its highest efficiency and with a minimum cost of renewals and repairs.

Perfect lubrication is therefore chiefly dependent on the *methods of lubrication employed* and the *selection of the correct oil* for each individual case.

If *too much oil* be used, lubrication under saturated steam conditions will not be any better than when the right quantity of oil is used; whereas under superheated steam conditions, the excess oil is detrimental, leading to the formation of carbonaceous deposits.

If *too little oil* be used, a satisfactory oil film will not be maintained between the frictional surfaces, so that not only will heavy friction and wear occur, but also excessive steam leakage.

There are a few vertical engines employing saturated steam which can be operated without the use of cylinder oil and without groaning. Non-lubrication will, however, mean excessive friction and excessive leakage of steam past the moving surfaces, which will be worth many times the cost of good lubrication.

If an *oil too heavy* in viscosity is used it will not atomize readily, resulting in poor distribution, and necessitating excessive consumption. Due to its heavy body, the fluid frictional losses will be higher than they need be, and if the steam carries over impurities to the engine, the use of such an oil will encourage the accumulation of deposits, particularly under conditions of high pressure and superheat.

If an oil *too light in viscosity* be used, it will readily atomize and distribute itself, but it will not be able to withstand the pressure between the rubbing surfaces; metallic contact will take place, resulting in excessive wear; also, excessive leakage of steam will occur, owing to the rubbing surfaces not being completely oil sealed.

With the *right quality oil* in use, correctly selected for the conditions and applied in right quantity, a satisfactory lubricating film will be maintained on all the internal surfaces. This film will be maintained with a lower consumption of oil than with any other grade of oil. Therefore the cost of lubrication will be low and the frictional losses, due to the fluid friction of the oil itself as well as the leakage of steam past the moving surfaces, will be reduced to a minimum.

For conditions of high pressure and superheat, the use of the right quality cylinder oil will also mean that, rightly applied and in the right quantity, the danger of the formation of carbonaceous deposits will be minimized, and the possibility of excessive wear much reduced.

In the following pages will be examined the conditions influencing the selection of the correct grade of cylinder oil, namely, steam pressure, size and construction, superheat, wet steam, load, impurities, exhaust steam.

Influence of Steam Pressure.—High steam pressure means high temperature, so that speaking generally, heavy viscosity oils are used for high steam pressures and low viscosity oils for low steam pressures (low pressure cylinders in particular).

Influence of Size, Speed, and Construction.—The weight of a piston increases very nearly as the cube of its diameter, but its bearing surface more as the square, so that large pistons in horizontal engines, when they are not supported by a tail rod, require very heavy viscosity oils. Smaller pistons and all vertical cylinders, other things being equal, will be best served with lower viscosity oils. High piston speed, which is found in most modern engines, particularly superheated steam engines, demands lower viscosity oils, so as to minimize the oil drag on the pistons.

Influence of Superheated Steam.—When steam of moderate superheat is used, it will enter the high pressure cylinder in a dry condition, but during the expansion of the steam in the cylinder it will cool, and toward the end of the stroke condensation will occur.

In the case of highly superheated steam, it is of the greatest importance that the oil should be thoroughly atomized in the body of the steam. There is no condensation, therefore no washing effect on the cylinder walls. The oil remains a long time in the high pressure cylinder, exposed to friction and heat; while ,therefore, only a small quantity of oil is required, it should be of such a nature that it will withstand the heat without appreciable decomposition and resultant formation of carbon.

Dark cylinder oils exposed to heat will form more carbon than filtered cylinder oils. The coloring matter, which is extracted during the filtration process consists of very high specific gravity bituminous matter (hence the reason why filtered cylinder oils have low specific gravities), which evidently decomposes and forms carbon.

It has been asserted by oil firms that dark cylinder oils are better lubricants than filtered cylinder oils. They are as a rule more *viscous*, which may perhaps excuse this fallacy of opinion, but a moment's reflection will make it obvious to anyone that the chief difference between filtered and dark cylinder oils is that the latter contain bituminous coloring matter, the greater portion of which is removed when manufacturing filtered cylinder oils; in other words, that the higher viscosity of dark cylinder oils is largely due to sticky non-lubricating ingredients, which are liable to decomposition exposed to heat and other influences.

As regards compounding superheat cylinder oils, the author recommends a small percentage, say, 4 per cent. to 6 per cent. acidless tallow oil, for most conditions of superheat, as the fixed oil improves lubrication appreciably.

The oil becomes very thin due to the high temperature, and the fixed oil improves the oiliness of a straight mineral oil; its presence is therefore nearly always desirable. No ill effects have ever been known to be caused by decomposition (formation of fatty acid) of such a small percentage of fixed oil. On the contrary, it will tend to prevent carbonized matter baking together and forming hard crusts, in this way making the nature of such deposits less dangerous.

Influence of Wet Steam.—Where the steam is wet it has a tendency to wash away the oil film on the internal surfaces. In compound or triple expansion engines, even if the steam is dry on entering the high pressure cylinder, the fall in pressure and expansion taking place produces condensation, so that the steam arriving at the low pressure cylinder usually is very wet.

It is obvious that the problem of lubricating the high pressure cylinder under dry steam conditions is different from lubricating the high pressure cylinder under wet steam conditions, or from lubricating the low pressure cylinders under very wet steam conditions.

In order to lubricate cylinders satisfactorily under wet steam conditions, the cylinder oil must readily combine with the moisture and cling to the cylinder walls, *i.e.*, it must be a *compounded* cylinder oil. It is therefore frequently desirable to use one grade of cylinder oil for the high pressure cylinder, and a different grade of cylinder oil (lower viscosity, more heavily compounded) for the low pressure cylinder in large compound or triple expansion engines.

Influence of Engine Load.—The greater the engine load the greater is the volume of steam passing through the steam pipe into the engine; and the higher its velocity, the better will it be able to break up the cylinder oil introduced through the atomizer.

As superheated steam does not atomize and distribute the oil so well as does saturated steam, engines employing superheated steam and likely to operate under light load conditions should have means for lubricating the internal parts direct in addition to introducing the oil where it can be atomized. Light load also means that the steam expands more in the high pressure cylinder, so that at the end of the piston stroke, the steam is much more moist (more condensation) than under full load conditions. Wet steam, calls for **compounded** cylinder oil, so that speaking generally, light load conditions demand *compounded oils of low viscosity.*

Influence of Impurities in the Steam.—It has already been mentioned how iron oxides, boiler salts, etc., have the effect of combining with the oil and forming deposits. The higher the viscosity of the oil the more difficult will it be to avoid such deposits, as such oils cling tenaciously to the impurities. Low viscosity oils are therefore to be preferred, where a great deal of impurities enter with the steam; this is particularly the case under conditions of superheat.

As the presence of impurities in the steam usually means that priming of the boilers is responsible, in the first instance, the steam will also be wet, so that oils heavily compounded are as a rule called for. There is one exception to this rule, this namely, that under conditions of high superheat, where it is only the *dry boiler salts* that reach the engine, and where these dry salts contain alkali (soda, for example), they will form a soap with the tallow oil present in the cylinder oil, which will aggravate the deposit trouble, whereas with a straight mineral oil such soap cannot possibly be formed.

For saturated low pressure steam conditions, there is no *great* difference between dark or filtered cylinder oils as regards formation of deposit by impurities; but for superheated steam conditions filtered cylinder oils are vastly superior, as under the dry high temperature conditions the bituminous matter in dark oils combines with the impurities, decomposes, due partly to oxidation (oxygen being taken from the iron oxides, for example) and forms hard brittle carbon.

Speaking generally, the presence of impurities under saturated steam conditions therefore calls for oils of *low viscosity* and *compounded* (filtered oils not particularly needed); whereas impurities under superheated steam conditions demand mineral oils of *low viscosity* and *filtered* (compounded oils may form soap).

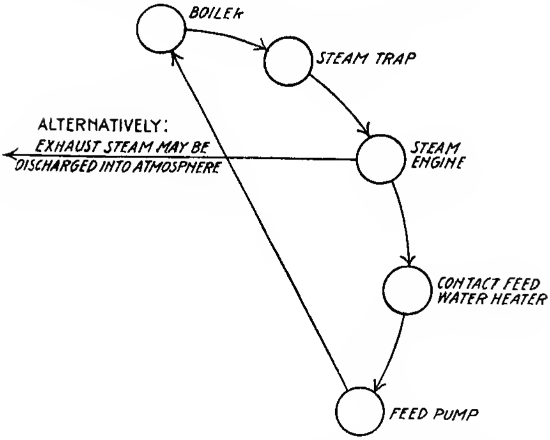
Influence of Exhaust Steam.—As mentioned elsewhere it is under certain conditions desirable to extract the oil from the exhaust steam and to eliminate as far as possible the danger arising from oil getting back into the boiler. All compounded cylinder oils are difficult to separate from the exhaust steam and from the feed water. All straight mineral oils are fairly easy to extract, but the dark oils combine rather intimately with the water, forming semi-emulsified clots of oil (which cannot be used again) and just a trace of the oil goes into a fine emulsion.

Well filtered straight mineral oils separate easily from the feed water and the oil can be recovered and used on less important work; the feed water will be practically free from emulsified oil.

It will, however, be found that more oil is required when using a straight mineral cylinder oil than when using a compounded cylinder oil, so that the best results will often be produced by using a slightly compounded filtered oil, as such an oil will give more efficient and more economical lubrication. The oil should be fed as economically as possible, so that there will be only a small quantity of oil present in the exhaust steam. Diagrams Nos. 1 to 6 may prove of interest in connection with the influence of exhaust steam on the selection of oil.

DIAGRAM No. 1

SMALL, NON-CONDENSING LAND ENGINES

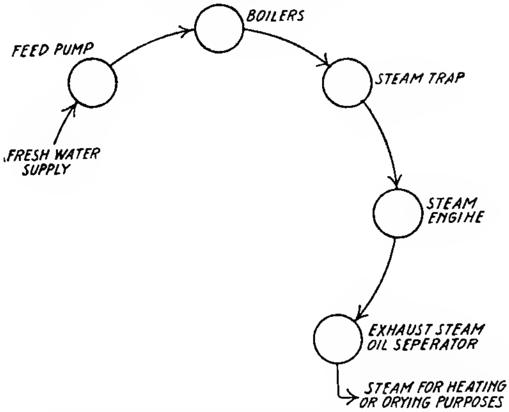


When the exhaust steam is discharged into the atmosphere, the cylinder oil may be chosen entirely with a view to suit the engine requirements.

When a contact feed water heater is fitted, straight mineral, dark or filtered steam cylinder oils must be used.

DIAGRAM No. 2.

LARGER SIZE NON-CONDENSING LAND ENGINES

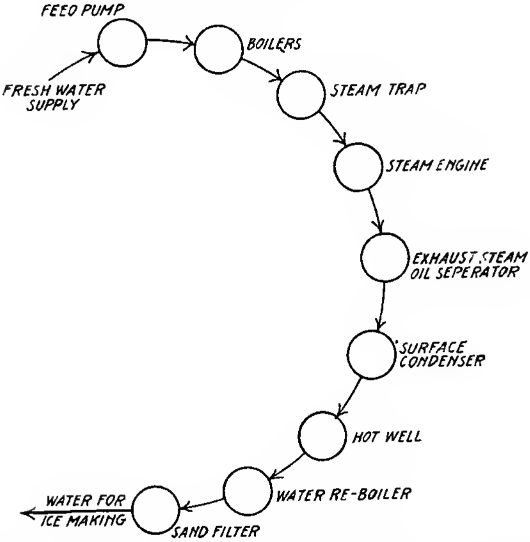


Straight mineral, dark or filtered cylinder oils must be used, or filtered oils, slightly compounded, used very sparingly.

With some vertical engines, aquadag has been used successfully, and the condensed steam from the heating system returned to the boilers. (See page 151).

Diagram No. 3

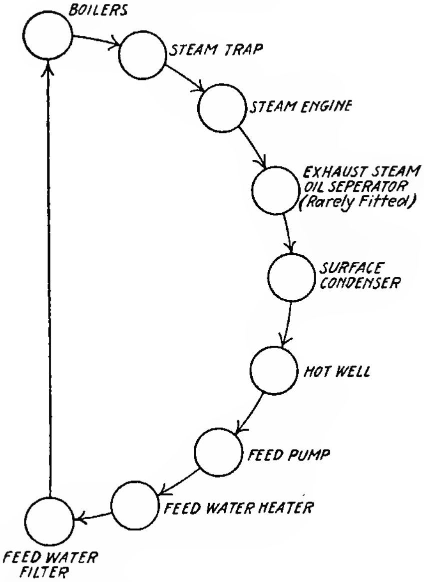
Surface-Condensing Engine in Ice-Making Plants



Straight mineral, dark or filtered oils must be used, or filtered oils, slightly compounded, used very sparingly.

Diagram No. 4

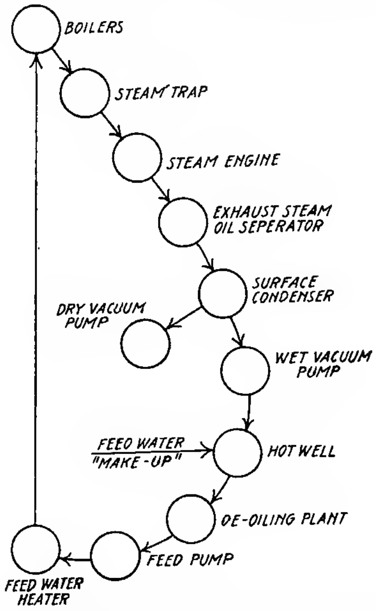
Marine Engines



Straight mineral, dark or filtered oils must be used, but when an exhaust steam oil separator is fitted, filtered oils lightly compounded are recommended and will give efficient lubrication; they *can* and *must* be used very sparingly.

Diagram No. 5

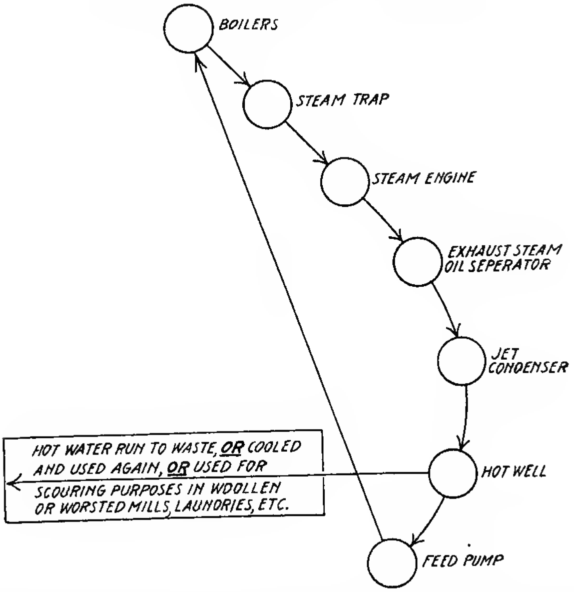
Large Surface Condensing Engines in Land Power Plants



The oil may be chosen entirely with a view to suit the engine requirements, as every trace of oil is eliminated from the feed water in the deoiling plant.

Diagram No. 6

Large or Small Jet Condensing Engines



When an exhaust steam oil separator is fitted, the oil may be chosen entirely with a view to suit the engine requirements; when no oil separator is fitted, and when the hot condenser water is used and comes in contact with textile fabrics, heavily compounded oils must not be used.

TESTING CYLINDER OIL

The oil should be tested for a period of at least three months in case the first few days' working has been satisfactory. It takes time for a good cylinder oil to produce a good working skin on the internal wearing surfaces; in fact, it takes much longer than for an unsuitable cylinder oil to destroy the good surface produced by a suitable oil. After a few days the consumption of oil should be gradually decreased and the minimum feed determined by which smooth and satisfactory running can be accomplished. At the end of three months' working on the reduced feed the cylinders should be opened up for inspection and should present a surface of rather dull appearance, coated with a film of oil.

The same remarks will apply to the appearance of valve rods, piston rods, valves and valve faces. Whenever a change of cylinder oil is made, irregularities may be experienced during the earlier period of its working, due to the new oil altering the wearing surfaces. Where unsuitable oils have been in use, and various deposits have accumulated behind the piston rings and in the glands, cylinder oil of a good grade will clean the surfaces. In such cases dirt may be carried out on to the piston rod and the new oil generally gets the blame.

PHYSICAL AND CHEMICAL TESTS

Before giving specific recommendations for different types of steam engines it may be well to examine briefly the physical and chemical tests most often referred to when judging the merits of cylinder oils.

These are: specific gravity, viscosity, flash point, percentage and nature of compound, color, cold test, and loss by evaporation.

Specific Gravity.—The lower the specific gravity for oils of similar viscosity, the purer is the oil. A highly filtered cylinder oil will be lower in specific gravity than one less purified. It must be kept in mind that these statements are true only because practically all steam cylinder oils are produced from paraffin base crudes, which are rather similar in nature.

Viscosity.—The viscosity taken at 212°F. is always useful. It has been often referred to in the preceding pages regarding "Influencing Conditions."

The admixture of tallow oil reduces the viscosity but increases the lubricating power of the oil—its oiliness. Filtered cylinder oils have lower viscosity than dark cylinder oils, but greater friction reducing powers. In comparing viscosities of different oils, one must therefore keep in mind whether they are compounded or more or less filtered.

Flash Point.—Although it is true that good cylinder oils for use with superheated steam do possess a fairly high flash point, yet it is by no means certain that a cylinder oil having a high flash point is suitable for work with superheated steam. The flash point is determined in the laboratory under atmospheric conditions. If the cylinder oil were to be tested under the high pressure carried in the steam pipe the flash point would undoubtedly be shown to be considerably higher, just as the boiling point of water, which at atmospheric pressure is 212°F., increases with any pressure above that of the atmosphere (for instance at 150 lb. per square inch the boiling point of water is 366°F.). This will explain why it is frequently possible to use a cylinder oil successfully for lubrication under superheated steam conditions where the temperature of the steam is even a *good deal higher than the flash point of the oil, measured under atmospheric conditions.*

Besides, there is practically no air present in the steam, and therefore no danger of the oil flashing anywhere. The temperature of the piston or valve rods, which are the only hot frictional parts passing out into the atmosphere, is always considerably lower than the maximum steam temperature, so that the flash point of the oil is never reached; and even if it were reached, nothing much would happen, there being no chance of an explosive mixture being formed of oil vapor and air, such as may be the case in air compressors.

Compounded Oils.—For most conditions, experience has proved that cylinder oils compounded with the proper kind and amount of fixed oil are more suitable than cylinder oils which are straight mineral. It is more particularly where steam engines are working with wet steam that the advantage of using compounded oils becomes apparent. Great care must be exercised in selecting the proper kind of fixed oil, as unsuitable fixed oils under the action of steam at high pressure and temperature decompose and develop acids and gummy residues which corrode the internal wearing surfaces and produce sticky, pasty deposits which unduly increase friction. Compounding mineral cylinder oils with the right proportion (from 4 per cent. to 15 per cent.) and quality of fixed oil, preferably acidless tallow oil, usually adds to its lubricating value and better results will be secured than if the cylinder oil was used without the admixture of fixed oil.

Color.—The more highly filtered a cylinder oil is the lighter will it be in color, so that light color (low Lovibond color number) usually signifies a high degree of purity.

Cold Test.—It is desirable that a cylinder oil keeps fairly fluid at ordinary engine room temperatures, especially when used through hydrostatic lubricators, with which difficulty is always experienced in feeding viscous cylinder oils at a regular rate of feed. When good mechanically operated lubricators are employed, the cold test of the cylinder oil is of less importance.

Loss by Evaporation.—Such laboratory tests as determine the percentage of evaporation when heating a sample of cylinder oil to a certain temperature for a certain time are of very little value in determining lasting properties of a cylinder oil, as these tests are carried out under atmospheric pressure and under conditions greatly different from those met with in actual work.

It will be understood from the above that the author considers the following tests of great importance.

Specific gravity and color—as indicating degree of purity.

Viscosity—to suit conditions of temperature and pressure.

Percentage and nature of compound—to suit wet steam condition and increase oiliness.

Cold test (equivalent to viscosity at low temperatures)—to ensure proper feeding of the oil through the lubricators.

THE USE OF TALLOW MIXTURES AND SEMI-SOLID GREASES AS CYLINDER LUBRICANTS

Acidless tallow oil and not *tallow* is generally used for compounding cylinder oils, because tallow is often acid or rancid and therefore inferior to acidless tallow oil. Tallow and black lead used to be a favorite cylinder lubricant at sea, when steam pressures were low; but with the advent of higher steam pressures such mixtures have almost disappeared. Yet it is not infrequent to find engine drivers both of stationary and locomotive engines in the habit of using tallow indiscriminately, particularly under wet steam conditions; it keeps the engine quiet and makes the cylinder oil last longer. The acidity produced by decomposition of the tallow (into fatty acid and glycerine) will however in time act most destructively on all cast-iron surfaces. A symptom often exhibited is that the acid "perforates" the skin on the piston rods, the rod becomes pitted and wears badly. It also causes deposits inside the valve chests and cylinders, composed chiefly of iron soaps and may soon cause sufficient corrosion and pitting to ruin the surfaces after a comparatively short life.

In locomotives a portion of the deposits reaches the smoke box exhaust nozzle and cakes, due to the great heat, closing the nozzle and causing a labored exhaust until cleared away.

Cast-iron, long exposed to the action of fatty acids from tallow becomes so crumbly that it can be cut with a knife like cheese. The metal is porous and filled with iron soaps, etc., which explains why it is so exceedingly difficult to introduce an oil, largely mineral in character, where tallow (or for that matter any fixed oil, such as rape oil—Colza—occasionally favored by engine drivers for troublesome engines), or cylinder oils containing a large percentage, say 20 per cent.–25 per cent. or more of tallow, tallow oil, or other fixed oil, has been in use for a long period.

The only way is to introduce the oil *very gradually* mixed with the old lubricant over a period of *at least* 3 *months*, gradually increasing the percentage so as to give the acid products of decomposition time to loosen, dissolve and get cleared away through the exhaust. If the oil is introduced too quickly, it will dissolve the deposits too rapidly, with the result that excessive scoring and wear inevitably take place, and a return to the old lubricant becomes necessary if the engine is not to suffer more serious damage.

In America semi-solid greases, containing more or less tallow, are not infrequently used as cylinder lubricants. They are more difficult to apply economically than a proper grade of cylinder oil, and cannot possibly give better lubrication, as they either contain a percentage of non-lubricating material, or, if they are rich in tallow and such like, give rise to troubles with corrosion of surfaces or with the feed water (too much compound). Weight for weight cylinder oil of the correct grade is always preferable, and besides it will be found that if the price per pound is compared with that of semi-solid grease, the latter is always dearer. The use of such lubricants cannot therefore be recommended from any point of view, except perhaps that of the manufacturer.

LUBRICATION CHART

The lubrication chart No. 10, shown on page 390, gives specific cylinder oil recommendations for all types of steam engines. Before describing how the chart is to be used, it will be necessary to describe what the various grades of cylinder oil represent.

Cylinder oils of four viscosity ranges, Nos. 1, 2, 3 and 4, have been found adequate for the lubrication requirements of all types and sizes of steam engines. These viscosity ranges are shown in Table No. 18, also the approximate specific gravities, flashpoints and cold tests, corresponding to these viscosities, for both filtered and dark oils.

There is no demand for dark oils of No. 1 viscosity, and it is not possible commercially to manufacture filtered oils of No. 4 viscosity, nor do the actual requirements call for such oils. Filtered oils of No. 3 viscosity are superior to dark oils of No. 4 viscosity as regards oiliness (which is more important than viscosity), but they are more expensive to manufacture. The various oils may also be straight mineral or more or less heavily compounded with acidless tallow oil.

There are a few dark cylinder oils marketed having higher viscosities and flashpoints than No. 4 viscosity range. Such oils are unnecessarily viscous, waste power, and easily carbonize and form deposits.

In Table No. 19 are indicated twelve grades of cylinder oils, six filtered oils and six dark oils, representing the author's recommendations based on practical experience with such oils on a vast number of steam engines.

TABLE NO. 18.—VISCOSITY RANGE, ETC., OF CYLINDER OILS

Cylinder oil	Saybolt viscosity at 212°F., sec.	Specific gravity		Open flash-point, °F.		Cold test, °F.	
		Filtered	Dark	Filtered	Dark	Filtered	Dark
No. 1 filtered	85–105	0.885	.....	500	...	40–50	.....
No. 2 dark, No. 2 filtered	115–135	0.887	0.900	525	520	50–60	40–50
No. 3 dark, No. 3 filtered	145–165	0.890	0.905	550	530	50–60	40–50
No. 4 dark	180–200	.....	0.910	...	580	...	50–60

TABLE NO. 19.—12 GRADES OF CYLINDER OILS

	Designation
No. 1 filtered cylinder oil, heavily compounded (10 per cent.)	No. 1 F.H.C.
No. 1 filtered cylinder oil, lightly compounded (4 per cent.)	No. 1 F.L.C.
No. 2 filtered cylinder oil, medium compounded (6 per cent.)	No. 2 F.M.C.
No. 3 filtered cylinder oil, medium compounded (6 per cent.)	No. 3 F.M.C.
No. 2 dark cylinder oil, medium compounded (6 per cent.)	No. 2 D.M.C.
No. 3 dark cylinder oil, medium compounded (6 per cent.)	No. 3 D.M.C.
No. 3 dark cylinder oil, heavily compounded (10 per cent.)	No. 3 D.H.C.
No. 4 dark cylinder oil, medium compounded (6 per cent.)	No. 4 D.M.C.
No. 2 filtered cylinder oil, straight mineral	No. 2 F.S.M.
No. 2 dark cylinder oil, straight mineral	No. 2 D.S.M.
No. 3 filtered cylinder oil, straight mineral	No. 3 F.S.M.
No. 3 dark cylinder oil, straight mineral	No. 3 D.S.M.

The twelve grades in Table No. 19 will be found in the first column of the Lubrication Chart No. 10, page 390. The other vertical columns refer to the conditions influencing the choice of cylinder oil. The black squares in each column indicate condition for which the cylinder oil (shown at the left extreme of the same horizontal line) is not suitable.

In order to find an oil suitable for a certain set of conditions, take a piece of paper and place it with its upper edge along the top

LUBRICATION CHART NO. 10

FOR STEAM CYLINDERS AND VALVES

	Size of Cylinders		Horizontal or Vertical Construction		Tailrod		Steam Pressure lbs./□″			Steam Temperatures Degrees Fahrenheit			Condition of Steam		Exhaust Steam Condition		
	Below 16″	Above 16″	Horizontal	Vertical	With	Without	Below 100	Between 100 & 110	Above 110	Below 100	Between 100 & 325	Above 325	Wet	Dry	Non-Condensg or Jet Condensg	Surface Condensg good means for Extracting Oil	Oil Elimination Particularly Important
1FHC		■						■	■			■		■		■	■
1FHC			■									■		■		■	■
1FHC			■			■					■	■		■		■	■
1FHC			Also Recommended for Large Low Pressure Cylinders with Wet Steam														
1FLC						■					■	■	■				■
1FLC						■		■	■			■	■				■
1FLC			■						■			■	■				■
2FMC			■				■					■					■
2FMC				■			■					■					■
2FMC		■	■				■			■	■						■
3FMC	■		■				■			■							■
3FMC	■			■		■	■			■							■
3FMC	■						■	■			■	■					■
2DMC									■		■	■				■	■
3DMC							■					■	■			■	■
3DHC	■						■					■		■		■	■
4DMC	■						■	■				■				■	■
2FSM or 2DSM									■			■			■		
3FSM or 3DSM	■						■								■		

NOTE 1.—For light load conditions choose an oil slightly lower in viscosity and/or more heavily compounded than the one indicated by the chart.

NOTE 2.—With impure steam (boiler's priming etc.) a filtered oil should preferably be used, and with saturated steam preferably compounded.

NOTE 3.—When the chart recommends more than one grade the one lowest in viscosity should preferably be chosen when a dark oil as well as a filtered oil is recommended, as will often be the case; the former unless there are special conditions (NOTE 2) may be preferred as it is (or ought to be) lower in price.

NOTE 4.—A straight mineral oil can always be used in place of the compounded oil recommended by the chart but it means an increased oil consumption as compared with a medium compounded oil of 50 per cent to 100 per cent the use of a straight mineral oil in place of a slightly compounded oil or the latter in place of a heavily compounded oil means an increase in oil consumption of 30 per cent. to 50 per cent.

NOTE 5.—From 10 per cent—15 per cent of compound may be required in case of (*a*) very wet steam in large engines, low pressure cylinders in particular; (*b*) heavily loaded Corliss valves or unbalanced slide valves; (*c*) very dirty steam, particularly saturated steam.

NOTE 6.—No. 2 FSM and 3FSM will separate easier from the exhaust steam and feed water than No. 2 DSM and 3 DSM and will give cleaner and better lubrication, particularly under conditions of super-heated steam and/or impure steam.

line, make a pencil mark on the edge of the paper corresponding to each set of conditions and opposite the condition found in the steam engine in question. It is important that a mark be made corresponding to all seven groups of conditions in order that the recommendation made by the table may be correct. Having marked the paper at seven places, move it down to the first horizontal line; if none of the seven marks clashes with (corresponds with) any of the black squares on this line, Cylinder Oil No. 1 F.H.C. (No. 1 filtered, heavily compounded is the correct grade of oil to use. If one or more of the black squares clashes with the pencil marks, move the paper down to the next horizontal line. If there are still obstacles in the way (black squares) move to the third line and so on until a line is found where there are no obstacles opposite the pencil marks. The correct oil will then be shown in column 1 of that particular horizontal line. Do not go from line 1 to line 5, because the first four lines all refer to No. 1 F.H.C.; they represent different sets of conditions and no lines must be missed.

LOCOMOTIVES. CYLINDERS AND VALVES

From a lubrication point of view there are two main groups of locomotives, namely, railway locos employed in more or less regular service on railways, and works locos, such as are employed in steelworks, mines, quarries, shunting locos, etc.

Works Locomotives.—It is often painful to see the crude way in which lubrication is provided in most works locos. Many small locos are only fitted with tallow cups, and at best some kind of hydrostatic lubricator—as a rule the cheapest possible—is installed.

With tallow cups, lubrication is always poor, whether the oil allowance is great or small. With hydrostatic lubricators there is always waste of oil, as they keep on feeding, quite independent of the actual requirements. The drivers are not so careful as railway engine drivers, and do not as a rule trouble to shut off the lubricator every time the loco stops for a little while. Mechanically operated lubricators, operated from one of the valve spindles, similar to stationary engine practice, will save a great deal of oil on all such locos and provide more uniform lubrication than hydrostatic lubricators.

It is necessary to fix the mechanical lubricator with heavy brackets to the engine frame, and take every precaution that vibrations from the engines are felt by the lubricator as little as possible. The oil should preferably be introduced by means of an atomizer (see page 346) into the steam pipe in the smoke box, before it branches off to each cylinder.

When the oil is thoroughly atomized, the steam lubricates both valves, cylinders and piston rods, so that there is no need for extra lubrication of the rods. But where hydrostatic lubricators or tallow cups are employed, it is necessary to have a swab or mop for the rod glands. Such swabs are made of worsted or cotton (lamp wicks), plaited and formed into a ring, placed round the rod and held in position by the gland nuts; they are preferably enclosed in a box to protect them from dust and grit.

Railway Locomotives.—Coming now to the other and more important group of locos, those employed in regular railway service, whether passenger or freight service, we find that there is one condition which vitally affects the lubrication question, namely, that when a train passes a down-gradient portion of the line, the steam is practically shut off; that is, the engine is what is termed "drifting" with a closed throttle. If the oil under these conditions were introduced into the steam pipe, there would be no steam to carry it into the valves and cylinders, and if the down-gradient were a long one the rubbing surfaces would soon be devoid of lubrication.

During periods of drifting another complication occurs; the valves and pistons act like pumps and may create a vacuum ranging from 3 to 9 lbs. on the exhaust side which sucks ashes and soot into the cylinders from the smoke box. These impurities adhere to the cylinder oil and may form very objectionable crusty deposits in the valves, passages and cylinders. To overcome this difficulty, good practice requires either that the driver shall very slightly open the regulator when the engine is drifting or that a bye-pass valve (snifting valve, anti-vacuum valve), be provided, which automatically admits sufficient *steam* to the cylinders, so as to kill the vacuum and prevent the entrance of soot and ashes. Some snifting valves are designed to admit *air* instead of steam or *air and steam.* This practice is permissible for saturated steam, but with superheated steam the internal temperatures are so high that the air immediately oxidizes the oil and causes the formation of sticky, carbonaceous deposits.

It will now be realized that the condition of "drifting" necessitates the oil being introduced straight into the valves and cylinders. With saturated steam an oil feed to the cylinder is seldom required, but with superheated steam the cylinder feed cannot be dispensed with.

Speaking generally, 75 per cent. of the oil is preferably introduced into the valve chest and 25 per cent. into the cylinders.

As to the method of introducing the oil, there can be no question of the superiority of the atomization system over all other systems, and for superheated steam conditions in particular, as will be explained presently.

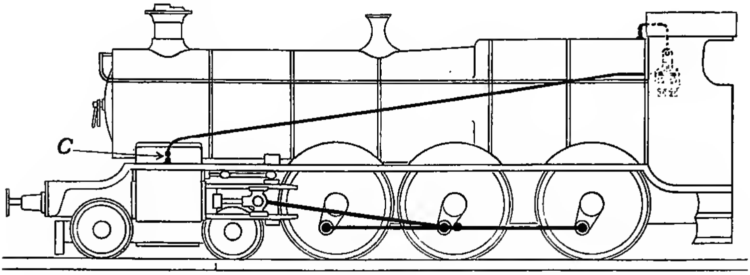


FIG. 157.—Hydrostatic loco lubricator.

LUBRICATORS

Both hydrostatic displacement lubricators and mechanically operated lubricators are employed and there have been great controversies of opinion as to their respective merits.

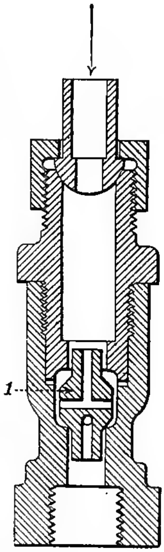


FIG. 158.—Choke plug *C* (Fig. 157).

Hydrostatic Lubricators.—These lubricators are fitted in the cab, as shown in Fig. 157. Steam is admitted to the lubricator, condenses in the upper part of same; by gravity displacement the oil is forced up through sight feeds, and through long feed pipes it finally reaches the valve chests and cylinders. The best hydrostatic lubricators admit saturated steam to the feed pipes. The steam keeps the pipes hot and more or less emulsifies the oil, so that it is readily atomized in passing through the choke plug (C) always fitted before the oil enters the engine. Fig. 158 shows in detail such a choke plug; a valve (1) is kept constantly vibrating on its seat by the motion of the engine; the mixture of oil and saturated steam passes through fine channels and cross channels in the valve, or between the valve and its seat; the churning action thoroughly atomizes the oil; in fact, what is produced is really oily steam—"Scotch fog"—which spreads quickly over the internal surfaces and forms the best means by which the oil can be distributed.

If the choke plugs were absent, the difference between the boiler pressure and the pressure in the valve chest or cylinder would cause waste of steam through the oil feed pipes, particularly when drifting. The choke plugs are therefore required for the dual purpose of checking the steam flow and atomizing the oil.

When applied to locos employing *saturated steam,* two feeds, one for each valve chest, will suffice for most high pressure engines; but the cylinders in large engines will occasionally be better lubricated if they are lubricated direct, so that a four-feed lubricator is required. An extra feed may be added for feeding the air pump cylinder. This oil feed must not have steam admission; the oil drops through a sight feed and gravitates to the air cylinder.

For *superheated steam* conditions *hydrostatic lubricators* are almost exclusively used in the United States and Canada. Some British railways are also using them and getting good results.

Although the lubricators first fitted had a great number of feeds, it seems now to be an established fact, that for all two cylinder engines one feed into each valve chest (into the middle with inside steam admission, or a divided feed into both ends with outside steam admission), one feed into each cylinder, one feed divided to the tail rods, and one feed for the air pump, making six feeds in all, will provide proper oil distribution. For four cylinder engines more feeds are required and it is advisable to fit two lubricators, one for either side.

In the United States the oil feeds on each side are often divided to serve both valve and cylinder, but in view of the uncertainty as to which path the oil will choose, it seems better practice to feed the valve and cylinder by separate feeds. If feeds are to be divided it would be better to divide one feed for both valves or for both cylinders, as one may then with better reason expect a fair distribution of the oil.

The division of feeds must, of course, be done *after* the oil has passed the choke plugs. As to British practice, at least one railway has divided the cylinder feed without any apparent ill effects, but the feeds to the valve chests have not to the author's knowledge been divided. As the greatest amount of oil has to be fed to the valves, this practice appears to be sound and preferable to the American practice of dividing the feeds, which certainly introduces an element of uncertainty.

Mechanically Operated Lubricators.—Mechanical lubricators have a container from which the oil pumps draw the oil; the container, therefore, is not under pressure, and can easily and quickly be refilled with oil. Filling a hydrostatic lubricator with oil is more complicated, as the water first must be emptied out, and there are several valves to look after every time to ensure correct working of the lubricator when starting up again. Mechanical lubricators start feeding as soon as the engine starts, and stop feeding with the engine, so that no oil is wasted while the engine is standing. Hydrostatic lubricators must have their oil feeds started about ten minutes before the running, and they keep on feeding while the engine is standing or running slowly.

Mechanical lubricators feed the oil according to the speed of the engine, whereas a hydrostatic lubricator will feed approximately the same amount of oil whether the engine goes fast or slow, whether on an uphill or downhill gradient. When superheated steam was first introduced on the Continent mechanical lubricators were thought necessary; the principle of atomization was not understood or appreciated and as a result the great majority of locomotives in Europe, South Africa, India and in the East generally are fitted with mechanical lubricators without any attempt being made to atomize the oil. Numerous troubles with excessive carbonization, heavy wear and friction, are recorded, too numerous to be disregarded.

What happens is that the oil is injected unatomized into the valves and cylinders; it is very viscous and spreads only with difficulty; the oil is exposed to high temperature, to the oxidizing effect of hot smoke box gases and boiler impurities and to contamination from soot and ashes. As a result, particularly if the oil consumption is liberal, very tenacious, sticky or hard carbonaceous deposits are formed. The rubbing surfaces become poorly lubricated and heavy friction and wear take place. Frequent cleaning of valves and cylinders and keeping the oil consumption as low as possible will assist in preventing trouble, but even with the best possible attention to these points, it is difficult to ensure perfect lubrication.

Of course, if suitable anti-vacuum valves are fitted, if the boiler water is of good quality, and priming only slight or absent, it is possible to get good results with mechanical lubricators. But results in practice generally fall short of perfection, and it is under more or less unfavorable conditions that feeding the oil unatomized is almost sure to give trouble. The fault is not with the mechanical lubricators themselves. Stationary practice has long since proved that they are superior to and more economical than hydrostatic lubricators; the cause of most carbonization troubles is simply that *the oil is not atomized.*

The good results obtained with hydrostatic lubricators under superheated steam conditions have proved that if the oil is introduced as oil fog, saturated steam being the carrying medium, it has the effect of keeping the rubbing surfaces free from deposit. Whatever impurities may be drawn into the engine during periods of drifting are prevented from caking and expelled through the exhaust when steam is again admitted.

Experience has proved that perfect atomization is imperative, if carbon deposits are to be avoided with superheated steam.

The author believes he was the first to suggest the combination of mechanical lubricators with atomizing boxes (in a paper read before the Institution of Locomotive Engineers, London, on March 25th, 1915). Fig. 159 shows the author's design (only patented in the United Kingdom), which has proved efficient in overcoming carbonization troubles. The feed pipes (1) from the mechanical lubricator (L) discharge oil through check valves (2) into the atomizer box (3), shown in detail in Fig. 160. Saturated steam is supplied through an auxiliary pipe (4) and causes the oil to be preliminarily atomized through the sawslits of the atomizer (5), the mixture of oil and saturated steam is finally atomized in passing through the choke plug (6).

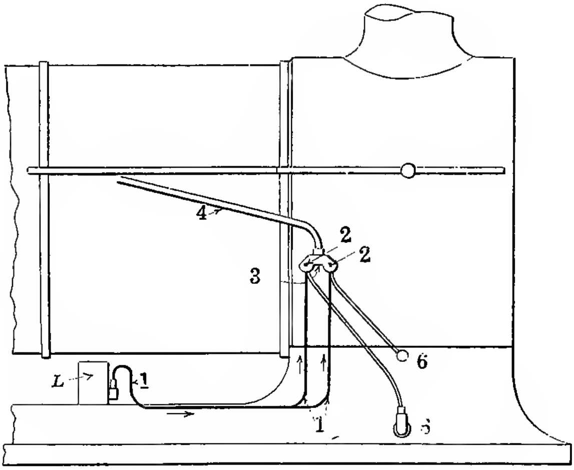


Fig. 159.—Thomen's atomizer arrangement.

It will thus be seen that the steam has an unobstructed flow through the atomizer box and each feed gets its fair share of the steam supply. The number of oil feeds required is exactly the same as with a hydrostatic lubricator. Without the atomizer box, piston valves require two oil feeds, one for each end, but with the atomizer box one feed for the centre, or one feed divided for each end, as the case may be, will suffice.

The combination of a mechanical lubricator with a suitable atomizer box, in the author's opinion, offers the chief advantages of the best types of hydrostatic lubricators with all the advantages of mechanical lubricators. Only those oil feeds requiring to be atomized are carried to the atomizer box. Oil feeds for feeding oil under pressure to the axle boxes may be taken from the lubricator, and if need be, the lubricator can be made with two compartments, so that a separate oil—axle oil—can be used for the bearings, and cylinder oil for the valves and cylinders. A hydrostatic lubricator can, of course, not be arranged to feed pressure oil to the axle boxes.

Mechanical lubricators are either fitted in the cab near the driver or on the framing near the main points of lubrication.

Motion may be taken from the back axle or from one of the rods, as shown in Figs. 161 and 162.

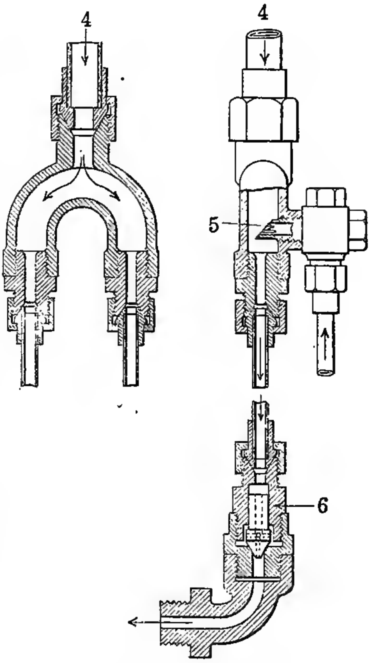


Fig. 160.—Atomizer box.

The check valves should be designed to avoid steam leaking back, and the vibration calls for special care; ordinary mitre seated valves are not satisfactory. Fig. 163 shows one designed by the author, which has proved efficient under trying conditions. It will be seen that the spring operating the valve is on the oil side and not exposed to the steam; the valve has to be lifted until the cylindrical part is above the seat before the oil will be discharged.

When oil is not pumped through the valve, the cylindrical portion below the head forms an effective seal against the entrance of steam into the oil pipe. By unscrewing the cleaning and testing plug a straight passage is disclosed for cleaning the oil passage leading into the valve or cylinder. This plug is screwed back when testing the oil feeds. There are three oil holes below the head, through which the oil will exude.

A similar type of check valve should also be used in the oil pipes from a mechanical lubricator to the axle boxes. The check valves should be fitted in accessible positions and as near the axle boxes as possible.

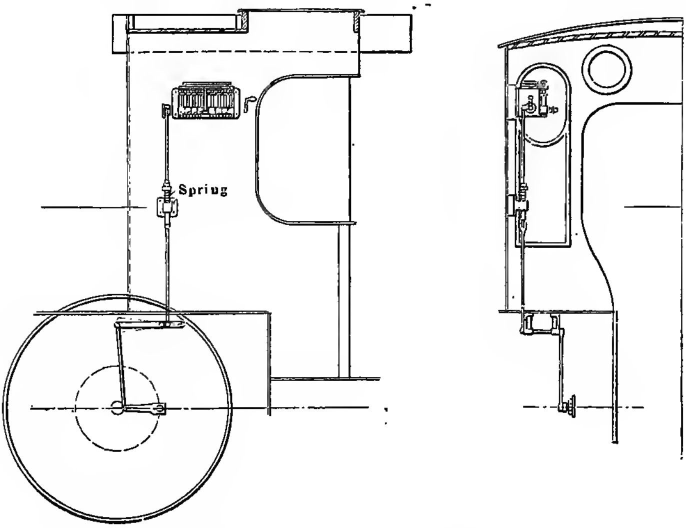


FIG. 161.—Back axle motion for mechanical lubricator.

Mechanical lubricators for locomotives, particularly when placed on the framing, should be provided with a steam heating arrangement, as, if the cylinder oil becomes very thick or congeals,

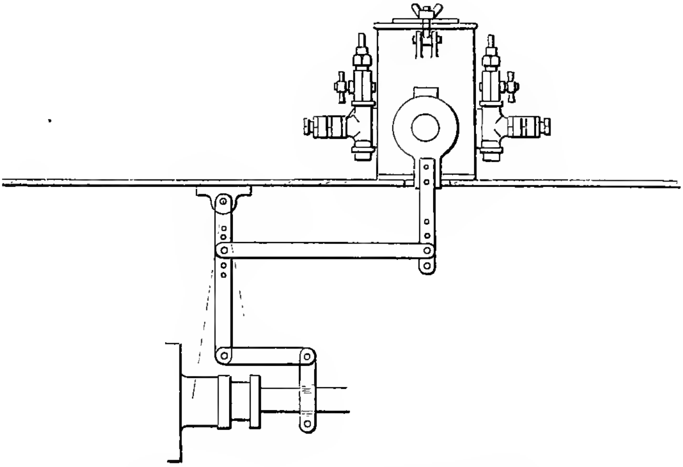


FIG. 162.—Rod motion for mechanical lubricator.

the oil feeds will be considerably reduced or stop altogether. As to placing the mechanical lubricators, they are undoubtedly best placed in the cab, where the lubricator is under the eye of the driver and stoker, and where each feed to each part of the engine can be properly controlled and regulated. This also makes it possible to give extra oil when required by having a flushing handle on the lubricator, by means of which all the oil feeds can be flushed. Where mechanical lubricators are placed on the frame, the driver cannot control and watch the feeds from the cab. If one of the feeds gets out of order, he will not be able to recognize this before the engine gives audible notice by grunting, or otherwise, and then a great deal of damage may already have been done.

It is felt by some engineers that the drivers should not be allowed to adjust the feeds when once set by an expert in the running shed, or during a couple of days' service on the road. The lubricators can of course be arranged with locked adjustments, but the drivers should in any case be enabled to watch the sight feed glasses and *test* the oil feeds; they should also have access to the suction valves and to the flushing arrangement.

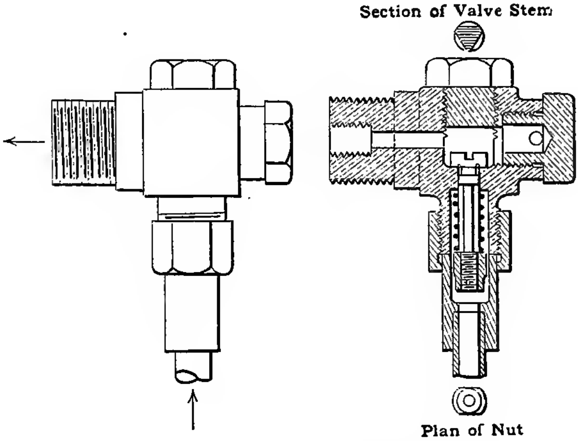


FIG. 163.—Locomotive check valve.

The combination of a mechanically operated lubricator with an atomizer box appears to be the best solution for lubrication of all locomotives in those outlying countries which employ native drivers, as it is desirable that the lubrication be as automatic and foolproof as possible and the control largely taken out of the driver's hands.

For those countries in Europe and America where intelligent drivers are available, the hydrostatic lubricator, with intelligent care, is capable of giving good service, and it will probably continue to be much used for saturated steam conditions. As however the consumption of oil with mechanical lubricators can be automatically kept nearer the actual requirements than with the hydrostatic lubricator, which requires frequent and intelligent adjustment by the driver, it would not be surprising to find the mechanical lubricator gaining in favor for saturated steam service. For superheated steam conditions the author thinks that the development will certainly be in favor of the mechanical lubricator, due attention being paid to the atomization principle.

LOCOMOTIVE CYLINDER OILS

Most locos operate with rather high steam pressures, ranging from 140 lbs. to 225 lbs. per square inch.

Most works locos have slide valves, but many railway locos have piston valves. Slide valves have been used with a moderate degree of superheat, but for high superheat piston valves are universally adopted, and in most cases also tail rods. Piston rings and pistons wear much better when tail rods are fitted. It is not considered advisable to exceed a steam temperature of 650°F.

In the early days much trouble was caused by the growth of cast iron when exposed to superheat temperatures. For a long time it was thought that the cylinder oil was to blame for the excessive wear and the many cracked cylinders, etc., but eventually the swelling was found due to the combined carbon in the iron. A more suitable cast iron was discovered and solved the difficulty, and many railways found that good quality filtered cylinder oils, which they had previously used with saturated steam, served quite well also with superheated steam.

Owing to the wet steam conditions often met with in locomotives, or to bad water, or to the necessity of keeping an extra high water level before negotiating a long uphill gradient, experience had already taught some railways that well filtered green cylinder oils, compounded with from 6 per cent. to 10 per cent. of acidless tallow oil, gave cleaner and better lubrication on a much reduced feed as compared with dark cylinder oils, whether straight mineral or compounded. The majority of railways, however, still use dark cylinder oils for all conditions, because they are lower in price per gallon than filtered cylinder oils.

Experience has proved that locomotive cylinder oils should certainly be compounded. If the conditions as regards priming, drawing in soot, etc., are not too trying, dark compounded cylinder oils will give a reasonable amount of satisfaction, but under unfavorable conditions, compounded, filtered cylinder oils should always be preferred, as they maintain the valves and cylinders in a much cleaner condition, which is worth a great deal from both a frictional and a wear-and-tear point of view.

For works locos fitted with poor lubricators, it is usually a waste of money to use filtered cylinder oils and dark compounded oils are recommended. The use of tallow should be discouraged, but it will often be found that collieries and steel works buy low priced, straight mineral, dark cylinder oils, that the locomotives use the oil extravagantly, and yet the lubrication is so poor, that engine drivers get tallow (or if they are not allowed to have it, get it all the same) to keep their engines quiet.

The bad effects of using tallow are mentioned page 387. Locomotive cylinder oils should obviously have good setting points, so that low setting point, filtered cylinder oils should be recommended which will flow freely in the lubricators and give a uniform feed. Compounded filtered cylinder oils will also lubricate the air pump cylinder satisfactorily, if fed sparingly, and very little oil vapor will be carried over with the compressed air into the air brake system.

The *consumption of cylinder oil* required for full lubrication varies from ¼ pint to 1¼ pint per 100 miles, according to the size of the locomotive. The oil consumption for the air pump varies between ¼ pint and ½ pint per 100 miles and should be kept as low as possible.

Where an engine has a long continuous run to make, it is good policy for one shift of driver and fireman to hand the engine over to the next shift with the lubricator *filled with oil;* in this way control of the various drivers' oil consumption is made quite easy.

LUBRICATION CHART No. 11

FOR LOCOS

Works Locos. [1]	
Small locos	Cylinder Oil No. 2 D.M.C.
Larger locos	Cylinder Oil No. 3 D.M.C.
Railway Locos.	
Saturated steam	Cylinder Oil No. 3 F.M.C. or No. 3 D.M.C.
Superheated steam	Cylinder Oil No. 3 F.M.C.

NOTE. [1]—For very wet steam, the same grades are recommended, but with 10 per cent. of compound.

CHAPTER XXV

BLOWING ENGINES AND AIR COMPRESSORS

Compressed Air.—Compressed air is used for a variety of purposes—for supplying blowing air to blast furnaces and Bessemer converters; for operating pneumatic tools, such as pneumatic hammers, drills, riveters, etc., as used in engineering works, boiler shops, foundries, forge shops, shipyards, docks, and bridge building; for rock drills used in mines and quarries; for operating underground machinery in collieries, and for sinking tunnels and shafts. It is also used for operating different types of lifting and hoisting gear, railway car brakes, electro-pneumatic signals, and pneumatic-tube carrying service; for pumping water; for lifting and conveying liquids in breweries, distilleries and chemical works; for aerating oils in large edible oil refineries and for spraying paint.

Compressed air is employed for starting gas engines and other internal combustion engines; also for injecting and atomizing fuel oil under furnaces or in Diesel engines. Very highly compressed air is used for producing oxygen and liquid air.

TYPES OF BLOWING ENGINES AND AIR COMPRESSORS

Blowing engines supply large volumes of air at low pressure. Blast furnaces require air at 10 to 25 pounds per square inch; Bessemer converters require air at 20 to 30 pounds per square inch.

Blowing engines operate at low speeds, from 30 to 70 R.P.M. and are single stage machines; they are operated by either steam or gas engines; the gas engines are nearly always horizontal, two-stroke cycle engines, driving the air cylinder tandem fashion. When driving the blowing engines by steam engines, the steam and air cylinders are also usually placed in tandem. In horizontal blowing engines the piston nearly always has a tail rod. When the tail-rod support is not present, the whole of the weight of the piston is sliding on the bottom of the cylinder, demanding the use of heavy bodied oils.

Air compressors compress air to high pressures. Colliery air compressors compress large volumes of air to a pressure of from

60 to 80 pounds per square inch; they are sometimes single-stage compressors but more frequently they are two-stage.

The majority of compressors used for a variety of purposes, as enumerated above, compress air to a pressure of from 80 to 120 pounds per square inch. Small compressors operating at a high speed, are frequently single-stage machines up to a delivery pressure of 120 pounds per square inch. Large compressors are nearly always two-stage machines when the air pressure exceeds 70 pounds per square inch. Small or medium size compressors used in connection with semi-Diesel oil engines compress air to about 400 to 450 pounds per square inch and are two-stage machines.

Air compressors used in connection with Diesel engines compress air to a pressure of about 1000 pounds per square inch. (See Diesel Engines, page 525.)

Air compressors when used in connection with the production of oxygen compress air to a pressure of 2000 pounds per square inch and are usually four-stage machines. The types used for charging torpedoes compress air to 3000 pounds per square inch and are usually four- or five-stage machines.

Horizontal air compressors are usually steam driven with steam and air cylinders in tandem. Vertical air compressors may be driven by steam, by an electric motor, or by belt from a transmission shaft.

TABLE NO. 20

CLASSIFICATION OF AIR COMPRESSORS AND BLOWING ENGINES

	Air pressure, lbs. per. sq. inch	R.P.M.	Single or double acting
Blowing engines			
Blast furnace	10–25	30–70	Double acting.
Bessemer converters	20–30		
Air compressors (exclusive of	Diesel engine	compres	sors)
Small vertical			
Single-stage	Up to 120	300–500	Single acting.
Two-stage	Up to 450		
Small horizontal			
Single-stage	Up to 120	150–250	Double acting.
Two-stage	Up to 450		
Large vertical			
Single-stage	Up to 70	60–360	Usually single acting.
Two-stage	Up to 150		
Large horizontal			
Single-stage	Up to 70	40–150	Double acting.
Two-stage	Up to 150		

Blowing engines and air compressors may be classified as shown in Table No. 20. A compressor, whether it be a single- or a two-stage machine, is classified as small or large, according to whether the *volume of free air entering* the machine is less or more than 1000 cubic feet per minute.

AIR COOLING AND FILTRATION

Cooling.—As blowing engines only compress the air to low pressure, the amount of heat produced is not very great, so that blowing engine cylinders are practically never water cooled. In air compressors which compress the air to higher pressures and which operate at much higher speeds, the heat of compression is great, particularly around the outlet valves, through which the hot compressed air is discharged.

Cooling of the air compressor cylinder therefore becomes necessary, and under severe conditions, attempts are frequently made to cool also the parts in close proximity to the outlet valves. Without adequate cooling, the temperature would rise, causing unequal expansion and distortion of the compressor cylinder, valves and valve seats. The lubricating oil film between the piston rings, and cylinder walls would be thinned out, losing its sealing power, and the compressed air would leak past the piston. The discharge valves would not keep air tight (distortion due to heat) resulting in wire drawing and recompression of the air, charring of the lubricating oil, excessive carbonization, friction, and wear.

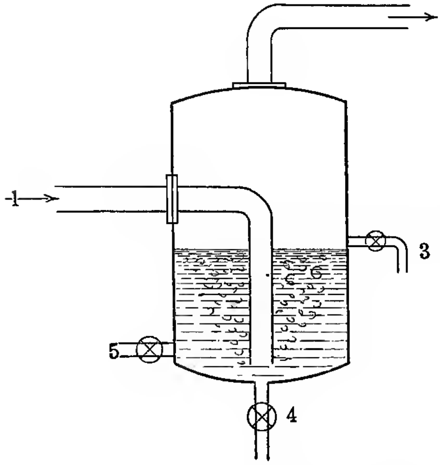
If air at a temperature of 60°F. is compressed in a one-stage compressor to 100 pounds per square inch, its temperature will theoretically increase to 485°F.; under actual working conditions the temperature will, however, be lower, due to the cooling effect of the cooling water jacket.

When air is compressed at a temperature of 60°F. to 100 pounds pressure in a two-stage compressor, compressing the air to, say, 35 pounds pressure per square inch in the low pressure cylinder, and cooling the air in an inter-cooler, the temperature of the air leaving the high pressure cylinder will be considerably lower, from 200°F. to 250°F., only in rare cases going as high as 300°F. This example shows the value, as far as lubrication is concerned, of compressing air in several stages when the final air pressure required is high.

The effect of the lower temperature is also that it takes considerably less power to compress the air (20 per cent. less in the case just mentioned), this forming another strong reason in favor of multiple-stage compressors.

The air is frequently cooled in an after-cooler when leaving the compressor. The air in cooling will deposit its surplus moisture and a large portion of the oil, which is thus prevented from reaching the receiver.

Occasionally a separator partly filled with water is fitted in series with or in place of the after-cooler (Fig. 164). The water assists in extracting dust and excess water from the air. A feed pipe and blow-off cock are fitted, as indicated, so that the water can be changed under pressure. Accumulated oil can be blown out from time to time through a scum cock. This may also be connected to an automatic trap.



1. Air inlet.
2. Air outlet.
3. Water level blow off cock.
4. Bottom blow off cock.
5. Water feed pipe connection.

Fig. 164.—Air purifier.

Filtration.—Where the air is charged with dust, a strainer or filter should be fitted. It may be made of screens of wire gauze and may contain cotton wool or fibre, in order ro retain the impurities. If the air is dirty and impurities reach the compressor, the impurities will adhere and cling to the oil film, baking together into carbonaceous deposits. The intake air should therefore be taken from outside the compressor room and from as clean a place as possible. The intake air may be freed from dust by passing through a container filled with 3-inch stones, coated with thick refuse oil and closed with grids to keep in the stones. The container and stones should be cleaned once or twice a year and the stones recoated with oil.

METHODS OF LUBRICATION

Feeding Oil into Air Intake.—In small and medium size air compressors, oil is occasionally introduced into the flow of air passing through the air inlet pipe. The air atomizes and carries the oil in the form of a fine spray into the cylinder. The oil is cold and the air is not a good carrying medium for oil, so that frequently this practice does not give the best results.

In horizontal air compressors or blowing engines, if the oil be introduced into the air intake, it will with difficulty reach the top portion of the piston, as it arrives there only by slowly wedging its way up around the sides of the piston. This practice is therefore uneconomical, as a large quantity of oil has to be fed in order to insure oil reaching the top of the piston.

In vertical air compressors the practice of feeding oil into the air inlet pipe has a greater chance of distributing the oil than in horizontal air compressors, but it is also here rather wasteful and not conducive to the best results.

Feeding Oil Direct.—Generally speaking, it is better to feed the oil direct to the frictional surfaces, feeding it sparingly and uniformly. In horizontal blowing engine or air compressor cylinders, the oil is introduced at the centre of the cylinder, either at one point, at the top, or at three points, one at the top and two lower down. It will then gradually work its way around the piston and form a complete sealing and lubricating film.

In vertical cylinders, oil is introduced at two points, front and back, or at several points evenly spaced around the cylinder. Each oil inlet to the cylinder should preferably be fed by a separate oil pump, so that each feed can be controlled with certainty. If one oil pump supplies several oil inlets to the cylinder, the oil will take the path of least resistance, and will not feed through those inlets which have become choked with dirt or deposit.

Splash from Crank Chamber.—In vertical enclosed high speed air compressors where the external moving parts are enclosed in a crank chamber, and lubricated either by means of the splash system of lubrication or the force feed circulation system, the oil is either splashed or forced to all parts requiring lubrication, so that no separate oiling of the piston is required. On the contrary, the difficulty is usually to prevent too much oil from passing the piston rings and getting to the top of the piston, where the oil, exposed to the high temperature and oxidizing effect of the air, will in time bake into a carbonaceous deposit.

The presence of a large amount of oil in the air also produces a similar deposit on the discharge valves, frequently causing great trouble.

VALVE LUBRICATION

Grid valves have large sliding surfaces which must be lubricated direct, by introducing the oil at several points, sparingly and uniformly, the oil gradually finding its way all over the sliding surfaces.

Flap valves have hinges which must be oiled, sparingly and uniformly, the oil being introduced through feed pipes passing through the cylinder head.

Leather disc valves need no lubrication, but the leathers must be kept flexible and in good order by occasional application of neatsfoot oil or lard oil.

Corliss valves (only used as suction valves) need lubrication, particularly at their ends where the valves have their bearing surfaces; the oil must be introduced direct to these ends, sparingly and uniformly. The practice of fitting grease cups supplying grease to the valve ends is not to be recommended, partly because grease spreads only with difficulty over the rubbing surfaces and partly because it bakes together with the impurities in the intake air, into a pasty, sludgy deposit, causing excessive friction and wear; some of the grease will reach the valve chamber, and even the cylinder, where it will bake together with impurities and cause an objectionable varnish-like deposit.

Poppet valves usually get sufficient lubrication from the oil in the air.

Plate or disc valves require no lubrication.

Bucket valves themselves require no lubrication, but their spindles must be sparingly lubricated.

Lubrication of external parts is by means of splash oiling or force feed circulation in the case of all high speed enclosed type air compressors; in open type air compressors any of the many systems employed for bearing lubrication may be employed and do not call for any special comments.

With splash oiling it is very important that the correct oil level be maintained, so that an adjustable overflow should preferably be fitted to the crank chamber.

Owing to the high efficiency of the force feed circulation oiling system and to the vertical construction, vertical air compressors may operate at much higher speeds than horizontal air compressors, as indicated in Table No. 20, page 403.

Care should be taken that the piston rings and oil scrapers on the lower part of the trunk pistons be pegged and in good order; they will then wear to a fit with the cylinder and keep oil tight and compression tight.

In vertical enclosed type air compressors employing the force feed circulation oiling system, the oil pressure should not exceed 5 to 15 pounds. With excessive oil pressure too much oil spray is formed and too much oil is inclined to pass the pistons, particularly so when the governor operates by throttling the intake air, as the high vacuum created in the cylinders tends to draw the oil past the piston rings.

Splash guards fitted over the crank webs and pegging the piston rings will assist materially in reducing the oil consumption.

LUBRICATORS

Usually sight feed drop oilers or mechanically operated force feed lubricators are employed.

Sight feed drop oilers are subject to considerable variation in oil feed. If the containers are full, they will feed, say, three drops per minute; when they are nearly empty, they will feed, say, one drop per minute. They also vary with the temperature of the oil, the feed increasing when the oil gets warm and thin; in addition, when they are adjusted to feed a very small amount of oil, which is required in air compressor practice, grit or dirt may easily choke the needle valve controlling the oil feed.

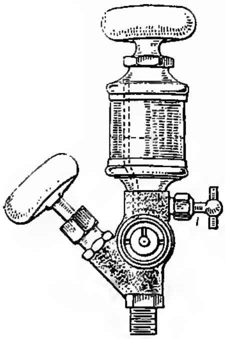


Fig. 165.

When a sight feed drop oiler is to feed oil direct into the cylinder it must be enclosed, so that it will feed notwithstanding the varying back pressure. (See Fig. 165.) A pressure equalizing pipe connects the sight feed chamber with the space above the oil in the oil container.

The oil should preferably be fed by means of a reliable *mechanically operated lubricator*, having positive visible oil feeds, and of such construction that it will feed a minimum quantity of oil with the greatest regularity and precision. The oil feeds, once adjusted, should remain absolutely constant, independent of the oil level in the container and independent of the viscosity of the oil.

OIL-DEPOSITS AND EXPLOSIONS

All open type compressors are so constructed that an oil specially chosen to suit the air compressor requirements can be employed and applied quite independently of the oil used for the external moving parts. In enclosed type air compressors the same oil must be used for air cylinders and bearings and both requirements must be given consideration. The chief trouble in air compressor lubrication is the formation of carbon deposits which may and may not bring about explosions or fires.

Deposits.—Deposits may form on the pistons, piston rings, valves, in the discharge chambers, pipes, coolers and receivers.

Deposit on the piston rings may fill up the grooves and make them inoperative, causing heavy friction and wear, and air leakage past the piston.

Deposit on the discharge valves and valve seats prevents the valves from seating properly; the hot compressed air will leak back into the cylinder on the suction stroke; recompression will cause the temperature of the discharged air to increase above normal.

If a discharge valve sticks in a partially open position, the air is wiredrawn and recompressed continuously; the hot air heats the valve and the temperature may easily rise to 700°F. or more, which is the spontaneous ignition temperature of average quality oil. The deposit now becomes incandescent, and accumulated oil will vaporize and burn or explode. Most explosions in colliery compressors appear to be caused by discharge valves sticking.

Deposit on the suction valve causes leakage on the compression stroke, and wiredrawing of the air causes heating of the valve and seat.

Deposits in the discharge pipe restrict the opening; cases have been known where they have been almost choked, causing abnormally high pressure and temperature of the discharge air.

Deposits may develop due to impurities in the intake air, inefficient cooling, too warm intake air, too much oil, or unsuitable oil.

Impurities in Intake Air.—When air compressors operate in dusty surroundings as in collieries and quarries, the dust frequently brings about deposits inside the compressor cylinders, valves, etc., unless the intake air is filtered.

In one colliery several explosions had occurred in one of their compressors, but when it was arranged to filter the intake air (which revealed how very dirty the air was) no further explosions took place.

In another colliery an electrically driven compressor was placed down a pit in a place where the coal trains passed by, with the result that the pistons and valves were constantly choking up with deposit, and heavy wear took place. A sample of deposit taken from the valves showed the following analysis:

Moisture	Traces
Oil	26.0 per cent.
Volatile matter (coal dust and oil carbon)	54.0 per cent.
Fixed carbon and oxides of silica	0.9 per cent.
Iron oxides (chiefly wear)	18.1 per cent.
Balance—undetermined	1.1 per cent.
	100.0 per cent.

A filter was then installed and the compressor kept very much cleaner.

Inefficient cooling may be due to furring up of the water jackets; the result is that the oil is charred and bakes together with metallic wearings from the piston, piston rings, and cylinder.

Neglect on the part of the attendant in not turning on the cooling water supply when starting the compressor has been responsible for such deposits and even explosions have taken place.

Warm Intake Air.—The warmer the intake air the hotter will be the discharge air, the results being similar to those of inefficient cooling. A certain difference in temperature of the intake air means a much bigger difference in the temperature of the discharge air, which emphasizes the desirability of having the intake air as cool as possible.

Too Much Oil.—Air compressors require very little oil for lubrication because the oil remains a long time once inside the compressor; there is no steam to wash the oil away as in steam engines, and no high temperatures to burn it away as in internal combustion engines.

Air compressors *can rarely get little enough oil;* the excess oil remaining on the piston or valves often gets charred into a hard carbonaceous deposit.

Unsuitable Oil.—The character of the oil itself greatly influences the character and amount of carbon deposit formed.

Pale oils containing chiefly saturated hydrocarbons—naphthenes or paraffins—produce less oil carbon than such dark colored oils which contain types of hydrocarbons easily decomposed by oxidation.

Distilled oils produce much less deposit than undistilled oils. Exposed to high temperatures they distil away almost completely, leaving comparatively little residue behind; whereas *undistilled oils*, exposed to high temperatures only distil partially, leaving a spongy, carbonaceous residue behind. Dark cylinder oils leave much more residue than filtered cylinder oils and ought never to be used for air compressor service.

As regards fixed oil, it is obvious that semi-drying or drying oils cannot be permitted as an ingredient in air compressor oils, but the presence of a small percentage, say, 3 per cent. of non-drying animal oil is not detrimental for air compressor lubrication; in fact, it has proved a distinct advantage in multiple-stage high pressure air compressors where the air in the higher stages is wet (see Diesel Compressors, page 525). For low or moderate pressure compressors, when the air is comparatively dry, the admixture of fixed oil is unnecessary.

Oils too heavy in viscosity are largely responsible for deposits; the dust and dirt in the air adhere to the sluggish oil and form a black pasty deposit.

The cry for *high flash point compressor oils* which comes up now and again after compressor explosions in mines, usually meets with a far too ready response. High flash point means high viscosity (large percentage of filtered cylinder stock in the oil) and this inevitably means more trouble with carbon deposit than ever.

In colliery compressors using air compressor oils with a flash point of over 500°F. (steam cylinder oils) the coal dust bakes together with the oil and presents a smooth glossy surface, due to the pitch and tar contained in the coal dust. Such high flash point oils have one virtue, however, in that they do not give off much vapor exposed to the normal air temperatures in an air compressor. Their use is therefore justified, in fact may be quite necessary, where lower flash point oils give off so much vapor that they affect the throats and lungs of the workmen in tunnel work, collieries below ground, air worked machinery in confined spaces, etc. For such conditions, reasonably low viscosity filtered cylinder oils should be employed. The flash point is no safe criterion as to the amount of vapor given off *below* the flash point. Speaking generally, *high viscosity oils* act sluggishly and are inclined to retain much of the dust, particularly on the discharge valves, where the *maximum temperature exists.* When such oils are used, and the air is dirty, it must be filtered and the compressor pipes and receivers should be frequently examined and cleaned, so that notwithstanding the sluggish oil, the danger of explosions may be avoided.

Low viscosity oils assist in maintaining the compressor in a clean condition, notwithstanding dirty surroundings; the dirt which gets in is kept moving, is largely passed through the compressor and out of the discharge valve into the discharge pipe, after-cooler and receiver.

Soap and water are excellent for cleaning purposes, but the use of soap and water as a lubricant does not dissolve existing deposits; in fact, more deposit is formed, as the water evaporates away. In one case a 2 inch deposit (which ignited at 400°F.) was formed inside the discharge pipe of a compressor, lubricated entirely by soap and water. Explosions have been reported to have occurred when soap and water have been exclusively used for lubrication, but the author has no personal knowledge of any such cases.

EXPLOSIONS

We have seen several reasons for the production of abnormally high temperatures. The heat emanates chiefly from the discharge valve or valves, and it is probably safe to say that fires or explosions originate at or near the discharge valve chamber.

Exposed to high temperature the accumulated oil or oily deposit will begin to emit vapor at 120°F. to 150°F. below the open flash point of the oil. As the temperature increases the oil will vaporize more vigorously, and when the temperature is well above the flash point, the mixture of oil vapor and air may easily accumulate in or near the discharge valve chamber and be in the right condition to explode. Perhaps a small piece of deposit on the discharge valve commences to glow sufficiently to fire the mixture. A temperature of about 700°F. is sufficient to ignite the oil vapors spontaneously, and a fire or explosion follows.

Experience seems to show that in *large moderate pressure compressors* explosions do not occur if the intake air is filtered or if deposits are not allowed to accumulate in too great quantities. When there are no deposits there can be no fire, therefore no explosions. The amount of oil used for lubrication in large compressors is so small compared with the large volume of air passing through the compressor that the oil vapors formed, even under high temperature conditions, are so diluted that they cannot explode. If an explosion occurs, it is frequently too weak to burst pipings or receivers.

The high temperature may, of course, ignite accumulated oily deposits in the discharge pipe, in which case the fire will spread slowly to the receivers. The burning deposit may make the receiver walls red hot, so that they burst, being unable to withstand the normal receiver pressure.

In one typical case of a colliery compressor the accumulation of coal dust and oil in pipes and receiver had not been cleaned out for two years; there was a weak explosion and the deposit burned for a considerable time, causing men in the pit operating coal cutters to cease work owing to the obnoxious fumes in the compressed air.

In another case, a leaking joint on the discharge pipe close to the compressor had been "cured" by driving a piece of wood into the joint. The point of the wood protruded inside the pipe and ignited spontaneously, due to abnormally hot discharge air. The fire spread to the receiver, and the latter being opened up three cwts. of deposit accumulated over seven years were removed, or rather what remained after most of the combustible matter had burned away.

If the dust, which together with the oil forms the deposit, is itself inflammable, such as coal dust, the danger of the deposit taking fire is, of course, greater than where it consists of non-inflammable ingredients, such as fine sand and dust in quarries, iron mines, etc.

In *multiple stage high pressure compressors*, where the volume of air discharged is comparatively small, the amount of oil used for lubrication and intermingled with the air, is appreciable, and under conditions of abnormal temperatures, explosive mixtures of oil vapor and air are formed, which will bring about violent explosions, when the spontaneous ignition temperature is reached. Such explosions may occur even if the amount of accumulated deposit is small.

After-burning of deposit, which is a characteristic feature of most "explosions" in large moderate pressure compressors, does not occur in high pressure compressors. If an explosion occurs in the very confined spaces, it is very violent and usually shatters the piping, receiver, etc.

Note: Valve pockets or discharge chambers and pipes should be so designed that there are no cavities where mixtures of oil vapor and air may remain stagnant.

Spontaneous Ignition Temperatures.—The temperature at which oil vapor and air ignite spontaneously, *i.e.*, without the aid of a spark, is *higher, the lower the viscosity of the oil.* Speaking generally, the more complex and the more viscous a petroleum product is, the lower is its spontaneous ignition temperature. For example, kerosene ignites spontaneously in air at a lower temperature than petrol. The compression in kerosene oil engines is lower than in petrol engines for this very reason, as the danger of preignition is greater with kerosene.

It will, therefore, be realized that the danger of explosions is not lessened by the use of very high flash point oils. Quite apart from the fact that such oils are very viscous and favor formation of deposits, the mixture of air and vaporized oil is spontaneously ignited at lower temperatures than with a lower viscosity oil. It might be asked, why then not go to the other extreme and use very low flash oils? Up to a certain point this view is certainly justified and correct. But with very volatile oils, although they will tend to keep the internal conditions clean, and thus minimize danger of explosion, yet they vaporize so much exposed to normal compressor temperatures, that the presence of vapors in the compressed air will become troublesome, and furthermore such oils will not satisfy the requirements as regards lubrication. Too thin oils will not seal the pistons and will cause excessive internal friction and wear.

In view of what is said above its seems probable that very few explosions have been caused on the discharge side of a compressor by injecting kerosene into the compressor for cleaning purposes; but when kerosene explosions have occurred they have usually been in the compressor cylinder itself, the ignition taking place through the suction valves on the approach of a naked light. For the same reason, no naked light should be used when opening up receivers or inter-coolers for examination.

The following case shows, however, that the flame caused by the presence of kerosene may be carried right through the compressor and ignite a mixture of air and oil vapor on the discharge side.

"In a compressor, in which the valves had been reseated and the cylinder cleaned out, the cleaning was done with kerosene. When the compressor was started up, the engine attendant came to the conclusion that something was wrong with one of the suction valves, and took up a candle for the purpose of inspecting it. The result was an explosion, the discharge pipe being blown to pieces for a length of about ten yards. It was evident that a quantity of kerosene was pocketed in the suction valve chamber, and that as the engine acquired the usual working temperature, after a short run, the heat was sufficient to vaporize the kerosene. When the engine attendant inspected the valve, the candle flame ignited the kerosene, the flame was carried through to the discharge pipe and the explosion followed."

Air Compressor Rules.—The following rules should be observed in order to avoid danger of explosions.

(1) Intake air should be taken from outside the engine room, should be cold, clean, and, if necessary, filtered.

(2) Sparing and uniform amount of a carefully selected com-

pressor oil, should be supplied, with frequent drainage of inter-cooler and after-cooler for water and oil.

(3) Good cooling of cylinder should be practised, including discharge valve chambers, as abnormal temperatures emanate from these valves. The cooling water must always be turned on before the air compressor is started.

(4) Temperatures should be taken regularly of intake and discharge air, as abnormal rise in temperature is a sure indication of trouble.

(5) An after-cooler should be fitted in discharge line before the receiver under difficult conditions, so that only cold air enters the receiver.

(6) Compressor pressure gauges should be periodically examined and corrected by comparison with standard gauges.

(7) There should be frequent inspection and cleaning of water jackets, valves, discharge pipe, after-cooler and receiver; in multiple stage air compressors, discharge valves should be examined every week; low pressure valves every month; receiver and coolers every month to every six months, depending upon the conditions.

(8) Kerosene should never be used for cleaning the compressor or pipes internally, as it evaporates and forms an explosive mixture with the air. Soap and water should preferably be used for cleaning, the surfaces being afterwards wiped clean and oiled with compressor oil to prevent rusting while standing.

SELECTION OF OIL

Air compressor oils, in view of what is said in the preceding chapter, should preferably be pale colored straight-run distillates, highly refined and filtered, containing as few unsaturated hydrocarbons as possible. Air compressor oils should preferably contain little or no cylinder stock.

Where, in order to obtain a heavy viscosity, the admixture of filtered cylinder stock becomes necessary, the distilled oil should be as viscous as possible so as to minimize the percentage of cylinder stock required in the finished oil.

Air compressor oils of four different viscosities are required to lubricate the cylinders and valves of all types of blowing engines and air compressors, as indicated in table No. 21.

These four oils are usually straight mineral oils but for multiple stage compressors, as Diesel compressors, oils Nos. 2 and 3 are recommended and should preferably contain from 3 per cent. to 6 per cent. of a non-drying, acid free, fixed oil.

TABLE No. 21

Compressor oil	Saybolt viscosity		Flashpoint open, °F.	Flashpoint closed, °F.
	104°F.	212°F.		
No. 1	150″	36″	380	355
No. 2	350″	53″	400	375
No. 3	650″	70″	425	400
No. 4[1]	1500″	120″	510	475

[1] Compressor Oil No. 4 is a filtered steam cylinder oil.

The following chart gives specific recommendations for the various types of blowing engines and air compressors.

LUBRICATION CHART No. 12 FOR BLOWING ENGINES AND AIR COMPRESSORS

	No. of stages	Final air pressure, lbs. pr. sq. inch	Compressor oil
Blowing engines:			
Blowing cylinder horizontal, no tail rod	Single stage	10–30	Compressor Oil No. 3
Blowing cylinder horizontal, with tail rod	Single stage	10–30	Compressor Oil No. 2
Blowing cylinder vertical	Single stage	10–30	Compressor Oil No. 1 or No. 2.
Air Compressors:			
Small compressors			
Compressing less than 1000 cu. ft. of free air per minute.			
Small compressors are usually enclosed and use the same oil for cylinders and bearings	Single stage	Below 70	Compressor Oil No. 1
	Two stage	Below 150	Compressor Oil No. 1
	Single stage	70–120	Compressor Oil No. 2
	Two stage	150–450	Compressor Oil No. 2
Large Compressors			
Compressing more than 1000 cu. ft. of free air per minute.			
Horizontal cylinders, no tail rod	Single stage Two stage	Below 70 Below 150	Compressor Oil No. 3 or 4.
Horizontal cylinders, with tail rod	Single stage Two stage	Below 70 Below 150	Compressor Oil No. 2 or 3.
For large compressors compressing above the pressures given			Compressor Oil No. 3 or 4.
Large horizontal compressors are usually open type and use separate bearing oils externally.			
Large vertical compressors are frequently enclosed type, employing force feed circulation for the bearings and the same oil is used throughout.			

NOTE 1.—Where a compressor is delivering air to air-worked engines placed in confined spaces (tunnel work, etc.) use a heavier viscosity (less volatile) oil than the one indicated in the chart.

DRY AIR PUMPS

Dry air pumps or *vacuum pumps*, as for example employed in condenser plants for steam engines or steam turbines, are a kind of air compressors; they compress the small amount of air leaking into the system and discharge it at atmospheric pressure.

Dry air pumps are often constructed with slide valves, and the lubrication of these valves is troublesome and difficult. The oil is subjected to the vacuum under conditions of high temperature, due to the surfaces being in touch with hot steam and to the additional heat created by valve friction. The result is that the oil is distilled, "vacuum-distilled," and is oxidized by the air, forming a sticky carbonaceous deposit. The remedy lies in using the oil with the utmost economy and applying it regularly and uniformly, preferably by means of mechanically operated lubricator. The less oil consumed, the less carbon is formed. An excellent idea is to introduce a jet of steam through a ½-inch exhaust steam pipe taken from the steam engine driving the air pumps (as for example in the Alberger pump). There must be no valves in this pipe; this admission of moist steam greatly minimizes the formation of carbon.

Many engineers, when they have experienced trouble with a medium viscosity compressor oil jump to the conclusion that by using a higher flash point oil the carbonization will be overcome; they therefore use steam cylinder oils, "the thicker the better," and find the carbonization much worse than before, notwithstanding their endeavor to use as little as possible. As the oil is volatilized during use, it is obvious that a distilled lubricating oil, which has already been volatilized when it was being manufactured, must have less tendency to leave a residue than steam cylinder oils which are *undistilled* oils.

Experience proves that the best results are obtained by using Compressor Oil No. 2, as pale as possible, without cylinder stock and preferably slightly compounded so as to make it combine with the moisture, which is always present.

No. 4 Compressor Oil must only be used if there are very special reasons for using such a heavy viscosity oil, as for example the necessity of having an absolute minimum of oil vapor in the compressed air or bad mechanical conditions in large horizontal compressors.

NOTE 2.—*Glycerine* must be used for compressors in breweries, as even slight traces of mineral oil vapor in the air will be absorbed by the beer and affect the taste, whereas glycerine has no detrimental effect whatever.

NOTE 3.—For *three- and four-stage compressors*, the same oils are recommended as for Diesel Compressors (see page 528) namely, Compressor Oils Nos. 2 and 3 compounded with 3 per cent. to 6 per cent. of fixed oil.

Similar conditions exist in a number of other vacuum pumps, for example, the pumps used in connection with sugar evaporating pans.

AIR OPERATED ENGINES AND PNEUMATIC TOOLS

Compressed air is used for operating a variety of engines, machinery and tools as indicated in the beginning of this section, page 402.

Air Operated Engines.—The operating temperatures of the engines, etc., determine what viscosity oil is to be used.

Air engines operating coal cutters are usually fairly warm, and demand an oil like Bearing Oil No. 5. As the temperatures are never more than moderate, there is no danger of carbonization taking place, so that a bearing oil of suitable viscosity will do all that is required. As a rule, the operating temperatures are low, particularly when the engines or tools operate with air *expansion,* because the air becomes cold when it expands.

Such low temperatures may bring about trouble by the lubricant congealing, or the engine becoming choked with snow. The amount of moisture in the compressed air is often considerable. When for example warm compressed air is sent down the shaft in a coal mine it cools and some of the moisture condenses; if it is not efficiently drained out just before reaching the engine, it will freeze into snow, lodge in the exhaust port, and accumulate till the engine pulls up. Even if the lubricating oil does not congeal, it will not clear the exhaust, but an admixture of glycerine with the oil, say from 30 per cent. to 50 per cent. will usually thaw the snow and keep the exhaust clean. The mineral oil should have a cold test of, say, minus 25°F. for such extreme cases, but usually a zero cold test will be found satisfactory. Large air operated hammers for forging purposes should preferably have the oil introduced by means of a mechanical lubricator, the movement being taken from the hand lever (see Fig. 166). For such large hammers medium bodied oils are preferable, as the operating temperatures are very moderate.

A class of air operated engine difficult to lubricate is the air engine in torpedoes. The engine may have three cylinders enclosed in a crank case. The oil is forced into the main bearings, then through tiny holes in the crank-shaft, say $\frac{1}{300}$ of an inch, into the crank pins, while the pistons are lubricated by splash from the crank case. The oily exhaust air from the engine may be used for lubricating some of the gears. The oil is forced into the bearings by means of air pressure. Towards the end of the run the air pressure drops and the oil supply diminishes, as the resistance towards the oil-flow through the tiny passages remains unaltered. Simultaneously, the air is heated to maintain sufficient engine power; the hot air burns and oxidizes the oil in the cylinders.

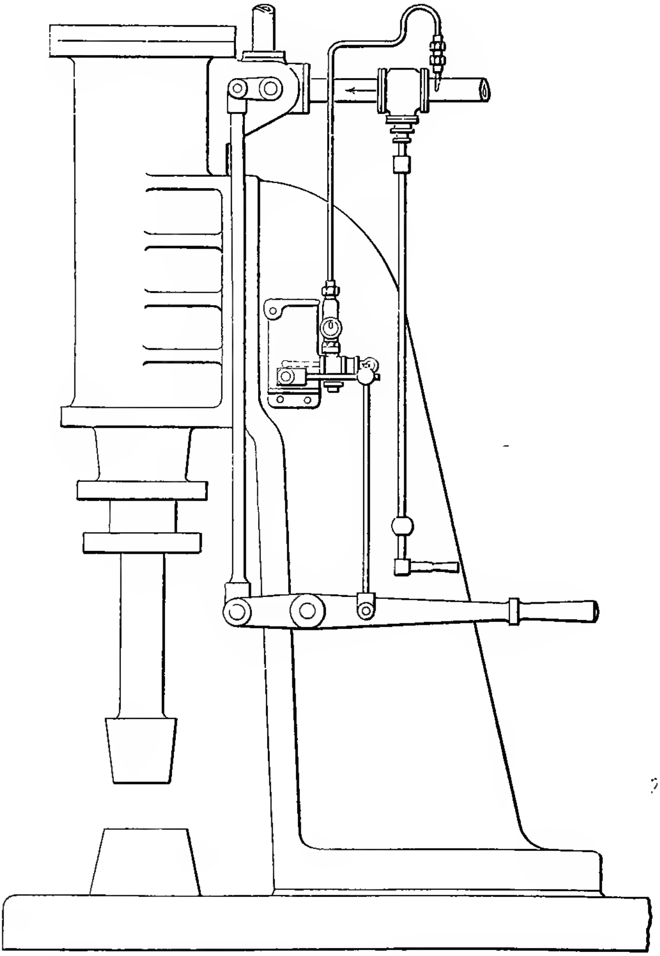


FIG. 166.—Air operated hammer with mechanical lubricator.

The conditions are therefore irregular oil feed, *i.e. overfeeding* most of the time, and exposure to high temperatures and air oxidation. All mineral oils produce too much carbon under these conditions. The oil which has given most satisfaction is *cold-pressed, highly refined, acid-free neatsfoot oil* or its equivalent.

Such an oil has a very high flash point without being unduly. viscous, and it gives practically clean lubrication.

Pneumatic Tools.—Pneumatic tools operate at very high speed (often several thousand strokes per minute) and the parts have exceedingly fine clearances. They are threrefore very sensitive and the air consumption may easily increase 25 per cent. or more if too viscous oils are used. Oils for pneumatic tools should therefore be very light viscosity oils and have low, sometimes very low, cold tests to prevent them from congealing and clogging the tools. The oil is usually fed into the tool at intervals, say every hour. If a tool freezes up, an injection of glycerine will usually thaw the snow and clear the exhaust, after which the usual low viscosity oil may again be applied.

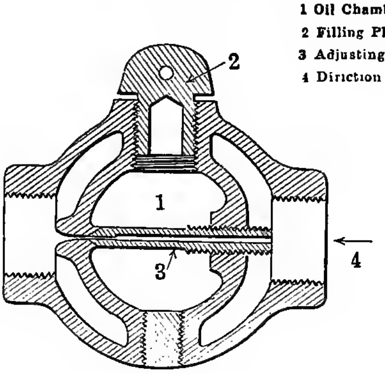


FIG. 167.

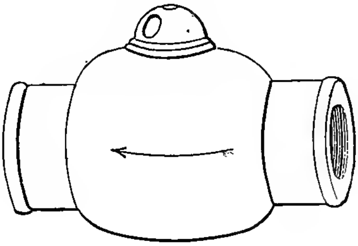


FIG. 168.

Pneumatic tool oiler.

Several attempts have been made to introduce the oil sparingly and uniformly into the air before it reaches the tool, so as to avoid *under* lubrication. Fig. 167 illustrates an oiler with a needle adjustment valve used by the Chicago Pneumatic Tool Co. Fig. 168 shows an outside view; the direction of the air must be indicated.

It has been found that delays caused by underlubrication and stoppage of tools are reduced as well as the cost of maintenance, when such oilers are used; the filling of the oil chambers can be done in the toolroom at night, when the tools are made ready for the following day's service.

Great care must be taken to ensure that the air supply piping and also exhaust piping (if the latter is fitted), shall be free from dirt and chips, and that they be thoroughly blown out before final connection is made to the tool, so that no dust or foreign matter will be carried to the working parts, and the exhaust pipe will be clear. There is usually a strainer at the end of the branch air pipe to which the flexible hose is attached. This strainer is made of fine mesh brass gauze or cloth and retains scale and impurities, which would otherwise injure the tools. Even a small piece of rubber of the air hose will put the tool out of action.

It is good practice to immerse pneumatic tools in a bath of gasoline or kerosene over night, then blow them out under pressure and oil them thoroughly before use.

For lubricating the gears in many types of tools a filtered, poor cold test (say 80°F.) filtered steam cylinder oil will give good service; it will be semi-solid at ordinary temperatures. This oil may be injected into the gear case by a syringe, say, every few working hours.

It is important that the compressed air pipe system be properly drained, to prevent water getting into the tools, as such water would cause rusting of the pipes and also of the working parts in the tools, besides clogging the tools with snow, when they operate with air expansion.

LUBRICATION CHART No. 13 FOR AIR OPERATED ENGINES AND PNEUMATIC TOOLS

Air Operated Engines:	
Air Operated *Coal Cutters* This oil also to be used for general lubrication of the coal cutter.	Bearing Oil No. 5 (see page 128)
Air Operated *Haulage Engines* and the like.	Refrigerator Oil No. 1 or No. 2 or mixtures of these with up to 50 per cent. of glycerine where the exhaust is liable to choke with snow.
Large Air Operated Forging *Hammers.*	Bearing Oil No. 4.
Belt Driven Pneumatic Forging Hammers in which air is compressed and used as an air buffer.	Air Compressor Oil No. 2.
Air Engines in *Torpedoes.*	Highly refined neatsfoot oil with a zero °F. cold test.
Pneumatic Tools:	
Large Pneumatic Drills and the like.	Refrigerator Oil No. 1 or No. 2.
Smaller Pneumatic Tools.	Light pneumatic tool oil[1] (see below).
For Gear Cases in Pneumatic Tools.	Filtered cylinder oil with a poor cold test, say 80°F.

[1] *Light Pneumatic Tool Oil:* Pale, straight-run distillate, highly refined, having a Saybolt viscosity at 104°F. of approximately 80″, and a setting point of –25°F. to +15°F. according to the temperature conditions under which the tools operate.

CHAPTER XXVI

REFRIGERATING MACHINES

Refrigerating machines are used for producing cold, being employed in a great variety of installations, such as ice manufacturing plants, breweries, distilleries, dairies, sugar factories, chocolate factories, slaughter houses, cold storage plants, oil mills, margarine works, stearine works, paraffin works, chemical works of various kinds, artificial skating rinks, for domestic purposes in large houses or hotels, hospitals, etc., public mortuaries, mining operations (sinking shafts through wet sand), also in fishing vessels (freezing fish), food transport ships, modern passenger ships, warships (cooling ammunition chambers), etc., etc.

CLASSIFICATION

There is a great variety of refrigerating machines in use; they can, however, be classified according to the system of refrigeration employed, as follows:

Absorption Machines.
Compression Machines.

Absorption Machines.—These machies usually operate with ammonia. They are manufactured only by a small number of firms. No lubrication is required except for the circulating pumps, the lubrication of which presents no difficulty.

Compression Machines.—In these machines the cooling medium, the *refrigerant*, at one stage of the process is compressed; hence the name compression machines. They are built in all sizes, requiring from ½ horse power for the smallest units up to 600 horse power for the largest units in large installations.

According to the refrigerant employed, these machines may be divided into:

Cold Air Machines
Sulphurous Acid Machines
Ammonia Machines
Carbonic Acid Machines

the refrigerants being, respectively:

Air
Sulphur Dioxide (SO_2)
Ammonia (NH_3)
Carbonic Acid (CO_2)

Cold air machines are very bulky and only a few machines are in existence. They were at one time used to some extent on board ship, but have now been displaced by carbonic acid machines. They usually have two large cylinders. The air is compressed in one of these cylinders and expands and cools in the other cylinder. Glycerine is used for lubrication, as mineral oil gives the air a burnt odor, which taints the meat.

Sulphurous Acid machines are bulky, about 2½ times the size of ammonia machines and are now seldom used. As the sulphurous acid is a lubricant in itself, no internal lubrication is required.

Ammonia machines and *carbonic acid machines* are practically the only two types of refrigerating machines employed in modern installations.

Ammonia machines are generally employed in land installations. They take less power to operate than carbonic acid machines, and the pressures carried in the system are considerably lower than the pressures in carbonic acid systems.

The principal objections to ammonia machines are that ammonia leaking out from the system has an unpleasant penetrating odor and is suffocating; on the other hand, the odor makes a leakage easily noticeable.

Carbonic acid (*CO_2*) *machines* are used almost exclusively on board ship; they take up considerably less room than ammonia machines. Carbonic acid is odorless; a leakage is therefore not easily detected and good ventilating arrangements are essential.

PRINCIPLE OF OPERATION

Fig. 169 illustrates the main elements found in all refrigerating plants working on the compression system. The principle of operation, whether ammonia machines or carbonic acid machines are employed, is exactly the same, only the pressure and temperatures being different.

The following description is given for ammonia machines, the particulars in brackets referring to carbonic acid machines.

The elements are the following:

Compressor.
Oil Separator.

Condenser.
Regulating or Expansion Valve
Evaporator.
Dirt Catcher.

The *compressor* (1) draws in gaseous ammonia from the suction pipe (7), leading into the suction valve. The ammonia is compressed to a pressure of from 120 lbs. to 180 lbs. per square inch (CO_2 from 900 lbs. to 1200 lbs. per square inch), and delivered at a temperature of 85°F. to 150°F. (CO_2 160°F. to 170°F.) through discharge pipe (8), through a non-return valve (9) into the oil separator (2), from which it is conveyed through pipe (10) into cooling coils in the *condenser* (3).

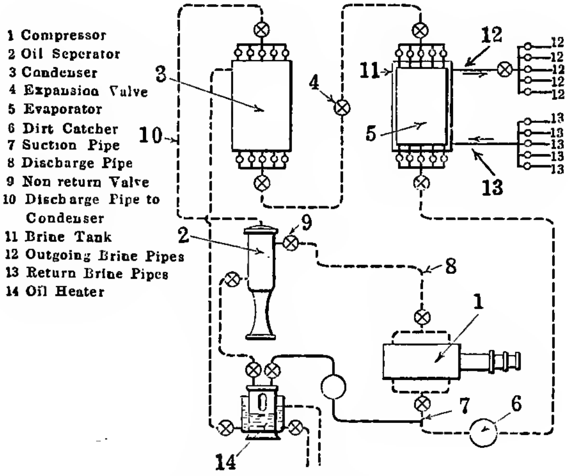


FIG. 169.—Refrigeration system.

Cold water passes through the condenser, cools and liquifies the hot ammonia. The cold and liquified ammonia now passes through the *regulating or expansion valve* (4) into the coils of the evaporator (5).

The pressure in the *evaporator* coils is low, from 15 lbs. to 45 lbs. per square inch (CO_2 from 200 lbs. to 400 lbs. per square inch).

The effect of this considerable fall in pressure is that the liquid ammonia evaporates and in doing so it cools down considerably below freezing point, the temperature being from minus 20°F. to plus 15°F. (CO_2: minus 30°F. to plus 15°F.).

The cold evaporator coils are seldom placed directly where it is desired to produce cold. Usually they are placed in a tank (11), through which is circulated a non-freezing brine (a salt solution); the brine, in passing over and around the cold evaporator coils, cools in contact with the coils. By means of a pump the cold brine can be pumped away through pipes (12) to the place where it is desired to produce cold. The brine returns through pipes (13) to the evaporator tank to be cooled again.

The ammonia vapor leaves the evaporator coils at a temperature slightly lower than the temperature of the brine, and returns through the dirt catcher (6) to the compressor, continuing the cycle of operations just described.

During recent years a new system of ammonia refrigeration, called the dry compression system, has come into use. It operates on the same principle as those machines already described, which are wet compression machines, the chief difference being that the temperature of the ammonia in passing through the compressor is from 160°F. to 190°F. higher than the temperature in wet compression machines. The heat developed in a dry compression machine is so high that it becomes necessary to surround the compressor cylinder with a cooling water jacket.

CONSTRUCTION

Small compressors are driven by belt or rope drive.

Large compressors are usually operated by a steam engine, the steam engine and the compressor having a common crank shaft. Sometimes the steam engine cylinder is placed in tandem with the compressor cylinder. All compressors operate at low speed, as at high speed the operation of the valves becomes irregular. The compressors are built either vertical or horizontal, the practice in this respect varying in different countries.

Most large compressors and many small compressors are double-acting, as the one illustrated in Fig. 170, but frequently *vertical* compressors are single-acting, even in large sizes, there being only one suction valve and one delivery valve.

The cylinders of *ammonia compressors* are constructed chiefly of cast-iron or steel, as copper or bronze parts would be attacked by ammonia. The cylinders of *carbonic acid machines* must be made very strong, on account of the high working pressure. The cylinder is generally made of a forged block of steel, suitably bored and finished.

Stuffing Box.—The most important part of the compressor and the most difficult part to keep in good working order and well lubricated, is the stuffing box. The object of the stuffiing box is to prevent the escape of ammonia or carbonic acid from the cylinder, and also to prevent air or moisture from the outside entering the compressor through the stuffing box.

Fig. 170 illustrates one type of ammonia compressor stuffing box. The bottom ring consists of white metal; the packing rings are of cotton, saturated with oil. (1) is the so-called "lantern" which has a hollow space filled with oil around the piston rod, then follow more cotton packing rings, and sometimes a rubber ring, all the packing rings being squeezed together by means of the stuffing box gland (2). For sealing this gland, oil is introduced through the inlet (3), and overflows through the outlet (4). Oil is prevented from creeping out along the rod by means of the small stuffing box (5).

The oil film on the piston rod absorbs ammonia vapors from the inside of the compressor. These ammonia vapors escape in the lantern and rise through the pipe (6), from which they are passed over into the suction pipe of the compressor, so that no refrigerant is lost.

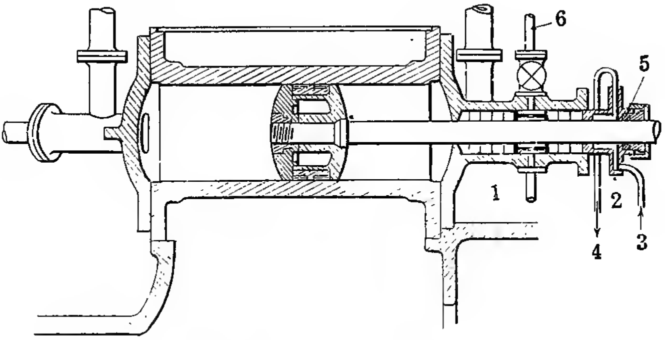


Fig. 170.—Ammonia compressor.

As the oil film swells on the piston rod inside the compressor, due to absorption of ammonia or CO_2, a portion of oil is continuously scraped off by the gland on the outward motion of the piston rod and this oil serves to lubricate the piston.

As rubber is destroyed by the action of mineral oil, and swells when absorbing CO_2, most manufacturers have discontinued the use of rubber in gland packings in favor of metallic packing or leather packing.

Fig. 171 shows one form of stuffing box for a CO_2 machine. The stuffing box is very accurately machined and in the bottom is introduced a bronze ring, after which three sets of bronze rings and leather rings are introduced, then the lantern to which the oil is applied under pressure, subsequently two sets of bronze rings and leather rings followed by a ring of cotton; and then the stuffing box gland keeps the whole packing in position. The bronze rings are all a good fit against the inside of the stuffing box, but do not touch the piston rod. The leather packing rings are thinned out towards the cylinder so that they form an elastic edge, and the pressure in trying to escape from the cylinder automatically causes the leather rings to press against the piston rod and thus to prevent leakage. The life of the leather packing is usually one season, sometimes two.

In some stuffing boxes there is an oil well near the front portion of the gland, covered with a lid. The gland should be so adjusted that occasional bubbles of CO_2 are to be seen rising from this well, but there should not be sufficient CO_2 escaping to cause foaming. If there are no bubbles the packing is too tight.

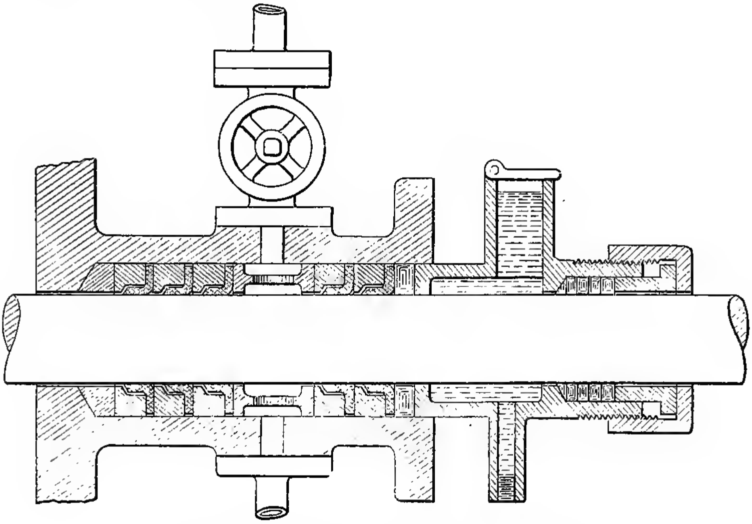


Fig. 171.—Stuffing box with leather packing.

Fig. 172 illustrates a metallic packing built up of two spirals screwed into one another, the spiral (1) being of white metal and of triangular section; this gets squeezed tightly against the rod when the stuffing-box gland (3) is tightened up. The spiral (2) is also of triangular section, but made of steel, and forces itself towards the walls of the stuffing box, leaving spaces near the rod where the lubricating oil can accumulate for the purpose of lubricating the piston rod. The small stuffing box serves the same purpose as in Fig. 170. When this gland is in good condition and properly adjusted, only very little oil reaches the interior of the compressor.

In *dry compression machines*, packings containing cotton, leather or rubber cannot be employed, as they will be destoyed by the heat. Metallic packings are used, as the one illustrated in Fig. 172. Another type of metallic packing used for dry compression machines consists of a number of rings, each in two halves surrounding the piston rod and pressed lightly against the rod by means of garter springs. The rings are held in accurately finished chambers, forming a casing around the piston rod.

When packings are renewed or when a new compressor is started, it is important to tighten regularly and evenly all round, as soft packing becomes softer through use. If the packings are screwed up tight at once, the rod will probably heat, the packing may be destroyed and the rod get scored.

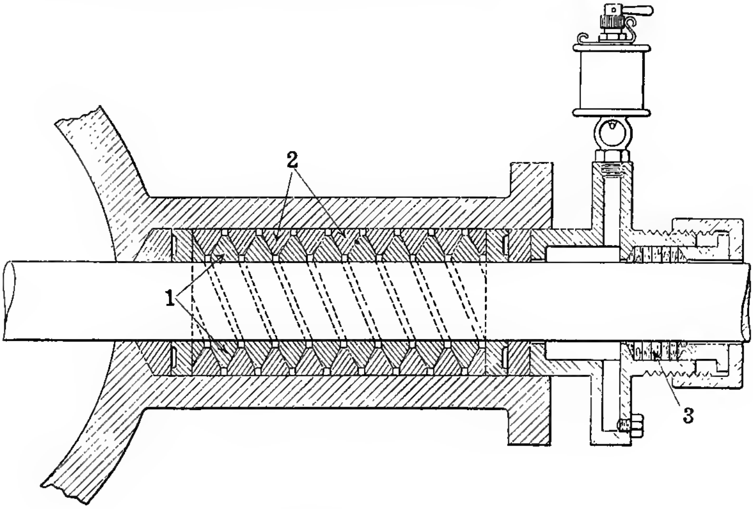


Fig. 172.—Stuffing box with metallic packing.

Oil Separator.—The greater portion of the oil reaching the compressor cylinder passes out of the compressor with the refrigerant and must be separated out by means of an oil separator. for reasons given later on.

Fig. 173 illustrates a typical oil separator, located in the engine-room near the compressor. The hot gases enter through the tube (1) and leave the separation chamber (2) through the pipe (3). The oil is separated and accumulates in the bottom of the chamber (2), from which, by opening the cocks (4) and a needle valve (5), it is allowed to pass through the sight-feed arrangement (6) into the bottom of the chamber (7). Below this chamber is a heating chamber (8) through which hot water is passed, entering through pipe (9), and leaving through pipe (10). When the oil has been drained into the chamber (7), the needle valve (5) and shut-off cocks (4) are closed; the hot-water service is put on: the heat frees the oil from the ammonia vapors, which are passed out through the pipe (11), leading into the suction pipe of the compressor. Having been freed from ammonia vapor, the oil is blown out through the drawoff cock (12) and pipe (13).

In some oil separators a mechanically operated rotating plug is continuously transferring the separated oil from the separator (2) into the chamber (7).

Great care should be taken in filtering and purifying oil reclaimed from the oil separator, as, if it is not entirely freed from impurities, the result when using the oil over again will be the wearing of the piston rod, piston and cylinder walls.

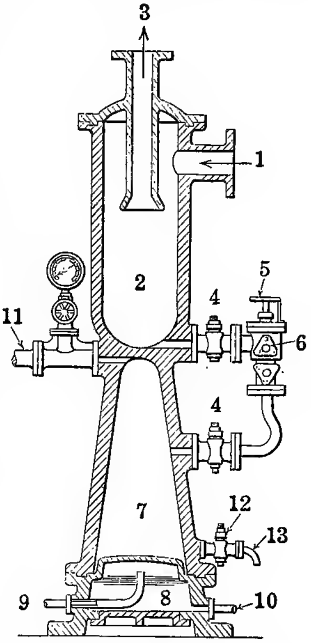


FIG. 173.—Combined oil separator and heater.

Expansion Valve.—The expansion valve is fitted for the purpose of wire-drawing the refrigerant from the high pressure existing before the valve to the low pressure existing after the valve. It must therefore be capable of very fine adjustment.

If any water gets mixed with the refrigerant, this water usually freezes in the expansion valve and clogs it; impurities have the same effect; for this reason it is very important that the expansion valve be kept absolutely clean.

Dirt Catcher.—In the suction line of the compressor is fitted a short piece of pipe provided with a sieve, for the purpose of preventing impurities, such as iron scale, little pieces of packing material, or even ice (frozen water) from entering the compressor. This sieve should be examined every day or so in the case of a new compressor installation, every three days for the next couple of weeks, and later on once every two months. If the sieve in the dirt catcher is allowed to get full of impurities, it may unexpectedly burst. All the impurities will at once be drawn into the compressor and almost certainly cause serious damage.

METHODS OF LUBRICATION

The lubrication of the compressor piston and cylinder is brought about entirely by the oil carried through to the interior of the cylinder from the stuffing box by the piston rod.

There are three principal methods of lubrication, viz:

Bath Oiling System.
Mechanically Operated Lubricator.
Splash Oiling System.

Bath Oiling System, Fig. 174. Oil is pumped continuously by means of a small oil pump through the pipe (1) into the gland (2) surrounding the piston rod (3); the oil overflows from the top through pipe (4) back again into the oil container, re-entering the oil pump and circulating afresh.

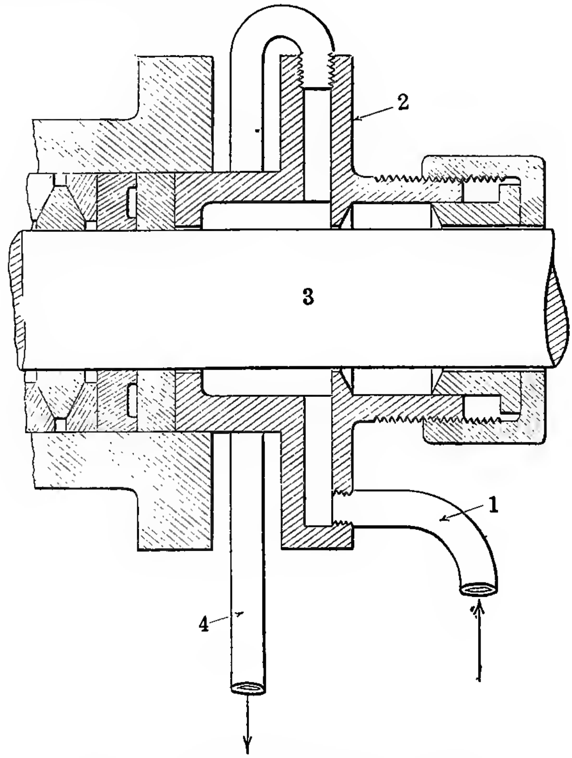


FIG. 174.—Bath oiling system for stuffing box.

Figs. 175 and 176 show a bath oiling system, where the oil is not circulated but seals the gland by maintaining a height of oil above the lantern in the gland. In Fig. 176 the oil flows to the gland under the full compression pressure.

When the stuffing box gland packing is too loosely adjusted, an excess amount of oil will find its way into the compressor. On the other hand, if the packing be adjusted too tightly, too little oil will reach the interior; the piston rod will heat and may even become scored through the extreme friction and pressure exerted upon the rod in the gland; also the packing will suffer from the heat; cotton or leather becomes brittle and small portions may be carried into the cylinder, causing excessive wear.

Mechanically Operated Lubricator.—In dry compression machines experience has proved the necessity of employing mechanically operated force-feed lubricators, which will introduce a small quantity of oil with precision and regularity, and in which the oil feed can be adjusted to a nicety. The mechanically operated lubricator is driven from some moving part of the engine, therefore starts and stops feeding with the engine, and delivers the required quantity of oil under pressure into the interior of the stuffing box.

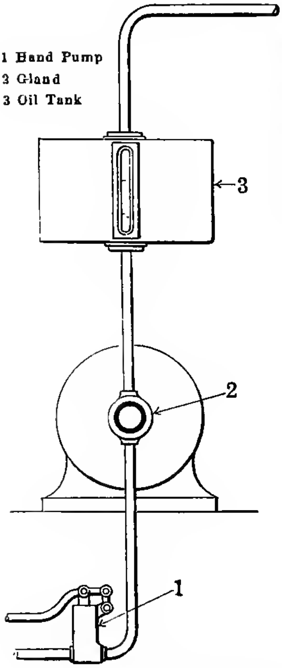


FIG. 175.—Bath oiling system with overhead tank.

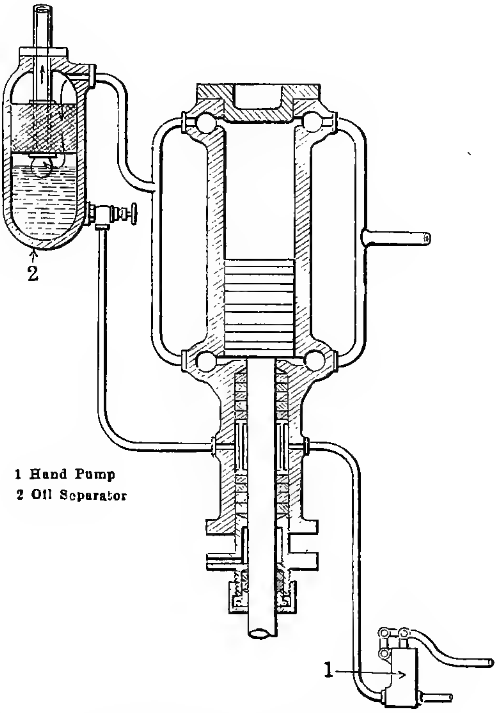


FIG. 176.—High pressure bath oiling system.

Whereas the lubricating oil in *wet compression machines* readily adheres to the moderately warm piston rod, and thus insures sufficient oil reaching the interior, the case is different in *dry compression machines.* Due to the high temperature of the piston rod, the oil film will be thin and very little oil will reach the interior of the compressor, unless the oil be introduced into the packing under pressure. That is the reason why mechanically operated force feed lubricators are used, as in this way the oil is certain to be carried along the piston rod into the compressor, and the oil feed can be adjusted to the correct amount required for piston lubrication.

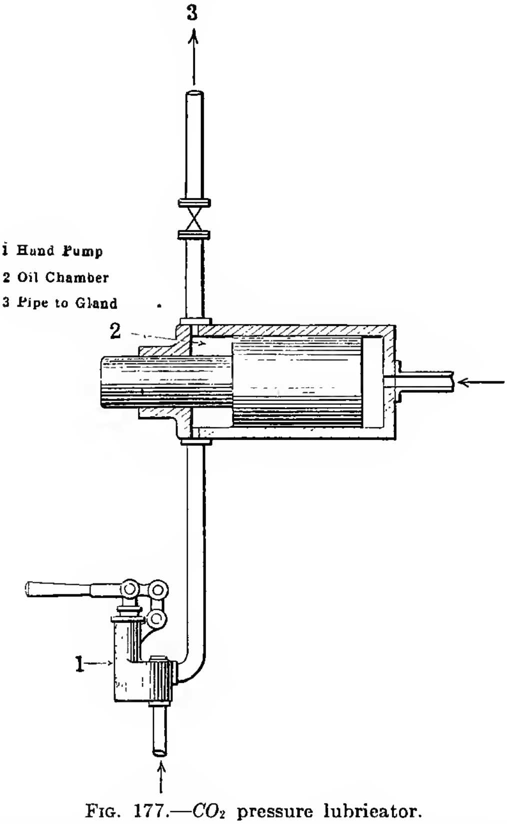


Fig. 177.—CO_2 pressure lubricator.

It is important that a type of mechanically operated lubricator be used that will feed oil only. Several types of mechanically operated lubricators feed air with the oil; the air thus introduced into the stuffing box is drawn into the compressor, increasing the pressure in the whole plant, and considerably decreasing the efficiency.

Fig. 177 illustrates diagrammatically a lubricator for CO_2 machines which delivers the oil into the gland under pressure, the same as a mechanically operated lubricator, but is not capable of such accurate adjustment or control. It consists of a cylinder in which there is a piston with a piston rod. The one side of the piston is subjected to the condenser pressure of, say, 70 atmospheres. The other side (where the piston rod is) holds the oil and has an outlet fitted with an adjustable throttle valve, through which the oil passes out to the gland.

The difference in area between the two sides of the piston is about 10 per·cent. and causes the over-pressure which forces the oil into the gland. By this method leakage of CO_2 from the gland is entirely obviated, and the outer gland is only required to prevent leakage of lubricant.

Splash Oiling.—Some few makes of small vertical enclosed type ammonia and CO_2 compressors have a bath of oil in the crank case, into which the crankpin bearing dips and splashes the oil to all parts.

The oil level should be a little below the underside of the crankshaft; if it is too high, the oil will froth with the vapors of the refrigerant, which are continuously drawn through the crank chamber.

LUBRICATION

The objects of internal lubrication of a refrigerating compressor are firstly to lubricate; secondly, to form an oil-sealing film so as to prevent leakage of refrigerant past the piston and out through the stuffing box; thirdly, to preserve the leather or rubber which may form part of the packing material.

If *too little oil* be used, the oil film will not be complete, so that excessive friction and wear takes place and leakage past the piston and piston rod occurs.

If *too much oil* reaches the interior of the compressor, or if the separator is not sufficiently effective, a fair amount of oil will be carried over into the condenser and through the expansion valve into the evaporator coils, where, owing to the low temperature, the oil becomes sluggish and is only slowly carried through the coils back again to the compressor.

The *oil,* in passing through the compressor, is exposed to the effect of the ammonia or carbonic acid, under moderately high temperatures. The result is more or less decomposition indicated by a darkening in color and an increase in gravity and viscosity.

Where the bath oiling system is employed, the system must be recharged with fresh oil, say once every year.

Oils with *too high a cold test,* when carried over into the separator coils congeal on the inside of the tubes, and, as oil is a bad heat conductor, the capacity of the condenser and evaporator will be appreciably reduced. It is therefore important that the oil should possess a sufficiently low cold test, so as not to become too sluggish to flow if it is carried over into the evaporator coils.

The oil must not contain any *moisture*, as the moisture will freeze and cause congealing of the oil. For this reason, engine attendants should be warned not to put the oil cans near suction pipes covered with snow in the vicinity of the compressor, as water dropping from the outside of such pipes may drop into the oil cans and contaminate the oil. Care should also be taken that the "save-alls" fitted under compressor glands and elsewhere to receive the waste oil are so made that no water dropping from the outside of the suction pipes can get into the "save-alls" and mix with the oil. Cases have been known where so much congealed oil has accumulated in the coils of the evaporator that they have become almost inoperative.

The oil for splash-oiled vertical compressors must have *a very low viscosity*, as otherwise it froths with the refrigerant; the froth fills the crank chamber, passes the piston, and clogs the whole system.

Even under the best conditions a slight amount of oil will certainly get over into the evaporator coils in all types of compressors, and it is therefore advisable to have the coils thoroughly and regularly cleaned. The coils are best cleaned by blowing through dry steam and afterwards air to dry the pipes. In bad cases, this treatment may be preceded by the application of a solution of soda ash.

Glycerine is used as a lubricant where the packing of the piston or stuffing box consists partly of rubber, which in time is destroyed by mineral oil, whereas glycerine has no appreciable deleterious effect on rubber or leather. With a packing containing only leather and brass or white metal, such as Figs. 171 and 172, mineral lubricating oils are used, and, if properly selected and of good quality, will be found superior to glycerine in reducing the piston and gland friction.

With efficient lubrication the piston rod assumes a smooth, glossy surface, covered with a thin clean film of oil, and the piston rod maintains a moderate temperature. The stuffing box, as well as the piston, will be perfectly sealed, so that no leakage of refrigerant occurs.

IRREGULARITIES

Where irregularities occur in a refrigerating plant, the effect is always to reduce its capacity for producing cold. The cause of the irregularity is not always easy to trace.

The following are typical causes of trouble:

Broken valve springs, preventing the valves from operating.

Leaky valves.

Leaky piston, piston rings out of order.

Dirty condenser coils: deposit from dirty cooling water on the outside, or a coating of oil on the inside of the tubes.

Expansion valve clogged or frozen (due to moisture in the oil, the use of poor cold-test oil, or impurities from the pipes).

Inefficient operation of the evaporator (due to oil or moisture congealing on the inside of the tubes, or to salt incrustations from the brine on the outside of the tubes).

Too little ammonia or carbonic acid in the system (due to leakage from the pipes or stuffing box).

The presence of air in the system, usually indicated by too high pressure in the system (air admitted through stuffing box).

ICE MAKING

A number of ice-making plants ashore are steam driven. The steam after passing through the steam engine is condensed and subsequently used for the manufacture of can ice. Plate ice is *not made* from *condensed* steam.

The cylinder oil used for internal lubrication of the steam engine may find its way into the ice, which is most objectionable, as it discolors the ice and gives it an unpleasant odor and taste.

Troubles with discoloration of the ice can, however, be traced to a variety of causes, such as the boiler water, the raw "make up" water, the exhaust steam oil separator, and the water filters.

Water.—The water used as boiler feed water for the boiler must be specially selected; it must not be hard; it must be free from sodium, calcium, or magnesium; it should be neither acid nor alkaline, or at the most should show only a slight reaction.

The boiler should be of ample capacity for developing the amount of steam required; the water level in the boiler should never be allowed to rise too high and should be as constant as possible; otherwise, priming of the boiler occurs and salts in solution and impurities will be carried over with the steam into the steam engine and finally mix with the water used for ice making.

Unsuitable water, used in the boiler or as raw "make up" water, produces discolored ice.

Oil Separator.—It is the duty of the oil separator to remove as much as possible of the oil contained in the exhaust steam. The oil and moisture from the steam separate out in the bottom of the separator and are removed at regular and frequent intervals, automatically or non-automatically. Most of the oil not caught by the oil separator will separate out in the re-boiler (in which the water is heated and freed from air bubbles) and is automatically skimmed off the surface. Any traces of oil still left should be caught in the water filters (coke, charcoal, or gravel).

Filters.—Rust from the pipes and impurities of various kinds gradually accumulate in the filters. It is therefore necessary to clean or renew the filtering material at least once every season.

Steam Cylinder Oil.—When using compounded steam cylinder oils, particularly dark cylinder oils, some of the oil may pass not only the oil separator, but also the re-boiler and even the filters, finally appearing in the ice.

Filtered cylinder oils separate easily from the water. A good grade of filtered cylinder oil is therefore to be recommended for steam engines in ice-making plants; and if a good type of mechanically operated lubricator is employed, so that the oil can be introduced in the best manner and used economically, the use of a compounded filtered cylinder oil in place of a straight mineral oil is permissible, containing not more than 3 per cent. acidless tallow oil, as the admixture of tallow oil will enable the cylinder oil to be used exceedingly economically, and better lubrication will be obtained.

The little oil which will be present in the exhaust steam is easily taken care of by the oil separator, or, at any rate, by the re-boiler or filters.

LUBRICATION CHART FOR REFRIGERATING MACHINES

Refrigerator oils must be straight mineral oils. Compounded oils have too high a setting point, they combine to some extent with ammonia, more or less saponification taking place, and they are rather inclined to absorb moisture from the atmosphere, which is very undesirable. Only low viscosity is required, the setting point being of supreme importance.

For most refrigerators in ice-making plants an oil with a zero cold test will be satisfactory, but many CO_2 machines operate with lower evaporator temperatures than is the case in ice making plants. A cold test of − 25°F. will however satisfy the vast bulk of refrigerating compressors. Many ice making plants prefer to use an oil with a better cold test than zero F. in order to have an extra margin of safety against the oil congealing in the system.

Oils specially low in viscosity are required for small splash oiled vertical compressors to avoid frothing.

To withstand the heat in the compressor without serious decomposition, refrigerator oils should be highly refined and highly filtered, pale colored, straight-run distillates, containing as few unsaturated hydrocarbons as possible.

Experience proves that three mineral refrigerator oils having the viscosities, setting points and open flash points shown in Table No. 22 will satisfy all requirements.

TABLE No. 22

Refrigerator oil	Saybolt viscosity at 104°F., in secs.	Setting point, °F.	Flash point open, °F.
No. 1	130–180	0	340–380
No. 2	130–180	– 25	320–360
No. 3	60– 70	Below – 40	Above 300

These three mineral oils and glycerine are recommended for the following types of compressors:

LUBRICATION CHART No. 14

FOR REFRIGERATING COMPRESSORS

	For compressor	For bearings
Cold air machines	Glycerine	Bearing Oil No. 4
Ammonia machines,[1] open type	Refrigerator Oil No. 1 or 2.	Bearing Oil No. 3 or 4.
Carbonic acid machines,[1] open type	Refrigerator Oil No. 2.	Bearing Oil No. 3 or 4.
Small vertical enclosed type splash-oiled machines, whether ammonia or carbonic acid.	Refrigerator Oil No. 3.	Refrigerator Oil No. 3.
Large vertical enclosed type, splash-oiled machines, whether ammonia or carbonic acid.	Refrigerator Oil No. 2.	Refrigerator Oil No. 2.

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[1] When rubber forms part of the packing in the stuffing box gland, glycerine must be used and not mineral refrigerator oil.

CHAPTER XXVII

GAS ENGINES

In order that the reader may understand and appreciate the lubricating problems met with in connection with gas engines, it becomes necessary to give first of all a picture of the mechanical and operating conditions.

The subject has been divided into "Small and Medium Size Horizontal Gas Engines," "Large Horizontal Gas Engines" and "Vertical Gas Engines." For each group of engines are given particulars of typical engines and the methods of lubrication. Some information follows in regard to cooling and gas, both of which have an important bearing upon the lubrication of gas engines. The formation of carbon deposits is then treated in detail, and finally the important part played by the oil itself, and the correct grades to be recommended for the principal types of engines.

SMALL AND MEDIUM SIZE HORIZONTAL GAS ENGINES

Classification.—Small horizontal gas engines have only one cylinder; they develop from 1 to 50 H.P. and operate at high speeds, ranging from 500 to 190 R.P.M. Medium size horizontal gas engines are made with one or two cylinders; the power developed per cylinder ranges from 50 to 250 H.P. and the speeds range from 190 to 130 R.P.M.

The cylinders are always water cooled and where the power per cylinder exceeds 150 H.P. the *piston* must also be water cooled. Indeed, many builders employ water cooled pistons in engines ranging in sizes from 80 H.P. per cylinder upwards.

Small and medium size engines are practically always of the four-stroke cycle type, and in view of the foregoing may be classified as shown in Table No. 23:

TABLE NO. 23

Size	No. of cylinders	H.P. per cylinder	Revolutions per minute
Small size....................	One cylinder.	1–50	500–190
Medium size (without water-cooled pistons)	Usually one; sometimes two, three or four.	50–150	190–140
Medium size (with water-cooled pistons)	Usually one; sometimes two, three or four.	80–250	180–130

The cylinders of medium size engines may be arranged in various ways (Fig. 178):

Two cylinders, opposed—*The Opposed Type Engine* (Fig. 178*A*).

Two cylinders, one behind the other—*The Tandem Engine* (Fig. 178*B*).

Two cylinders, side by side—*The Twin Engine.*

Three or four cylinders, side by side—*The Multiple Cylinder Engine* (Fig. 178*C*).

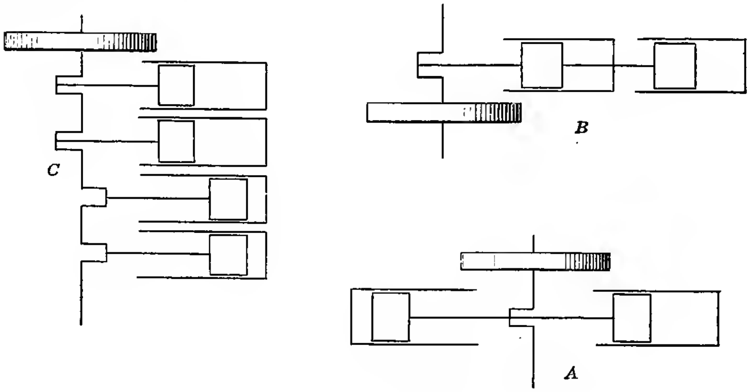


Fig. 178.—Types of horizontal gas engines.

METHODS OF LUBRICATION

Principle of Operation.—The four-stroke cycle principle of operation may be described as follows:

First or Suction Stroke.—Gas and air, constituting the fuel charge, are sucked into the cylinder through the open inlet valve as the piston moves away from the cylinder head. The exhaust valve is closed.

Second or Compression Stroke.—The piston moving towards the cylinder head compresses the fuel charge. Both inlet and exhaust valves are closed.

Third or Power Stroke.—Ignition by the spark of the compressed fuel charge produces explosion and expansion of the gases, forcing the piston away from the cylinder head *during the power stroke.* Both inlet and exhaust valves are closed.

Fourth or Exhaust Stroke.—The piston moving towards the cylinder head drives the burned gases out through the open exhaust valve. The inlet valve is closed.

Thus the four strokes of the piston, *i.e.*, one power stroke and three preparatory strokes, complete the cycle of events; hence the expression four-stroke cycle.

Main Bearings.—These are generally ring-oiled bearings, having an oil reservoir from which one or two revolving oil rings continuously carry the oil to the bearing surfaces. In some medium size gas engine the main bearings are, however, fed by gravity from an elevated tank and kept in continuous circulation by a pump.

Crank Pin Bearing.—This is lubricated by means of the well-known banjo arrangement. The oil is fed into the banjo either from a sight-feed drop oiler, or the feed may come from a mechanically operated lubricator.

Piston.—Small engines are often fitted with only one oiler to supply the piston and wrist pin. The surplus oil on the piston collects in a groove at the top and through a tube drops into the wrist pin bearing, more or less contaminated with carbon. With this method it is always necessary to overfeed the piston in order to ensure a reasonable supply of oil reaching the wrist pin. Many small engines and most medium size engines have therefore separate oilers for piston and the wrist pin, so that the right amount of oil can be distributed.

The piston oiler, if it be a sight feed drop oiler, should preferably be provided with a ball check valve to prevent "blow back" of escaping gases into the sight feed. (See Fig. 20, page 110.)

Gravity sight feed drop oilers will vary from say 40 drops per minute when nearly full to 16 drops per minute when nearly empty. If the quantity fed at a lower level is sufficient, as it must be if the engine is not to suffer, the extra quantity fed when the container is full is sheer waste, and in the case of the cylinder positively detrimental. The oil feed is very susceptible to temperature changes and the needle valves easily choke with dirt. The idea has therefore been steadily gaining ground that something more reliable is needed, and the foremost engine builders are adopting a centrally placed multi-feed lubricator operated mechanically from the cam shaft. The lubricator should be designed on principles that will ensure a constant uniform oil feed, independent of the height of the oil level in the container, and independent of the viscosity of the oil. Each feed should be from a separate pump unit, independent of the other feeds and should preferably have a sight fed arrangement showing the oil on its way to the engine; also the feeds should be capable of being flushed and of instantaneous adjustment between wide limits.

The lubricator usually has an operating lever actuated by a cam on the cam shaft; the oscillating lever gives motion to the internal mechanism in the lubricator, so that pump plungers automatically pump oil through the various oil pipes. The individual feeds of the lubricator once adjusted require no further attention.

In order to insure that the oil pipes shall be always full they should be provided at the extreme ends with check valves. When the lubricator is stopped and the lubricator ceases to operate, the check valves prevent the oil from running out of the pipes. The pipes are thus kept constantly full of oil and instant lubrication is assured whenever the engine, and, consequently, the lubricator starts to operate.

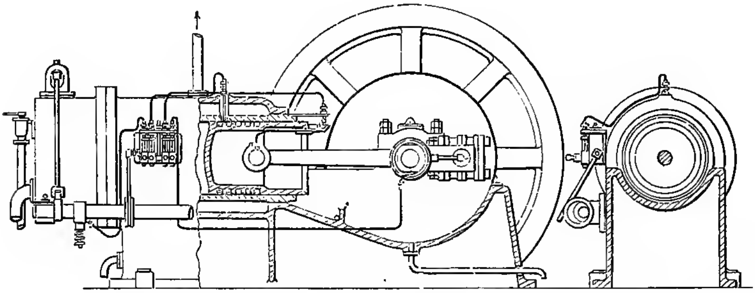


FIG. 179.—Timed oil injection to piston of gas engine by a mechanical lubricator

Timed Oil Injection to the Piston (Fig. 179).—When the mechanical lubricator is designed to pump oil only and not oil and air, the piston oil feed can be timed to inject the oil under pressure at the right moment and to the ideal place, which is between the first and second piston ring, when the piston is at its most outward position. This enables the piston to carry the oil well into the cylinder. Feeding the oil in this way the piston will act as an oil distributor; cleaner and more economical lubrication of the piston is obtained and practically no oil runs to waste from the lip of the liner. It is necessary that the oil should be fed through a combined check valve and oil injector (see Fig. 180) the end of which barely touches the piston, so that for every impulse of the oil pump a small portion of oil is wiped off by the piston and taken right into the inner portion of the cylinder, distributing itself uniformly over the entire surface. Any deviation from this practice, either by feeding the oil nearer the front of the liner than indicated, or feeding it through a lubri-

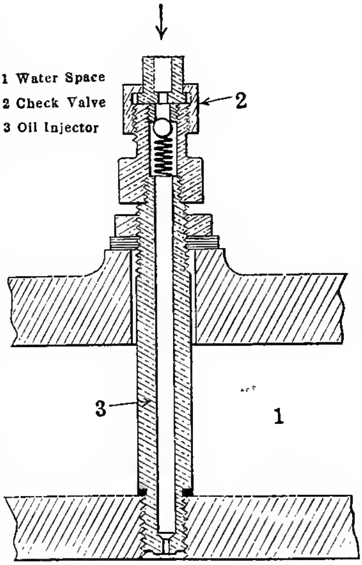


FIG. 180.—Oil injector.

cator that does not time the injection of the oil, will mean a larger oil consumption (waste), more carbon deposit, and a lower margin of safety.

On the Continent practically all gas engines are fitted with some kind of mechanical lubricator, so as to ensure that the oil feed to the piston shall be as regular as possible, but the importance of timed injection does not appear to be fully realized. The installation of such a mechanical lubricator means extra initial cost to the consumer and to the engine builder, but it also means a saving in oil consumption as compared with sight feed drop oilers of as much as 50 per cent., and what is much more important, it means a greatly increased margin of safety, as well as cleaner and more efficient lubrication throughout.

One engine builder who had for years been using sight feed drop oilers in connection with pumps (the oil dropping from the sight feed drop oilers into the oil pumps) found that after installing mechanical lubricators of a good make, practically all their trouble during the guaranteed period of their engines ceased. In many cases engine attendants forget to adjust the sight feed drop oilers, forget to start them or stop them, or they allow them to run empty. With a mechanically-operated lubricator there is only one container to fill, and one filling of the container will last several days; less attention, is therefore required!

Valve Spindles and Cams.—The valve spindles of inlet and exhaust valves (as well as the cams) are sparingly hand-oiled but in the case of larger gas engines, say above 50 H.P., it is becoming general practice to lubricate the exhaust valve spindle by one of the feeds from the mechanically operated lubricator. The feed must be very sparing and absolutely uniform. With an excessive oil feed the excess oil burns and carbonizes. With too sparing a supply of oil, too little lubrication is provided. The spindle becomes overheated and carbonizes what little oil it gets. In either case the exhaust valve spindle will be inclined to "stick."

LARGE HORIZONTAL GAS ENGINES

Large gas engines are used for driving electric generators in iron and steel works, in collieries, occasionally in large central power stations, and , in rare instances, in textile mills.

Large two-stroke cycle gas engines are also extensively used in iron works to drive blowing engines which produce compressed air for the blast furnaces.

All large gas engines are double acting; most of them are of the four-stroke cycle type, built usually as tandem-cylinder engines, rarely with one cylinder only. The largest power units consist of two tandem engines placed side by side—a twin tandem engine—operating an electric generator mounted between them on the main shaft. Two-stroke cycle gas engines have only one cylinder and operate at a lower speed than four-stroke cycle engines.

Table No. 24

Classification	No. of cylinders	H.P. per cylinder	R.P.M.
Four-stroke cycle double acting....	One to four	300 to 1500	150/90
Two-stroke cycle double acting....	One	400 to 2000	100/60

METHODS OF LUBRICATION

Internal Lubrication.—The cylinder, stuffing boxes, and exhaust valve spindles are always lubricated by means of a mechanically operated lubricator delivering the oil under pressure to the various parts and operated from the cam shaft.

Cylinder.—The oil is introduced into the cylinder at from three to six points, through ¼ inch copper pipes from the mechanically operated lubricator. The oil inlets are sometimes located at the middle of the cylinder of four-stroke cycle engines, but in the case of two-stroke cycle engines this is not possible on account of the exhaust belt around the middle of the cylinder. In this case the oil inlets are placed about half-way between the exhaust belt and the cylinder ends.

It is important that the oil be introduced into the cylinder at the moment when it will be fed directly to the piston and the piston rings. If introduced when the oil inlets are uncovered, the oil is burned by the hot gases, resulting in waste of oil and the formation of deposits.

Stuffing Boxes.—The stuffing boxes located in the cylinder heads are the parts which usually give the most trouble. The oil is introduced under pressure into the middle of the stuffing box and distributed over the entire frictional surfaces of the packing rings. (See Fig. 181.) The packing rings are usually cast-iron rings made in two halves and held together around the piston rod by means of light garter springs. Outside the packing rings there is occasionally a second stuffing box, employing soft packing.

Exhaust Valve Spindles.—Although the exhaust valve guides surrounding the exhaust valve spindles are water cooled, it becomes necessary to lubricate the spindles with a uniform and very sparing supply of oil for the same reasons as mentioned under medium size gas engines.

Mixing and Inlet Valves.—The mixing and inlet valve spindles are sparingly hand oiled, except in very large engines, where they are supplied with oil through separate feeds from the mechanically operated lubricator.

Gas and Air Pumps.—As the gas and air are sucked into these pumps at a slight vacuum and delivered from the pumps to the working cylinders at a pressure of 4 to 6 pounds, the temperature of the pump cylinder walls, due to compression, is not much above 100°F. There is, therefore, no need for water jacketing these cylinders and their lubrication presents no difficulties where the gas and air are clean.

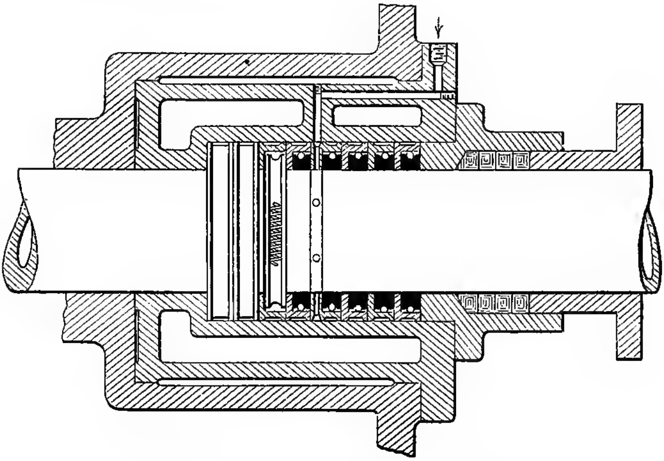


Fig. 181.—Stuffing box for large gas engine.

The practice has been to feed the oil through sight feed drop oilers into the centre of each pump cylinder, with additional oil feeds to either end of both gas and air valve chambers. Frequently, however, an accumulation of deposits has been experienced due to moist, dirty gas, and overfeeding of the oil, the impurities adhering to the excess oil. Under these conditions it has been found better practice not to lubricate the pump cylinder and valve direct, but to introduce the oil uniformly and sparingly, by means of a mechanically operated lubricator, through atomizers in the respective intake pipes.

EXTERNAL LUBRICATION

Circulation System.—In the external lubrication of large gas engines a circulation system is usually employed. The lubrication of main bearings, crank pin, cross head, tail-rod support and guides is accomplished by means of oil fed by gravity from a top supply tank through a distributing pipe and its branches, into the various bearings. Adjusting valves are fitted in the branch pipes to regulate the oil feeds. Having done its work, the oil drains back to the bottom receiving tank.

An oil pump driven by the engine draws the oil from the receiving tank and delivers it through an oil cooler into the top tank. If more oil is delivered to the top tank than is required for the bearings, the surplus oil overflows through an overflow pipe back into the receiving tank. The top tank may be omitted and the oil passed directly from the oil cooler into the distributing pipe, in which case it becomes necessary to have a relief valve, through which the surplus oil is passed back into the bottom tank.

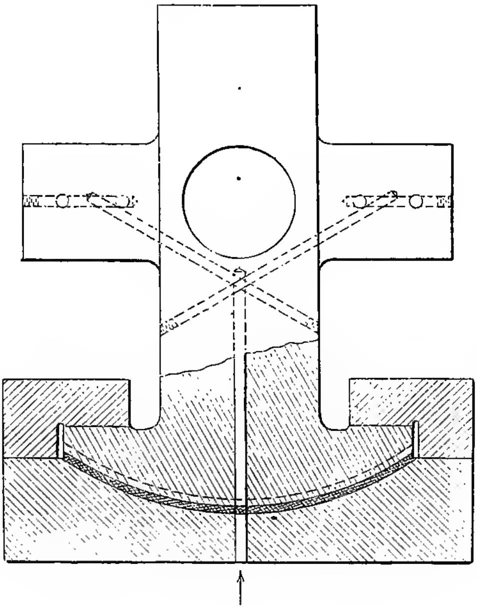


FIG. 182.—Crosshead of large gas engine.

The oil is delivered to the crank pin through the hollow crank shaft, and in order to distribute the oil well there are usually three or four radial holes (120° apart) through which the oil reaches the large bearing surface.

The oil for the crosshead bearings is delivered to the crosshead guide. The crosshead shoe is so long that the oil hole in the guide is never uncovered; consequently, the oil is enabled to force its way through drilled passages in the crosshead, as indicated in Fig 182.

To give an idea of the dimensions of bearings and oiling system, the following two examples are cited as typical of existing engines.

Circulation System for 1000 *B.H.P. Two-stroke Cycle Single Cylinder Gas Engine*

Engine speed	94 R.P.M.
Quantity of oil in circulation	40 gals.
Type and size of pump	Plunger pump, 1½" dia. × 1½" stroke.
Speed of oil pump	94 strokes per min.
Height of oil pump above oil level in bottom tank	4 ft.
Three main bearings	18" diameter × 33" length.
One crank pin	18" diameter × 30" length.
Oil delivery pipe	1½" diameter.
Oil return pipe	2" diameter.

All waste oil flows direct to bottom oil tank, which has two vertical strainers, through which the oil passes to the oil pump; the suction pipe is fitted with a strainer and a non-return valve (foot valve).

Circulation System for 1000 *B.H.P. Four-stroke Cycle Tandem Cylinder Gas Engine*

Engine speed	140 R.P.M.
Quantity of oil in circulation	80 gals.
Type of oil pump	Rotary, 4" wheels.
Speed of oil pump	140 R.P.M.
Height of pump above oil level in bottom tank	6 ft.
Three main bearings	16" diameter × 25.5" length.
One crank pin	15.5" diameter × 19.0" length.
Two crosshead bearings for forked connecting rod	9" diameter × 9.5" length.
Oil delivery pipe	2" diameter.
Oil return pipe	2" diameter.

All waste oil is led to a separating tank, which retains most of the water and impurities. The oil then passes through a filter before being delivered to the bottom oil tank through a strainer.

Timing Shafts are usually supported by ring oiled bearings.

Eccentrics are equipped with sight feed drop oilers or automatic compression grease cups.

Valve Levers are sparingly hand oiled.

Governor.—The governor is oiled partly by sight feed drop oilers and partly by hand.

VERTICAL GAS ENGINES

Vertical gas engines are principally used for driving electric generators which produce current for lighting or for operating electric motors. They are also used, occasionally, for driving air compressors, large centrifugal pumps, refrigerating plants, etc.

TABLE No. 25

Type	No. of cylinders	H.P. per cylinder	R.P.M.
Four-stroke Cycle.			
Multiple cylinder type	One to six.	5 to 125	$^{350}/_{225}$
Multiple tandem cylinder type	Four to twelve	5 to 125	$^{350}/_{225}$
Two-stroke Cycle.			
Double acting, with oil or water-cooled pistons.	Two to four	200 to 500	$^{160}/_{140}$

Practically all vertical gas engines are of the four-stroke cycle types.

Some large two-stroke cycle vertical gas engines have been developed in England, but may be said to be still in the experimental stage.

Constructional Points.—There are two types of vertical four-stroke cycle gas engines: the multiple cylinder type and the multiple tandem-cylinder type (shown diagrammatically, Fig. 183). Multiple cylinder vertical engines are rarely built with one cylinder only; they generally have three or four cylinders. The multiple tandem-cylinder type usually has 4 or 6 pairs of cylinders, *i.e.* 8, or 12 cylinders, and is developed only in England: by the British Westinghouse Company and the National Gas Engine Company.

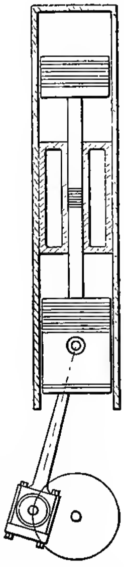


FIG. 183.—Diagram of vertical tandem-type gas engine.

As vertical gas engines are always enclosed, and the cylinder walls copiously supplied with oil, the pistons are frequently designed with oil scrapers at the bottom in connection with grooves from which the oil can be drained through holes to the interior of the piston, and thence down into the crank chamber. Also it is good practice to design the pistons in two parts, inserting between the top and bottom portion a plate, which prevents the oil from the gudgeon pin splashing into the hot hollow piston head, where it would otherwise burn and char. As an alternative the piston may be cast with a projecting internal lip above the gudgeon pin, the hole being closed by a plate.

In the case of the vertical tandem-type gas engines, the two pistons are connected by means of a piston rod working in a sleeve between the two cylinders. The air below the top piston is compressed on the downstroke and acts like an air buffer.

Methods of Lubrication.—Vertical four-stroke cycle gas engines operate at high speed. In order to prevent the lubricating oil from splashing away from the bearings, all external motion parts are enclosed in a crank chamber or casing, so that the parts may be copiously supplied with oil, either by the splash system of lubrication or by the force feed circulation system.

CRANK CHAMBER LUBRICATION

Splash Oiling System (Fig. 184).—The lower portion of the crank chamber is filled with oil to the level indicated in the drawing and an adjustable overflow pipe is fitted to one end of the crank chamber in order to maintain a correct oil level. The bottom ends of the connecting rods dip into the oil and splash it to all parts requiring lubrication.

Oil is fed into the outer main bearings by sight feed drop oilers. Leaving these bearings the oil drops into the crank chamber and thus makes up for the amount of oil that goes away as oil spray or is burned away inside the cylinders. In place of sight feed drop oilers, a mechanically operated lubricator is preferably employed to supply oil uniformly to the main bearings, in this way making the lubrication system entirely self-contained and automatic in action.

A correct constant oil level must be maintained, in order to secure uniform splash to all parts and to obtain greatest economy. Connecting rods should dip into the oil to the same depth, and the oil level should be lowered until the formation of carbon deposits on the pistons is reduced to a minimum.

Irregular or *too high an oil level* means waste of oil and excessive carbonization. *Too low an oil level* or the use of *an oil too heavy in viscosity* means unequal distribution and insufficient lubrication for some of the parts, resulting in excessive wear of those parts. It cannot be too strongly emphasized that an adjustable overflow should be installed, in order that the correct oil level, once established, can be automatically maintained.

Force Feed Circulation System.—This system delivers the oil under a pressure of from 5 to 20 pounds per square inch to all bearings, the oil leaving the gudgeon pins splashing on to the cylinder walls. The circulating oil sometimes passes a filter or a cooler.

Oxidation.—In passing through the main bearings, crank pin bearings, and wrist pin bearings, the oil is subjected to high temperature and speed of the rubbing surfaces. Oxidation takes place which is indicated by a darkening in color, an increase in viscosity and gravity, and the development of acidity.

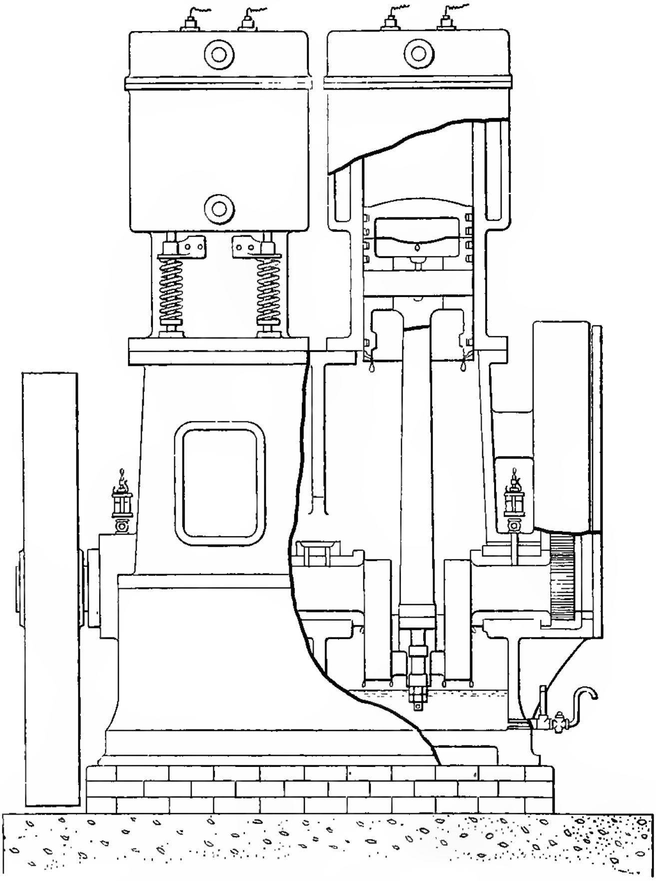


FIG. 184.—Splash oiled vertical gas engine.

Temperature.—As the crank chamber is enclosed, the heat radiated from the pistons and cylinder walls is, to a large degree, retained in the crank chamber, so that the oil in the crank chamber gets warm, reaching a temperature of from 100°F. to 160°F. If a temperature of 140°F. is greatly exceeded, the life of the oil will be shortened, and it may throw down a dark deposit caused by oxidation similar to that which may take place with turbine oil.

The force feed circulation system is always employed in vertical four-stroke cycle, multiple tandem-cylinder gas engines and is superior to the splash lubricating system. The splash system is used in some multiple cylinder engines, but the majority of these engines employ the force feed circulation system.

It is a common trouble that oil in the crank chamber becomes contaminated with carbonized matter working down from the pistons. In order to prevent dirty oil from the trunk pistons dropping into the crank chamber some builders of vertical two-stroke cycle gas engines and vertical multiple cylinder four-stroke cycle engines raise the cylinders above the crank chamber by means of a distance piece. The piston rods pass through scraper glands and are connected inside the crank chamber to crossheads.

By this construction carbonized matter can be prevented from entering the crank chamber, but as the pistons are not lubricated by splash from the crank chamber, it becomes necessary to lubricate them independently, by means of a multiple feed mechanically operated lubricator. This practice permits the use of a different oil for piston lubrication, which is often desirable.

As burned gases occasionally escape past the pistons into the crank chamber, this is provided with an air-vent pipe, frequently fitted with a fan, which sucks away from the enclosed crank chamber fumes and vaporized oil. At the same time cold air is constantly drawn through the engine and helps to cool the pistons and crank chamber.

As regards the piston lubrication, one oil feed from the lubricator goes to each piston, delivering the oil through a check valve into an annular oil tube surrounding the cylinder, from which 2, 4 or 6 leads go through the water jacket and distribute the oil over the piston surface. As the oil is introduced at one point of the annular oil tube it is likely to pass into the cylinder through the leads nearest this point, so that the opposite side of the cylinder may get little or no oil direct from the leads. For this reason it is good practice to have each point of entrance to the cylinder fed by a separate oil pump, so that each feed can be controlled with certainty. Two oil feeds suffice up to 21-inch cylinders, one feed for the front and one for the back of each piston.

Further, the oil should preferably be introduced in line with the level between the first and second piston ring, when the piston is in its lowest position. The oil feeds from the mechanically operated lubricator should be capable of independent adjustment, so that the exact amount of oil required can be supplied to the sleeves and pistons.

Pistons.—The piston rings should be in good condition and pegged, so that only a sufficient amount of oil for full lubrication will reach the entire piston surfaces. Too much oil splashed from the crank chamber (too high oil level, too high oil pressure), or too much oil fed directly to the piston, means that excess oil will pass to the piston tops, where it will burn and char and ultimately form deposits.

In the case of multiple tandem cylinder engines, care should be taken that the quantity of oil fed from the mechanically operated lubricator to the top pistons and the sleeves be reduced to the exact amount required. This applies also to multiple cylinder engines with a distance piece between the cylinders and the crank chamber.

The importance of pegging the piston rings is clearly shown by an experience related in "The Gas World" for May, 1918. Having explained that preignition occurred badly in only one out of several 4-cylinder engines, the writer continues:

> "I believe in one of my letters I mentioned the theory I had previously put forward, that oil vapor passing the pistons might account for the pre-ignition. I now took this up again and it seemed possible that this oil vapor might result from the high oil pressure we have always carried on this engine, viz. 10 lbs. per sq. in. A reduced pressure was tried and a better run was obtained before pre-ignition occurred and the pre-ignition was now in No. 2 cylinder, whereas No. 1 cylinder had previously given most trouble. I then concluded, if oil vapor was passing, it could only be at the gaps of the piston rings, since the rings were free to revolve, and the fact of the pre-ignition shifting from one cylinder to another looked as if a certain number of ring gaps, coming into line, allowed the oil vapor to pass in that particular cylinder. Upon drawing the pistons, four of the six rings in No. 2 cylinder where the pre-ignition had occurred, were found to have their gaps in a vertical line, whereas the rings of the other three pistons had their gaps fairly evenly distributed. I therefore had all piston rings pegged.
>
> On the next run all cylinders ran dry, and the oil pressure had to be increased to 10 lbs. per sq. in. before the cylinders appeared to get sufficient lubrication. Pre-ignition had, however, disappeared, and although the engine has now run on a good load on seven separate days, no further trouble has occurred.
>
> Later, since the above was written we have had two full days' run on this engine on three-quarters to seven-eighths load and she has run perfectly with no sign of pre-ignition."

COOLING OF GAS ENGINES

Cooling of all parts of the engine that come in contact with the hot gases is necessary. Without adequate cooling, unequal expansion and distortion of the overheated parts, excessive wear. and piston seizure would occur.

Small gas engines employ the thermo-syphon system, but most medium size and all large gas engines employ pump circulation. In large gas engines provision is made for adjusting the supply of cooling water to the various parts (cylinder walls, piston, piston rods, cylinder covers, and exhaust valves). All return water pipes are ca ried to a central place where the temperature and the quantity of cooling water from each part can be controlled. The cooling water, after its return from the various parts is pumped through a cooling tower, cooled and again pumped through the engine.

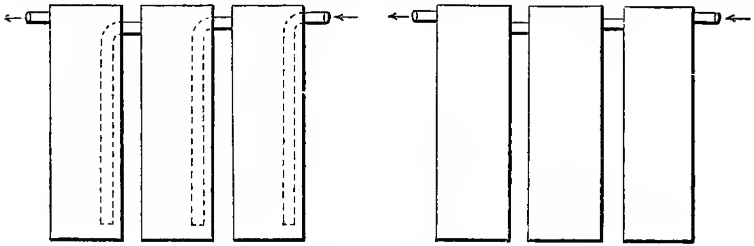


Fig.185A Fig.185B

Fig. 185.—Cooling tanks.

Smaller engines employ cooling tanks, which must be so arranged that the water from one tank flows into the bottom of the next one (Fig. 185*A*). With the arrangement shown in Fig. 185*B* the water flow is short-circuited and the water is not properly cooled.

In the inlet and outlet pipes should be fitted thermometers for registering the temperature of the cooling water. The average temperature of the return cooling water should be between 100° and 130°F. in large gas engines and between 100°F. and 140°F. for smaller engines. If the outlet water from the water jacket is too high, the temperature of the cylinder wall will rise; the oil film thins out, losing its sealing power and the explosion gases blow past the piston. If the outlet water is much below 100°F. the cooling of the cylinder walls is too efficient. The oil film becomes sluggish, the oil spreads with difficulty and a great deal of power is lost in overcoming the oil drag on the piston. A temperature of 115°F. to 120°F. is therefore preferable in order to insure good piston seal and a free sliding motion of the piston.

The cooling water must be clean, for if impurities settle in the water jacket the cooling of the cylinder walls and pistons (where pistons are water-cooled) becomes defective, the temperature rises and pre-ignition, caused by incandescent deposits inside the combustion chamber, is likely to occur.

Where the gas contains an excessive amount of sulphur (large gas engines) successful results have been obtained by allowing the cooling water to run through the engine at a higher temperature, as high as 160°F. The higher temperature of the cooling water minimizes, or entirely prevents, the condensation of moisture from the expanding gases and thereby the formation of sulphurous acid, which would attack the internal surfaces of the engine that come in contact with the gases.

GAS

When using rich, highly inflammable gas, such as natural gas, the compression pressure at the end of the compression stroke must be proportionately low; otherwise pre-ignition will occur, due to the heat developed by compression. With weak, less inflammable gas, such as the producer gases, the compression pressure can be made much higher.

This is shown in Table No. 26 which gives average comparative heat values of gases and corresponding average compression pressures:

TABLE No. 26

Kind of gas	Heat value, B. Th. U.	Compression pressures lbs. per sq. in.
Natural gas	1000	100
Illuminating gas	600	120
Coke oven gas	520	130
Producer gases	130	150
Blast furnace gas	100	190

Small and medium size gas engines are operated by natural gas, illuminating or town gas, suction producer gas, or pressure producer gas. Large gas engines are operated by blast furnace gas, coke oven gas or pressure producer gas.

Natural Gas.—Natural gas is found in the oil districts of the United States, Canada, Russia, and Mexico. It is dry in its natural state, with a degree of purity that makes cleaning unnecessary.

Illuminating or Town Gas.—Illuminating gas is used practically only for small gas engines. It is made from bituminous coal by dry distillation. It is free from impurities and is, therefore, an excellent fuel.

Suction Producer Gas.—Suction producer gas is usually made from coke, anthracite coal, lignite, wood refuse, etc. The engine draws the gas from the producer by suction—hence the name *suction* producer gas. Suction producer gas plants are used for installations comprising one or more engines with a total power not exceeding 500 H.P.

Pressure Producer Gas.—Pressure producer gas is made from a variety of fuels, such as bituminous coal, lignite, coke, anthracite, charcoal, sawdust, wood refuse, etc. The gas is produced under slight pressure—hence the name *pressure* producer gas.

Pressure producer gas plants are sometimes used for installations as small in size as 200 H.P., but the installations usually range from 400 H.P. to 2000 H.P. or more, employing medium size or large size gas engines.

Where bituminous coal is used, rich in tarry matters, the cleaning plant for the gas must be more elaborate and efficient, and therefore more costly than in the case of suction producer gas plants, which preferably use fuel free from tar.

Producer gas, whether suction gas or pressure gas, should be thoroughly scrubbed, cooled and cleaned; but notwithstanding all precautions taken the gas always contains, besides moisture, more or less impurities, such as soot, fine dust (coke dust, ash) and tar, which are carried into the engine and interfere with lubrication.

Blast Furnace Gas.—The blast furnace gas coming from the blast furnace contains a great quantity of impurities, consisting of lime dust, fine iron oxide, coke dust and volatile matter from incomplete combustion in the blast furnace, water impurities from the water used in washing the gas, and a small amount of sulphur. The quantity of impurities varies from 12 to 25 grams per cubic meter of gas, and is reduced in the cleaning plant to 0.01 to 0.03 gram per cubic meter. If the impurities are more than 0.05 gram per cubic meter the gas is dangerous for the engines and will cause deposits and excessive wear of piston rings and cylinder walls.

The gas is freed from the dust and tarry impurities by either the wet or the dry cleaning process. By the latter process the gas is filtered dry through filter bags and is delivered in a less moist condition to the engines, so that it is less liable to deposit dust in the mixing valves and cylinders.

Coke Oven Gas.—Coke oven gas is produced from bituminous coal during the production of coke. A portion of the gas is used in the coke oven, but the surplus gas can be used for operating gas engines. The coke oven gas contains, besides coke dust, tar and sulphur.

Sulphur in Coke Oven or Producer Gas.—Heavy wear is often noticed when the gas is not sufficiently low in sulphur contents. The wear is chiefly on the piston rod, but only on the part of the rod rubbing in contact with the rings in the metallic packing. The greatest wear is where the rod is coolest, *i.e.* where the water enters; the wear is less on the tail rod, where the water leaves the rod warm. The rod does not get pitted, but wears uniformly, maintaining a bright polished surface, with dark colored patches showing here and there.

By allowing the cooling water to pass warmer through the rods, the wear, as mentioned page 453, is reduced or eliminated.

If a piston rod gets splashed with water from the water discharge tubes (outside the cylinder) it will wear rapidly, if the gas contains an excessive amount of sulphur. A water leak from the cylinder head into the metallic packing will have a similar effect. In the case of a porous cylinder, allowing cooling water to leak into the cylinder, sulphur will cause extremely rapid wear.

DEPOSITS

Deposits form in the mixing and inlet valves, in the cylinders, on the piston, behind and between the piston rings, on the exhaust valves, and in the stuffing boxes. In two-stroke cycle engines deposits are also formed in the gas and air pumps. Deposits may arise from one or several of the following causes: dust or dirt in the intake air, incomplete combustion, impurities in the gas, overfeeding of oil, the use of an unsuitable oil. The formation of deposits under certain conditions leads to preignition and backfiring.

Intake air is usually not filtered, even when the engines are placed in dirty surroundings. Impure intake air is therefore a frequent cause of deposits in gas engines, regardless of the kind of gas used. (See Examples Nos. 34, 37 and 39, pages 458, 459, 461.) In such cases a chemical examination will prove the presence or sand, brick dust, lime dust, etc. The deposit will also contain oil and partly decomposed oil, due to the oxidizing action of the impurities on the oil under high temperature conditions, and there will always be present a percentage of iron and iron oxide, due to wear of the piston rings and cylinder.

In large gas engines the air should be filtered through coarse canvas or similar material before passing to a large settling chamber, which will collect more of the solid impurities.

Incomplete combustion will bring about sooty crumbly deposits and may be due to poor ignition or improper timing of the valves.

Impurities in the Gas.—(See Examples Nos. 37, 38 and 39.)

Where *producer gas* is in use, deposits may be caused by such impurities as ash, fine coke dust, free soot or tar passing into the engine. All fuels contain ash, and a regular feeding of fuel through the generator and removal of clinker from the grates are very desirable, because if the grate is not covered with a sufficient layer of fuel, fine ash is likely to be carried over with the gas. Regular firing is therefore important, as it prevents the layer of fuel from getting too low.

Where coke is used, there is no tar, but coke dust may be carried over in such fine form that neither the water trap, scrubber, nor filter will remove it.

Where gas is produced from anthracite coal, tar and soot may both be carried over, although anthracite contains only a small percentage of tar.

Where gas is produced from lignite, which contains more tar and soot, the danger of forming deposits inside the engine is more pronounced.

Lignite also contains a small percentage of sulphur; this in many cases will cause a blackening of the piston surface, but rarely causes serious trouble.

Where gas is produced from bituminous coal which contains a large percentage of tar, there is greatly increased likelihood of the gas carrying soot and tar into the engine.

Coke oven gas and pressure producer gas contain some volatilized tar which cannot be elminated in the producer plant and which settles in the gas inlet valve and mixing chamber or in the gas pump (two-stroke engines). When inlet valves stick they can be "freed" by applying creosote. The tar affects the lubrication, encouraging the formation of carbonaceous deposits. It is this formation of tar which makes it necessary in suction producer plants to employ coke or non-caking anthracite coal.

The moisture in wet gas, such as the producer gases and blast furnace gas, forms a paste with the impurities in the air or gas, thus providing a base for the ready formation of deposits. The impurities collect in the mixing and inlet valves and on the internal surfaces of the engine exposed to the gas, adhering to and contaminating the oil film on the piston, piston rings and cylinder walls. The pasty deposits in the mixing valve chambers in time become crumbly, peel off and are swept into the cylinders, causing excessive wear, pre-ignition, etc.

In two-stroke cycle gas engines moist gas will also deposit the dust, in the form of a dark sludge, in the valve chamber of the gas pump. The sludge causes increased resistance in moving this valve, with consequent sluggish action of the governor.

Deposits arising from air or gas, or both, always contain oil and also partly decomposed oil, the latter due to action of the impurities on the oil under high temperature conditions.

Over-feeding of Oil.—The surplus oil, fed to the internal parts, burns and chars; it also attracts and collects the impurities from the gas and air, resulting in a dark colored carbonaceous deposit of a harder or softer nature, depending upon the nature of the oil in use. Even with a good quality oil in use, the oil feeds should be reduced to the exact amount required for full and efficient lubrication. This will lead to cleaner lubrication as the impurities find less oil to which they can adhere.

Deposits accumulating behind the piston rings may cement the rings in their grooves, so that they lose their elasticity and break easily. Heavy wear takes place, the oil film is burned away, the burning gases pass the piston, and in the case of double acting engines pass from one side of the piston to the other, igniting the fuel charge on the opposite side and causing pre-ignition. Increased oil feed will only aggravate the trouble. Frequently the stuffing boxes in large gas engines are overlubricated, with the result that carbon deposits are formed, causing the packing rings to stick in their grooves. Wear follows and the gases blow past the rings.

Pre-ignition.—When carbon deposits or other deposits develop inside the combustion chamber, and particularly if the water cooling is inefficient, the deposits often become incandescent and pre-ignitions occur, causing abnormally heavy strains on the engine.

But deposits are not the only cause of pre-ignition. Jointing material—asbestos, red lead—is often the cause of this trouble. Pre-ignition may also be due to the use of rich gas, for example, town gas in engines designed for suction gas, as the richer gas ignites spontaneously at a lower temperature.

With blast furnace gas it is difficult to prevent pre-ignition, owing to the quantity of fine lime dust in the gas, which, when it settles inside the cylinders, easily becomes incandescent.

In large engines pre-ignitions occur every 2 to 3 hours, under the most favorable conditions, and under unfavorable conditions every few revolutions.

Pre-ignitions may be caused by the explosion gases leaking past the piston rings from one side of the piston to the other. This happens when the rings are badly sealed, due either to accumulated deposits causing the rings to be inflexible in their grooves, or to the use of too low viscosity lubricating oil, or to a furred up water jacket (the oil film gets hot and thins out), etc.

A FEW EXPERIENCES

Example No. 34. Dirty Intake Air.—The following analysis of two deposits taken simultaneously from the piston indicates dirty intake air, which has caused a great deal of wear (iron oxides). The hard deposit at one time has no doubt passed through the stage represented by the soft deposit, the oil gradually charring and hardening the mass. The oil in use was a straight mineral paraffin base oil; had it been an asphaltic base oil, and preferably compounded, the deposit would not have hardened, but would have been in the form of a crumbly or greasy paste.

	Soft deposit		Hard deposit	
Oil	34.9	68%	12.1	66.4 %
Volatile matter insoluble in petroleum spirits	33.1		54.3	
Iron oxides	28.0%		30.4%	
Oxides of silica	1.6%		1.2%	
Balance undetermined	2.4%		2.0%	
	100.0%		100.0%	

It is surprising many times to see the lack of care in not providing gas engines with reasonably clean intake air.

Example No. 35. A Curious Case of Spontaneous Ignition.—An old gas engine of about 25 H.P. with leaky piston rings and with a temperature of about 200°F. in the water jacket, was using a heavily compounded oil. The gudgeon pin and piston were very hot. The engine was in a wooden shed close to saw benches, and as the door of the shed was always open a considerable amount of wood dust was always entering the engine room. In particular where the crank pin had thrown the oil on the side of the shed, the dust and oil had formed a layer a quarter of an inch thick. One day the heat of the piston caused the oil to ignite, throwing out a flame sufficiently long to reach the layer of oil on the side of the shed, which it also ignited.

The ignition took place in the hollow part of the piston where the gudgeon pin end of the connecting rod works. The saw-dust had accumulated in the hollow of the piston and was saturated with the highly compounded oil in use. As time went on this oil became gummy, oxidizing more and more, and as the heat from the piston increased, owing to the gas engine being heavily loaded, the oxidizing effect raised the temperature up to ignition point.

Example No. 36. Bad Alignment.—A 60 H.P. gas engine was continually breaking piston rings; the back piston ring could not be lubricated and the piston could therefore never be kept tight. The makers had overhauled the engine time and time again without locating the cause; a special attachment was fitted which lubricated the back ring, but the breakages continued. Finally, the seat of the trouble was discovered; the cylinder was out of line with the crank pin to the extent of $\frac{3}{16}$ inch, which caused a great pressure between the piston rings and the liner.

Example No. 37. Deposit Caused by Impurities in the Gas.—Several large blast furnace gas engines of the Cockerill type (double-acting, four-stroke, tandem engines, 1500 H.P.) were wearing badly owing to deposits which continued to develop inside the cylinders. The cylinder wear had averaged 0.7 mm. per annum, as compared with the normal wear for large blast furnace gas engines which ranges from 0.3 to 0.5 mm. per annum.

Samples of deposit were obtained from the following points and analyzed:

	Piston surface outside the rings, %	Piston surface between the rings, %	Inside of piston rings, %	Piston rod, %
Oil and moisture	Traces	Traces	Traces	Traces
Volatile matter insoluble in petroleum spirit	34.9	43.3	37.8	56.9
Silicates and oxides of silica	16.6	12.1	17.7	12.5
Iron oxides	18.3	22.4	11.2	10.8
Aluminium oxides	5.7			6.4
Calcium oxides	12.6	22.2	33.3	10.2
Balance, containing magnesium oxides and traces of other metallic salts	11.9			3.2
	100.0	100.0	100.0	100.0

All the deposits were hard, granular and black, and their composition shows that the gas is mainly responsible for their formation, the dust contents in the gas ranging from 0.025 to 0.035

grammes per cubic metre. The lubricating oil in use was a deep red straight mineral paraffin base oil containing filtered cylinder stock which carbonized and caused the deposit to bake into hard crusts. It is possible that some of the dust came with the intake air, as the intake air pipes were placed with their ends turned up, so that the dirt and dust had free access. Besides, on this particular side of the power house were situated the stores of coal, coke, etc. It would have been better had the air pipes been placed on the opposite side of the power house, taking the air through large settling chambers, fitted with suitable filter screens.

Fig. 186 shows a good arrangement for preventing impurities from entering a gas engine with the intake air.

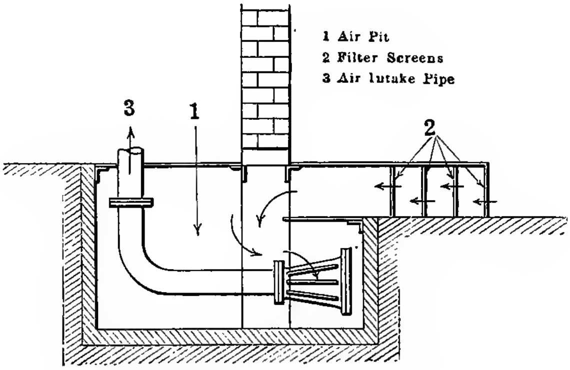


Fig. 186.—Filtering intake air.

Example No. 38. Tarry Deposits.—Two-stroke gas engines employing coke oven gas are often troubled with tarry deposits, which accumulate in the gas pumps, on the inlet valves and inside the cylinders.

A 500-H.P. Koerting engine had to be dismantled every four weeks to clean away the deposits. A straight mineral dark red paraffin base oil was used, fed through sight feed drop oilers. A mechanically operated lubricator was installed in order to bring about a regular feed, so that a minimum oil consumption could be established. At the same time an oil made chiefly from asphaltic base mineral oil and compounded with 7 per cent. of nut oil was introduced with most remarkable results, it being found possible to operate the engine for five months before it was considered desirable to clean out the deposit. In addition it was found that the engine now started quite easily on compressed air, whereas with the previous oil it was necessary to "motor" the generator when starting.

Example No. 39. Deposit Due to Water Leakage.—In the case of seven 800-H.P. blast furnace gas engines, single cylinder engines with open-ended trunk pistons, a dark brown, almost black, oily deposit was continuously working its way out from the cylinders. A sample showed the following analysis:

Oil	35.3 per cent.
Water	8.2 per cent.
Iron, iron oxides and silica	21.9 per cent.
Volatile matter insoluble in petroleum spirit	34.6 per cent.

The water came from the leaky cooling pipe connections; the silica came in with the intake air or the gas and caused heavy wear, the action being accentuated in the presence of water.

OIL

General.—The frictional losses in a small or medium size gas engine range from 15 per cent. to 30 per cent., in large gas engines from 10 per cent. to 20 per cent. of the rated horse power, this loss being constant and independent of the actual engine load. It is easy to waste from 5 per cent. to 10 per cent. of the engine power in unnecessary friction by using unsuitable lubricating oil or an inefficient lubricating system.

SMALL AND MEDIUM SIZE HORIZONTAL GAS ENGINES

Piston Lubrication.—The *piston* of the gas engine is the most vital part from a lubricating standpoint. With impure gas or unsuitable oil or overfeeding, deposits develop on the piston head and behind the piston rings, and will appear in the form of a black, oily coating. These deposits soon cause the piston rings to cement in their grooves; the gases blow past the piston; excessive friction and wear take place on the piston rings and on the cylinder walls.

It is important that the oil shall have a suitable viscosity. If an oil of *too heavy viscosity* is used, it does not spread easily over the piston surface. The friction is high owing to the heavy oil drag on the piston, and impurities in the gas or air will cling to the heavy oil and bake into crust-like deposits.

In the United States practically all large gas engines are lubricated with oils which are highly filtered cylinder stock, having viscosities ranging from 125″ to 175″ Saybolt at 210°F.

The very same types of engines are lubricated successfully in Europe with oils having Saybolt viscosities ranging from 45″ to 70″ at 212°F. It is practically certain that the American engines would operate better, with less friction, easier starting and less carbon deposit, if they used oils more in line with European practice.

If an oil of *too light viscosity* is used, it will break down under the influence of the high temperature in the cylinder; it will loose its sealing power, causing excessive friction and wear. Carbonaceous deposits are formed which on account of the wear will be found to contain a large percentage of iron and iron oxides.

Bearing Lubrication.—*Main bearings* usually give no trouble: it is bad practice to add oil to ring oiled main bearings daily. The bearings do not run cooler, but the oil is wasted, overflowing from the bearing ends.

The bearing reservoirs should be emptied, cleaned, and recharged at regular intervals, from 3 to 6 months, depending upon the purity (absence of dust) of the air in the engine room.

The *crank pin* is a very important part of the engine as it transmits the power from the piston to the main shaft.. Occasionally, a heavy-bodied oil is required for lubricating the crank pin of medium size engines owing to the heavy crank pin bearing pressures. As this oil may be too heavy in body for the cylinder lubrication, two different oils are sometimes used, although usually one oil is used throughout.

The *gudgeon or wrist pin* requires particular care in lubrication as it is located in the interior of the heated hollow trunk piston, where it is subjected to high temperature. The pressures on the wrist pin are high, and, as the oscillating motion of the connecting rod is slight, the oil spreads with difficulty over the bearing surfaces. Consequently, the lasting and lubricating properties of the oil used are very important.

The blackened waste oil coming from the piston and wrist pin in small and medium size engines should be arrested by a division plate (see Fig. 179, page 441) and drained away so that it will not run into the crank pit and contaminate the oil coming from the crank pin.

LARGE GAS ENGINES

Piston Lubrication.—Owing to the large diameter of the pistons, it is of the greatest importance that the oil be introduced direct to the piston at several points, and in such a manner that the correct amount of oil is delivered to the piston at the correct moment, positively and regularly. Incorrect methods of lubrication, or lubricators that cannot be relied upon to feed the oil in the best manner, mean excessive oil consumption; the waste of oil is less important than the fact that the impurities in the gas adhere to the surplus oil, which leads to the formation of carbonaceous deposits.

Stuffing Box Lubrication.—When an oil too low in viscosity is used it cannot seal the packing properly, and allows gas to blow through the stuffing boxes. The gas burns and chars the oil, causing heavy wear and the formation of deposits. The action of the gas is extremely erosive, cutting grooves in the piston rod and shortening the life of the metallic packing. The gas escaping from the stuffing boxes into the engine room is very poisonous.

It is quite usual to find that the oil is fed to the stuffing boxes by means of sight feed drop oilers and that, therefore, a great deal more oil is used than when the stuffing boxes are lubricated by means of a mechanically operated lubricator. It is very important that the lubrication of the stuffing boxes should be kept clean and economical. Excessive oil feed means formation of carbon deposit, excessive friction and wear, accentuated by continuous "blowing" of the glands.

Where the stuffing boxes are worn and blowing takes place, they should be put in good order at the earliest opportunity, although as a temporary arrangement an oil heavier in body may be used in order to seal the packing and prevent blowing. Satisfactory operation of the stuffing boxes is perhaps a more difficult problem from a lubricating point of view than any other part of the engine; it pays, therefore, to give special attention to selecting the correct oil for their lubrication and applying the oil in the best manner, using it as economically as possible.

Only *fresh oil* should be used for lubrication of stuffing boxes, pistons, valves, etc. Any *waste oil* that may be collected from underneath the stuffing boxes, valve spindles, etc. may be treated in a heated separating tank and filter, after which the oil can be used for less important work, but it should not be used on the gas engine itself, as it is usually very dirty.

External Lubrication.—The *circulation system* in large gas engines should preferably contain not less than 100 gallons of oil, in order to give the oil a chance to rest and separate from the impurities that may enter the system. The oil is in constant circulation, exposed to the effect of air and more or less water which leaks in from the cooling system or from the water cooled main bearings. The action is very similar to what takes place with oil in a steam turbine, only the effect is less marked owing to the temperatures and speeds being lower than in turbines, and the circulation less rapid.

Unsuitable oil may throw down deposits of various kinds which are liable to accumulate in the most dangerous places, namely, the oil passages inside the main bearings and crank pin, and may cause dangerous heating of the bearings.

Leakage of water into the oil system is a source of great annoyance and often produces emulsion. The life of the oil is much reduced, and wear of crank pins and crosshead pins is increased. It is almost impossible to keep all water out of the system, but leakage may be largely overcome by careful attention to packing and joints of the cooling water inlet and outlet pipes.

In view of the unfavorable influence of water in the circulation system, any accumulation of water and impurities should be carefully drained away at frequent intervals. Where a great many impurities enter the system the oil or part of it should continuously pass through a filter. As an alternative, from two to six gallons of oil should be removed every day for treatment in a steam heated separating tank, and afterwards in a good filter. The purified oil should be returned to the circulation system at the same time that a corresponding quantity of oil is removed from the system for treatment. When the oil tank capacity in the system is small, this practice is particularly desirable. In this way the vitality of the oil is kept at as high a standard as possible, and the life of the oil is greatly lengthened.

Circulation oils should preferably be used. Such oils under reasonably good conditions of service are practically indestructible and under adverse conditions (air, water, impurities) they are not so liable as other oils to emulsify or throw down deposits.

Vertical Gas Engines.—Unsuitable oil (easily oxidized) will throw down deposits of various kinds which are liable to accumulate in dangerous places, such as the oil passages inside the main bearings, crank pins and connecting rod. This may result in reduction of oil feed to some parts of the engine; the bearing surfaces of the parts affected will overheat and may be partially or wholly destroyed.

Owing to the high speed at which vertical gas engines operate, it is of very great importance that the correct oil be used in the crank chamber, which will give continued perfect service, notwithstanding the severe conditions of speed and temperature to which the oil is exposed. Consideration must be given to the temperature of the oil in circulation, as with a high oil temperature it is necessary to use an oil heavy in body.

It must also be kept in mind that the lubrication requirements of the cylinders of a vertical gas engine are different from the lubrication requirements of the external moving parts, enclosed in the crank chamber. In larger size vertical gas engines which are constructed with a distance piece between the cylinders and the crank chamber, the lubrication of cylinders and bearings is carried out by means of two separate and distinct systems, viz.

mechanically operated lubricator for the cylinders and usually force feed circulation for the bearings. For bearing lubrication of such engines, circulation oils should preferably be used.

The oil for the cylinders should preferably have non-carbonizing properties and can be chosen entirely with a view to suit the cylinders.

Where engines have cylinders with trunk pistons mounted directly on top of the crank chamber, and where all parts, including the pistons, are lubricated from a common system of lubrication, one grade of oil must be used throughout; so that it becomes necessary to select an oil possessing such qualities as will enable it to meet the double requirements of cylinder and bearing lubrication as perfectly as possible.

For *piston cooling* of large vertical engines, cooling oil is preferably used, as it is difficult to guard against leakage, and water would cause emulsification of the oil in the crank chamber.

Circulation oils should preferably be used as cooling oils and should preferably be of light or medium viscosity, as the lower the viscosity the better is the cooling effect; but when joints are leaking a viscous oil may be preferred, as it does not leak so readily and in mixing with the crank chamber oil has less thinning effect on the oil in circulation than a light viscosity cooling oil.

OIL CONSUMPTION

In all *small or medium size gas engines*, the oil is frequently fed irregularly, and a great deal of oil is wasted, either because of the lubricators themselves or because it is not possible to give the engines the same close attention and supervision as in large power plant installations. Frequently, the practice is to use plenty of oil all around the engine, collect the waste oil and use it, after having filtered it more or less efficiently, for shafting and machinery in the works. This practice is false economy.

Fresh oil only should be used for piston lubrication.

Waste oil from the bearings should be collected, and if filtered in a good filter it can be used again on the bearings; good quality oil can be used over and over again almost indefinitely, producing great economy. If the waste oil, whether filtered or otherwise, is used for the machinery in the plant, the gas engine attendant feels that he need not use the oil economically, as the oil is made use of afterwards; and the men using the waste oil feel that it is *only* waste oil and in consequence use it extravagantly.

Using the waste oil in the engine room and keeping the gas engine attendant responsible for his oil consumption ensures the best results; besides, in many cases it will be found that much better results can be obtained on the machinery and shafting in the plant by using, instead of the filtered waste oil, one or several oils, specially selected to suit the various conditions in the plant.

For *small gas engines* up to 50 H.P. the oil consumption will range from 2 to 5 grams per B.H.P. hour.

For *medium size gas engines* between 100 and 500 B.H.P. the oil consumption will range from 1 to 3 grams per B.H.P. hour, being lower for the larger engines.

For *vertical gas engines* the consumption ranges from 1.5 to 3.0 grams per B.H.P. hour, depending largely upon the condition of piston rings, oil pressure, or oil level, etc.

For *large gas engines* the oil consumption ranges from 0.6 to 2.0 grams per B.H.P. hour and averages 1.0 grams per B.H.P. hour. This consumption is divided among cylinders, piston rod packings and bearings, approximately in the ratios of 35 per cent., 15 per cent. and 50 per cent. respectively.

SELECTION OF OIL

Before selecting the correct grade of oil in order to secure perfect lubrication it is necessary to consider carefully a number of influencing factors, such as the quality of the gas, the piston clearance, number of piston rings, whether pegged or not, whether the whole weight of the piston is supported by external means (large gas engines), or whether the weight of the piston is sliding on the bottom of the cylinder, the temperature of the water jacket, the method of lubrication, also whether there are any mechanical or operating conditions which call for special consideration.

The object of lubrication of gas engines is to provide clean and efficient lubrication of all parts: *clean*, because if the oil film is dirty or blackened with carbonized oil or with impurities from the gas or dirty intake air, one cannot possibly expect good lubrication; *efficient*, meaning that lubrication is not only clean, but that the oil is of the correct quality and body to produce as complete a film as possible and reduce the total loss in friction to a minimum.

To show how important it is not to allow mere guess work to determine the grade of oil to be used, some of the influencing factors mentioned above are commented upon in the following:

The Quality of the Gas.—Illuminating gas and natural gas are always clean and dry, which qualities are favorable to good lubrication. Occasionally producer gas, particularly in large installations, may be said to be fairly clean and dry. For engines employing such gas, straight mineral oils of medium or heavy viscosity *may* be used.

It is probable that most users of producer gas, whether suction or pressure producer gas, whether large or small plants, would always answer the question as to whether the gas was pure, in the affirmative. It is a fact, however, that the gas from practically all producer gas plants is fairly moist and contains fine impurities, of a tarry and a dusty nature, which in time accumulate inside the gas engine cylinder, producing carbonaceous deposits.

When the gas contains an excessive amount of impurities or moisture, it will be found that pale colored compounded oils will show marked superiority over dark colored straight mineral oils as regards clean lubrication. The fixed oil contains oxygen which burns the carbon, and the result is that the deposits are prevented from caking and the amount of carbonaceous deposit formed is considerably reduced, whereas straight mineral oils will frequently fail to give satisfaction.

Another advantage of using a compounded oil is the easier starting of the engine. When the engine stops, the piston is hot and the oil film, when the movement of the piston ceases, is practically squeezed out. Experience proves that the presence of animal or vegetable oil helps to retain a better oil film, which makes starting of the engine easier.

In Germany 15 per cent. to 20 per cent. of kerosene is frequently mixed with the lubricating oil for the cylinders of large gas engines. The kerosene has a cleansing effect when the gas contains a large amount of impurities.

Piston Clearance.—The larger the engine the greater will be the piston clearance, so that larger size engines require an oil heavier in viscosity than smaller engines, in order to completely seal the piston and prevent "blowing." The number and position of the piston rings are also important in this respect, particularly whether they are pegged (which is customary) or otherwise. If the piston rings are few and not pegged, a heavier viscosity oil is required than with a greater number of pegged piston rings, the effect of the pegging being that the rings wear to a fit in the cylinder and are easier to seal.

A heavy viscosity is also required for engines with worn pistons or cylinders. Although it would be better in most cases to rebore the cylinder and fit a new piston, yet circumstances may make it desirable, at any rate as a temporary arrangement, to use a heavy viscosity oil until such time as the engine is put in order, when the correct lighter viscosity oil can be used.

Cooling Water.—If the cooling water leaves the cooling water jacket at a temperature much above 140°F. the cooling of the cylinder walls will be inefficient and the high temperature will thin the oil, so that this condition may demand an oil of heavy body. In the same way, if the cooling water leaves the engine at too low a temperature, say, below 90°F., this condition may demand the use of an oil of light body.

Water cooling of large pistons means that smaller piston clearances can be employed and therefore favors the use of lower viscosity oils. This is the reason why large gas engines can be so satisfactorily lubricated with medium viscosity oils.

The piston friction is much influenced by the temperature of the water jacket. On this subject Prof. Bertram Hopkinson gives in reference to small gas engines some interesting data, recorded in "Mechanical World" for September 6th, 1895. He concludes:

> "The saving in consumption when the engine is running light may be as much as 30 per cent. but at full load it is very small, and in some cases the consumption per brake horse power is increased with a hot jacket. This, however, depends to a great extent upon the design of the engine. The great economy in consumption, when the engine is running light with a hot cylinder, is due to a decrease of friction between the piston and liner."

From these experiments the conclusion may be drawn that gas engines when running light should preferably operate with hot cooling water, or, if this condition is permanent a *lighter viscosity oil* will have the same effect with normal water temperature, as regards bringing about low friction losses.

Method of Lubrication.—When, due to the method of lubrication or other reasons, the oil consumption for internal lubrication is high, say more than 1.5 grams per B.H.P. hour, particular attention must be given to selecting an oil with "non-carbonizing" properties. When the oil consumption is low this point is of less importance. "Non-carbonizing" oil means pale colored "non-paraffinic" base (*i.e.*, asphaltic or naphthenic) oils, preferably compounded.

All distilled lubricating oils produce less carbon than undistilled oils—cylinder stocks—and filtered cylinder oils produce less carbon than dark cylinder oils. Heavy viscosity gas engine oils should therefore contain little or no cylinder stock, if non-carbonizing qualities are required. If cylinder stock is required to give the desired high viscosity, the distilled oil used for blending should be as viscous as possible in order to reduce the amount of cylinder stock required.

In *medium size gas engines* the tendency is towards using separate oils for internal and external lubrication, as the bearing requirements call for oils which will stand great pressure and give a good cushioning effect in the crank pin bearings. Such oils are preferably mixtures containing filtered cylinder stock, whereas for internal lubrication a minimum of filtered cylinder stock is desirable, as above mentioned.

The main bearings, being ring oiled, are of course best served by a pure mineral oil. Straight mineral oils are required for large gas engines externally, preferably circulation oils in order to avoid as much as possible trouble from emulsification.

In vertical gas engines, where no water gets into the crank chamber, circulation oils are not absolutely needed; the oils may be chosen chiefly with a view to suiting the piston conditions, and of course the crank chamber temperatures.

For splash lubrication the oil must not be too viscous, as it will then only splash and distribute itself with difficulty.

When compounded oils are used in enclosed vertical gas engines, the compound must be a sweet, non-gumming oil, either nut oil or high quality lard oil made from corn-fed pigs; lard oil from distillery fed pigs oxidizes and gums, even if it is free from acid.

In Table No. 27 are given viscosity figures for four gas engine oils, which may be either straight mineral or compounded with from 6 per cent. to 10 per cent. of fixed oil; in the latter case a "c" is added to the No. of the oil. The specifications for circulation oils Nos. 1, 2 and 3 will be found on page 236.

The Lubrication Charts Nos. 15 and 16 give general recommendations for oils suitable for the main types of gas engines.

TABLE NO. 27

Grade of oil	Saybolt viscosity at	
	104°F.	212°F.
Gas engine oil No. 1 or 1c	175″	38″
Gas engine oil No. 2 or 2c	300″	45″
Gas engine oil No. 3 or 3c	400″	56″
Gas engine oil No. 4 or 4c	650″	70″

Lubrication Chart No. 15
for Horizontal Gas Engines

	Grades of gas engine oil recommended	
	Quality of gas	
	Dry and clean	Moist and impure
INTERNAL LUBRICATION:		
Small Size	1 or 2	1*c* or 2*c*
Medium Size.		
* Up to 80 H.P. per cylinder, piston not water cooled	2	2*c*
80–150 H.P. per cylinder, piston not water cooled	3	3*c*
With worn cylinders, or very hot water jacket	3 or 4	3*c* or 4*c*
* *NOTE:* The dividing line with small piston clearances may be as high as 120 H.P. with large piston clearances as low as 50 H.P. per cylinder. Oils Nos. 3 and 3*c* to be used above the dividing line, Oils Nos. 2 and 2*c* below the line.		
Large Size.		
Internal		
4-stroke cycle, 300 to 750 H.P. per cylinder	2	2*c*
For stuffing boxes only, if not sealed properly by 2 or 2*c*	3 or 4	3*c* or 4*c*
4-stroke cycle, 750 to 1500 H.P. per cylinder	3 or 4	3*c* or 4*c*
2-stroke cycle, all sizes	3 or 4	3*c* or 4*c*
For gas and air pumps only	2*c* or 3*c*	2*c* or 3*c*
EXTERNAL LUBRICATION:		
Small Size.	1 or 2	1*c* or 2*c*
Medium Size. Oils Nos. 2, 3 or 4 or Bearing Oils of similar viscosities (*i.e.* Bearing Oils Nos. 4. 5 and 6).	2,3 or 4	2,3 or 4
Large *Size*	Circulation Oil No. 2 or 3	

LUBRICATION CHART No. 16

FOR VERTICAL GAS ENGINES

	Quality of gas	
	Dry and clean	Moist and impure
Small Size.		
Up to 50 H.P. per cylinder, cylinders and bearings	2 or 2*c*	2*c*
Large Size.		
Above 50 H.P. per cylinder.		
For *bearings only*, crank chamber separated from cylinders by a distance piece		
Oil temperature above 120°F	3 or 4	3 or 4
Oil temperature below 120°F	2 or 3	2 or 3
For *cylinders only*, oil fed separately to pistons by a mechanically operated lubricator	2 or 2*c*	2*c*
For *cylinders and bearings*, pistons lubricated from crank chamber	3 or 4	3*c* or 4*c*
For *piston cooling.*		
Cooling system separate from lubricating system	Circulation oil No. 1	
Ditto, but joints leaking badly	Circulation oil No. 2.	

CHAPTER XXVIII

GASOLENE ENGINES

Gasolene engines are now employed for a great many purposes, such as:

- Stationary Engines
- Automobiles
- Motor boats
- Motor Cycles
- Aeroplanes and Dirigible Airships
- Agricultural Tractors

As the design and lubrication of motor-boat and stationary engines are similar to those of automobile engines, the lubrication of the former is not specially dealt with.

Agricultural tractors are mostly run on kerosene, but their design and lubrication are usually more closely related to gasolene engines than to stationary kerosene engines; for this reason agricultural tractors are here only briefly mentioned. The following chapters therefore refer to:

- Automobile Engines
- Motor Cycles
- Aero Engines
- Agricultural Tractors

AUTOMOBILE ENGINES

Classification.—

Number of Cylinders: 1 to 6, usually 4.
Horse Power per cylinder: 2.5 to 15 H.P.
Speed: 1000 to 3000 R.P.M.
Cooling: Nearly always water cooling.
Piston Rings: 2, 3 or 4.
Piston Diameters: 60 to 150 m.m.
Piston Strokes: 60 to 180 m.m.
Piston Skirt Clearances: { *Cast iron:* 0.003″ to 0.008″. *Aluminium Alloy:* 0.008″ to 0.012″ (chiefly for aeroplane engines).

Cylinders.—Practically all automobile engines are of the 4-stroke cycle type with 4 or 6 vertical cylinders, the great majority having 4 cylinders. A few low power automobile engines have 1 or 2 cylinders, usually vertical, rarely horizontal. Six- and 8-cylinder "V" type engines are coming into use in a few high power cars.

Cooling.—Automobile engines are practically always water cooled. Air cooled engines are less frequent than formerly and are not likely to increase in numbers as water cooled engines give greater security of operation over long periods of service.

Piston Rings.—The number of piston rings is usually three or four, more often the former. In a very few engines the number has been reduced to two, and there is probably no question about the soundness of reducing the number of piston rings to two or three if they are well designed and pegged. The piston friction consumes more than half the total amount of friction so that by having fewer piston rings the piston friction is appreciably reduced.

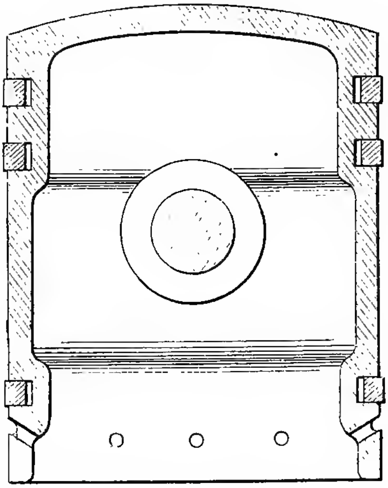


Fig. 187.—Piston with oil scraper ring.

The question of oil scraper rings has been the subject of much discussion. Fig. 187 illustrates a type of piston with oil scraper by which excess oil is scraped off the cylinder walls and drained back to the inside of the piston through small holes.

Piston rings should preferably be pegged, as unpegged piston rings may rotate in use and often get into line, which allows the oil to pass freely to the top of the piston. When piston rings are allowed to rotate and remain round while the cylinders become slightly oval, it is difficult for the rings to maintain a complete seal, as the oil film is too thick at certain points and therefore unable at those points to keep compression or explosion tight. This applies particularly to engines that have been in use for some time and have become worn. A good method of pegging is shown in Illustration Fig. 188. This method prevents unscrewing of the peg and does not weaken the ring. In the early days piston rings were nearly always pegged as the desirability of pegging was realized, but unfortunately many pegs came undone and caused great damage to pistons and cylinders. The peg illustrated has however given complete satisfaction.

Pistons.—The piston is receiving heat all over the top at a very high rate. This heat must find its way through the piston barrel into the cylinder walls until it finally reaches the cooling water or is radiated into the atmosphere. The heat travels from the centre of the piston outwards. Dr. Charles E. Lucke therefore proposes a larger thickness of the piston head at its circumference. When the heat gets to the edge of the piston it must flow down the piston barrel, and the thickness of the barrel below the top piston ring should decrease regularly towards the open end of the skirt.

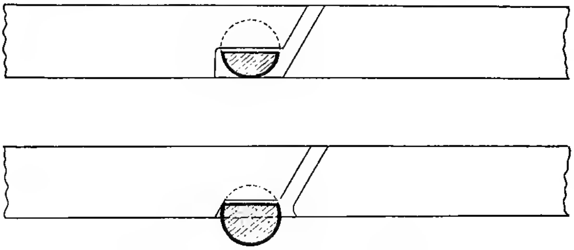


FIG. 188.—Pegged piston rings.

The piston expands irregularly under heat, principally due to the gudgeon pin bosses. Even if the piston and cylinder have been turned and ground quite true, they cease to be round when they become warm. These deformations are not very considerable in the case of cast iron cylinders and pistons, but with aluminium alloy pistons this point is particularly important as the coefficient of expansion of aluminium is twice as great as for cast iron. Several French builders have overcome the deformation difficulty by so shaping the piston that when hot its shape coincides with that of the cylinder. Aluminium pistons conduct the heat away much more rapidly than cast iron pistons, the heat conductivity of aluminium being about 15 times greater. Aluminium pistons therefore keep much cooler and higher compressions can be employed without "pinking."

Carbon deposits do not readily collect on aluminium pistons and preignition is therefore less likely to occur. The advocates of aluminium alloy pistons claim that their use will increase acceleration, horse power, flexibility, maximum speed, and mileage per gallon of gasolene, and at the same time decrease vibration and carbon deposit, both in the combustion chamber and in the crank case.

METHODS OF LUBRICATION

The parts requiring lubrication are the main shaft bearings, the crank pin bearings, wrist pin bearings, cam shaft bearings, timing gears, cams, cam lifter guides, and cylinder walls. Lubricating systems may be classified under five headings:

1. **Full Force Feed.**—Oil is fed under pressure to the main bearings, a portion of the oil continuing its way to the crank pins through drilled holes in the crank shaft, reaching finally the wrist pins through either the hollow connecting rods or the oil pipes attached thereto.

The oil splashed away from the crank pins and wrist pins lubricates the cylinder walls and finally returns to the oil reservoir, being circulated afresh by the oil pump.

2. **Force Feed.**—This system is the same as the full force feed system with this exception, that the wrist pins are not supplied with oil under pressure but are lubricated entirely by oil spray.

3. **Force Feed and Splash.**—Oil is forced to the main bearings and crank pins as with the force feed system, but in addition the connecting rods dip into the oil collected in the bottom of the crank case or in troughs below the crank pins, a constant level being preferably maintained in the crank case or in the troughs; the oil overflows to the oil reservoir below, whence the oil is circulated afresh. By this system the oil thrown from the connecting rods is, therefore, not only the oil leaving the crank pins, but also the oil splashed from the dippers to all parts of the engine.

4. **Semi-Force Feed and Splash.**—Oil is supplied at low pressure to a sight feed arrangement on the dash board, flowing from this point by gravity to the main bearings, or it may go direct to the main bearings, while a pressure indicator (see Fig. 189) on the dash shows that the oil is being circulated. The oil leaving the main bearings collects in the bottom of the crank

case or in troughs below the crank pins; the connecting rods dip into the oil and splash it to all parts. Th eoil overflows from the troughs or crank case into the oil reservoir below, whence the oil is circulated afresh.

5. **Splash System.**—Oil is supplied to the crank case; the connecting rods dip into the oil and splash it to all parts.

Pressure Oiling Systems.—Supplying oil by the full force feed system to the wrist pins has now been practically abandoned, except for racing cars, as the difficulty in ordinary automobile engines is not that of getting oil to the wrist pins but of preventing too much oil from splashing on to the cylinder walls. With a high oil pressure the large amount of oil leaving the wrist pins tends to overlubricate the cylinders. In fact, with most pressure oiling systems, splash guards fitted above the main bearings, as illustrated, Fig. 190, will often prove advantageous, reducing the oil consumption to 1000 miles per gallon or better, whereas the average oil consumption of motor car engines is nearer 500 miles per gallon.

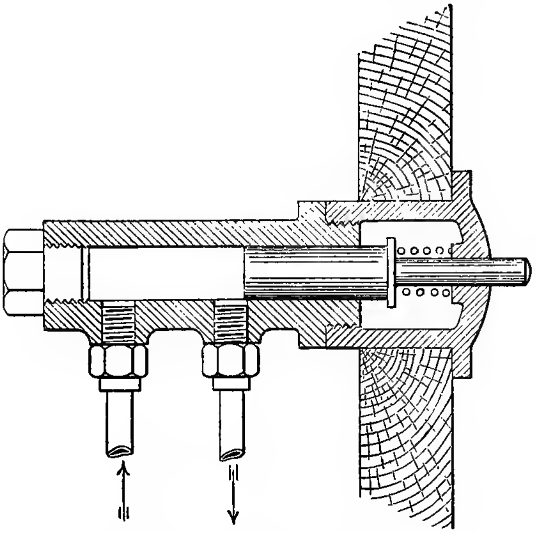


FIG. 189.—Oil pressure indicator.

The splash guard must be fitted as low as possible over the crank pin path, as otherwise the disturbance in the crank chamber, created by the piston expelling and drawing in the air through the slits, causes excessive oil spray and increases the oil consumption instead of reducing it.

An oil relief valve should always be fitted in connection with pressure oiling systems. The relief valve should be so arranged as to measure the pressure at a point near the bearings, and the oil pipes and drillings should be large so that there will always be a good pressure in the crank shaft and no danger of the oil channels choking up.

A pressure gauge should be arranged to indicate that the oil is circulating under pressure; it is not necessary to give the actual oil pressure. An arrangement like the one shown in Fig. 189 is all that is required and may be preferable, because with ordinary pressure gauges having a scale indicating from 0 to 25 or 50 pounds it is difficult to read the pressure when it is only a couple of pounds; and if a low reading pressure gauge is used, the pointer, when the car is started on a cold morning, will be forced against the extreme end of the scale, and is frequently bent owing to the very high oil pressure created by the cold thick oil.

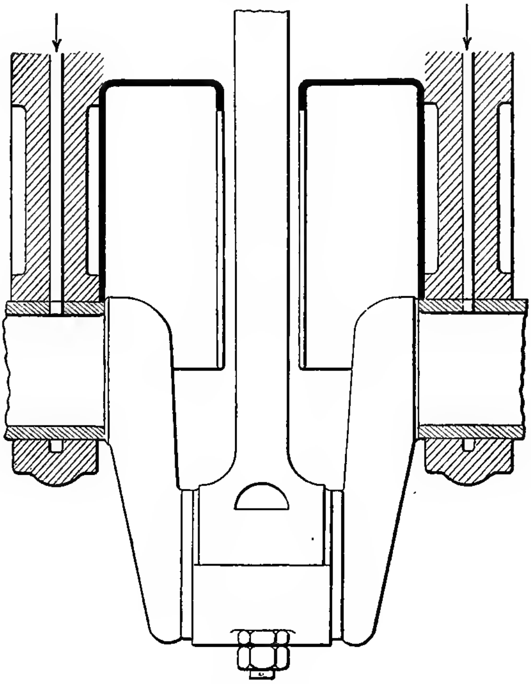


Fig. 190.—Splash guard.

Racing car engines are frequently supplied with oil direct to the piston in addition to the oil spray from the crank case. Experience proves the necessity of this, the spray from the crank chamber under high speed conditions not being adequate for the cylinder lubrication.

One weak point in a pressure system is that if the brasses are worn or a slack fit the oil escapes freely, to the detriment of the other bearings. On occasions oil pumps have been found to wear and being worn they have not been able to pump sufficient oil to keep up the oil pressure, with the result that lubrication has failed. For these reasons some builders prefer the semi-force feed and splash system, which saves drilling the crank shaft.

Briefly, the essential problem of lubrication is to supply the maximum quantity of oil to the bearings without throwing too much on to the cylinder walls. Most pressure oiling systems fulfil the first of these requirements, and if the oil pressure is reasonably low, and if suitable splashguards are fitted, or the piston rings are pegged, the cylinder lubrication will not be excessive.

With the pressure oiling systems, main bearings and crankpin bearings have worked for long periods without any wear at all, a result which can never be obtained with splash lubrication. With splash lubrication a slight alteration in the oil level means either over-lubrication or under-lubrication. The margin of safety is undoubtedly greater with pressure oiling systems.

Splash Oiling Systems.—The oil spray is produced by dippers fitted to the big ends. These dippers should be only 1/16 inch wide and say 1/4 inch deep, and when cutting through the surface of the oil they should only dip to a depth of 1/16 to 1/8 inch. If the dippers are wider or dip more into the oil the excessive oil spray thus formed means unnecessary waste and carbon deposit.

.In the early days the dippers were made in the form of a tube with the point bent forward, it being thought that the oil would find its way in through the tube and into the crank pin bearings. A moment's consideration will, however, show that the centrifugal force will at all times be sufficiently strong to throw out any oil that might be present in the oil tube. The effect of the dipper is merely to spray and splash oil to all parts of the engine, and the entrance of the oil to the crank pins should be made from above, the oil collecting on the lower end of the connecting rod being guided into the oil hole or holes and thus reaching the crank pin bearings.

With the splash lubricating system and when going up or down hills, the rear cylinders get too much oil and the front cylinders get starved or vice versa. This is the reason why the separate trough system was designed and numerous other arrangements by which the oil pump or the flywheel distributes the oil to separate chambers below each crank pin, in order to ensure satisfactory distribution of the oil also when the car is not on the level.

As regards keeping up the supply of oil in the splash system, the simplest arrangement is to have an oil container on the dash board. Frequently, this container is on the chassis level or attached to the crank chamber. Either the exhaust pressure or a pump may be used to force the oil to the bearings or to the crank chamber, feeding so many drops per minute. Most of these arrangements offer plenty of scope for forgetfulness or for failure of the oil feed.

The trough system is really a splash system in which the oil level can be maintained at the proper height. This system has met with wide favor. The amount of splash varies considerably with the speed of the engine. Some builders have arranged adjustable troughs, which are raised or lowered simultaneously with the opening or closing of the throttle, this being, however, considered by many an unnecessary refinement.

The semi-force feed and splash system is reliable and can be designed not to cause over-lubrication of the cylinders, but it has the disadvantage that the oil is picked up from an open trough in which dirt can collect.

CARBON DEPOSITS

Carbon deposits may develop on the piston heads, between and behind the piston rings, on the valves and sparking plugs, and inside the piston hollows. Carbon deposit on the piston heads may cause pre-ignition and "pinking" (which means detonations caused by excessive compression, due to carbon reducing the clearance space). Deposit behind the rings may make the rings inflexible in their grooves, preventing them from functioning properly; the result is "blow past" the piston, excessive friction and wear, and frequently piston seizure. Excessive deposit on the valve seats prevents them from seating properly, causing loss of power.

Carbonized oil inside the piston hollow bakes into a crust which in time cracks and falls into the crank chamber contaminating the oil, often with disastrous results. Carbon deposits may be due to several causes, such as incomplete combustion, road dust, over-lubrication, too thin piston heads, etc.

Incomplete combustion is frequently caused by a badly adjusted carburettor delivering an incorrect mixture of the vaporized fuel and air. Faulty timing of valves, possibly brought about by wear and unsuitable fuel, will also bring about incomplete combustion, likewise a choked muffler or silencer; another cause is defective or incorrectly timed ignition.

Road Dirt or Dust.—Road dirt or dust is drawn into the cylinders with the intake air and forms a base to which any excess oil will readily adhere. The soot resulting from imperfect combustion will likewise form a base for the building up of carbon deposit. Eventually, the deposit if not removed will increase to such an extent that it becomes incandescent, causing pre-ignition, and resulting in heavy knocking of the engine.

Over-lubrication.—The excess oil always chars and causes a certain amount of carbon deposit. Excess oil may be caused by ill-fitting piston rings or worn cylinders, by too high oil pressure or too high oil level (splash oiling system).

The *oil pressure* in pressure oiling systems is nearly always too high. In order to supply a reasonable flow of oil to the last point in the oiling system, only two or three pounds' oil pressure is usually required. Any excess pressure simply means that too much oil spray is formed inside the engine from the oil leaving the bearings and this excessive oil spray finds its way out of the engine through the air vent or elsewhere and causes a very excessive consumption of oil. Another portion of the excess oil spray leaks past the pistons to the piston tops and helps to increase the formation of carbon deposit.

Over-lubrication of the piston is very general in connection with the splash system of lubrication owing to the oil level varying and usually being too high, or owing to the dippers dipping too deeply into the oil.

Whereas a black exhaust indicates incomplete combustion, a blue exhaust indicates burning of excess oil inside the combustion chamber. When the engine is working with the throttle almost closed as in coasting or when the car is standing with the engine running (Doctors' cars), the vacuum formed in the cylinder, particularly in high compression engines, sucks the oil past the pistons into the combustion chamber. When the car comes under normal load again the accumulated oil is burned, giving a blue smoke in the exhaust, and the result is the formation of carbon deposits.

When the piston rings are worn they should be renewed and whether the cylinders are worn or not, pegging of the piston rings will always help to overcome carbon trouble by maintaining a perfect piston seal.

Carbon deposits may be formed inside the hollow of the piston caused by too thin a piston head. Heat entering the centre of the piston cannot get away quickly enough when the piston head is thin. The result is that the piston gets overheated and the oil splashed up into the piston from the crank chamber burns and chars. For ordinary automobile engines the thickness of the piston head (cast-iron) must not be less than 1/4 inch.

TRANSMISSION

The transmission consists of *clutch*, *gear box*, and *rear axle*.

Clutch.—The clutch is located between the engine and the gear box and there are two main types of clutches, viz.:

(*a*) Metal to metal clutches.
(*b*) Leather or fibre-faced clutches.

The latter require no lubrication of the contact surfaces, but the leather requires dressing with neatsfoot oil or castor oil at intervals to preserve it, say, every 500 miles. Metal to metal clutches must be lubricated in order to prevent wear of the metal surfaces and insure easy operation.

Experiments have been carried out with multiple disc clutches showing that without lubrication the friction losses and the rise in temperature are quite small, but oil is required to prevent rusting and abrasion of the plates and to make the plates engage without gripping fiercely. A very thin lubricating oil is required with a view to minimizing the friction losses. At the same time the oil must have sufficient oiliness to prevent abrasion of the metal surfaces, and sufficient viscosity to act as a cushion when the discs or plates are forced into contact.

If the oil is too heavy in viscosity it becomes difficult to disengage the plates and it may not be possible to uncouple the engine quickly enough. This difficulty is experienced with such cars as the Ford, where the engine oil is also used for lubricating the clutch and particularly in cold weather when the oil becomes more viscous. If an oil too light in viscosity is used, excessive wear takes place and the plates grip too fiercely.

With insufficient oil in the clutch over-heating and wear take place, but the oil level must be kept below the clutch spring.

With a view to preventing abrasion of the plates an admixture of fixed oil is desirable. A very suitable mixture is one containing, say, 10 per cent. to 20 per cent. of sperm oil with a viscosity not exceeding 120″ Saybolt at 104°F. A mixture of the engine oil with, say, 50 per cent. of kerosene is often used with good results.

Gear Box.—The gears are best lubricated by means of oil which should be filled into the gear box to the proper level. If the oil level is too high the oil runs out of the gear shaft bearings. If the oil level is too low the gears do not dip sufficiently to splash the oil to all parts requiring lubrication.

The gears are a source of great loss of power. Experiments carried out by the National Physical Laboratory showed that when the gear box of a 32 H.P. Leyland gear box was filled with thin oil to a depth of ¼, ½, ¾, 1, the efficiencies of the power transmission were 97.5, 94, 90 and 74 per cent.; thus the efficiency is appreciably reduced when the box is more than a quarter full. These experiments were made on the top gear, but corresponding results were obtained on the second and third gears. Other oils were tried, showing that the losses increased in direct ratio to the viscosity of the gear oil.

Makers are beginning to realize the importance of keeping a proper oil level; and instead of the oil being filled in from the top when it is practically impossible to judge whether the correct oil level has been obtained, the arrangement illustrated in Fig. 191, with a filling plug from the side, is being adopted by a number of builders.

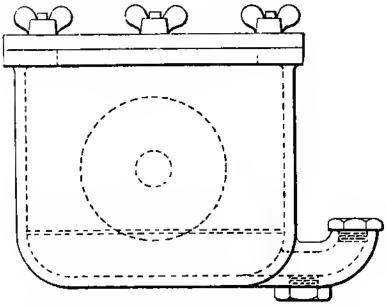


Fig. 191.—Oil filling arrangement for gear case.

A refinement recently introduced is to have a trough below each gear wheel, into which they dip. The gear oil is circulated by a pump to keep the troughs filled with oil. It has also been proposed to squirt the oil into the mesh of the teeth. Both with this system and with the one just mentioned thick gear oil cannot be used, as it cannot be pumped. The gear box must therefore be so constructed that a low viscosity gear oil can be employed without excessive loss of oil.

It is obviously desirable to use as low a vicosity oil as possible, and the only reason why the engine oil is not used in the gear box is because the gear box is not sufficiently tight to permit the use of such an oil, so that in order to prevent excessive leakage a heavy viscosity oil is used or even a semi-solid lubricant, so-called transmission greases.

Transmission grease may be more economical than oil but has the disadvantage of causing greater loss in power and it does not distribute itself effectively to all bearings, so that trouble is often experienced, particularly when there are ball bearings in more or less inaccessible positions.

Greases which are too stiff or made from unsuitable materials harden in use and cause excessive heating. The oil melts out; the revolving gears cut tracks in the grease and leave the gears without any lubrication whatsoever.

When the gears are inclined to engage noisily, a heavier viscosity oil must be used, or even a transmission grease. The transmission grease should be of soft consistency, known in the trade as No. 2 Consistency, or even softer, and should preferably be strained during manufacture. The lime cup grease variety is less inclined to cake and harden than the solidified oils, so-called soda greases.

Rear Axle.—The remarks made as regards the oil level in gear boxes also apply to rear axle casings, and it is desirable to fit a filling plug similar to the one shown in Fig. 191.

The oil level must not rise as high as the axle housing, as, notwithstanding the packings provided, the oil will find its way along the housing, pass through the outer bearings to the brake drums, and cause the brakes to slip. Oily brake drums are sure evidence of excess oil in the rear axle casing.

When the packings and bearings are worn, a transmission grease or a mixture of grease and heavy gear oil must be used to prevent leakage, but ordinarily a heavy viscosity gear *oil* should be preferred.

In case of the worm wheel drive, the pressure between the worm and the worm wheel is very great and only oils having great oiliness will prevent wear and give satisfactory results. For this reason several builders are recommending castor oil for the worm wheel casing.

Experiments prove that all heavy viscosity fixed oils give better results for the worm lubrication than any type mineral oil, but the heavy viscosity filtered cylinder oils come very near in lubricating qualities to the fixed oils, and being much lower in price are almost universally used, preferably compounded with from 5 per cent. to 10 per cent. of fixed oil.

An interesting type of worm gear is the one designed by Mr. F. W. Lanchester which is of the hollow worm type, as distinct from the parallel type. The advantage of the hollow type is that the oil is continuously drawn in between those parts where it is wanted, so that extreme pressures can be carried without trouble. This also explains why at higher speeds the efficiency of the Lanchester gear is increased, because the higher speed helps the oil to wedge itself in between the surfaces.

The grease used for wheel bearings and other parts should also be of a No. 2 Consistency, in order to distribute itself all over the ball or roller bearing surfaces. Most oil firms to-day sell a No. 3 Consistency, which has been the cause of innumerable failures of bearings, through failing to reach all parts, with the result that rusting and corrosion have set in, and the bearings have been ruined. The grease must comply with the requirements for a ball-bearing grease as outlined, page 190. The grease used for the water pump bearings should be a high melting point grease of, say, No. 4 Consistency.

Chain Drive.—Where a chain drive is employed, the chains, being exposed, get quickly covered with dirt and dust. They should be oiled daily with the engine oil (gear oil does not penetrate to the link bearings), but it is important to clean the chains frequently (say every 1000 miles) by soaking them in kerosene and afterwards immerse them in a bath of molten graphite and tallow. By this treatment the chain will get thoroughly soaked with lubricant and wear will be minimized.

Lubrication of Other Parts.—The lubrication of parts of the cars other than the engine, transmission, and rear axle is, as a rule, much neglected, and for this reason all parts should be designed with a view to maintaining good lubrication, even if the parts do not get the very best attention.

Shackle pins, for example, are now made much larger than in earlier days and instead of being lubricated by grease they are frequently designed with oil lubrication. A neat method is to place a small ball valve in each pin which, when oiling, is pressed from its seating by the spout of the oil can.

MOTOR CYCLE ENGINES

Classification.—The vast majority of motor cycle engines are vertical, air-cooled, single-cylinder engines, operating on the four-stroke cycle principle. Other types have two cylinders, either placed horizontally—opposed type—or at an angle—"V" type. Two-stroke cycle engines are coming into use as vertical one-cylinder engines, usually of small power.

Horse Powers range from 1¼ to 8 H.P.

Speeds range from 2,000 to 5,000 R.P.M.

Piston Rings.—Pistons in four-stroke cycle-engines usually have three piston rings. Pistons in two-stroke cycle engines usually have only two piston rings, but these are nearly always pegged.

Piston Diameter, Stroke and Clearance.—Piston diameters range from 60 mm. to 80 mm. Piston stroke ranges from 60 mm. to 100 mm. Piston clearances range from 0.002″ to 0.005″, usually 0.003″ to 0.004.″

Compression.—50 to 80 lbs. per square inch.

Bearings.—Roller bearings with short rollers are frequently used for the connecting rods and main bearings in order to reduce friction and lubrication difficulties.

Lubricating Systems.

(*a*) Hand Pump.
(*b*) Semi-automatic Drop Feed.
(*c*) Mechanically-operated Pump.
(*d*) Oil-gasolene System.

(*a*) *Hand Pump.*—The principle of "little and often" should never be forgotten where the oil is fed to the engine crank case by hand pump. It is better to give half a charge every 50 miles than one charge every 100 miles. Where the oil is introduced at great intervals it means over-lubrication after giving the charge, possibly followed by under-lubrication later on.

Care must be taken when raising the pump plunger to make sure that the pump barrel fills with oil. When the oil is cold and thick it is not uncommon to have considerable engine trouble, simply because the oil never enters the hand-operated pump, and because the rider has no means of ascertaining whether the oil is being pumped. For this reason even hand pumps should preferably be fitted with some means in the way of sight feeds which indicate to the rider whether the oil is being pumped or not.

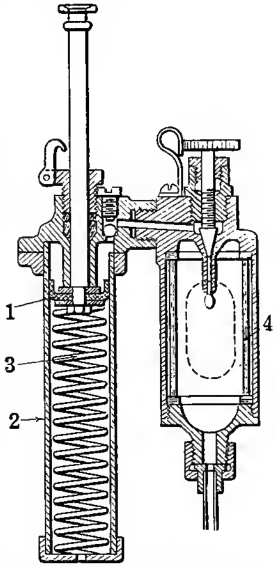


Fig. 192.—Sight feed lubricator for motor cycle.

(*b*) *Semi-automatic Drop Feed.*—Several sight feed lubricators have been designed to give a more or less continuous feed of oil, one of the best being illustrated in Fig. 192. The plunger (1) is depressed and the pump barrel (2) fills with oil from the supply tank. The spring (3) will then endeavor to force the piston upwards, discharging the oil through the sight feed (4) from which the oil is delivered to the engine. The oil is delivered under a pressure of a few pounds per square inch, and may therefore be delivered either to the crank case itself or to the piston main bearings, etc., as required.

By this lubricator a fairly regular feed of oil can be maintained, but of course the feed will vary with the temperature and the viscosity of the oil, and is easily interfered with if dirt gets in between the adjusting needle and its seat. As, however, the rider can always watch the sight feed, any difficulty in this direction is quickly discovered and easily remedied.

(*c*) *Mechanically Operated Pump.*—There is a distinct tendency towards the more general use of this system, which consists of a plunger pump, preferably with adjustible pump stroke and operated by means of gearing from the engine.

It is very desirable that the speed of the plunger be as low as possible, as otherwise a low oil feed cannot be maintained with certainty, because of the exceedingly short stroke of the plunger.

The mechanically operated pump should preferably be provided with a sight feed arrangement in order that the driver may know whether the pump parts are in working order and the oil is discharged regularly to the engine.

(*d*) *Oil-gasolene System.*—In this system the oil is mixed with the gasolene in proportions ranging from 1 part of oil to from 4 to 10 parts of gasolene and the lubrication of the engine is therefore not dependent on the skill of the rider.

There are, however, many disadvantages to this system. If too much oil is used, excessive carbonization takes place and if an attempt is made to reduce the proportion of oil it is frequently found that the engine is poorly lubricated, particularly when the engine has been in use for some time and has become slightly worn. The engine runs with a harsh noise indicating that the running parts are not properly lubricated.

Oil has also a tendency to combine with the road dust which is always drawn in with the air through the carburetor, the effect of this being to clog the working parts, particularly the needle.

Points of Delivery.—The simplest method of lubrication is to deliver the oil straight to the crank-case, so that the fly wheel dips into the oil and distributes it to all parts by creating an oil fog in the crank case. This is the method practically always used in connection with hand pump lubrication. Many manufacturers provide ducts cast in the crank-case which collect the oil spray formed by the fly wheel and distribute it to the main bearings, etc.

In modern motor cycles the development is, however, in the direction of feeding the oil first of all to the main bearings and sometimes also to the piston, the oil escaping from the main bearings being caught by a rim on the fly wheel and by centrifugal action carried into the big end. Feeding oil direct to the piston appears only to be necessary in high power engines and for racing purposes. Lubrication of the gudgeon pin is usually well taken care of by the oil fog alone.

In most systems the oil, having done its work, collects in the sump at the bottom of the crank-case, is drawn off at intervals and not used over again. In some systems, however, the oil is circulated over and over again through the main bearings, the oil feed being very slow, and done by means of a mechanically-operated pump.

Carbon Deposit.—In case of over-lubrication, excessive carbonizaton takes place on the top and in the hollow of the piston. In order to prevent the formation of carbon deposit inside the piston, some motor cycles are made with a distance plate over the gudgeon pin, which never attains a temperature high enough to carbonize the oil splashed up from the crank-case. This arrangement also keeps the crank case and the working parts enclosed therein much cooler.

In order to keep the piston rings compression tight, all two-stroke engines should have their rings pegged, so that the rings will wear to a fit with the cylinder. If they are not pegged they are inclined to move in their grooves until the gaps get into line, resulting in bad compression, excessive carbonization of the oil, an overheated crank case, and heavy wear. The method of pegging the rings should of course be such that under no circumstances can the pegs unscrew and damage the cylinder. (See page 474.) It is the excess oil that causes carbon deposit, and to which impurities arising from bad carbonization, bad combustion or road dust, will adhere.

Oil Consumption.—The oil consumption for motor cycle engines ranges from 1000 to 4000 miles per gallon of oil, the average being 2500 miles per gallon.

Oil.—It is very important that the oil should have a sufficiently low setting point (say 20°F. to 25°F.) so as to flow freely during the winter season; poor cold test oils may not reach the working parts and the engines are difficult to start when cold.

Motor cycles usually do not get too good attention, being often in the hands of men who have had little or no technical training. As a result plenty of oil is the "cure all" employed for most troubles. Such overfeeding with oil means that a great deal of the excess oil is burnt inside the cylinder and oil manufacturers should therefore aim at producing an oil with a particularly low tendency to carbonize. That can be accomplished by using pale, non-paraffinic base oils, compounded with say 10 per cent. of good quality fixed oil.

A low contents of free fatty acid is desirable from the point of view of bearing lubrication. A high percentage of free fatty acid does not seriously affect the cylinder lubrication, although when the engine is put aside for some weeks, the result is usually to be seen in heavy rusting of the piston, rings, and cylinder due to the acid. The real trouble caused by free fatty acid is, however, corrosion and pitting of the balls or rollers in the bearings. For this reason only fixed oils having a low percentage of free fatty acid—say below 5 per cent.—should be used.

Semi-drying oils like rape oil, cottonseed oil, whale oil, etc., should not be employed on account of their gumming tendency, as the choking of oil grooves, etc., may easily cause a lot of trouble.

The following tests are characteristic of good motor cycle oils which will suit practically all motor cycles.

Specific gravity	.900–.925.
Setting point	20°F.–25°F. for winter use. 30°F.–40°F. for summer use.
Open flash point	400°F.–420°F.
Fire point	440°F.–465°F.
Saybolt Viscosity at 104°F.	600″–750″
Saybolt Viscosity at 140°F.	240″–300″.
Saybolt Viscosity at 210°F.	70″–80″
Compound	10 per cent. good quality fixed oil.

AERO ENGINES FOR AEROPLANES, AIRSHIPS, ETC.

The three main types of aero engines are:–

Rotary Engines, with revolving cylinders, air cooled.

Radial Engines, with cylinders radially arranged, either air or water cooled.

"V" Type Engines, with inclined double row of cylinders, mostly water cooled.

Rotary Engines.—The rotary type aero engine, as for example the Gnome, presented from the beginning a great many lubricating problems. In the early types the inlet valve for the petrol-air mixture was in the centre of the piston and this valve got easily choked with deposit. In a later type, the Monosoupape type (single valve type), one valve placed in the top of the cylinder serves as both exhaust and inlet valve, thus doing away with the inlet valve troubles of the earlier type.

Only one piston ring is used, made from sheet brass or phosphor bronze and of "L" shape as illustrated in Fig. 193. On the compression and the explosion stroke the ring is expanded by the pressure in the cylinder and at the same time is forced down on its seating in the piston ring groove, which also holds a light piston ring of the ordinary type in order to keep the expanding piston ring in position. This ring being the only one must be an absolute fit in the steel cylinder and it has a vertical straight cut at the point where its two ends meet. This cut is the weak part of the ring and gets eaten away by even a slight trace of fatty acid in the castor oil used for lubrication. As soon as the corners of the cut in the brass ring get rounded, the ring is no longer able to prevent the explosion gases from passing the piston; and the cylinder immediately becomes overheated in a straight line following the position of the cut in the ring. The cylinder in question will be found out of shape, being only about $\frac{1}{16}$ inch in thickness, and must be replaced.

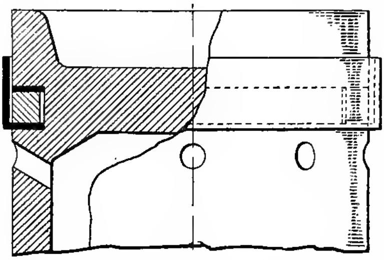


FIG. 193.—"Gnome" piston with single piston ring.

The gasolene is introduced through the hollow shaft and immediately evaporates inside the crank chamber. Gasolene has a dissolving effect on mineral lubricating oil but does not affect castor oil.

The lubricating oil is fed to the oil pump through a tube from an elevated oil tank. This makes it necessary in cold weather, in case the aeroplane rises to a considerable height, to use an oil with a good cold test, say not above zero Fahrenheit. It is good practise to empty the oil tank every night and before a new flight to put the oil into the tank hot. The tank should preferably be placed so that it may benefit to some extent by the heat from the engine during flight.

By means of a mechanically operated plunger pump with piston valves the oil is introduced through the hollow shaft under a slight pressure, and the main stream of oil divides itself in seven different directions, *i.e.*, for supplying oil to the seven different crank pins, connecting rods, gudgeon pins, and pistons. Obviously, the oil holes all being very tiny, the amount of resistance to the oil will differ, and if there is a slightly greater resistance in one direction than in the other six, this will mean that in order to give sufficient oil in the one direction, the oil must be fed very copiously. This is one of the reasons for the heavy oil consumption in this type of motor. Another reason for a heavy oil consumption in the "Gnome" motor is the fact that it is a rotary engine, and the centrifugal force tends to throw the oil outwards and to tear it away from the cylinder walls.

This means that in order to keep a sufficiently thick oil film on the cylinder walls, there must be a constant spray of oil to make up for the oil that is thrown out through the cylinders due to the centrifugal force. As the engine is air cooled, the top portion of the cylinders gets very hot, in fact, the metal turns blue. Consequently, all the oil used for lubricating the pistons, etc., is eventually burned in the combustion chambers, and if it leaves deposit, the carbon will soot up the sparking plugs and prevent the valves from seating properly.

For the old type of Gnome motor the oil consumption was about 80 grams per horse power hour. With the "Monosoupape" engine the consumption has been reduced to about 25 grams per horse power hour. If the oil consumption is reduced below these figures, the margin of safety is so low that there is danger of one or several of the pistons seizing.

Experience generally with internal combustion engines proves that whenever the cylinder consumption of mineral lubricating oil exceeds 5 grams per B.H.P. per hour, excessive carbonization, due to burning of the excess oil, takes place. Mineral lubricating oils can therefore not be used for lubricating the "Gnome" or any other rotary type of aeroplane engine, but this is not the only reason. Mineral lubricating oils are deficient in oiliness as compared with fixed oils. They do not cling sufficiently to the cylinder walls to provide efficient lubrication; they are thrown out through the the cylinders so quickly that the cylinder walls are left dry, and if the engine runs with such oils for more than a few minutes, the pistons seize, the cylinders get overheated, and the speed of the engine falls below normal. If exceedingly viscous mineral lubricating oils are used it has been proved possible to maintain the cylinder walls in a greasy condition, but the fluid friction of such oils is so high that the engine loses power and the speed is reduced. Furthermore, such oils produce a very excessive amount of carbon deposit which is obviously fatal, and, finally, they have a poor setting point; for this reason alone they could not be accepted, as aeroplanes are exposed to cold weather and the oil would congeal.

Medicinal castor oil, practically free from fatty acid, is the only oil which has given satisfactory results for rotary type aeroplane engines. It can be used in great excess without leaving any carbon deposit inside the cylinders; all the oil passing through the combustion chambers burns away clean. Castor oil is only slightly affected by the gasolene vapors in the crank chamber. It has sufficient viscosity to seal the pistons and is possessed of sufficient oiliness to keep the cylinder walls well lubricated in spite of the centrifugal force, and it has a viscosity sufficiently low that the speed of the engine can be maintained at normal for long periods. Castor oil has a good cold test and will not congeal in cold weather or at high altitudes.

Radial and "V" Type Engines.—The great majority of aero engines are now of the radial type or the "V" type. Although these engines operate very satisfactorily with castor oil as a lubricant, yet there is not the same need for castor oil as in the case of the rotary type engine. The oil is kept warm in the engine and circulates continuously under pressure. The question of cold test is therefore not so important and as the centrifugal force does not act here as in the case of the rotary type engines, lubricating oils, largely mineral in character, can nearly always be employed with complete satisfaction. It is advisable to have a certain percentage, about 10 per cent., of good fixed oil, say neatsfoot oil, mixed with the mineral oil in order to minimize the danger of seizure and to reduce friction. Castor oil can also be used in such mixtures, but only in the presence of an animal oil. An admixture of 5 per cent. castor oil and 5 per cent. of lard oil or neatsfoot oil forms an excellent mixture. If more castor oil is desired, as much as 20 per cent. can be mixed with 74 per cent. of asphaltic base mineral oil in the presence of 6 per cent. of lard oil By increasing the percentage of animal oil, even greater proportions of castor oil may be employed.

Aluminium pistons are particularly liable to cut and seize during the first five or six hours testing owing to the initial "growth" of the aluminium. It is particularly during this period that castor oil or oils containing a high percentage of fixed oil show their superiority over straight mineral oils.

When aero engines with aluminium pistons are running at maximum power the piston clearance is reduced to proper working value, but when the engines are running at lower power the lower temperature of the piston brings about larger piston clearances, which explains why under these conditions aero engines may have a high oil consumption.

The consumption of lubricating oil is usually reduced when using castor oil mixtures in place of pure mineral oils. Sometimes excessive oil consumption is caused by the oil pressure being too great. The following figures taken from trials with an 8-cylinder "V" type engine developing 200 H.P. at 1400 R.P.M. clearly show the effect of oil pressure:

Oil pressure, lbs. per sq. inch	Oil consumption, gallons per hour
70	1.5
50	0.9
30	0.5

Aero engines when used for war purposes are examined and cleaned thoroughly after each trip, so that any gumminess brought about by the use of pure castor oil is removed. When the engine parts are not frequently cleaned the gummy products of oxidation soon become very troublesome.

AGRICULTURAL TRACTORS

During recent years agricultural tractors have come much into prominence and their design has largely been developed following the design of automobile engines, only experience has proved that they have to be built more strongly to stand up to the more severe conditions. They are prone to overheating and therefore must have good radiators and fans in order to keep the cooling water from becoming too hot. In many engines the cooling water is always boiling hot. For this reason very heavy viscosity oils are generally employed, so as to retain sufficient lubricating power exposed to the higher temperatures.

Kerosene is the fuel generally adopted instead of gasolene, both the fuel and the intake air being preheated by the jacket water and the exhaust heat respectively, and in some tractors the air passes a dust extractor to prevent dust entering the cylinders.

Many different systems of lubrication are employed, ranging from splash to force feed, as well as intermediate systems, and in addition a number of tractors have adopted mechanically operated lubricators which distribute the oil by means of plunger pumps to the various points requiring lubrication. As the oil feed pipes from such lubricators are generally exposed, low setting point oils are demanded.

There is a general endeavor to enclose the gear and differentials and to lubricate them with oil in preference to grease.

There are many different types of agricultural tractors; and although their design often approaches automobile designs, a great many are adaptations of stationary kerosene oil engines. The lubrication requirements must therefore be studied for each particular type and make, and the author will not attempt to give any specific recommendations in the same way as was done with gas engines.

LUBRICATING OILS FOR GASOLENE ENGINES

The oil must have such a viscosity and setting point that it can be distributed with certainty to all parts of the engine, even in cold weather. Low setting point oils are particularly required where the feed pipes are exposed as is frequently the case in the "Semi-Force Feed and Splash System" of lubrication. A low setting point is always advantageous in a motor oil, particularly during cold weather, because of the greater ease in starting the engine from cold.

When the engine has cooled down over night and the oil has become very thick it may be difficult to start the engine. This is important in connection with high power engines which are at all times difficult to start by hand, and even where self-starters are fitted a low setting point is always appreciated, because it practically ensures starting at the first attempt. With a thick sluggish oil the self-starter has so much work to do that it only revolves the crank shaft slowly; the magneto may not give a spark at such a slow speed and carburation will be too sluggish to provide a satisfactory explosive mixture.

The temperature of the cylinder walls in water cooled engines will not be higher than 250°F. to 300°F. This moderate temperature enables the lubricating oil to remain on the cylinder walls and perform its function as a lubricant. The inner surface of the oil is, however, swept by the hot explosion gases, the maximum temperature of which is about 2500°F. and the inner part of the oil film is therefore continuously being burned away. Some oils volatilize without leaving residue; other oils decompose and deposit free carbon similar to what happens when "cracking" oils during distillation. Lubricating oils made from naphtenic and asphaltic base crudes belong to the first-mentioned variety and have therefore proved better oils for motor cylinders than paraffin base oils, which are more inclined to "crack" and form carbon.

Pale, low setting point, non-paraffinic base oils are therefore the best lubricants when considering the *cylinder requirements* only. Air cooled cylinders obviously require oils of higher viscosity than water cooled cylinders. As the same oil is used for lubricating cylinders and bearings, the requirements of both must be taken into consideration when selecting a motor oil.

Bearings with small clearances are usually lubricated by a *pressure oiling system*, and *oil of practically any viscosity can be used* as long as the pump will circulate the oil.

In order to guard against the oil pressure dropping too low (worn oil pump, worn bearings, choked oil passages) medium or heavy viscosiy oils are nearly always used with pressure oiling systems. France is the country which has particularly favored pressure oiling systems and heavy viscosity motor oils.

Bearings which are worn and have large clearances *need a heavy viscosity oil* to prevent knocking.

With the *splash system of lubrication* a *thin or medium viscosity oil must always be used* because a heavy viscosity oil cannot be splashed to all parts with certainty.

The use of an oil of the wrong viscosity will cause wear, due either to the oil being too light in viscosity or to the fact that the oil is too viscous to be distributed with certainty under the conditions prevailing in the engine. Whereas wear of the crank pin bearings or main bearings is indicated by a dull thumping noise, wear of the wrist pins is indicated by a clear metallic knocking.

Thinning of oil has been generally experienced during recent years, due to the use of unsuitable gasolene substitutes or petroeum spirits containing too high a percentage of "heavy end" products. The less volatile products pass the piston freely and thin the oil in the crank chamber. The only remedy is to use a heavier viscosity oil than the one which is known to give satisfaction, change the oil in the crank case more often, at least every 2000 miles.

It is a curious fact that the "heavy ends" at the same time as they cause thinning of the oil tend to keep the pistons clean and free from carbon deposit. The heavy ends are of a kerosene nature and are present on the piston in liquid form. Their cleansing action is therefore akin to the effect of mixing kerosene with lubricating oil to give cleaner piston lubrication in large gas engines.

Thinning of the oil due to crank case heat is experienced with racing car engines or racing motor boat engines, and is counteracted by passing the oil through coolers, i.e., nests of tubes cooled by the air rushing past or by sea water.

The bearing oil requirements call for oils that retain their viscosity well under heat. In this respect paraffin base oils are better than asphaltic base oils. For this reason many oil firms use mixtures of asphaltic base and paraffin base oils so as to produce oils which have reasonably low setting points, and a fairly low tendency to carbonize, and which will not thin too much under heat. Other firms use straight paraffin base oils highly filtered to remove coloring matter, but such oils have high setting points and produce carbon of a hard brittle nature, although a lesser amount than dark colored oils.

The admixture of fixed oil, preferably non-drying oils like lard oil or cocoanut oil, improves the viscosity curve and reduces the tendency to carbonize. An admixture of from 5 to 10 per cent. of good quality fixed oil is nearly always conducive to good results, providing that the mineral oil is of suitable character.

For racing purposes castor oil is frequently used on account of its excellent viscosity and non-carbonizing quality. Other fixed oils are much lower in viscosity, in fact, too low to give good results unless mixed with heavy viscosity mineral oils, but such mixtures do not equal pure castor oil for racing purposes.

For everyday use in touring cars, etc., no oils should be used containing more than, say, 10 per cent. of fixed oils, as in continuous service all fixed oils produce gummy deposits, which may choke the oil passages and bring about excessive heating of the bearings or even worse results.

As regards the tendency to carbonize it has been suggested that a good motor oil (or the mineral base of a motor oil) must have only a slight tendency to emulsification with water and that the percentage of the oil distilling over below 300°C. under vacuum is important. As regards emulsification tendency, water rarely enters the oiling system in an automobile engine, and if it does so accidentally (leaky water jacket), the water will never get a chance to separate from the oil. The oil pump draws from the very bottom of the reservoir and will certainly churn any water effectively together with the oil in circulation and form an emulsion, no matter what oil is used. But the suggestion is based on an element of truth, because if the mineral oil emulsifies badly with water, it contains a portion of unstable hydrocarbons, which on decomposing (coloring matter for example) *may* produce carbon. The author feels, however, that too much value should not be attached to the emulsification test when judging motor oils.

As regards the distillation test of motor oils under vacuum up to 300°C., the oil film as a whole is not exposed to such conditions. The author thinks very little oil evaporates in the oil film, but that the inner portion of the oil film is "cracked," the oil being suddenly decomposed or volatilized. In the distillation test the nature of the oil undergoes no change whatever.

The carbon test suggested by Conradson (see page 64) or some test on those lines is much more likely to reproduce conditions akin to what takes place inside a motor cylinder.

INFLUENCE OF ENGINE CONSTRUCTION ON THE CHOICE OF MOTOR OIL

In selecting a motor oil it is necessary to scrutinize closely the details of construction.

High Viscosity Oil is called for with large diameter pistons, long piston strokes (tendency to piston "rocking"), large piston clearances (aluminium pistons in particular), few or ill-fitting piston rings, worn pistons and cylinders, high compression, worn bearings, air cooling or poor water cooling (agricultural tractors, for example) hot climatic conditions, racing car engines, most pressure oiling systems, etc.

Low Viscosity Oil is called for with small diameter pistons, short piston strokes, high piston speed, small piston clearances, normal number of well fitting or pegged piston rings, low compression, normal bearing clearances, efficient water cooling, cold climatic conditions, splash oiling systems, etc.

"Non-Carbonizing" Oils (i.e., pale colored, non-paraffinic base oils with or without admixture of fixed oil) are called for where the oil consumption is excessive. When the oil consumption is maintained at 1000 miles per gallon or less one need not fear much trouble from carbonization of the oil.

Admixture of fixed oil appears to be *necessary* or at any rate desirable with aluminium pistons operating in steel cylinders, as aluminium does not work well together with steel and easily "drags" and seizes. Mineral oil does not give the same margin of safety when used straight, i.e., without admixture of fixed oil.

When the *oil consumption is very excessive*, as with the rotary type aeroplane engines, only *pure medicinal castor* can be used.

MOTOR OILS

Most oil firms market several grades of motor oil under proprietory names, and each can or drum is also marked with the consistency of the oil, such as light body, medium body, etc.

Opinions differ among oil firms as to what constitutes a light oil, medium oil, and so on, but the following viscosities, setting points and colors may be considered as representing the best practice for temperate climates. In hot climates low setting points are not needed. Table No. 28 gives some characteristics of typical motor oils.

TABLE 28

	Extra light	Light	Medium	Heavy	Extra heavy
Saybolt viscosity @ 104°F......	175	250	400	650	1000
Setting point °F...............	0	10	35	40	40
Color, Lovibond (¼ inch cell)..	20	30	100	200	300

Rough recommendations for the various grades are given in Lubrication Chart No. 17.

LUBRICATION CHART NO. 17

FOR GASOLENE ENGINES

"Extra Light" and "Light." For Ford cars and other cars, chiefly American make, employing the splash system of lubrication, also for many European cars with small power, high speed engines. The extra light grade is usually too light for European cars.

"Medium." This is the correct grade for the vast majority of cars, other than Ford cars, also for a fair number of motor trucks.

"Heavy." Largely used in Europe for motor trucks and for Continental cars, French and Italian make in particular, employing force feed lubrication.

Mixed with 6 per cent.–10 per cent. of good quality fixed oil, this oil will suit most water cooled aeroplane engines of the "V" type or the radial type; it will also prove an excellent oil for most motor cycles.

"Extra Heavy." This grade compounded with up to 10 per cent. of good quality fixed oil is recommended for "V" type and radial type air cooled aeroplane engines.

Medicinal (Pharmaceutical) Castor. For rotary aeroplane engines exclusively.

Clutch Oil.—For multiple plate metal clutches. This oil should have a Saybolt viscosity at 104°F. not exceeding 100″, and should preferably contain 10 per cent. of non-drying fixed oil.

When clutch oil is not available a mixture of engine oil with at least 50 per cent. kerosene may be used.

Gear Oil.—For gear box and rear axle casing. A dark or filtered cylinder stock having a rather high setting point usually gives good results. A high setting point makes the oil thick at ordinary temperature, so that no oil leaks out from the gear box, but as soon as the car starts runnng the oil thins, so that the friction losses in the gear box are kept low. Some makers give the gear oil a high setting point by mixing with it a percentage of petroleum jelly or paraffin wax. For worm gear back axle drives the gear oil should preferably contain 5 per cent. to 10 per cent. of non-gumming fixed oil.

CHAPTER XXIX

KEROSENE OIL ENGINES AND SEMI-DIESEL ENGINES

As the hot bulb or vaporizer is a characteristic feature of practically all of these engines, they are frequently called hot-bulb engines.

Horizontal oil engines are used for driving shafting and machinery in machine shops, woodworking shops, dairies, also used for driving refrigerating plants, electric generators, pumping machinery, agricultural tractors and for a variety of purposes in "out of the way" districts.

Vertical oil engines are chiefly used for marine service, for fishing boats and pleasure boats; they are also used for driving agricultural tractors and for many purposes in "out of the way" districts, in the same way as horizontal oil engines.

Classification.—Oil engines may be classified as shown in Table No. 29.

TABLE NO. 29

	No. of cylinders	H.P. per cylinder	Revolution per minutes
Horizontal oil engines (pistons not water-cooled)	1 to 4	1 to 90	600 to 180
Horizontal oil engines (pistons water-cooled)	1 to 4	90 to 200	180 to 120
Vertical oil engines....................	1 to 8	1 to 125	900 to 160

Starting.—When starting, the hot bulb is heated to a dull red color by means of a gasolene or kerosene blow lamp. Engines employing electric ignition are started on gasolene till they get warmed up.

Small oil engines are started by hand, *large oil engines* by compressed air. The air used for starting is compressed by a small belt driven compressor operated by the oil engine and the air is stored in reservoirs.

After starting, the engines operate automatically and the blow lamp is removed, the hot bulb being thereafter kept hot by heat from the explosions.

Injecting the Fuel.—The fuel is injected under great pressure through a specially constructed spray nozzle in order to produce a very fine fuel spray and get complete combustion. Several makers use compressed air of 250 to 450 lbs. pressure for injecting the fuel, which greatly assists in producing a finely atomized fuel spray and in getting complete combustion.

In some small engines the fuel is fed by gravity from a tank into the air inlet valve so arranged that every time the air valve opens, fuel is admitted, atomized by the in-rushing air and carried into the engine. Obviously, only light oils like kerosene can be used in this manner.

In some Semi-Diesel engines the piston head is apt to get very hot, and can only be kept sufficiently cool by employing water injection. The hot piston head heats the air in the crank chamber and reduces the capacity of the engine; it also means a warm gudgeon pin. For these reasons it is good practice to make the piston in two parts, a partition plate preventing the crank chamber air from coming into contact with the piston head.

In vertical oil engines employing force feed circulation, the piston should be at least ¼ inch thick in the centre to avoid overheating and carbonization of the oil in the piston hollows.

PRINCIPLE OF OPERATION

Oil engines operate on the four-stroke cycle, or the two-stroke cycle principle, but by two different methods, the fuel being either introduced during the suction stroke or at the instant of maximum compression (Semi-Diesel principle).

Four-Stroke Cycle Principle of Operation.—*First Method* (Fig. 194). Practically exclusively used in *low compression* oil engines (40 to 70 lbs. compression) employing light fuels, chiefly kerosene.

1st Stroke (Suction).—Air is drawn in through air inlet valve and at the same time:

(1) fuel is admitted into the air (by gravity or carburetor) and atomized or

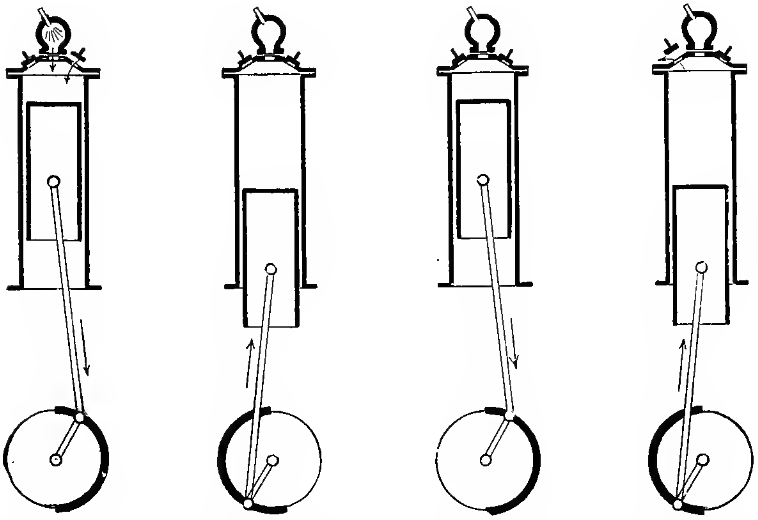
(2) fuel is, by means of the fuel pump, injected into the hot bulb and there vaporized. In either case the piston moves outwards, the cylinder being filled with a more or less complete mixture of air and fuel vapor, constituting the fuel charge. Exhaust valve is closed.

2nd Stroke (Compression).—The piston moves inwards, compressing the fuel charge into the hot bulb to a pressure of 40 to 70 lbs. Inlet valve and exhaust valve are closed.

3rd Stroke (Power).—Firing of the compressed fuel charge by electric ignition or spontaneously by the high temperature existing in the hot bulb, explosion and expansion, the piston being forced outwards during its power stroke. Inlet valve and exhaust valve are closed.

4th Stroke (Exhaust).—Piston moving inwards, driving out the burnt gases, through exhaust valve. Inlet valve is closed.

A few makers fit an extra valve called a "timing valve" in the "neck" between the hot bulb and the cylinder. It is operated from the cam shaft and opens communication between the hot bulb and the working cylinder at the moment it is desired



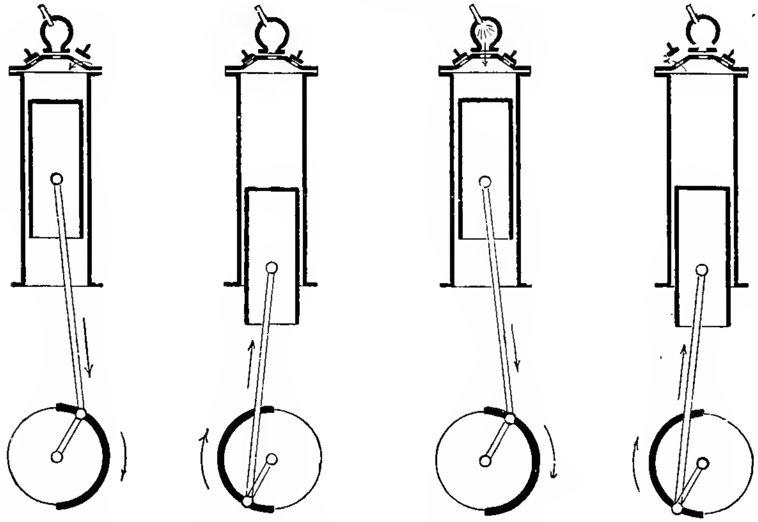
First Stroke
Suction

Second Stroke
Compression

Third Stroke
Power

Fourth Stroke
Exhaust

Fig. 194.—Four stroke cycle principle of operation, kerosene oil engines.



First Stroke
Suction

Second Stroke
Compression

Third Stroke
Power

Fourth Stroke
Exhaust

Fig. 195.—Four stroke cycle principle of operation, semi-Diesel engines.

that the explosion shall take place. A fairly high compression can therefore, be employed without the danger of premature explosions.

Second Method (Fig. 195).—Used in four-stroke cycle semi-Diesel engines employing besides kerosene also heavier fuels, such as gas oil and black fuel oil.

1*st Stroke* (Suction).—The piston moves outwards, sucking in air through the air inlet valve. Exhaust valve is closed.

2*nd Stroke* (Compression).—The piston moves inwards, compressing the air into the hot bulb to a pressure of 150 to 300 lbs. Inlet valve and exhaust valve are closed.

3*rd Stroke* (Power).—Fuel oil is sprayed into the hot bulb (either solidly or mixed with compressed air); the fuel burns and the high pressure developed forces the piston outwards during its power stroke. Inlet valve and exhaust valve are closed.

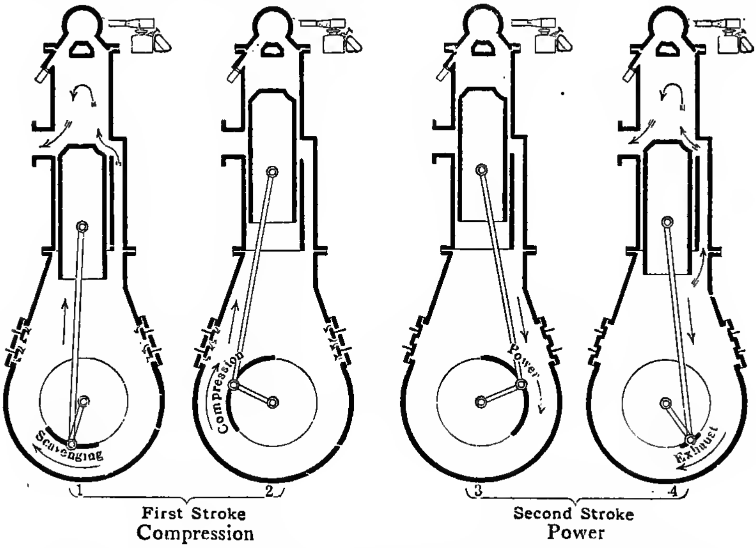


FIG. 196.—Two stroke cycle principle of operation, semi-Diesel engines.

4*th Stroke* (Exhaust).—The piston moves inwards, driving out the burnt gases through exhaust valve. Inlet valve is closed.

As the fuel is injected under pressure at the instant of maximum compression (same as in Diesel engines) this method is called the "*Semi-Diesel*" principle of operation. It is called "*Semi*-Diesel" because the compression (150 to 300 lbs.) is considerably lower than in Diesel engines (500 lbs. compression), so that the heat of compression must be assisted by the heat from the hot bulb in firing the fuel.

Two-stroke Cycle Principle of Operation, as employed by *two-stroke cycle semi-Diesel Engines* (Fig. 196).

All moving parts of the engine are enclosed in a crank chamber fitted with large air inlet valves.

1*st Stroke* (Compression).—The rising piston covers the air port and the exhaust port. The air which has filled the cylinder is compressed to a pressure from 150 to 300 lbs. pressure per square inch.

This is the compression stroke.

During the upward movement of the piston, air is sucked into the enclosed crank chamber through the air valves.

2*nd Stroke* (Power).—When the piston is near the top of its stroke, fuel is injected through the spray nozzle into the hot bulb. The atomized fuel is ignited and burned by the heated compressed air and the hot bulb, and the high pressure developed forces the piston downwards. Shortly before reaching the bottom of its stroke the piston uncovers the exhaust port through which the burned gases escape; later the air port is uncovered, allowing compressed air from the crank chamber to enter the cylinder, driving out the burned gases and filling the cylinder with clean air.

This is the power stroke.

While the piston is moving downwards, it is compressing the air in the enclosed crank chamber, the air valves being closed.

Thus the cycle consists of two strokes (one idle stroke followed by one power stroke).

Cooling.—Oil engines are cooled in a similar manner to gas engines except that a number of small, low compression oil engines, used for agricultural purposes, have no cooling water *circulation.* The cooling water jacket is open at the top, forming a hopper containing a fair quantity of water, which during operation of the engine heats up and boils. Marine oil engines, of course, use sea water for cooling purposes.

Water Injection.—In some engines, it is customary on heavy loads to arrange for a small amount of water droppng into the vaporizer or into the air inlet valve or passage. The water turns into steam and has a softening effect on the character of the explosions, resulting in smoother running of the engine. It also enables higher compression to be carried.

FUEL

Fuels used in oil engines are: Kerosene, Gas Oil and Black Fuel Oil (often referred to as "Crude Oil").

Kerosene is the fuel mostly used in low compression oil engines and also frequently used in semi-Diesel oil engines. It is too heavy to vaporize properly in most carburettors, but will vaporize satisfactorily in the hot bulb. If the heat of the hot bulb is much above a faint red heat, the kerosene decomposes and forms soot. If the heat of the hot bulb is much below a faint red heat, the kerosene does not vaporize properly.

Keeping the temperature of the hot bulb uniform is consequently of the greatest importance. In some oil engines an adjustable portion of the exhaust gases is carried around the vaporizer, which makes its possible to regulate the temperature of the hot bulb as required to suit the load. Advancing or retarding the ignition according to the load also helps to regulate the hot bulb temperature.

When the work done by the engine varies considerably, the hot bulb will generally get too hot on a heavy load and too cold on a light load.

Gas Oil.—Gas oils constitute the principal fuels used in semi-Diesel oil engines. The hot bulb must be slightly warmer with gas oils than with kerosene, as gas oils are not so easily vaporized.

Black Fuel Oil is generally the residuum from crude petroleum after all gasolene and kerosene have been distilled off. It may also be a mixture of heavy petroleum residual oils and gas oil. Black fuel oils are largely used in semi-Diesel oil engines.

Uniform Fuel.—When the engine has been carefully adjusted to suit a particular class of fuel, it is very important that the fuel supplies should be as uniform in quality as possible, in order to obtain highest efficiency and to obviate the necessity of further adjustment; otherwise, incomplete combustion will take place and will interfere with lubrication.

METHODS OF LUBRICATION

Horizontal Oil Engines and Semi-Diesel Engines are lubricated exactly in the same way as horizontal small or medium size gas engines, the oil being distributed from separate lubricators or from a mechanically operated lubricator to all points.

Vertical Oil Engines due to the high speed at which they operate, have the working parts enclosed in a crank chamber, and employ the following methods of lubrication:

(*a*) Splash System of Lubrication, similar to vertical gas engines or automobile engines.

(*b*) Force Feed Circulation System, similar to vertical automobile engines.

(*c*) Mechanically Operated Lubricators.

Systems (*a*) and (*b*) are fully described under sutomobile engines and are used only in connection with low compression four-stroke cycle oil engines.

As the crank chamber is enclosed, the heat radiated from the pistons and cylinder walls is, to a large degree, retained in the crank chamber, so that the oil in the crank chamber gets very warm, the resulting temperature being from 100° to 160°F. If a temperature of 140° is greatly exceeded, the life of the oil will be reduced, and it may throw down a dark deposit.

The oil in the crank chamber is always more or less affected by the admixture of fuel, which has not been properly vaporized (and burned) inside the working cylinder, but mixes with the oil on the cylinder walls and gradually works down past the piston rings and drops into the crank chamber. The result is that the oil becomes thinner and its lubricating qualities are greatly affected. The oil becomes dark in color, due to black residual or carbonized matters coming down from the pistons, dropping into the crank case and mixing with the oil.

System (*c*).—A mechanically operated force feed lubricator is always used in connection with the two-stroke cycle oil engines or semi-Diesel engines, whether vertical or horizontal. A splash or force feed system must not be used, as the oil spray would contaminate the air which is drawn through the crank chamber. The lubricator is operated by the engine and feeds oil to the cylinder, crank pin (by a banjo arrangement), gudgeon pin, and sometimes also to the main bearings, which, however, are sometimes ring oiled and occasionally lubricated by grease.

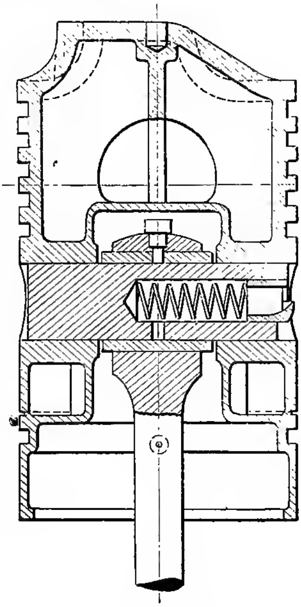


FIG. 197.—Wrist pin lubrication.

Piston.—The oil is introduced under pressure into the cylinder, usually at two points, one at the front and one at the back, and preferably timed, so that the oil is injected between the first and second piston rings at the exact moment when the piston is in its lowest position.

Gudgeon or Wrist Pin.—One of the oil feeds from the mechanically operated force feed lubricator feeds oil through the cylinder wall, so timed as to inject the oil into the cylinder to a central oil passage in the wrist pin. Fig. 197 shows a scoop arrangement now very generally employed.

As in two-stroke cycle engines cold air is constantly drawn through the crank case, this is kept fairly cool, but there is always the danger of impurities and dirt in the air getting into the working surfaces of the various bearings.

Main Bearings.—Where the main bearings are lubricated with grease, there is considerable loss in power, due to the friction, as the bearing temperature must rise to a point where the grease melts before it starts lubricating.

Leakage of air from the crank chamber must be guarded against, the troublesome places being the main bearings and the exhaust port. Fig. 198 shows the most common form for preventing leakage through the main bearings. It consists of a bronze ring revolving with the shaft; it has a very good sliding fit on the collar and is pressed against a turned face of the crank case by means of light springs.

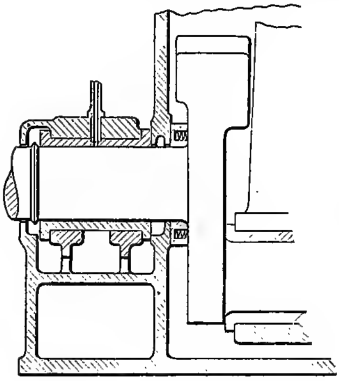


Fig. 198.

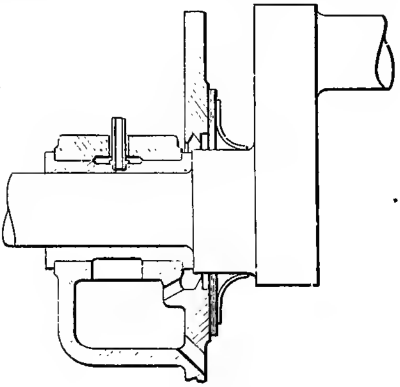


Fig. 199.

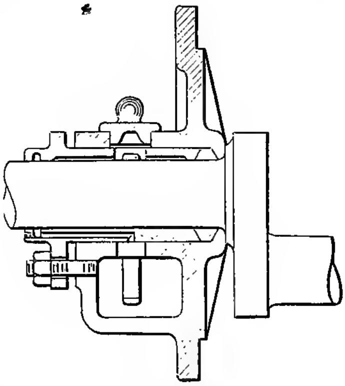


Fig. 200.—Preventing leakage from crank chamber.

Fig. 199 shows a simple type, consisting of a leather ring fitting snugly against the shaft and revolving together with a thin brass ring, say ⅛ inch thick, which is forced against the casing by the leather and the air pressure. The leather must be renewed at intervals, as it perishes due to the action of the lubricating oil.

Fig. 200 shows a design embodying a packed gland.

Leakage of the rings is often due to dirt in the intake air getting between the faces; the grit may often be "washed" out by liberal use of an oil syringe.

Some builders of low power engines employ grease for main bearing lubrication, the film thus provided being sufficient to prevent air leakage. The grease is applied through Stauffer cups or spring grease cups, or preferably through compressed air grease cups like the "Menno." The grease should be of a soft to medium consistency, so as not to increase the friction more than need be.

The feed pipes should have no bends and should be placed at a steep angle, say over 60°, so that if the bearings get unduly warm some of the grease in the pipes will melt and run into the bearings on its own accord.

Governor.—Irregular running is sometimes experienced with engines, governed on the hit-and-miss principle. The cause is often that governor parts stick, due to the use of an unsuitable oil. Occasional cleaning with kerosene is therefore desirable, as many of the best oil engine oils are slightly gumming, and it is not often practicable to use a thin straight mineral oil for the special benefit of the governor.

If the exhaust valve spindle sticks, a liberal supply of lubricating oil will only aggravate the trouble. Kerosene should be applied and will usually prove effective.

DEPOSITS

Deposits may arise from one or several of the following causes: impurities in the intake air, overfeeding of oil, unsuitable oil, impurities in the fuel, unsuitable fuel, hot bulb too hot or too cold, improper fuel vaporization, incomplete combustion, water injection.

Where in low compression oil engines deposits have developed inside the combustion chamber, they often (and particularly if the water cooling is defective) become incandescent and cause pre-ignitions.

Impure Intake Air.—The same remarks apply as for gas engines (page 455).

Overfeeding of Oil.—Excess oil passing to the cylinders causes carbon deposits to develop behind and between the piston rings, the amount depending upon the quality of the oil.

Unsuitable Oil.—Too low viscosity oil fails to provide satisfactory lubrication; wear follows, the metallic wearings baking together with charred oil and forming deposits; an increased oil feed will only aggravate the trouble. Too viscous an oil will not spread properly and may thus bring about similar results.

Impurities in Heavy Fuel Oils.—When the fuel oil contains too much free carbon and ash, the unburned impurities will deposit themselves on the cylinder walls. They will adhere to the lubricating oil and form a deposit, causing heavy wear of cylinder walls and piston rings.

Unsuitable Fuel.—A fuel containing too much asphalt or being too thick to flow readily will not be properly atomized and does not burn completely during combustion. The unburned portions will accumulate on the piston top, behind and between the piston rings, etc., and form carbonaceous deposits.

Hot-Bulb Temperatures.—The hot-bulb temperature may become too high, usually owing to heavy engine loads. This high temperature causes cracking of the oil particles when they meet the highly heated wall of the hot bulb and the combined effect of the high temperature and pressure prevailing is to gasify the fuel, and at the same time to decompose the fuel to a great extent. The splitting up of the heavy hydro-carbons into light hydro-carbons always throws out a certain amount of carbon in the form of coke, which accumulates in the hot bulb and when it reaches the cylinder interferes with lubrication.

Too low a temperature of the hot bulb is frequently experienced under light load conditions and the result is that when the fuel particles reach the wall of the hot bulb they become only partially gasified and some of the heaviest hydro-carbons in the fuel leave a bituminous residue of a sticky nature which is bound to reach the piston and piston rings and is very objectionable. When the engine becomes cold these sticky deposits solidify like glue and many cases have been known where it has been almost impossible to move the piston once the engine has cooled down.

For each class of fuel, whether kerosene, gas oil, or black fuel oil, there is a certain range of hot-bulb temperature within which the fuel will be completely gasified without leaving any appreciable residue in the hot bulb. It is obviously desirable that this range of temperature should be as wide as possible.

Improper fuel vaporization is apt to take place where the fuel is fed by gravity through the air inlet valve, as, due to the fact that the fuel is not heated, the inrushing air does not afford sufficient means for breaking up and atomizing the fuel; the results are similar to those under light load conditions with the vaporizer too cold.

Incomplete combustion is chiefly due to bad atomization, but may also be due to the vaporizer being too cold, or to faulty timing of the valves. When the spray is coarse, due to the fuel being too viscous or to the fuel valve being out of order, or to too low fuel pressure, etc., the combustion of the fuel charge becomes incomplete, *i.e.* some particles of the fuel are so big that they burn only on their surfaces—they are charred. The result is that, during the power stroke and the exhaust stroke, the cylinder is full of dense black smoke (black exhaust) which blackens and contaminates the oil film on the cylinder walls.

A finely atomized spray is, therefore, very necessary if lubrication troubles are to be avoided, and in many engines unsatisfactory atomization and incomplete combustion are often unavoidable under light load conditions.

Water Injection.—In some engines, particularly marine engines, it is customary to arrange for a small amount of water dropping into the vaporizer or into the air inlet valve or passage. The water turns into steam, and has a softening effect on the character of the explosion, resulting in smoother running of the engine on heavy loads. The "water drips" should be used only under heavy loads. If used under light load conditions, or if used in excess, the water will not evaporate completely; it will tend to wash away the oil film and destroy lubrication, resulting in heavy wear and carbonaceous deposits. In enclosed engines oiled by the splash or force feed circulation system, excess water will reach the crank chamber and, mixing with the oil, cause trouble through emulsification.

The water, unless it is distilled water, contains a certain amount of salts which are deposited inside the engine when the water evaporates and act like grit between the piston rings and cylinder walls.

SELECTION OF OIL

In order to select the correct oil for an oil engine, it is necessary to consider the piston clearance, the piston rings (their number and whether they are pegged or no), the temperature of the water jacket, the method of lubrication, whether the combustion is clean or otherwise, etc., etc. A few of these points are considered in the following.

Piston and Piston Rings.—By far the largest amount of friction is between the piston, piston rings and cylinder walls. Nothing is therefore so important as the satisfactory and efficient lubrication of the piston.

It is important that the piston clearance should not be excessive. In some of the early types of semi-Diesel engines the piston clearance is large and tends to bring about "piston rocking," necessitating the use of exceedingly viscous lubricating oils to prevent the explosion gases from blowing past the piston.

Some semi-Diesel engine manufacturers are still recommending oils as viscous as steam cylinder oils for piston lubrication, and the result, as might be anticipated, is that besides an excessive amount of power consumed by piston friction there is excessive wear of the piston rings and cylinder walls. Such viscous oils aggravate troubles with deposits from whatever source they may arise.

If friction is to be reduced to a minimum the piston clearance must only be sufficient to allow easy sliding motion of the piston under conditions of heavy load, and the piston rings should be slightly softer than the liner and pegged, so that they will wear to a fit with the shape of the cylinder.

This "pegging" of the rings is most essential. Each piston ring should be numbered and always put back in the same groove after examination. If piston rings are not pegged they move in their grooves and the gaps may easily work into line, with the result that the explosion gases blow past the piston, charring the lubricating oil and causing excessive wear.

The piston rings should be a good fit in their grooves; they act like valves, being bright on their bottom surface and dull on their top surface. If the outer surface of the rings in contact with the cylinder wall is dull, the dullness indicates leakage past the ring during operation. If piston clearances are normal and piston rings of the right material and pegged, it is possible to use medium viscosity lubricating oils, and the piston friction will be found to be very reasonable. Where the piston rings are not "pegged," a very heavy-bodied oil is occasionally used, in order to seal the piston and prevent too much oil from passing the piston rings.

Combustion.—When clean combustion is maintained, straight mineral oils often give satisfactory results. But when carbon deposit is formed inside the engine, due to the hot bulb temperature being too high or too low, or due to incomplete atomization of the fuel or to unsuitable fuel, etc., such deposits will ordinarily accumulate and clog the piston rings, making them inflexible in their grooves, with the result that they no longer keep compression or explosion tight, and heavy friction and wear immediately follow.

Experience has, however, proved that even extreme cases of carbonization of the nature just referred to have been cured by using castor oil, rape oil, olive oil, lard oil, or mixtures of such oils with mineral oil in various proportions.

All fixed oils, *i.e.* vegetable oils and animal oils, contain a fair proportion of oxygen and in all probability this oxygen during the explosion period assists in burning away the carbonaceous deposit.

The effect of the compound is to prevent deposits from baking together and forming a crust. The little globules of compound mixed with the mineral oil burn away clean and continuously break up the deposits, so that they may be swept out with the exhaust or work their way past the piston to the outside.

We know that many vegetable oils are much more inclined to produce gumminess exposed to the air than animal oils, so that animal oils should generally be preferred for mixing with mineral oil, the percentage of animal oil required being entirely dependent on the degree of carbonization taking place inside the engine.

Speaking generally, an admixture of from 6 per cent. to 15 per cent. of lard oil to a mineral oil of suitable characteristics will give clean lubrication in all normal cases.

Water Injection.—Many marine semi-Diesel engines are in the hands of fishermen and others who are not particularly conversant with the working of the engines, with the result that the engines get scant attention generally. As regards the water injection it is generally kept on whether the engine is on a heavy or a light load. The result is that the internal lubrication becomes very poor unless compounded lubricating oils are used. Pure mineral oils are simply washed away from the piston, rusting of parts and heavy friction and wear being the unavoidable result. The excess water also contaminates the bearing oil; but when the bearing oil is compounded it emulsifies with the water and the bearings may be quite satisfactorily lubricated, the only drawback being that the emulsified oil collecting in the base of the engine cannot be filtered and used afresh.

For oil engines in which the combustion is not clean, or where water injection is employed, compounded oils are therefore essential to satisfactory lubrication, while for oil engines with clean combustion and without water injection, straight mineral oils may be used.

For obvious reasons, compounded oils are not so satisfactory as straight mineral oils in force feed circulation oiling systems; if a compounded oil is needed because of the cylinder requirements, a non-drying fixed oil should be used for compounding and as small a percentage as possible.

Oil Consumption.—Oil engines are frequently extravagantly lubricated, either because of the lubricators, or because it is not possible to give the engines the necessary close attention. Excessive oil consumption means, however, not only waste of oil but also increased tendency to form carbon deposit, so that oils having "non-carbonizing" properties will be given a decided preference in most cases where overfeeding takes place.

These remarks apply particularly to marine oil engines and Semi-Diesel land engines.

Whereas the consumption of oil in horizontal oil engines is very similar to the oil consumption of small and medium size horizontal gas engines (page 466) the consumption of other oil engines may be anything from 50 per cent. to 100 per cent. higher, depending upon circumstances.

For lubrication of oil engines, oils similar in viscosity and general characteristics to gas engine oils Nos. 2c, 3c, and 4c are required.

The oils should be compounded with 6 per cent. to 15 per cent. of non-drying fixed oil unless for special reasons, such as having to use the oil engine oil also on other machinery for which a compounded oil is considered unsatisfactory, it is preferred to use the oil without the admixture of fixed oil.

Some white bearing metals, rich in lead, are quickly attacked by free fatty acid in the oil, and may for this reason demand the use of a straight mineral oil.

In the Lubrication Chart for oil engines and semi-Diesel engines given below, gas engine oils Nos. 2c, 3c and 4c are recommended, but a note is made as to the percentage of fixed oil required which, speaking generally, is greater than for gas engine oils proper, but otherwise characteristics are similar.

LUBRICATION CHART NO. 18

FOR KEROSENE OIL ENGINES AND SEMI-DIESEL ENGINES

	Horse power per cylinder	Gas engine oil	Per cent. of compound required
Low Compression Oil Engines:			
(*a*) *Open types,*[1] nearly always horizontal..................	Up to 50	No. 2c	Up to 15
(*b*) *Enclosed types,* nearly always vertical...............	Above 50	No. 3c	Up to 15
Employing splash oiling system.................		No. 2c or No. 3c	Less than 10
Employing force feed oiling system.............		No. 3c or No. 4c	Less than 10
[1] *Semi-Diesel Engines, Whether Vertical or Horizontal*......	Up to 50	No. 3c	Usually less than 10
	Above 50	No. 4c	Usually less than 10

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[1] In such rare cases, where very excessive carbonization and gumming takes place, the engine is either badly designed or adjusted, or out of order, or the operating conditions are very exceptional (long periods of light load operation, for example). Under such conditions pure castor, lard, rape, olive, etc., may be used temporarily and will give clean or comparatively clean lubrication, but such oils are expensive and usually have other drawbacks, causing gumming or corrosion.

CHAPTER XXX

DIESEL ENGINES, LAND AND MARINE

LAND DIESEL ENGINES

Classification.—Practically all land Diesel engines are of vertical construction; only a few, notably in Germany, are of horizontal construction. Land Diesel engines may be classified as shown in Table No. 30.

Table No. 30

	No. of cylinders	H.P. per cylinder	R.P.M.
Four-stroke cycle engines.........	1 to 4	10 to 300	450 to 150
(Practically all land Diesel engines are of this type.)			
Two-stroke cycle engines..........	4 to 6	200 to 650	150 to 100

Land Diesel engines below 100 H.P. are used for various purposes, but from 100 H.P. to 4,000 H.P. they are principally used for driving electric generators in electrical power stations or in large works or mills.

MARINE DIESEL ENGINES

Classification.—All marine Diesel engines are vertical and can be classified as shown in Table No. 31.

Table No. 31

	No. of cylinders	H.P. per cylinder	R.P.M.
Four-stroke cycle engines.........			
Slow speed....................	2 to 8	50 to 350	300 to 90
(Practically all main engines in motor ships are of this type.)			
High speed...................	2 to 12	12 to 350	600 to 300
(Practically all auxiliary engines in motor ships and all main engines in submarines are of this type.)			
Two-stroke cycle engines..............	2 to 6	12 to 650	450 to 90
(Very few main engines in motor ships are of this type. Small auxiliary engines in motor ships are occasionally of this type. Main engines in submarines are seldom of this type.)			

Slow Speed Marine Diesel Engines are used as main engines in the merchant marine service for ship propulsion and are usually reversible. A few ships have been built with non-reversible Diesel engines, either driving electric generators which produce current for operating slow speed electric motors driving the propeller direct, or driving centrifugal pumps supplying water under pressure to "Foettinger" transformers, which can be made to rotate in either direction and at variable speeds, driving the propellers direct.

The auxiliary machinery, such as pumps, winches, steering gear, etc., on board a Diesel motor ship is operated either electrically, by steam, hydraulically, or by compressed air.

High Speed Marine Diesel Engines are used as main engines in torpedo boats, submarines, small coasters, yachts, launches, etc., and in other cases as auxiliary engines (electric generator engines for example) where limited weight and space are of primary consideration.

SPECIAL TYPE DIESEL ENGINES

Double-Acting Diesel Engines.—A great deal of experimental work is being done to develop the double-acting Diesel engine employing either the four-stroke cycle or the two-stroke cycle principle. Their construction is very similar to that of large gas engines. There are only a few double-acting land Diesel engines in operation and they are of horizontal construction.

The Junker Diesel Engine, often called the double-piston engine, is a special type embodying the two-stroke cycle principle, with two opposed pistons in each cylinder.

Solid Injection Diesel Engines dispense with the air compressor and inject the fuel under an enormous pressure (4000 lbs. per square inch), atomizing it mechanically. These engines (Vicker's type) are largely used for submarines.

CONSTRUCTIONAL POINTS

The main engines aboard a Diesel ship are always of the crosshead type, with the external parts partly or entirely enclosed.

With trunk piston engines, wear of the thrust collars on the propeller shaft would cause trouble with pistons, but does not affect the flat crosshead guides in crosshead type engines. Quite apart from this consideration, there is a growing tendency to construct all Diesel engines, land and marine, except those developing 50 H.P. or less per cylinder, as crosshead type engines, because there is less trouble with piston distortion, the crosshead bearing can be kept cool, being remote from the piston; carbonized dirty oil from the piston may be prevented from reaching the crank chamber, and the oil in the crank chamber can be prevented from reaching the cylinders; it is kept cooler and cleaner and therefore retains its vitality much longer.

Most auxiliary Diesel engines and other high speed engines are of the trunk piston type and of necessity always entirely enclosed. The pistons, when above say 18 in. in diameter, are always built in two parts, a plate being inserted between the top and the bottom portion, which prevents oil from the gudgeon pin splashing into the hot, hollow piston head, where it would burn and char.

Two-stroke cycle engines are more difficult to lubricate than four-stroke engines. The pressure is never relieved on the moving parts, making it difficult for the oil to get in between the bearing surfaces. The long trunk pistons needed to close the scavenging and exhaust ports have large friction surfaces and are more liable to wear and seizure than the pistons in crosshead type engines. Two-stroke engines may be constructed with crossheads, but it makes a very tall engine, as the long trunk pistons must be retained.

Cooling.—The piston head in larger engines is frequently built with provision made for cooling, the cooling medium being either oil or fresh water. The cooling water for the pistons must be fresh water; sea water is liable to deposit salt incrustations inside the pistons. In navigating in muddy or shallow waters, it is obvious that such water is totally unsuitable for piston cooling purposes. It is bad enough for the cylinder jackets and for cooling the piston cooling water; and as incrustations, scale or mud, greatly reduce the heat transmission, all cooling spaces must be so designed that they can be easily examined and cleaned, which should be done, say every three months.

In shutting down the engine, cooling of the pistons and cylinders must be continued for half-an-hour to prevent boiling of the water and formation of deposits of salt, lime, etc. This is particularly important where hard water or sea water is used, and also with piston cooling oil in marine Diesel engines, as the oil is cooled by sea water and it is not always possible to guard against leakage of a little sea water into the cooling oil. Leakage from the joints or telescopic pipes carrying water or oil into the piston is difficult, almost impossible, to avoid. If cooling water gets into the oil it may cause emulsification in the same way as water in turbine oil. Leakage of cooling oil into the lubricating oil system is not so serious, but if cooling oil is very thin, it may in time reduce the viscosity of the lubricating oil sufficiently to be noticeable.

PRINCIPLE OF OPERATION OF DIESEL ENGINES

In the Diesel engine fuel is injected into the cylinder and is directly converted into power. It operates on either the four-stroke cycle or the two-stroke cycle principle, as follows:

Four-stroke Cycle (Fig. 201).

First Stroke (Suction).—The piston moves downwards away from the cylinder head, sucking in air through the open air inlet valve. Exhaust valve and fuel valve are closed.

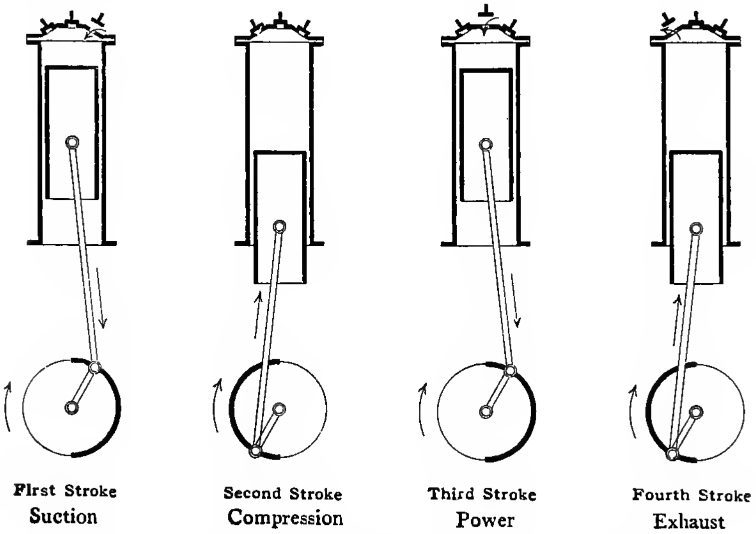

Fig. 201.—Four stroke cycle principle of operation, Diesel engines.

Second Stroke (Compression).—The piston moving upward toward the cylinder head compresses the air to a pressure of about 500 pounds, resulting in a temperature of about 1000°F., which is sufficient to ignite and burn the fuel.

Air inlet valve, exhaust valve and fuel valve are closed.

Third Stroke (Power).—The fuel valve opens; fuel is blown in the form of a fine spray into the cylinder by means of the highly compressed air coming from the air reservoirs. There is no explosion, but the fuel, due to the high temperature existing in the cylinder, burns completely as it enters, maintaining a constant pressure during fuel injection. The fuel valve is then closed; the expanding gases force the piston away from the cylinder cover during the power stroke, all valves being closed.

Fourth Stroke (Exhaust).—The piston, moving upwards towards the cylinder cover, drives out the burned gases through the open exhaust valve. Air inlet valve and fuel valve are closed.

Thus four strokes of the piston, *i.e.* one power stroke followed by three idle strokes, complete the cycle of events.

Two-Stroke Cycle (Fig. 202).

First Stroke (Compression).—At the beginning of the stroke, the piston has uncovered the exhaust ports through which the burned gases are expelled, the scavenging air entering either through the scavenging valves in the cylinder cover, or through the scavenging ports in the cylinder; the piston, rising, covers the exhaust ports. The scavenging valve or ports are closed and the air is compressed to a pressure of about 500 pounds.

Second Stroke (Power).—At the top of the piston stroke, fuel is sprayed into the cylinder and the piston descends on its power stroke.

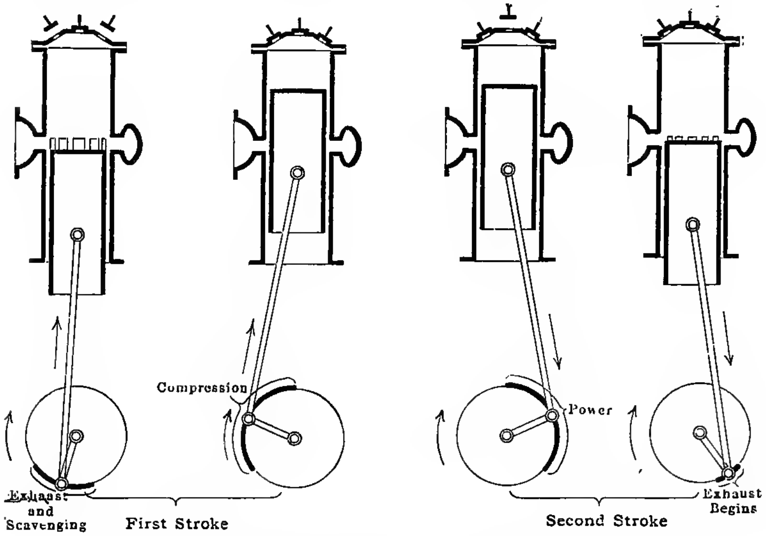

FIG. 202.—Two stroke cycle principle of operation, Diesel engines.

Towards the end of the stroke the piston uncovers the exhaust ports and the exhaust gases escape, being assisted by the scavenging air blown into the cylinder through the scavenging valves or ports.

Thus two strokes of the piston, *i.e.*, a compression stroke followed by a power stroke, complete the cycle of events.

Starting.—The Diesel engine is always started by means of compressed air. The starting air reservoirs are filled with compressed air, usually at a pressure of 350 pounds; occasionally higher pressures are employed. This pressure should never fall as low as 200 pounds. Starting air is delivered to the starting air reservoirs either from an auxiliary air compressor or it is taken from the injection air bottles. A pipe conveys the air from the starting air storage bottle to the starting valve casings. The starting valves in all cylinders are automatically opened and closed, so that the starting air is admitted only into those cylinders in which the pistons are in the right position for their downward strokes.

When the engine has made a few revolutions by means of compressed air, the fuel pump is put into service. The starting handle which throws the fuel pump into automatic service, throws the starting air valves out of service.

In the case of two-stroke cycle engines, starting is occasionally performed by admitting compressed air into the scavenging pump cylinders. The resultant motion of the seavenging pump is transmitted through levers to the main engine crosshead.

Reversing.—For the purpose of reversing marine engines, two sets of cams are employed; "ahead cams" and "astern cams." For going ahead, "ahead cams" are in action, operating all valves; for going astern, "astern cams" are put into action, controlling the operation of the valves. The necessary alterations in the position of the cam shafts when reversing are carried out by means of compressed air or in the case of smaller engines, by hand.

FUEL

The fuels in use are:

Gas oil.
Black fuel oil.
Coal tar oil or Lignite tar oil.
Coal tar.
Vegetable oils and Animal oils.

Gas Oil.—Gas oils are excellent fuels for Diesel engines but are more expensive than black fuel oils.

Black Fuel Oil.—Fuel oils (see page 504) for Diesel purposes must not be too viscous; if they are too viscous at the temperature prevailing in the fuel valve space, they are badly atomized. Fuel oils of a Saybolt viscosity, say, less than 200″ at 104°F. will normally be found to atomize readily.

Coal Tar Oil and Lignite Tar Oil are produced from bituminous coal and lignite, respectively, the distillation being directed with a view to producing a suitable quality of tar oil for Diesel engines. Usually a small percentage of gas oil or other light petroleum fuel oil is injected into the Diesel engine cylinder by an ignition oil pump, just before the tar oil is sprayed in, by means of the fuel pump. The burning gas oil helps to ignite the atomized tar oil, so that it burns completely without "sooting."

Coal Tar when produced from bituminous coal in vertical retorts can sometimes be used, but it must be heated in order to flow freely and can be employed only with the addition of about 10 per cent. of light petroleum fuel oil used in the same manner as described under tar oil.

Vegetable and Animal Oils, such as castor oil, palm oil, earth nut oil, cottonseed oil, whale oil, etc., can also be used as fuel in Diesel engines, and may come into consideration for tropical countries where there is no easy access to other fuels.

Fuel Storage, etc.—When the fuel is pumped from the storage tanks it should be carefully strained before entering the daily supply tanks. The latter are fitted with a drain pipe for removing water which may accumulate. The fuel delivery is taken from the daily supply tank at a height of, say, 10 inches above the bottom, so that only clean fuel passes down through this pipe and through an additional filter to the fuel pump.

When the engine has been carefully adjusted to suit a particular class of fuel, it is very important that the fuel supplies should be as uniform in quality as possible, in order to obtain highest efficiency and to obviate the necessity of further adjustment; otherwise, incomplete combustion will take place and will interfere with lubrication.

METHODS OF LUBRICATION

Trunk piston, enclosed type Diesel engines, land and marine, are always lubricated by a full force feed circulation system, the oil being circulated under a pressure of up to 25 pounds per square inch, depending upon the size of the engine.

Trunk piston, open type, land engines have all parts lubricated from mechanically operated lubricators, except the main bearings, which are always ring oiled.

Crosshead Type Diesel Engines, Land and Marine.—The *piston lubrication* is always by means of *a mechanically operated lubricator.*

The external parts are lubricated by means of:

(*a*) *Force feed circulation,* all parts enclosed.

Most marine engines (Burmeister & Wain type) employ this system.

(*b*) *Oil distribution by gravity feed* or *by mechanically operated lubricators* to all parts.

Most large two-stroke cycle Diesel engines employ these systems; also some four-stroke cycle marine engines.

Piston Lubrication.—The oil feeds from the mechanical lubricator should preferably be timed to inject the oil at the right moment. It is often convenient to have the lubricators arranged for a rotary drive, the cams or levers inside the lubricator being so placed as to operate their respective plungers at the right moment for their respective pistons.

One method which is much used is to have one lubricator for each cylinder unit, all pumps operated simultaneously by means of an oscillating lever, actuated by a cam on the camshaft or by some other part having a reciprocating motion.

For pistons up to 20 in.–22 in. in diameter, two separate oil feeds, one at the front and one at the back are sufficient; for larger pistons four oil inlets are preferred.

Fig. 203 shows an oil injector for timed injection of the oil through a *small hole* on to the piston. With a large oil hole it is obviously not possible to get a satisfactory timing effect.

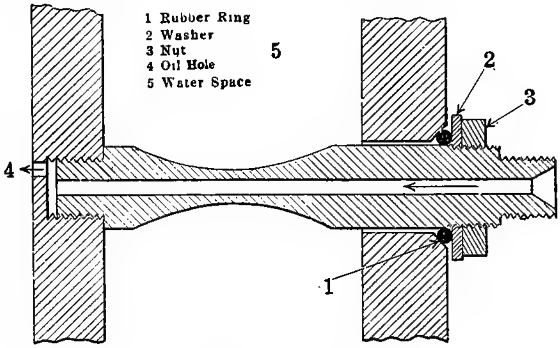

FIG. 203.—Oil injector.

Force Feed Circulation (referring to all types of engines, employing this system). The strainers for the oil should be in duplicate. When one of the strainers is removed for examination or cleaning, the oil pump connection from that particular strainer should be automatically closed by a spring loaded valve, which is pushed open again when the strainer is put back in position.

Some makers instal a filter—filter pads, sand filters, etc.—somewhere in the circuit. They are of doubtful value as regards extracting carbon particles and may absorb a great deal of power.

With a Diesel engine, as with all internal combustion engines, the bearings are subject to full pressure almost from the starting moment. A hand pump should therefore be provided to prime the oil pipes before starting the engine. Many bearing troubles are caused by injury done to the surfaces, due to absence of oil in the bearings when the engine is started up before the oil pipes are primed.

Oil Temperature.—Heat radiated from the pistons and cylinder walls is, to a large degree, retained in the enclosed crank chamber, so that the oil in the crank chamber becomes very warm, the resulting temperature being from 100°F. to 160°F. If a temperature of 140°F. be greatly exceeded, the life of the oil will be much reduced, and it will oxidize and throw down a dark deposit.

In large marine Diesel engines in Merchant Marine service, the quantity of oil in circulation is large, being about one gallon per horse power. For this reason, special cooling of the oil is not always needed, particularly so as the engine room temperature is low as compared with the temperature in the engine room of a steamship, where the hot steam cylinders and pipes radiate much heat.

In naval craft, such as submarines, owing to the limited space, the Diesel engines are very compactly designed, all parts being cut down in weight to the minimum. This, fact, combined with the high speed of revolutions and the relatively high temperature of the engine room, produces high oil temperature and makes it imperative to provide for adequate and efficient cooling of the oil in circulation.

Distribution of Oil by Gravity or by Mechanical Lubricators.—Two-stroke cycle marine Diesel engines, notably those of German make, have experienced a great deal of trouble with heating and heavy wear of main bearings (bottom halves), crank pin bearings (top halves), and crosshead bearings. One of the main reasons for these troubles has been the use of gravity feed circulation systems embodying a filtering arrangement which necessitated the use of straight mineral oils. Owing to the severe pressures very heavy viscosity oils had to be employed, which were too viscous to filter properly (cold engine rooms) and were found incapable of withstanding the high unrelieved bearing pressures. As far as the crosshead bearing is concerned, the difficulty is entirely overcome by forcing the oil in between the bearing surfaces by means of a small plunger pump fixed on the crosshead and operated by the swinging motion of the connecting rod. Improved distribution of the oil in the crank pin bearings and main bearings has been obtained by having narrow "flats" on the revolving journals which receive the oil and help to distribute it to the bearing parts under pressure.

The most effective solution of the problem is, however, to use oils, heavily compounded with fixed oil, such as rape oil, blown rape oil or the like, to the extent of 15 per cent. to 25 per cent.

of fixed oil. The mineral base should have a low setting point, so that the compounded oil will combine great oiliness with satisfactory fluidity at all times, even in the cold. An oil of this character will feed more uniformly through gravity feed or syphon oilers than oils having a higher setting point and viscosity. Such compounded oils cannot very well be used in a circulation system, but can be applied in a gravity feed system, or, if great economy is desired, by a mechanically operated lubricator. The oil, when leaving the bearings, is usually run to waste into the bilges.

In the few two-stroke marine Diesel engines built in England, compounded engine oils have been used for bearings and have given complete satisfaction. One maker finds that with a compounded engine oil, there is even no need to force the oil into the crosshead bearing by a special pump. The oil wedges itself in between the surfaces without any apparent difficulty. Another point in favor of compounded oil is that if water at any time should be needed to cool a bearing, the water will not wash away the compounded oil, but might easily do so with a straight mineral oil.

Oil Consumption.—The oil consumption of Diesel engines ranges from .75 to 5.0 grams per B.H.P. hour. The lowest oil consumption is obtained with large four-stroke cycle Diesel engines of the crosshead, enclosed type, employing force-feed circulation. The following oil consumption is typical of such engines:

Cylinders	.15 grams per B.H.P. hr.
Force feed circulation system	.60 grams per B.H.P. hr.
Air compressors	.05 grams per B.H.P. hr.

The oil consumption in the force feed circulation system increases greatly in Diesel ships when going through the Tropics, as, due to the higher oil temperature, the oil becomes thinner, which means more oil spray, more oil creeping and more leakage through joints.

Smaller Diesel engines use more oil per B.H. P. hour than large engines. The small open type engines do so because the high R.P.M. throws the oil into the engine room, and with the enclosed trunk piston type engines it is difficult to avoid excess oil passing to the piston tops, where it burns and chars.

In open type land engines the waste oil should be collected and kept in large settling tanks, containing several hundred gallons of oil, so that the oil slowly frees itself from the exceedingly fine carbonaceous matter by the force of gravity alone. Filtering the oil in the ordinary way is useless, as the pores and interstices in any filtering material are like tunnels for the fine carbon particles which therefore cannot be retained. An apparatus to free the waste oil from carbon is described page 554, Fig. 217.

In enclosed trunk piston type engines the fitting of splashguards over the crank webs, the pegging of piston rings, and maintaining a reasonable oil pressure are points to keep in mind when the oil consumption is excessive.

In average size Diesel engines, 250 to 500 H.P., the oil consumption if given reasonable attention should not exceed from 2.0 to 3.0 grams per B.H.P. hour, but will rarely be as low as 1.0 gram per B.H.P. hour.

Carbon Deposits.—Carbon deposits may be caused by overfeeding of oil, the use of an unsuitable oil, impurities in the intake air, impurities in the fuel, unsuitable fuel or incomplete combustion. The first three causes are exactly similar to those mentioned for gas engines, except that with marine Diesel engines the intake air is nearly always pure, but is has been known to carry with it fine sea water spray in suspension into the engine, producing salt deposits and rapid wear.

Impurities in the Fuel.—When the fuel oil contains too much free carbon or ash, the unburned impurities will deposit themselves on the cylinder walls, adhering to the lubricating oil and forming a deposit which will result in heavy wear of cylinder walls and piston rings. Too much water in the fuel will cause irregular fuel charges and interfere with proper combustion, the result being irregular running and even misfiring. Water in the fuel also attacks the fuel valve and its valve seat, causing cutting and fuel leakage.

Sulphur does not appear to affect the lubrication of Diesel Engines.

Unsuitable Fuel.—A fuel containing too much asphaltum or too thick to flow readily will not be properly atomized when injected through the fuel valve, and does not burn completely during combusiton; the unburned portions will accumulate on the piston top, behind and between the piston rings, etc., and form carbonaceous deposits.

Incomplete Combustion.—Correct proportion of injection air to the fuel used is important, in order to obtain complete combustion. Incomplete combustion may be due to the blast pressure being too high or too low, to the fuel valve being out of order, or to the use of an unsuitable fuel.

Blast pressures too high for the load, which is particularly likely to occur under light load conditions or when starting the engine, result in too much air passing through the fuel valve. Owing to the great fall in pressure, the expansion, resulting in cooling, will cool the fuel spray, so that the fuel is incompletely burned. The unburned portions deposit themselves on the piston tops, and every few strokes the accumulated fuel will spontaneously ignite when the piston rises on the compression stroke, causing preignition and violent knocking.

If the blast pressure is too low, imperfect atomization of the fuel produces deposits due to the larger particles of fuel in the spray not being completely burned. With incomplete combustion the exhaust will be black.

Fuel valve out of order will result in incomplete combustion, due to fuel leakage into the cylinder during the exhaust, suction, and compression strokes of the piston. Preignition of the accumulated fuel on the top of the piston will take place at the end of the compression stroke and cause knocking. The constant leakage of injection air through the fuel valve will result in cutting and destruction of the fuel valve and its seat.

DIESEL ENGINE AIR COMPRESSORS

The air compressor which supplies air at high pressure for the fuel injection is in land Diesel engines usually built as part of the engine, being driven from the main crank shaft; but in marine Diesel engines it is sometimes driven by an auxiliary high speed Diesel engine. The air compressor in two-stroke cycle Diesel engines usually draws its air from the scavenging air supply.

In land Diesel engines below 500 H.P. and marine engines below 300 H.P. the air compressors are usually of the two-stage type, but many manufacturers fit three-stage air compressors, even for small-sized engines, the tendency being to abandon the two-stage type, in order to obtain lower temperature of the air leaving the compressor. The air compressor in Diesel engines above 500 horse power is practically always three-stage, or for marine service even four-stage.

Pressure Distribution in Two- and Three-stage Air Compressors

		Gauge pressure, lbs. per sq. in.
Two-stage.	Leaving 1st stage	120 to 150
	Leaving 2nd stage	900 to 1000
Three-stage.	Leaving 1st stage	40 to 60
	Leaving 2nd stage	120 to 220
	Leaving 3rd stage	900 to 1000

Air Compressor Lubrication.—The internal lubrication of the air compressor is considered an important feature in connection with the lubrication of Diesel engines. The oil is here subject to oxidation from the compressed, highly heated air.

If an excess amount of oil, or an unsuitable oil is used, the result of oxidation is the formation of carbon deposits which accumulate principally on the pistons, on the valves, and in the discharge pipes. The valves work at high speed, and even a slight deposit may cause them to work sluggishly or to stick. Under these conditions the air is wire drawn and recompressed through the delivery valves, the hot air heats the valves and the temperature may easily rise to, say, 700°F.–800°F. or more which is above the spontaneous ignition temperature of a mixture of oil vapour and air. The deposit now becomes incandescent and any accumulated oil will vaporize and explode. Restricted openings in discharge pipes will have the same effect. It is therefore necessary to use only the very best oil, one which has only a slight tendency to carbonize.

The oil must be fed sparingly and uniformly, preferably by means of a mechanically operated lubricator, to the low-pressure piston. The air usually carries sufficient oil from the low-pressure stage to lubricate also the intermediate and high-pressure pistons, but in large compressors these pistons may have to be lubricated direct as well.

The intercoolers and oil separators should be drained regularly and frequently enough to prevent the accumulaton of oil or water being carried over to the last stage air cylinder where the water might cause the cylinder to burst.

It is perhaps safe to say that over half the troubles experienced with Diesel engines have been in connection with the air compressors; and the general feeling is, quite correctly, that the quality of the oil and the quantity used are chiefly responsible. This whole question therefore demands a thorough analysis.

Dust has been responsible for carbon deposit and is usually easy to discover by chemical analysis of the deposit.

Inefficient cooling of air compressor cylinders or valve casings has been responsible for a good deal of carbonization trouble; the water spaces have become incrustated with scale or mud from the water, or the water supply has been too scanty, causing high temperatures of the discharge valves, etc.

Fuel oil getting in with the intake air will almost certainly lead to the formation of deposits.

Oil spray in the intake air may be the cause of carbonization when the air compressor take its air supply from the crank chamber, in which the air is charged with finely atomized oil spray.

Too infrequent drainage of intercoolers allows water to be carried over to the smaller dimension higher stage cylinders. The clearance space in the H.P. compressor cylinder is so small that it is easily filled with water from the preceding intercooler; the water cannot escape through the discharge valve quickly enough and so the cylinder is fractured.

Intercoolers should be fitted with relief valves, big enough to allow all of the air coming from the preceding cylinder to blow off, if the suction valves in the succeeding cylinder are choked; otherwise the intercooler will burst.

Aftercoolers and blast vessels should be drained at intervals. Accumulated oil has been ignited and exploded by high temperature caused by a semi-choked discharge valve or pipe on the H.P. compressor cylinder, or by back fire from the engine cylinder, and particularly when oxygen has been used to recharge the blast vessels. This latter practice is now condemned. Of course, such accumulation of oil ought not to occur and will not occur with sufficiently frequent drainage.

Too small number of compression stages means excessive air temperature and increased tendency to carbonize the oil. Under light load conditions some air compressors throttle the air intake, with the result that the air is really compressed in one stage less and therefore becomes much hotter than under full load conditions.

Excessive oil consumption is responsible for many cases of heavy carbonization. Where air compressors have L.P. trunk pistons lubricated by oil from the force feed circulation system, oil may pass the L.P. piston in large quantities. The piston rings should be pegged, and splash guards may be fitted to prevent excessive splashing to the cylinder walls. But the amount of oil needed for air compressor lubrication is small, much smaller than the minimum consumption obtainable under the conditions just described. It is therefore better to design the air compressor so that it can be separately and *economically* lubricated, only receiving the amount of oil actually needed.

There is another reason why the oil consumption should be reduced to a minimum. All the oil which passes through the compressor is subject to the oxidizing effect of the air, and consequently the unsaturated hydrocarbons and perhaps some of the more easily decomposed saturated hydrocarbons as well combine with oxygen, partly decompose and form petroleum acid, which is said to assist in the thinning of the copper tubes in the coolers, particularly those in the after cooler. As a confirmation of this explanation one maker found that when he introduced mechanically operated lubricators for the compressors, feeding the oil sparingly to the L.P. stage only, the life of the cooler tubes was much prolonged—due to less oil passing through the compressor and therefore less acid being formed by oxidation.

It is possible that galvanic action may assist in corroding the pipes. In the after portion of the coil, where the moisture condenses, the copper is covered with water, which is slightly acid, and as the coils are joined to steel covers we have here the three factors needed for galvanic action.

The chief cause of the thinning of the pipes is, probably the condensed moisture in the compressed air, and it must not be overlooked that air at 80 atm. pressure is very dense and in rushing through the pipes creates great friction, which assists in eroding the soft copper surfaces.

Air Compressor Oil.—In view of the foregoing facts, the question that remains to be answered is: what kind of oil should be used to minimize the danger of explosion?

Formation of carbon deposit is obviously at the root of the problem, because if no carbon were formed, there would, normally, be no excessive temperatures, at any rate not high enough to vaporize or to explode accumulated oil, which, by the way, ought not to be there. Feeding the oil economically by a mechanically operated lubricator reduces oil consumption, and therefore means less carbon deposit and less acidity in the water separating out in the coolers and purgepots.

But the character of the oil is of very great importance. About ten years ago the author introduced for the first time a compounded oil (containing three per cent. of animal oil) for Diesel, compressors, and the results were that compressors would operate with *perfectly clean valves and pistons* sometimes for periods extending over several months *and notwithstanding rather excessive oil feed.* The explanation appears to be very simple: the interior surfaces of the higher stage air cylinders are very wet, in fact streaming with water, which tends to wash away the oil; with mineral oil the water succeeds in doing so; dry streaks develop; slight wear produces a rusty, spongy deposit, which cakes together with the oil and sticks to the valve seats and discharge pipes, etc. This deposit attracts more oil, continually grows, and being soaked with oil may bring about an explosion, as explained on page 412.

A slightly compounded oil will behave differently; it combines with the water and produces a *complete oil film* on the cylinder walls, exactly in the same way as compounded steam cylinder oils give more efficient lubrication of steam engines employing saturated steam, and therefore can be used very economically.

A suitably compounded air compressor oil will practically prevent cylinder wear. There will be no rust to form nuclei for the formation of carbon deposits; the valves and discharge pipes will keep clean, and high temperatures are avoided. Such an oil will maintain a better seal on the pistons and valves and will therefore reduce the air leakage past pistons and valves which always pr duces high temperatures of the compressed air.

The oil should contain about 3 per cent. of acidless tallow oil or prime lard oil which must be practically free from acid. Three per cent. lard oil, containing a fair amount of free fatty acid, or even 3 per cent. oleic acid has been used and gives good results as far as freedom from carbonization is concerned, but the fatty acid attacks the copper tubes in the intercoolers, and the after-cooler in particular, forming large amounts of verdigris and causing more rapid destruction of the tubes than when there is no fatty acid present.

The air compressor oil should have a reasonably high flash point, not below 400°F. nor above 450°F. There is no special virtue in using a high flash point oil as that also means a heavy viscosity oil, which is undesirable. A sluggish oil will attract impurities that may enter with the intake air and it will thus increase the tendency to form deposits. (See further under Air Compressors.)

Scavenging Pump.—The lubrication presents no difficulty, as the air is compressed only to from 3 to 10 pounds. Air compressor oil should be supplied sparingly and uniformly, preferably by means of a mechanically operated lubricator.

DIESEL ENGINE OILS

The lubrication requirements of Diesel engines, in normal operation, are very similar to the requirements of vertical gas engines, and the selection of suitable grades of oil follows similar lines, except in the case of marine Diesel engines of the large, open, two-stroke cycle type, which, as mentioned page 522, require compounded bearing oils for external lubrication. The air compressor, wherever possible, should also be lubricated by a slightly compounded oil, unless the oil for the compressor is supplied from the Diesel engine circulation system, in which case the compressor must make the best of the oil used in the main system.

Gas Engine Oils Nos. 2, 3, 4, 2*c*, 3*c*, and 4*c*, Compressor Oil No. 3*c* and Marine Engine Oil No. 1 are recommended by the author for lubrication of all types of Diesel enines, and a rough guide for selecting the correct grade is given in lubrication chart No. 19.

LUBRICATION CHART NO. 19
FOR DIESEL ENGINES

	Lubrication system	Horsepower per cylinder	Grade of oil recommended
Four-stroke Cycle Engines:			
Open Types:			
For *Cylinders and Bearings*....	Gravity feed or mechanical lubricator.	Up to 50.	Gas engine oil No. 2*c* or No. 2.
For *Cylinders and Bearings*...	Gravity feed or mechanical lubricator.	Above 50.	Gas engine oil No. 3*c* or No. 3.
Enclosed Types:			
For *Bearings only*, crank chamber separated from cylinders by a distance piece.	Force feed circulation.	All sizes.	Circulation oil No. 3 or Gas Engine oil No. 3.
For *Cylinders only*...........	Mechanical lubricator.	Up to 50.	Gas engine oil No. 2*c* or No. 2.
		Above 50.	Gas engine oil No. 3*c* or No. 3.
For *Cylinders and Bearings*....	Force feed circulation. Trunk pistons lubricated by splash from crank chamber.	All sizes.	Gas engine oil No. 3 or No. 4.
Two-stroke Cycle Engines:			
Open Types:			
For *Cylinders only*...........	Mechanical lubricator.	Up to 80.	Gas engine oil No. 3*c* or No. 3.
		Above 80.	Gas engine oil No. 4*c* or No. 4.
For *Bearings only*.............	Gravity feed or mechanical lubricator; oil not recovered.	All sizes.	Marine engine Oil No. 1.
Enclosed Types:			
For *Cylinders and Bearings*....	Force feed circulation. Trunk pistons lubricated by splash from crank chamber.	All sizes.	Gas engine oil No. 3 or No. 4.

	Grade of oil recommended
For *Piston Cooling* of large Diesel Engines, when cooling oil is employed:	
(*a*) When the cooling system is separate from the lubrication system	Circulation oil No. 1.
(*b*) Ditto, but joints leaking badly	Circulation oil No. 2 or No. 3.
(*c*) When a combined cooling and lubrication system is arranged, the oil must be a pure mineral oil.	Gas engine oil No. 2 or No. 3.
For *Air Compressors.*	
For the vast majority of compressors, in which a separate oil can be fed to the compressor.	Air compressor oil No. 3*c*.
When the air compressor cylinders are not separately lubricated, the oil supplied for the Diesel engines has to be used, whether it be straight mineral or compounded, but under no circumstances must Marine engine oil No. 1 or similar oils be used.	
For *Scavenging Pumps.*	
Use the same oil as supplied for the air compressor.	

BRIEF NOTES ON THE LUBRICATION OF VARIOUS WORKS AND MACHINERY

CHAPTER XXXI

STEEL AND TINPLATE MILLS

In all tinplate mills (sheet mills), rolling tinplate, and in steel mills, rolling armor plates or very heavy "sections," the roll necks attain a very high temperature, from 400°F. to 700°F. Ordinary oils will vaporize and leave the necks dry. Such necks are, however, successfully lubricated by so-called hot neck greases, which should have high melting points to suit the running temperatures of the necks. The spent grease is collected, melted in a grease boiler, mixed with a certain amount of new grease and "mixing" grease, and can then be used over again. When starting the mills cold on Monday mornings, soft cold neck grease is used until the necks get sufficiently hot to allow the hot neck grease to be employed. The hot neck grease is applied hot by a "swab" or when the temperatures are not too high, in the form of strips, nearly as long as the brasses and of a section suitable for the available room between the top and bottom brasses.

In steel mills rolling not too heavy sections, the roll necks may be kept reasonably cool by a trickle of water running over them continuously. An emulsifying low melting point grease, usually a tallow grease ("Tallow Compound"), should then preferably be used, as it gives excellent lubrication and reduces the wear considerably, as compared with hot neck greases. If the necks cannot be kept cool enough, the tallow grease melts away too quickly and hot neck greases may prove more advantageous, notwithstanding the greater wear and friction.

Tallow greases are applied by placing a lump of the grease against the neck on an inclined plate on both sides of the bearing so that it continuously tends to slide towards the neck. The bottom roll necks frequently have no upper brasses. The tallow grease can then be placed in a sheet metal housing placed over the neck and having an opening in the centre through which the water trickles on to the neck. Tallow grease may also be applied in the form of strips, as mentioned for hot neck greases.

When steel mills only roll light sections, the necks are much cooler and cold neck grease can be used (No. 2 or 3 Consistency) applied either direct to the necks or in canvas bags. The grease slowly melts through the bags and the lubrication is more uniform and more economical than applying the grease direct. Soft tallow greases may also be applied in bags.

In electrically-driven rolling mills the high speed bearings on the electric motor and the gear bearings are usually lubricated by a force feed circulation system, using an oil like Bearing Oil No. 4 or Circulation Oil No. 2.

For bearings which are exposed to heat, as for example, bearings of hot metal cars, bearings near soaking pits, etc., a high melting point soft or medium graphite grease will give good results.

For bearings exposed to flame, as certain bearings in galvanizing machines, any oil burns immediately it is applied. The best lubricant is finely powdered graphite applied as a powder; if that is not practicable, it should be applied mixed with oil; the graphite will remain in the bearings and prevent undue wear.

For pinions and gearing, cold neck grease is frequently used, but it is better and more economical to use a suitable pinion grease. Good pinion greases are very adhesive; they should be melted and applied hot by a brush after the teeth have been previously cleaned. The grease solidifies as a thin rubbery coating which will preserve the teeth and assist towards getting silent running. Owing to the great amount of dust and dirt always floating about in steelworks and tinplate works, all bearings which are lubricated by oil should have the oil holes as well protected as possible. Far too little attention is generally paid to this important point.

Bearing Oil No. 5 is a good all-round oil to use in steelworks and tinplate works, but there are many purposes for which a black oil of similar or slightly heavier viscosity can be used to advantage, such as table roll bearings, shears, racks, etc. For mills in cold climates good cold test is important, as most of the machinery is more or less exposed to the cold and draught.

COLLIERIES

In modern collieries, steam turbines, high pressure as well as exhaust steam turbines, are largely used, and where large coke ovens are installed, large gas engines are often employed to make use of the surplus gas.

The fan engines are treated with special care. The fans are the lungs of the mines and the colliery manager does not change oils or lubricating appliances on the fan engines unless he feels pretty certain that the change will prove beneficial. The lubrication of the various forms of power units, whether operated by steam, gas, or electricity, is treated elsewhere under their respective headings. The lubrication of steam haulage and winding (hoisting) engines is treated pages 418, air operated engines, page 370. The lubrication of mine cars used in collieries is treated specially pages 320–328.

Of other special machinery employed in collieries may be mentioned coal cutters and screening plants.

Coal Cutters.—There are four principal types of coal cutters, viz.: the disc cutter, the bar cutter, the chain cutter and the percussion drill type. All of these machines may be operated either by an electric motor or by a high-speed air-worked engine. The wear and tear of most of these machines is great, due to the rough service under which they usually operate, and also to the fact that the men operating the machines do not as a rule give the attention to lubrication that is really most necessary in order to prevent too frequent breakdowns.

The machines require two different oils, one for the gear case, which should be a heavy dark steam cylinder oil which does not leak out easily from the gear case; and another oil like Bearing Oil No. 5 for the motor bearings in electrically-operated coal cutters, and for the air-operated engine in an air-operated machine.

The troublesome bearings to lubricate are the long sleeve surrounding the base of the bar (bar cutters), the vertical disc bearings (disc cutters), and the bearings supporting the chain wheel operating near the coal face (chain cutters).

When the long sleeve bearing in bar cutters is worn, the oil from the gear case is wasted due to leakage. As to the other bearings mentioned they are exposed to coal dust and best lubricated by soft grease fed through tubes, so that the bearings are entirely filled with lubricant.

It would seem as if roller bearings or ball bearings could be introduced with advantage for coal cutters in connection with those bearings particularly exposed to coal dust.

The percussion type of drill is operated direct by compressed air at high speed, 1500–3000 blows per minute, requiring a thin oil (Pneumatic Tool Oil Light, page 421), or it may be operated by a pulsator, as in the Ingersoll electric air rock drill. The pulsator is an electrically driven air compressor with two cylinders, and no valves. The pistons force and draw air alternatively to and from the two ends of the drill cylinder; the piston in the drill cylinder moves forwards and backwards and strikes, say, 300 blows per minute on the drill head. This machine requires a more viscous oil like refrigerator oil No. 1, page 437.

In *colliery screening plants* the machinery works in a dusty atmosphere. For this reason ring-oiling bearings have only been a qualified success. The oil wells must be cleaned frequently in order that the oil may render satisfactory service.

Oil syphons are easily choked by dust, but glass bottle needle oilers have proved very reliable and satisfactory in a good many cases. They are, however, liable to be broken off or smashed.

Lubricating grease is frequently used either through Stauffer screw-down cups, or through compression grease cups, and has given good service under a variety of conditions. The grease fills up the bearing completely and forms a protective fillet at either end, which prevents the entrance of dust to the bearing surface. There is a marked tendency to introduce ball or roller bearings for colliery screening plants and the like, preferably using grease as a lubricant.

MINES AND QUARRIES (EXCLUDING COLLIERIES)

It will be unnecessary to describe the numerous kinds of machines installed in mines and quarries. Most of the power units are described elsewhere, also lubrication of the mine cars. Steam engines often operate with wet steam, requiring low viscosity, heavily compounded cylinder oils. This applies particularly to small steam units, as steam cranes, steam rock drills, etc.

One feature to keep in mind with air compressors, gas and oil engines is to have the air intake pipes situated so that only clean air is drawn in, or if the air is full of dust, as for example in limestone quarries, to provide suitable air filters.

As much of the machinery is exposed, low cold test oils must be used in temperate or cold climates, and it is often desirable to use grease in place of oil on bearings exposed to dust or grit. An exception is the stonecrusher bearings, which frequently employ grease and are badly lubricated, because grease is not suitable for high speed work. It is, however, difficult to fix lubricators in the pitman bearing; they usually shake off or go to pieces in a very short time.

Fig. 204 shows a method which overcomes the difficulty. A bridge (1) is fixed to the stationary bearings and holds two sight feed drop oilers in position. These oilers are connected by flexible rubber tubing (2) to the pitman head. Figs. 205 and 206 show in detail the tapered fittings to which the rubber tubing is attached. The tubing has an inside diameter of ⅜ inch and an outside diameter of ¾ inch.

As there is a great risk of pieces of stone being thrown about by this jaw type of crusher it is at all times advisable to have light wrought iron box-like covers made which can be used to slip over the drop oilers to protect the glasses from breakage and the brass work from damage. Bearing Oils Nos. 4 or 5 will generally give satisfaction.

In certain types of pneumatic stamping machines there is an air cylinder interposed between the stamp and the connecting rod which delivers the blow. The connecting rod takes hold of the air cylinder and on the down-stroke compresses the air above the piston which is connected to and actuates the stamp.

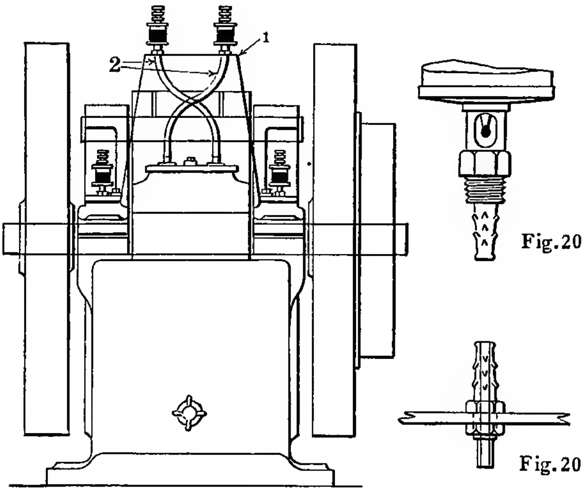

Fig.205

Fig.206

Fig.204

FIGS. 204, 205, 206.—Stone crusher lubrication.

When the blow is delivered the compressed air acts like a buffer and softens the blow. The piston in the air cylinder must be lubricated and owing to shocks and vibrations, lubricators fixed on the cylinder generally shake off. One method is to have Stauffer grease cups and to stop the stamps now and again to give the grease cups a turn. Very little lubricant is, of course, required. Grease is, however, a bad lubricant and output is decreased due to the stoppages. A viscous oil like Compressor Oil No. 2 (page 416) is much more efficient, and it can be fed successfully by the method indicated in Fig. 207. The oil is fed from the mechanically operated lubricator (1) into the pipe (2) which is telescopically connected to the pipe (3). The latter delivers the oil into the air cylinder, being connected to a fitting which allows it to oscillate. As the air cylinder moves up and down, the two telescopic pipes oscillate and actuate the lubricator, and a sparing supply of oil is continuously and automatically delivered to the air cylinder. Fig. 207 shows a two feed lubricator feeding two stamp cylinders.

PAPER MILLS

The exhaust steam from the main steam engines is passed through the drying rolls ("dryers") on the paper machines. It is therefore important to use good quality filtered cylinder oils which are easily removed from the exhaust steam, and to use them sparingly. If oil is carried over to the dryers their efficiency is considerably reduced. Many paper mills could probably with advantage mix oildag with their steam cylinder oil with a view to reducing the consumption. All of the exhaust steam is used for heating purposes, so that even a considerable saving in power in a paper mill by improved lubrication is not important from a power point of view. The reduced quantity of exhaust steam available has to be made up with fresh steam to satisfy the demand for heating and drying purposes.

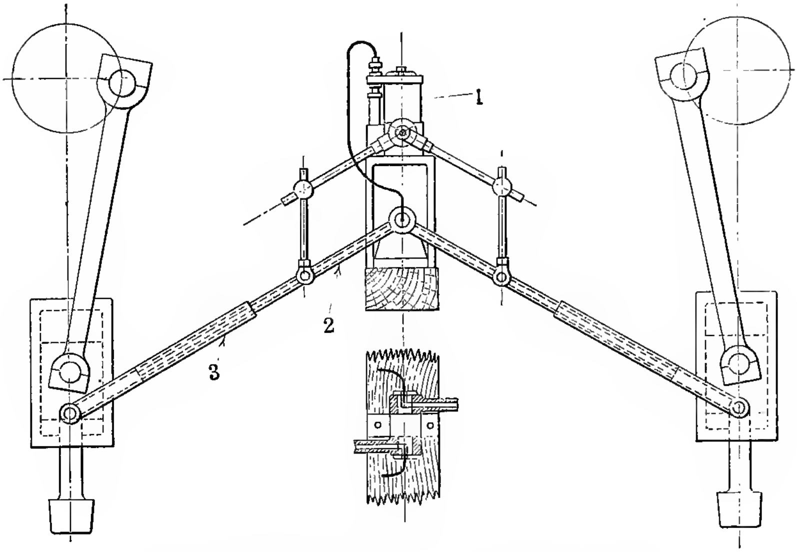

FIG. 207.—Mechanical lubricator for stamping machines.

Improved lubrication is, however, of great importance from a wear and tear point of view, which is a considerable item in every paper mill.

The *paper machines* at the "wet end" have a number of rollers, the bearings of which get splashed with water. A very soft, clinging grease should be used for the bearings, or a medium body compounded oil which will "lather" with the water. Next come the dryers, of which there may be a great number, say twenty. The paper, which is delivered as a "wet carpet" to the first dryer, passes over or under the other dryers and becomes drier and drier, being finally wound up on to a large reel and taken to the calendars for finishing purposes. The dryers have large bearings placed in cast-iron frames. The bearings become hot due to heat conducted into them from the steam, particularly on that side of the machine where the steam enters through their hollow journals. These large bearings are best lubricated by a self-oiling arrangement, a collar fixed on the journal dipping into an oil well and a stationary scraper wiping the oil off the collar and guiding it into the "on" side of the bearing.

In many of the older paper machines plain bearings are employed with the upper half of the journal exposed and the lubrication is effected by means of pieces of suet simply laid against the journal. Suet is a peculiar lubricant. It consists of sinewy films with fatty matter interposed between the films. The journal gets very warm and grinds through a film, then some fat melts and greases the journal, until the next film is worn through. Although the friction and wear are great, suet is an exceedingly safe lubricant. The journal never seems to seize and the consumption of suet is very low indeed. Rancid suet causes pitting and the lubrication is always very inefficient.

Most bearings employ a high melting point, hard, fibrous grease in place of suet and have bearing covers cast with grease chambers. The best of these greases are quite economical and give better lubrication than suet, but the wear is still considerable. Several methods have therefore been devised to convert these troublesome bearings to oil lubrication. The difficulty is to provide lubricators which will give a very sparing oil feed and which will stand rough usage. When the paper breaks on one of the dryers, the attendant has to hurry, and generally treads on the bearings as he jumps about. Fig. 208 shows the Payne dryer box, consisting of an oil box with hinged cover, placed on a frame (1) which rides over the journal and is fixed to the lower bearing half (2). A felt pad (3) draws oil from the oil box and spreads it over the journal. The oil consumption can be regulated to a nicety by squeezing the felt more or less by means of the clamp (4) and adjusting screw (5).

Fitted with these oilers an oil consumption of, say, 2½ gals. per fortnight for a 20-roll machine (20 dryers, 40 bearings) can be maintained. The lubrication is cleaner and more efficient than with grease, but is not to be compared with the "collar and wiper" self oiling arrangement referred to on the previous page. A viscous oil like Bearing Oil No. 5 should be used for both oiling systems.

It is quite customary and good practice to hand-oil sparingly grease lubricated dryer bearings, say, twice per day; it improves lubrication and reduces wear.

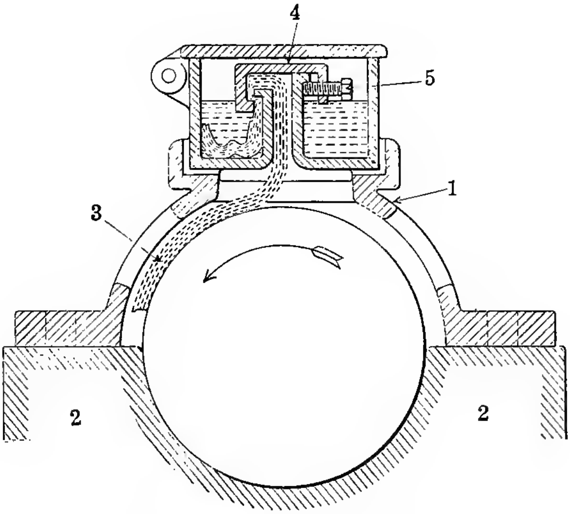

FIG. 208.—Payne dryer box.

The *calendars* are similar to calendars used in the textile industries and require a very viscous oil of great oiliness, as Bearing Oil No. 6, or Marine Engine Oil No.1, or even a Filtered Cylinder Stock, heavily compounded like Cylinder Oil No. 1 F.H.C. (page 389). High melting point fibre grease is occasionally used, but suitable oil is much to be preferred.

Beater bearings are usually very troublesome. The pulp is often thrown up into the bearings and causes heating and scoring. *Suet* is probably as good a lubricant as any, for the bearings as now designed. It would seem very desirable to design some form of grease filled bearing, either plain or roller type, which would stand the heavy strain and which by virtue of being filled with grease would be protected from the entrance of pulp, etc.

There are usually a fair number of small steam engine units scattered about in paper mills, for driving various machines, pumps, etc. The steam is generally wet and demands heavily compounded cylinder oils. With high speed, enclosed engines, employing either splash oiling or force feed circulation, great trouble is often experienced due to an excessive amount of water getting into the oil. Low viscosity circulation oils and a system of daily treatment for the oils is therefore essential.

CEMENT WORKS

Some of the most important bearings in cement works are the bearings for ball mills and tube mills and for the rotary kiln supporting rollers. Most of these bearings receive a great deal of conducted heat from the kiln or from the hot clinker (ball or tube grinding mills). It is good practice to watercool the bottom halves of these bearings, so as to facilitate lubrication. When grinding mills are grinding cold material, the water service is, of course, not required.

The upper "halves" of the bearings are only fitted for the purpose of keeping out grit and dirt and to act as receptacles for the lubricant. Lubrication by means of fibre grease and yarn grease is now customary and quite satisfactory.

Jaw crushers are not often used in cement works; their lubrication is similar to that of stone breakers used in quarries.

Cement works consume a great deal of power; the transmission drives are heavy and require a viscous oil like Bearing Oil No. 5. For electric motors, Bearing Oil No. 4 should be used as there are usually heavy belt pulls to deal with.

A fair amount of grease is generally used in cement works (for bearings of elevators, conveyors, etc., etc.) to prevent the dust from entering the bearings.

Pinion grease should be used for the pinions and gears on rotary kilns, etc.

FLOUR MILLS

It has been repeatedly mentioned that in dusty surroundings the use of grease is desirable to keep the dust out of the bearings. In applying this principle to modern flour mills, it must be kept in mind that much of the machinery operates at high speeds, such as the grinding machines (450 to 600 r.p.m.). Grease is not suitable for high speed, except in ball and roller bearings; it wastes a great deal of power, so where power is costly, grease should not be used. Where there is sufficient water power to drive the mills all the year round, power saving is of no importance, but this is seldom the case, and it should be kept in mind that suitable oils employed in place of grease will save from 8 per cent. to 10 per cent. in the full mill load. A saving in power of 8 per cent. was obtained in one case by replacing very viscous oils by oils of the right character and viscosity.

Bearing Oil No. 4 is a good general oil for flour mills. Bearing Oil No. 2 or 3 will be preferable for the grinding machines; being less viscous they will reduce the power consumption of these machines appreciably as compared with Bearing Oil No. 4.

WOODWORKING MACHINERY

For high speed circular saws and planing machines Bearing Oils No. 2 or 3 preferably slightly compounded, are usually satisfactory.

Heavy band saws require Bearing Oil No. 4 or even Marine Engine Oil No. 1 when the band pull is great. Marine Engine Oil No. 1 may also be used for chains and chainwheels, as it clings tenaciously to the surfaces. For very rough slow speed bearings and guides of log machinery, Black Oil is often used and is quite good enough.

Owing to the high speeds at which most machines operate in the finer class of wood working machines, the selection of the correct grade of oil with a reasonably low viscosity will often accomplish excellent results from a power saving point of view, and the use of grease should be confined to slow speed bearings, unless they are ball or roller bearings.

PRINTING MACHINERY

The important machines are Type Machines and Rotary Presses.

Type Machines.—For linotype machines, Bearing Oil No. 4 will prove satisfactory. For monotype machines, a highly filtered steam cylinder oil, straight mineral, or slightly compounded with acidless tallow oil will prove efficient. Unsuitable oil carbonizes exposed to the great heat and the type sticks together.

Rotary Presses.—These machines operate at high speed and are driven by variable speed electric motors. The power consumption is an important factor and, speaking generally, most presses employ oils far too viscous to give the best results.

Savings in power ranging from 10 per cent. to 25 per cent. have been accomplished by the introduction of Bearing Oil No. 2 or 3. The oils are preferably compounded with a non-gumming oil like good lard oil, as most bearings are hand oiled, but straight mineral oils will also render good service. For the electric motors, Bearing Oil No. 2 will generally be found to be the correct grade.

HYDRAULIC PLANTS

Apart from pumping engines in water works, hydraulic pumps are extensively used in steelworks, collieries, many engineering works, and for hydraulic elevators, etc. All hydraulic pumps operate at slow speed. Large pumping engines are usually operated by steam, small hydraulic plants either by steam or electric motors. Gas and Diesel engines are very occasionally used; they have the disadvantage that they run at high speeds and so necessitate a great reduction in speed, either by two or three sets of reducing gears or by worm reduction gears. Steam engines are easily operated at low speeds and drive the pumps direct.

Most hydraulic pumps operate at very low speed and pump water against great pressure. These conditions call for viscous oils with great oiliness for lubrication of cranks and main bearings such as Bearing Oils Nos. 5 and 6 and Marine Engine Oils Nos. 1 and 2. Occasionally white greases, or other greases, rich in animal oil or fat are used and give satisfaction for very slow speed work. Mineral cup greases or solidified oils are seldom suitable, being deficient in oiliness.

The pump plungers are often difficult to lubricate, particularly when the stuffing boxes are packed with soft fibrous packing like hemp or flax. Such packing is usually soaked with tallow or graphite or steam cylinder oil and graphite. The addition of graphite is very desirable; it helps to produce a good surface and prevent scoring. Pressure water, when it leaks through the stuffing box has an intense cutting action on the plunger surface, and it is the rule rather than the exception to find hydraulic plungers scored. If the attendant, to stop a leak, screws the packing up hard, intense friction is set up in the gland, lubrication may fail and the trouble is aggravated. The plungers are often lubricated externally by cylinder oil or grease. A compounded low viscosity cylinder oil or a mixture of lard oil and heavy engine oil is quite suitable, but most greases increase the gland friction enormously; they do not distribute themselves properly and cannot withstand the great pressure between the plunger and the packing.

U. or L. shaped leather packing is coming much into use (on lines somewhat similar to the packing shown in Fig. 171, page 428) and are easier to lubricate than fibrous packing.

In plants where the water, after use in the various hydraulically operated engines, returns to a main tank and is circulated afresh, the ideal method of lubricating the plungers and valves in all pumps and engines is to make the water carry the lubricant. This is best done by adding 10 per cent. of a soluble oil or compound, which forms an oily emulsion with the water. A rich cutting oil can also be made to emulsify when the requisite amount of borax or soda is added to the water (see page 573). In plants where the water is used over and over again the introduction of soluble lubricants into the water, where this system has not previously been used, gives results which are never forgotten.

The very long plungers in hydraulic elevators are also efficiently lubricated in this manner, but when the water is run to waste and therefore cannot be used as a lubricant, the plunger must be oiled; an oiler as shown in Fig. 209 may be used. The oiler is made in two halves clamped together around the plunger. The oiling chamber is filled with oil-soaked felt or waste, and oil can be applied through a filling hole closed by a screw plug, or by a self-closing ball valve.

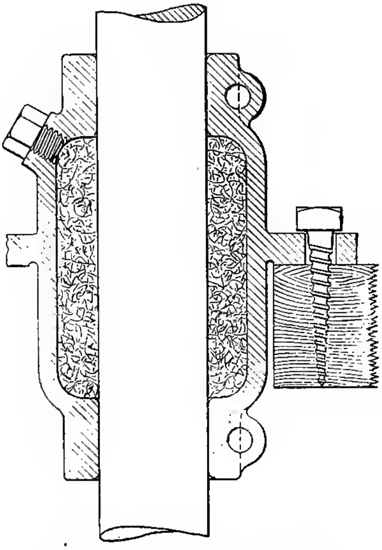

Fig. 209.—Elevator rod lubricator.

Some hydraulic plants, as for example hydraulic elevators, employ wire cables running over a number of sheaves. The sheaves are lubricated by cup grease (of No. 2 or No. 3 consistency), as it is not possible to get near the bearings. Most sheaves have a number of grease cups with feeding tubes going to the bearings, so that in any position there is always one grease cup close at hand, which can be given a turn. The cables should always be well oiled to preserve the strands from corrosion and wear. Grease does not penetrate the cables and should not be used.

GEARS

Large, heavy type toothed gearing as employed in steel works, many hydraulic pumping stations, cement works, etc., is best lubricated by an occasional application—say every four to eight weeks—of a suitable semi-solid lubricant. The gears must be cleaned before the first application and the grease should be applied hot and sparingly by means of a brush, so as to form a thin resilient coating.

The lubricants most satisfactory for heavy gear lubrication are good quality pinion grease and exceedingly viscous, semi-solid petroleum residues, similar to certain wire rope lubricants. The admixture of fine graphite is often advantageous, particularly with worn gears. Low viscosity products are unsuitable; they do not produce a thick enough film to reduce noise and prevent wear.

High speed toothed gearing as employed in gear boxes of automobiles, motor trucks, elevators, certain machine tools, etc., is usually enclosed in an oil tight casing and is best lubricated by oils of suitable viscosity.

As most semi-solid lubricants containing soap are inclined to cake and cause trouble, a mixture of such lubricants and gear oil should be resorted to only when there is a very great leakage with gear oil.

Worm gearing and worm-wheel gearing require oils of great oiliness, owing to the great pressure per square inch between the teeth. The most successful lubricant for extreme conditions of pressure and temperature is castor oil. It possesses great oiliness and an excellent cold test. For elevators, it is very serviceable, as the worm gears are often exposed to the cold. A mineral oil to stand up to the pressures must be of a steam cylinder oil nature and compounded with, say, 6 per cent. to 10 per cent. of tallow or rape, but such oils have poor cold tests as compared with pure castor. As a result they may be in a congealed state when the gear starts up in the morning; they do not therefore distribute themselves over the worm and wheel, and before they become liquefied by the frictional heat, the gears may have seized.

Where too low temperatures are not encountered, compounded steam cylinder oils are often preferable, as they do not gum like castor oil. Dark cylinder oils are usually better than filtered cylinder oils as regards cold test. The admixture of a small percentage of fixed oil is almost as effective as a higher percentage; it greatly improves the oiliness of the mineral base and assists in reducing friction and preserving the teeth from wear.

Semi-solid lubricants containing soap are not so satisfactory as good quality oils, and high melting point greases should always be avoided, as the worm or wheel simply pushes the grease to one side and it never gets a chance to distribute itself, unless the temperature rises high enough to melt it.

As to methods of application, there is generally an oil well into which either the wheel or the worm dips, according to their position relative to one another. Fig. 210 shows how it is possible to make use of the oil thrown away from the worm, by collecting it in side troughs whence it may be guided to the thrust bearing and other bearings, finally returning to the oil well.

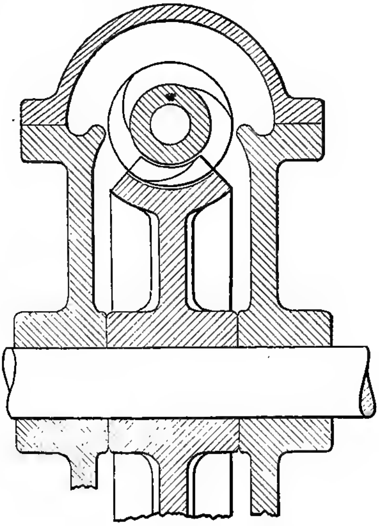

FIG. 210.—Worm gear lubrication.

CHAINS

When chains are entirely enclosed in an oil tight casing, they are best lubricated by a bath of oil, like Bearing Oils Nos. 4 and 5, or oils of even higher viscosity, if the casing is not perfectly tight.

Where chains operate exposed to dust and dirt, as transmission chains in automobiles, motor trucks, etc., it is best to remove them at intervals, clean them with kerosene or cleaning oil, and afterwards soak them in a bath of melted good quality tallow and finely powdered graphite. The tallow may be replaced by a No. 2 Consistency Cup Grease containing a heavy viscosity mineral oil. The solidified coating stays a long time and prevents to a large extent the entrance of dirt and moisture.

Lubricating exposed chains by dropping oil on to them before or during operation is wasteful and seldom effective. Viscous oil is almost useless. When it is not possible to remove the chains for soaking in lubricant, as for example, heavy chains in steam shovels, dredging machinery and the like, the lubricant should be applied hot by means of a brush, the same as with heavy gears.

ROPES

Wire Ropes.—Most wire ropes, as used in collieries and other mines, etc., have a hemp core to make them flexible. When ropes have to withstand severe heat or great crushing stresses. hemp cores are unsuitable and steel centres are substituted.

There are two main types of wire rope, those with ordinary coil construction and those with locked coil construction (absolutely smooth surface) as shown in Figs. 211 and 212, respectively.

Wire ropes deteriorate with use, and their life is greatly influenced by lubrication. If the strands of the rope are not thoroughly lubricated or protected, moisture will penetrate into the rope and cause rust and corrosion. The corrosion may be accelerated by galvanic action, if there be acid present in the water or in the lubricant. "Stockholm Tar" at one time was a cherished rope lubricant, either used alone or mixed with tallow, rosin, graphite, etc. Such mixtures are unsuitable, as Stockholm tar and rosin contain acids. Tallow also gets rancid and assists in causing corrosion. It is very difficult to prevent corrosion in wire ropes, in which the hemp core has become "chewed up," due to the rope having been subjected to excessive strains.

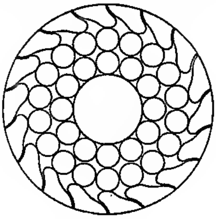

Fig. 211.

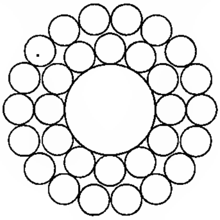

Fig. 212.

Lubrication of wire ropes is important, not only to prevent corrosion but also to minimize the friction between adjacent strands rubbing against one another when the rope passes over pulleys or drums; a well lubricated rope in turn lubricates the sheaves, pulleys, etc., over which it passes.

Too much attention cannot be given to saturating the rope with lubricant during manufacture and so giving it a good start. The hemp core should first of all be thoroughly saturated with melted lubricant which afterwards solidifies. Before each successive layer of strands is laid on, the rope must be coated with melted rope lubricant, so that the rope when leaving the manufacturer's works is filled and saturated with lubricants which possess great staying and moisture-resisting properties. It is very important that the lubricants be free from acid, alkali and moisture, and free from animal or vegetable oils or fats, tar, rosin, filling matter, etc. Otherwise corrosion sets in, and if the different layers of strands are not identical in quality of steel, galvanic action takes place in the presence of moisture, acid or alkali, and accelerates corrosion of the strands.

The best lubricants for saturating wire ropes, and also for their lubrication, are very viscous dark steam cylinder oils or other viscous petroleum residues, either used alone or mixed with petroleum jelly to solidify them. Such lubricants can be obtained pure and free from acid, alkali and moisture, and they possess good lubricating properties. They are applied hot. The rope is passed down through the bath of liquid lubricant, surplus lubricant being squeezed off, as the rope leaves the bath. When in use, the strands have a tendency to force the lubricant to the surface, so that occasional application of rope lubricant is required, say, every fortnight under dry conditions and more frequently under wet conditions, or when the ropes work in inclined mine shafts or horizontally as the lubricant then gets rubbed off sooner.

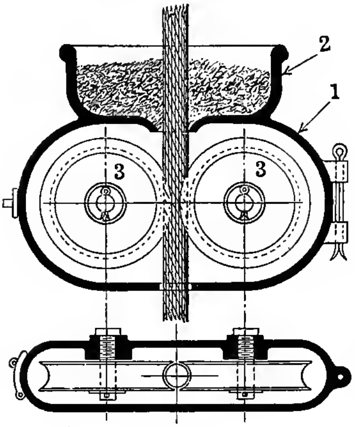

Fig. 213*A*.

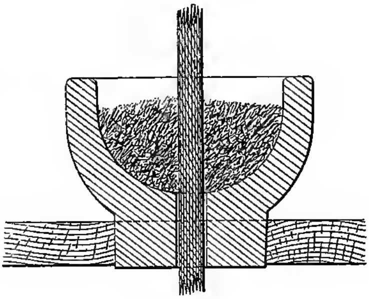

Fig. 213*B*.

Rope oilers.

As to methods of applying the lubricant, hand greasing is still largely used. The lubricant is applied by a brush, and usually hot, so as to give a thin coating. If the rope gets dirty it should be cleaned before applying the lubricant. A simple method is to run the rope through a mop which removes loose dirt and moisture.

Hand application is now often replaced by rope oilers, as for example, the one shown in Fig. 213*A*. It consists of a cast casing (1) made in two halves, which are hinged together and clasped round the rope. The cup shaped portion of the casting (2) is filled with the lubricant or with sponge cloth, thoroughly soaked with lubricant. In action the rope passes down through the oiler. The guide pulleys (3) keep the rope central and serve to distribute the lubricant over the rope surface. The oiler can be used on horizontal ropes, but the cup (2) must then be enclosed.

Some oilers have a metal washer, an old rubber pump valve or a piece of ordinary burlap fitted round the rope before it leaves the oiler, so as to wipe off surplus lubricant. Metal washers are undesirable, as with loose strands in the rope (owing to wear) the washers will strip the rope. Rubber washers wear out quickly. One pint of lubricant will suffice for coating 100 yards of 2-in. -2½-in. rope.

Quite a simple oiler is shown in Fig. 213*B*. It consists of a wooden cup made in two halves; the cup is pushed into a hole in a plank which may be fixed across the king posts of the winding head. A sponge cloth is placed in the cup soaked with lubricant. A wooden cup will last a long time if made of good hard wood and will not be torn by a stranded rope.

The author is not in favor of rope oilers which employ saturated steam or compressed air for atomizing the rope lubricant and spraying it on to the rope. Steam introduces moisture into the lubricant and the rope, and it is difficult both with steam and compressed air to avoid waste of lubricant.

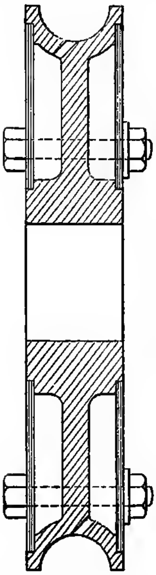
Fig. 214.—Lubricating transporter ropes.

The lubrication of *transporter ropes* of aerial ropeways is sometimes done by a man being carried along the rope and painting the rope, but a much simpler method, which saves labor and time, is shown in Fig. 214. One of the rope pulleys running on the transporter rope has both sides covered in by steel plates, secured by bolts as shown. The annular space forms an oil reservoir, provided with a filling plug through which oil is introduced. The oil must be just fluid enough at atmospheric temperature to leak slowly through the small hole or holes provided in the rim, and thus reach and lubricate the transporter rope. Adjustment is made by plugging some of the holes until a suitable feed is attained.

A satisfactory wire rope lubricant must fulfil the same requirements as the lubricants used for saturating the rope. It must remain soft and pliable under the atmospheric conditions and must not be attacked by the mine waters with which it comes in contact and which often contain acid or chemicals. It must not be thrown off or rubbed off too easily, yet it must be sufficiently fluid to penetrate through the strands to the core and so keep the rope well lubricated internally. It must not harden or peel when exposed to cold and dirt.

It will be clear from these remarks that very viscous or semi-solid lubricants of a pure hydrocarbon character will fulfil these conditions. Thin oils, black car oils, or waste oil, are often used but are almost useless, as they lack viscosity and lubricating properties.

Rope greases containing rosin soap or soap of any kind or filling matter, should not be used. They do not work their way into the rope, are inclined to cake and peel, and if they contain acid, cause corrosion.

Wire ropes should be examined daily by a competent person, when the condition as regards wear, lubrication, etc., can be observed.

Driving Ropes.—In the foregoing, reference has been made only to wire ropes. The driving ropes employed for power transmission are made entirely of fibrous material, such as cotton, manila hemp, etc., and seldom require to be lubricated, but in manufacture they should be more or less soaked with a preservative and lubricant. A serviceable compound is made from saponified tallow, paraffin wax and graphite. The compound will solidify and remain in the rope during its entire life.

CHAPTER XXXII

OIL RECOVERY AND PURIFICATION

The waste oil from bearings of steam engines, gas engines, large shaft bearings, etc., if collected, may often mean a considerable amount, particularly if reasonable care has been taken to stop leakages by fitting efficient splashguards and savealls.

Such waste oil, if pure mineral or only slightly compounded, can easily be made as good as new and used over again. If the oil is heavily compounded, and has been mixed with water, only the non-emulsified portion of the oil can be recovered. This is best done by simple heating in a settling chamber, when the non-emulsified oil will accumulate at the top.

The greatest economy is generally obtained by placing oil purifiers—settling tanks or filters—in the respective engine rooms or departments, and the attendant should be made responsible for the oil consumption.

In the following will be described some of the interesting aspects of oil purification, also a few notes regarding clarification of oil charged with carbonized matter, cylinder oil from exhaust steam, and the recovery of oil from cleaning materials.

Oil Purification.—Purification of oil, whether it be waste oil from engines or machinery or oil in continuous circulation, as in steam turbines, consists of three processes, namely, Screening, Precipitation, and Filtration, provision for all of which is usually embodied in oil purifiers, or as they are generally termed, oil filters.

Screening.—The prime object of the screen is to retain the coarser impurities and relieve the filter section of as much work as possible.

Precipitation.—In the precipitating chamber fine impurities of higher specific gravity than the oil, such as fine metallic wearings or water, are precipitated. The action is sometimes accelerated by heating the oil, as the lower its viscosity the quicker will the impurities separate out. Efficient precipitation is very desirable to enable the filter section to operate for long periods without cleaning. Separated water should be automatically ejected from the system by an automatic overflow.

Filtration.—The object of filtration is to remove the very finest floating impurities in the oil which cannot be retained by the screen, or precipitated in the precipitating chamber.

Filtration must not be done by the wet method. Passing dirty oil through water does not remove impurities. The oil rises through the water in drops; the impurities are inside the drops and cannot possibly be absorbed by the water, however hot the water may be. Dry filtration is the only satisfactory method.

In some small oil filters, the oil is purified by syphoning from the dirty oil compartment through woollen syphons into the clean oil compartment. Only clean and fairly dry oil will pass through the syphons.

Most small filters employ cotton waste, wood wool or other loose material as a filtering medium, but in larger filters, filter cloth is now universally adopted.

The disadvantage of loose material is that, when this is loosely packed, the oil passes through channels and passages without being filtered. When the filter material is tightly packed, the capacity is very small, say not more than one or two gallons per day. Even for small filters, filter cloth in the form of a simple bag is preferable to loose filter material.

In Europe small filters are seldom made with settling chambers. When the waste oil is very dirty, it is first treated in a steam heated settling tank, and the oil, freed from water and coarse impurities, is then afterwards treated in the filter.

Filter cloth should preferably be so arranged that the impurities retained have a tendency to drop away from the surface. With horizontal filter surfaces the oil should therefore pass upwards. Vertical filter surfaces are more satisfactory than horizontal surfaces with oil passing downwards through the cloth, as with the latter the dirt tends to clog the filter cloth more than with vertical surfaces.

It is desirable to have the two sides of the filtering surface exposed to the same difference in oil pressure at all points. If the oil at the bottom of a filter cloth is forced through at greater pressure than at the top, the cloth at the top will pass less oil than the bottom portion, and on the other hand, coarse particles may be forced through at the bottom, unless the cloth is tightly woven.

When the oil contains very fine impurities, a large area of filter cloth is required, and a slow flow of oil through the filters.

The filtering surface should preferably be arranged in several units, so that any unit can be removed for cleaning, or be quickly replaced by a clean filter unit, without interfering with the operation of the other units. Fig. 215 shows a No. 5 Peterson oil filter, made by The Richardson-Phoenix Co. The precipitation chamber is illustrated in Fig. 216 and shows how water from the various trays passes to the bottom without any danger of being picked up again by the oil. The head (1) in the automatic water overflow is adjustable vertically to suit the gravity of the oil. The oil flows from the precipitation chamber (Fig. 215) through connection (1) into the filter chamber, passes through the cloth in the filter units to the interior of each unit, and through the outlets (2) into the clean oil compartment formed between

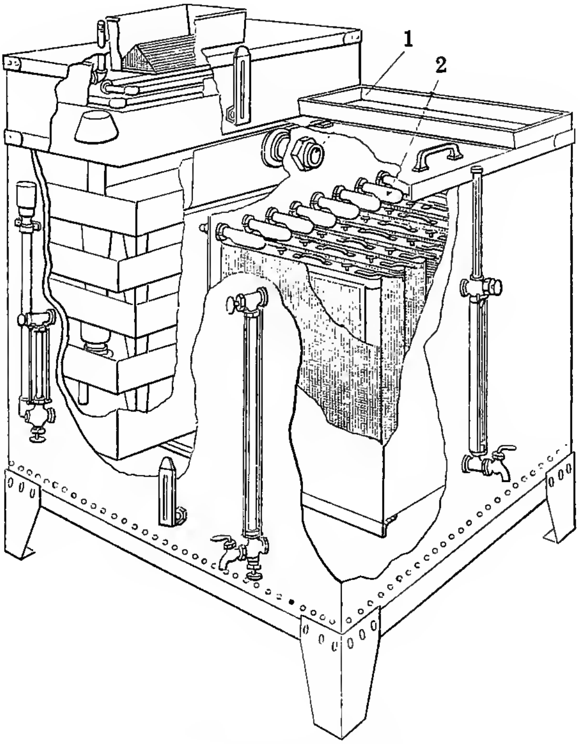

Fig. 215.—Peterson oil purifier.

and below the precipitation chamber and the filter section. When one of the filter units is removed, its respective passage (2) is automatically closed by a spring actuated valve, which is pushed open when the unit is again placed in position. The pressure which drives the oil through the filter cloth is the same at all points, being equal to the difference in height between the oil level in the filter chamber and in the outlets (2).

When desired, a cooling coil may be fitted in the clean oil compartment. Such filters are used as separate units to deal with batches of waste oil and also in connection with gravity circulation oiling systems for steam engines, the whole of the return oil passing through the filter.

In steam turbine plants, the flow of oil is too great to be taken care of by the filter, but it is quite sufficient to by-pass, say, 5 per cent. of the circulating oil through the filter, to maintain the oil in the best possible condition.

Such firms as Richardson-Phoenix Co. and S. F. Bowser & Co. have done good work in the United States by making manufacturers and power plant owners realize the great benefits to be derived from efficient circulation oiling and filtration systems. In this respect, Europe has something to learn from the best American practice.

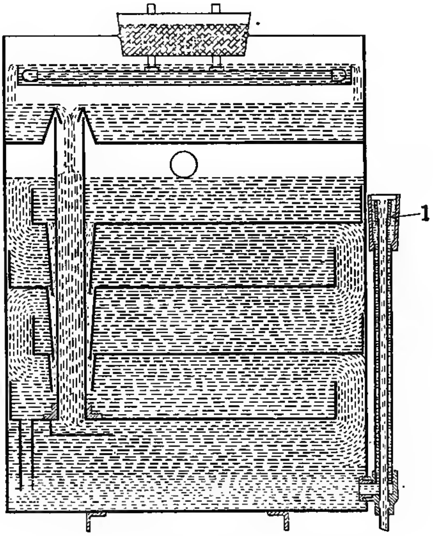

Fig. 216.—Precipitation chamber.

Purification of Oil Charged with Carbonized Matter.—The waste oil from internal combustion engines is always dark because of contamination with fine carbonized matter, which cannot be separated out by filtration. Gravity separation in large tanks will in time allow the oil to free itself, but it means a large volume of waste oil, and the process is very slow.

Several attempts have been made to coagulate the carbon particles,so that they will become large enough to settle out quickly. A patented process, which is reported to be working successfully in the United States, has been adopted by the De La Vergne Machine Co. The process consists in a brief but violent agitation of the dirty oil with a solution of hot water containing the coagulant, which is a phosphate of the alkali metals, as for example, trisodium phosphate. The action is purely mechanical. Within a few hours after agitation all carbonaceous matter is precipitated in the form of a layer of sludge between the oil and the water. It is claimed that the oil is not affected by the coagulant. Fig. 217 illustrates one form of this apparatus.

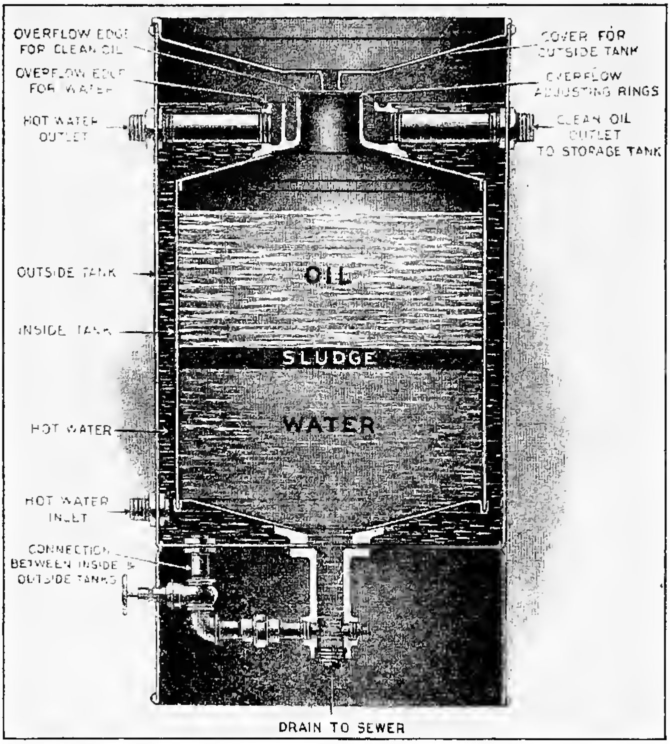

Fig. 217.

Synopsis of Operation:

1. Fill equal parts of water and oil into the inside tank.
2. Heat the contents and keep it hot during the entire process by circulating hot water through the outside tank.
3. Dissolve about one pound of coagulant for each four gallons of oil in hot water and put it in inside tank.
4. Agitate thoroughly for 10 minutes by compressed air, if available, otherwise by mechanical stirring.
5. Let the contents settle for about ten hours.
6. Draw off the clean oil by opening the communicating pipe between the two tanks. It will overflow over the inside edge of the top collar at a gradually decreasing rate. Adjust the height of edge by adding

rings until the overflow stops automatically shortly before all clean oil is drawn off.

7. Drain the tank and it will be ready for the next charge.

Cylinder Oil from Exhaust Steam.—As mentioned elsewhere cylinder oil in exhaust steam is usually present in a more or less emulsified condition. The oil skimmed off the hot well or recovered from the exhaust steam oil separator contains water, which is difficult to remove.

A fair amount of success has been obtained by passing the wet oil through a separator, similar to a cream separator. The oil corresponds to the cream, the water to the milk, and by proper adjustment, practically all the oil can be recovered in a reasonably dry condition.

Recovering Oil from Cleaning Material.—The cotton waste or rags, sponge cloths, mutton cloths, etc., used for wiping or cleaning machinery absorb a great deal of oil, which can be recovered, as well as the cleaning material, by treatment in machines exactly similar to those used for the recovery of cutting oils from swarf and mentioned page 566. The waste, cloths, etc., may be washed in a washing machine and dried on wire netting trays in a drying cabinet, being then as good as new. The recovered oil is dirty, and must be treated in a steam heated settling tank, and afterward filtered, before use. Unless it be completely purified, it must be used only on rough machinery.

CHAPTER XXXIII

OIL STORAGE AND DISTRIBUTION

In most plants, whether large or small, great economies may be secured by paying proper attention to the system of oil storage and distribution. In small plants the oil is usually stored in the barrels as received. It is important, as mentioned page 69, that they be stored under cover in a dry place. The barrels are placed on racks along one side of the room and fitted with barrel taps for drawing off the oil. It pays to have good barrel taps, particularly for thick oils like cylinder oil. The taps should have a large bore and opening (say 1 in. to 1¼ in.) and a clean "cut off," so that a minimum of dripping takes place after the oil cans or oil jacks are filled. The drippings should be caught by drip pans and can be used for less important machinery after accumulated dirt and impurities are separated out.

The practice of storing the oil in the barrels is not at all satisfactory. A great deal of oil is often wasted, and if the oil from the drip pans is not thoroughly cleaned, it may cause a great deal of trouble. It is better practice to keep the oil in cabinets fitted with a lid, which can be padlocked, so that no unauthorized person can get access to the oil. The cabinets are filled direct from the oil barrels. The oil in the cabinets is kept clean. They have a hand pump for delivering the oil into the oil cans, and surplus oil drains back through a sieve into the main reservoir, so that no oil is wasted.

Such cabinets may also be arranged with self-measuring oil pumps, as supplied by S. F. Bowser & Co. The pump can be adjusted to give a half-pint, pint, or quart for one full stroke of the pump. An advantage of oil cabinets is that they are practically fire proof. They can be placed not only in the oil house, but also in engine rooms or anywhere in the mill or factory where it is desired to have an oil distributing unit. Cabinets for departmental use, when empty, may be transported to the oil house, refilled, and again delivered to their respective departments, which are then debited with the amount of oil filled into the cabinets.

Another method is to distribute oil in portable tanks, which are filled in the oil house and wheeled into the mill, and discharge measured amounts of oil into the various cabinets.

In larger plants padlocked oil cabinets are impracticable for main storage purposes and a row of oil storage tanks, usually cylindrical, are provided for the various grades of oil. It is good practice to have the storage tanks so arranged that barrels of oil can be placed above them when discharging and allowed to remain there until properly drained. Oil barrels may also be emptied by means of a hand operated rotary pump, or by compressed air; but it is difficult to empty them completely in this manner, when the oil is very viscous, as for example heavy machinery oils or steam cylinder oils.

The oil house should preferably be at a siding so as to save labor in delivering the oil. Where the consumption of one or several grades of oil is large enough to justify installation of the necessary storage capacity, the oil should be purchased in tank cars. The price per gallon is lower and the labor of handling the oil and the empty barrels is saved, as the tank cars discharge straight into the storage tanks. Delivery of oil from storage tanks may be done by rotary pumps, or compressed air, or by self-measuring pumps. The tanks should be fitted with tank indicators or glass gauges, showing the amount of oil present. The indicators or gauges should be graduated to show the amount of oil in gallons, to facilitate stocktaking.

The oil is delivered from the oil house either in padlocked cabinets for departmental use, or in oil jacks, say ½ gal., 1 gal., 2 gal. or 5 gal. capacity. The oil should always be poured through a strainer when drawn from the storage tanks.

The amount of oil delivered is debited to the department concerned and totalled up at the end of each month. A careful entry must also be made of all supplies, and a check made every month to see whether the stock at the beginning of each month plus supplies received minus total amounts delivered tallies with the stock on hand at the end of the month. This will frequently be found not to be the case, and the source of leakage must be immediately traced and rectified.

Keeping a record of oil delivered does not, however, prevent waste of oil. Securing full benefit from a proper storage and distribution system can only be done by someone, usually the Chief Engineer or Master Mechanic, taking an intelligent interest in the amount of oil required for the various units throughout the works. Oil must never be delivered to any department in barrels, or other receptacles which are not locked. There should be a system of daily or weekly allowance for each engine room or department and the oil stores open only at certain stated hours. The fixed allowances should not be exceeded by the storekeeper, except on receipt of a special order, signed by the Chief Engineer.

Another system which is equally efficient, if the Chief Engineer takes the necessary interest in it, is for the Chief Engineer on his daily round to give the engine attendants a check in duplicate for all oils required. The check is given to the storekeeper and the engine attendant retains the copy.

The Chief Engineer should every month scrutinize the consumption sheets and revise the allowances, say, every three months. Heads of departments, foremen, overlookers, etc., should receive a copy of the monthly consumptions, not only of their own departments, but also of other departments, particularly if the conditions are similar, as it tends to create rivalry and reduce waste.

Empty barrels should be taken care of and returned when a sufficient number have accumulated to make a car load. Barrels which have contained black oils are rated as second-class barrels, whereas barrels which have contained engine or cylinder oils are rated as first-class barrels, and grease barrels as third-class barrels.

In works where no organized system of storage or distribution has been in use, and where some responsible person will take an intelligent interest in introducing proper methods, including regular allowances for every department, savings in cost of lubrication, ranging from 10 per cent. to 30 per cent. are often obtained, as a great deal of unnecessary waste is eliminated throughout.

Large oil firms employ oil experts for the purpose of assisting their customers in securing maximum economy of their lubricants. Most consumers will do well to avail themselves of the services of such experts.

CHAPTER XXXIV

CUTTING LUBRICANTS AND COOLANTS

In this section the author has made use freely of the material which he prepared for the Department of Scientific and Industrial Research, and which was published in 1918 in Bulletin No. 2 entitled "Memorandum on Cutting Lubricants and Cooling Liquids and on Skin Diseases produced by Lubricants."

The part dealing with skin diseases was prepared by Dr. J. C. Bridge, H. M. Medical Inspector of Factories, Home Office, and is reprinted in the Appendix.

(1) Cutting Lubricants and Cooling Liquids—coolants—are oils or emulsions used in connection with the cutting of metal. They possess lubricating and cooling properties in different degrees, and the various classes into which they are divided may be defined as follows:

Soluble Oils. The products known as soluble oils are oily liquids which form an emulsion when mixed with water.

Soluble Compounds, also known as Cutting Compounds. Soluble compounds or cutting compounds are greasy pastes which form an emulsion when mixed with water.

Cutting Emulsions. Cutting emulsions are aqueous emulsions formed by mixing soluble oils or soluble compounds with water.

Cutting Oils. Cutting oils are oils such as lard oil, rape oil or mineral oils, or a mixture of such oils free from water and from soap. These oils do not ordinarily form emulsions with water.

(2) Cutting lubricants and coolants are used for the purpose of:

(*a*) Cooling.
(*b*) Lubrication.
(*c*) To produce smooth finish.
(*d*) To wash away chips.
(*e*) To protect the finished product from rust or corrosion.

(*a*) *Cooling.* During operation the heat developed warms not only the tool but also the material which is being machined. On cooling the latter will contract, and the dimensions will differ from the measurements taken during the process of machining. The importance of properly cooling the product is, therefore, obvious, particularly under high-speed conditions and with materials, such as aluminium, which have a high coefficient of expansion.

If the tool heats too much the cutting edge will wear rapidly. The heat generated at the point of the tool is conducted into the body of the tool. If the tool is of large section the heat is more readily dissipated than is the case with a tool of light section. Efficient cooling of the tool edge reduces wear and enables a greater output to be obtained. This is most apparent with high speed steel, the gain in cutting speed on steel and wrought iron being from 30 per cent. to 40 per cent., and on cast-iron from 16 per cent. to 20 per cent. Efficient cooling of the shavings on the side not in contact with the tool is particularly important with tough material, as the difference in temperature between the two sides of the shaving causes contraction on the cold side and thus helps to reduce the friction produced by the shavings rubbing over the nose of the tool.

(*b*) *Lubrication.* Lubrication is of little importance where the machined article is made of brittle material, as the material is removed in the form of powder or fine chips.

Lubrication is very important where the metal is tough, and therefore removed in the form of spiral shavings, which grind their way over the nose of the tool. The character of the chips or shavings produced will depend upon the form given to the tool by grinding and also upon the angle at which it is used. The tougher the material the greater will be the metallic friction and the greater the necessity for lubricating the nose of the tool; otherwise the shavings will produce great friction, resulting in rapid destruction of the tool and in rough finish.

(*c*) *To Produce Smooth Finish.* When the requirements of cooling and lubrication are satisfied the product will receive a good finish. Where a perfect finish is desired, experience has shown that cutting oils possessing great oiliness must be applied. For this reason various animal or vegetable oils, or rich mixtures of such oils with mineral oils, are usually employed. Some engineers find vegetable oils possessing great oiliness, such as rape or cotton seed oil, preferable to either mineral or animal oils in producing a very smooth finish. Dies, taps, reamers and form tools have a longer life when used on tough steel if a cutting oil is employed in place of an emulsion prepared from a compound or soluble oil. For finish boring, rifling, etc., a mixture of castor oil and mineral cleaning oil (gravity about .860–.890) in the proportion of 3 parts of cleaning oil to 1 of castor oil has been used with good results. Although those oils do not form a homogeneous mixture, the addition of an equal volume of turpentine substitute (white spirit) causes perfect solution to take place and is said to be advantageous for finish-turning on guns and other hard material.

For high speed work it is always desirable that the cutting oil should have sufficient fluidity to ensure a rapid stream being concentrated where required.

(*d*) *To Wash Away Chips.* Frequently the washing away of chips is quite an important function of the cutting lubricant or cooling liquid, particularly in cases of deep drilling, as in drilling rifle barrels and the like, also in most milling operations.

If the cutting emulsion is used too weak it will not carry away with it the minute particles of metal and scale, which may prove detrimental to the machine tool.

In the boring of deep holes, gun-tubes, etc., a solution of sodium carbonate (50 lbs.) and soft soap (25 lbs.) in water (200 gallons) has been found to give very satisfactory results.

In solid deep-hole boring, where cutting emulsions are used it is sometimes found that the emulsion, in filtering through the chips in the bore, becomes changed in character in such a manner as to lose some of its lubricating quality.

In the case of cast-iron considerable advantage may be obtained by using an aqueous emulsion in order to wash the dust away from the working parts and to prevent its dispersal in the air.

(*e*) *To Protect Finished Product from Rust and Corrosion.* Good cutting oils used "straight" (*i.e.*, not emulsified with water) will not cause rusting.

Cutting oils containing fixed oils (animal or vegetable oils) such as tinged lard oil, with a large percentage of free fatty acid, will cause verdigris on brass parts. Fixed oils containing only a small percentage of free fatty acid, such as rape oil or high quality lard oil, when employed in cutting oils do not produce verdigris unless the oils are rancid.

Cutting emulsions made up from cutting compounds or soluble oils and water cause rusting if they are used too weak, or if they contain acid.

Emulsions of oil and water are not stable in the presence of even minute quantities of acid. The acid causes separation of the emulsion into layers of oil and water. The water settling out at the bottom where the pump suction is located is immediately circulated by the pump and causes rusting of the work. To a limited extent the emulsion can be reformed by adding a calculated quantity of ammonia sufficient to neutralize the acid, but any excess of alkali may facilitate corrosion of the metal being worked. Sodium chloride (common salt) and other salts act in much the same way as acid, in causing the emulsion to separate, only the action is less pronounced.

The admixture with a soluble oil of kerosene (5 per cent. or more) prior to the addition of water has been reported to give good results. A thin film of kerosene forms on the top of all standing oil in barrels and tanks and prevents the access of air. Similarly a thin film of kerosene forms over machined parts, machines and tools which prevents gumming and rust. It should be noted, however, that the addition of kerosene to a soluble oil reduces its lubricating and emulsifying properties.

Emulsions must not be made by mixing soluble oils or cutting compounds with hard water owing to the precipitate caused by the action of the calcium and magnesium salts in such water. Soft water must be used, which may be either rain water or distilled water, or good quality town water, or if only hard water is available it must be boiled or softened by chemical means and clarified.

APPLICATION OF CUTTING LUBRICANTS AND COOLANTS

The cutting lubricant may be applied by hand-brush or oil can, by drop-feed from a reservoir fixed in a suitable position, or it may be circulated over and over again by means of a pump operated by the machine itself, or independently operated, serving a group of machines.

The two first mentioned methods are only used for slow speed work where cooling of the tools is of no importance. Practically all modern machines require, however, before everything else efficient cooling of the tools and the cut articles, as without such cooling the high speed and output made possible by the employment of high speed machine tools could not be taken advantage of to the full extent.

It will therefore be understood that what is usually required, is a large volume of low viscosity coolant (cutting emulsion or thin cutting oil) delivered as near as possible to the cutting edge of the tool or tools and delivered in a stream having a low velocity—large cross sectional area—so as to avoid splashing. To deliver the coolant in a high velocity thin stream does not ordinarily remove the heat effectively (an exceptional case where high velocity and pressure are required being that of "deep drilling" work) and it causes a great deal of splashing, which means a very excessive consumption of cutting oil.

The delivery pipes should come as close up to the tool cutting edges as possible (sometimes flexible tube delivery pipes are used with this object in view) and they should have *wide mouths* —flat bell mouths—to reduce the velocity of the delivered coolant.

A simple device embodying this principle is shown in Fig. 218. On the delivery pipe (1) with closed end is suspended a plate with its lower edges bent together, leaving openings, however, for discharging the coolant, which is delivered from holes in the underside of the pipe.

Great savings in consumption of cutting oil or coolants can be made in most machine shops by paying attention to the prevention of excessive splashing. The loss of cutting oil depends obviously also to a large extent on the viscosity of the oil.

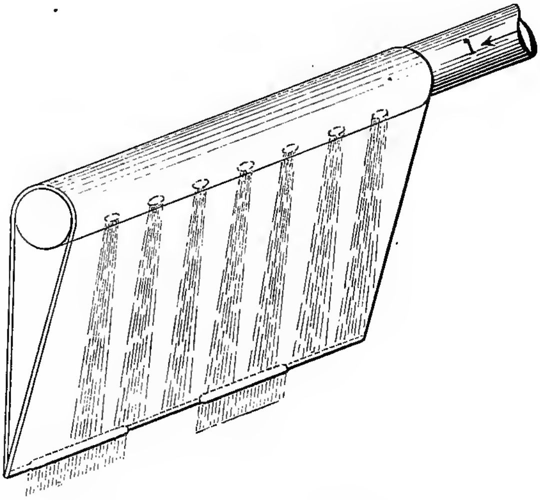

FIG. 218.—Cutting oil distributor.

As regards the type of pump to be used for circulating the coolant, plunger pumps have practically been discarded on account of their pulsating discharge. Rotary gear wheel type of pumps are now more widely used than the rotary vane pumps and the centrifugal pumps. With the two former pumps a spring loaded relief valve must be fitted in the discharge pipe to allow discharge back into the reservoir, when the delivery exits are closed. Rotary gear pumps are often made so that they will deliver the coolant when running in either direction. Centrifugal pumps are very suitable for delivering large volumes of oil at low pressure and are not so easily choked as the rotary gear or vane type of pumps.

When a pump is not self priming a non-return valve should be fitted on the suction side, or the pump should *preferably* be submerged in the reservoir.

It is good practice to have a *large volume* of coolant in the circulation system, as it helps to dissipate the heat and the coolant therefore keeps cooler.

When a group of machines are engaged on similar work or their cutting oil requirements are practically identical, they may with advantage be supplied from a common circulation system, with discharge pipes distributing the oil through branch pipes to each machine, the return oil passing through return pipes to a central tank, whence the oil is circulated afresh. Group systems with central tanks are excellent where one mixture is used on all machines on the circuit.

Return pipes should be large and should be arranged for easy access for cleaning. In large systems isolating valves should be employed to sectionize the system. Efficient strainers should be fitted on all return pipes and pump sections and should be cleaned daily. Tanks as a rule should be cleaned out every 6 weeks and return pipes every 6 months. Any scum formed should be skimmed off the tanks daily.

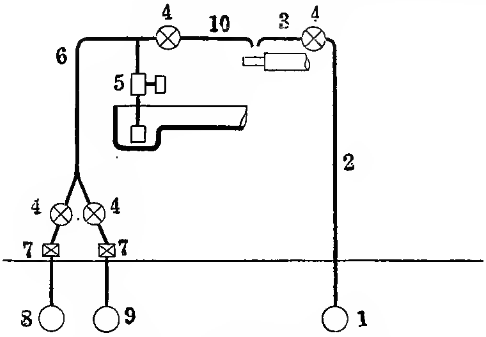

FIG. 219.—Cutting oil circulation.

It is important both with this system and where machine tools have individual pumps that the pump's suction should be always covered so that air cannot be drawn into circulation, since aeration of the circulating medium has a strong oxidizing effect upon the oil or emulsion.

When, however, the machine tools or the kinds of work done are of a varied character, it is necessary, when a circulation system is employed, to be able to cut out certain machines from the general supply so that they may use a separate quality of cutting oil or coolant and have their circulation system self-contained. Fig. 219 is a diagram illustrating a supply system by Richardson-

Phoenix Co. of Milwaukee, Wis., U. S. A., which embodies this feature. The cutting oil is discharged from the 1½-in. delivery main (1) through ½-in. branch pipes (2) and a ⅜-in. service pipe (3) controlled by a gate valve (4). The used oil is lifted by a rotary pump (5) from the base chamber into the ¾-in. return branch pipe (6) fitted with gate valves (4) and check valves (7), delivering the oil either into the 3-in. steelwork return main (8) or the 3-in. brass work return main (9), there being separate return mains and filtration tanks for the oil coming from the steel work and brass work section respectively.

When a machine is cut out from the circulation system, the rotary pump circulates the oil through the ⅜ in. service pipe (10), the service pipe (3) being shut off by the gate valve (4). In America such systems are generally used and their design may of course be adapted to the particular requirements of large machine shops. It deserves to be mentioned that filtration and sterilization of the return oil are features of many large plants. The filters are very much of the designs mentioned, page 552, but in addition chambers heated by steam coils sterilize the oil, heating it to about 200°F. and the oil returned from the steelwork section passes a magnetic separator, which is very effective in removing steel and iron particles, but naturally has no effect on brass, aluminum or other non-magnetic metallic particles. The iron and steel chips adhering to the magnet may be automatically removed by scrapers fitted to an endless chain which travels over the surface of the magnet, the chips dropping into a receiving vessel at the side.

Although filtration even through finely woven cloth will not remove the very finest particles, yet *well* filtered oil appears to be quite satisfactory without the need of long time separation by gravity in steam heated settling chambers.

RECLAIMING OIL FROM SWARF

The consumption of cutting oil is made up of various losses, principally those due to oil splashing away from the machines, as already mentioned, and oil adhering to the swarf chips and turnings.

In the case of cutting emulsions the swarf drains fairly clean by gravity alone, but when cutting oils, particularly if they are viscous, like lard oil, are used straight, a large amount adheres to the swarf. From 50 per cent. to 80 per cent. of the daily consumption can be saved by reclaiming cutting oil from the swarf in separators operating at high speed, the peripheral speed being as high as 6000–7000 feet per minute. Fig. 220 illustrates a turbine driven machine; smaller machines are mostly belt driven. The turbine is of the de Laval type. The steam has a slight emulsifying effect on compounded cutting oils, so that in this respect belt driven machines are preferable. When removing oil from wiping materials (for which these separators are also used), the presence of steam helps to liquefy the oil and thus separate it more completely from the wiping material, the recovery of which is the prime object.

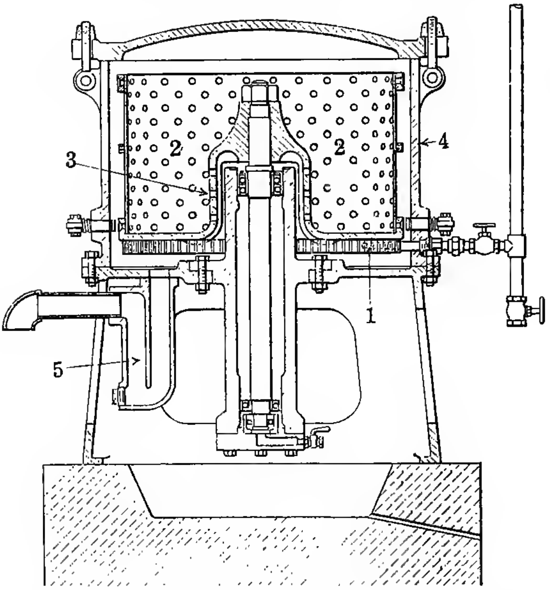

Fig. 220.—Separator for oil recovery.

1. Steam nozzle.
2. Revolving cage.
3. Perforations in the dome admitting steam to cage; useful when removing oil from waste.
4. Exterior stationary chamber.
5. Syphon for oil discharge.

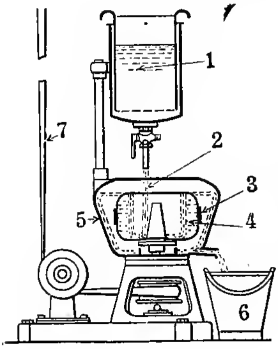

Fig. 221.—Spratts oil purifier.

1. Dirty oil receptacle.
2. Oil feed into revolving cage.
3. Revolving cage.
4. Water.
5. Outer, stationary chamber.
6. Purified oil receptacle.
7. Belt drive.

Steam of 20 to 40 lbs. pressure is generally employed. The wiping material is afterwards washed and dried. The clean swarf is remelted on the works or sold.

The reclaimed oil is dirty, containing fine metallic particles in suspension and must be further purified by heating in large settling tanks where the metallic impurities and emulsified oil separate out by gravity alone, or the oil must be well filtered. The oil cannot very well be completely purified by separators, as the very finest particles float like fine dust in the oil and take a long time to separate out.

Spratt's separator used for purifying oil is shown in Fig. 221.

Sufficient water (4) is first of all poured into the cage (3) to form a vertical cylindrical wall, when the cage revolves. The oil rises in a thin film up this wall and is thrown out at the top, whilst the heavy impurities leave the oil film, dive through the water and collect on the inside of the cage, whence they can be removed at intervals.

SELECTION OF CUTTING LUBRICANTS

Before selecting the correct grade of cutting lubricants it is necessary to consider several important factors such as:

(*a*) Cutting speed and depth of cut.
(*b*) The material under manufacture.
(*c*) The system of application of the lubricant or emulsion.
(*d*) The production of skin diseases. (See page 600.)

(a) Cutting Speed and Depth of Cut.

Low Speed and Shallow Cut. Low speed and shallow cut require little cooling and little lubrication.

Low Speed and Heavy Cut. Low speed and heavy cut particularly if the material is tough, demand a cutting lubricant possessing great oiliness.

High Speed and Shallow Cut.—High speed and shallow cut demand a cutting medium with great cooling properties, consequently emulsions are frequently used. Where a perfect finish is desired, low viscosity cutting oils are used "straight."

Where the speeds are particularly high emulsions only should be used, as otherwise there will be excessive heating of the tools and of the product. A mixture of kerosene with lard oil or other cutting oil for high speed work in connection with aluminium has given good results but is somewhat dangerous and has led to several fires. It is perhaps better to use cutting emulsions which possess the necessary cooling properties and are not inflammable.

High Speed and Heavy Cut.—High speed and heavy cut demand a cutting lubricant with great cooling as well as lubricating properties, so that heavily compounded cutting lubricants of low viscosity must be used. Low viscosity is necessary to give good cooling effect, and heavy compounding with animal or vegetable oils is requisite so as to lubricate the tools and shavings effectively and prevent wear as far as possible. A rich emulsion produced from an oil containing a high percentage of vegetable oil has also proved satisfactory, as the excellent cooling properties of the rich emulsion compensate for its lower degree of oiliness as compared with heavily compounded cutting oils used straight.

(b) **Material under Manufacture.** The influence of the material upon the choice of cutting oil has already been referred to.

Where material is brittle, cutting emulsions are nearly always used, as very little lubrication is required. When cutting oils are used, there will be no need for any compounding with fixed oil, so that straight mineral oils may be employed.

The amount of soluble oil or soluble compound used for preparing the cutting emulsion varies from 2½ per cent. to 20 per cent., the richer mixtures being used for severe conditions, and the weaker mixtures for light duties or for materials such as brass and aluminium where there is no danger of rusting.

Where the material is tough, but the speeds are high and the cut not too heavy cutting emulsions are also frequently employed; but where the material is tough and the cut medium or heavy, it is often preferable to employ cutting lubricants used "straight" and containing a percentage of animal or vegetable oils (ranging from 10 to 50 per cent.) or consisting entirely of such oils (see also remarks in previous paragraph).

Straight mineral oils may have to be used with tough material and light or medium cutting, if the oil is particularly exposed to oxidation, as for example in the Gridley Automatics, which are designed for very rapid production and therefore also "*punish*" the oil much more than most other machines. The oil is in rapid circulation, gets mixed with air and exposed to heat when touching the tools or the articles—in other words, the oil is exposed to the strong oxidizing effect of heat and air. Any admixture of fixed oil may under these conditions produce gumminess and semi-carbonized deposits, whereas with *pale*, well refined mineral oils the system will keep clean and free from troublesome deposits.

The absence of fixed oil means less oiliness of the cutting oil, so that the tools will wear more and have to be reground more frequently.

Cutting oils or emulsions are sometimes affected by small percentages of acid or alkali, etc., introduced into the oil in circulation by the swarf from materials such as galvanized fittings, pickled castings or forgings, etc.

(c) **System of Application.**—The important point to keep in mind in regard to the system of application is that where the oil or the emulsions are circulated over and over again, they are exposed to the oxidizing effect of air and to admixture with dust and dirt from the machine shop, and oils should be selected which will withstand this effect without gumming or carbonizing too much.

When the oil is not circulated but used once only, it need not possess non-gumming properties.

The bearings and slides of machine tools should be protected as far as possible from the spray of cutting oil or emulsion, as they will often be inclined to gum, corrode or rust and thus cause trouble with lubrication. Many cutting emulsions, cutting oils containing vegetable oils, and those containing very poor animal oils (high acidity) are the worst offenders. Cutting oils containing non-drying fixed oil, low in acid contents, do not give any trouble if they get mixed with the lubricating oil in the bearings or on the slides.

COMPOSITION AND CHARACTERISTICS OF CUTTING OILS, SOLUBLE OILS AND COMPOUNDS

Cutting Oils.—The *mineral oils* which are best suited to be used as cutting lubricants, either alone or mixed with animal or vegetable oil, are pale in color and of low viscosity, ranging from 100 in. to 200 secs. Saybolt at 104°F. The lower viscosity oils must be used for high speed conditions, and oils with higher viscosity may be used for slow speed conditions.

The oils must not be lower in viscosity than indicated, because they will then be too volatile; a large proportion will vaporize exposed to the heat at the tool edge and create smoke and fumes which are very objectionable. With cutting emulsions steam only is produced.

Of the *animal oils* used either alone or in admixture, *tinged lard oil* containing as much as 10 per cent. to 15 per cent. of free fatty acid is often used. *Whale oil* is also frequently employed, but under severe conditions these oils are inclined to gum and a better quality lard oil must be used, with a low acid contents, say below 6 per cent. Such lard oils—Prime lard, Extra No. 1 lard (they go under different names)—are of course more expensive.

All lard oils congeal in cold weather and always cause a certain amount of gumming, so that, wherever possible, a mixture of lard oil and low cold test mineral oil is to be preferred on account of its greater fluidity in the cold and less tendency to gum.

Cutting oils containing *vegetable oils*, particularly if they are heavily blown (*i.e.*, thickened by oxidation) are liable to produce gummy deposits in circulation systems of individual machines or in the pipe systems serving a group of machines. These deposits interfere with the proper operation of the machines and necessitate frequent cleaning, which not only increases the costs, but also decreases the output.

Cotton seed oil oxidizes more readily than rape oil, and should never be used in the manufacture of cutting lubricants that are to be used in a circulation system.

Animal oils on the whole are not so easily oxidized in a circulation system as are vegetable oils and should therefore be preferred unless the oil is used only once and not circulated.

Cutting oils are nearly always used "straight," *i.e.*, without admixture of water. Certain cutting oils, however, containing at least 5 per cent. of free fatty acid and preferably at least 25 per cent. of saponifiable oil (animal or vegetable oil) may either be used "straight" or in the form of cutting emulsions. They will emulsify with water to which the requisite amount of alkali (soda ash, borax, etc.) has been added. An excess of alkali causes rapid wearing away of the tool edge and must therefore be avoided.

NOTE.—When the cutting oil has been sterilized by the addition of say 1 per cent. carbolic acid and is also used for lubrication, it occasionally gives trouble, as for example in the case of some clutches in automatic machines, having a very short movement, about $\frac{1}{16}$ in. They were oiled when the clutch was put together and then expected to do without lubrication for many months. The effect of the carbolic acid in the stagnant oil was to absorb moisture from the air and cause the clutches to rust and stick.

GRADES OF CUTTING OILS

Before giving specific recommendations for cutting oils a few remarks may prove useful on the subjects of viscosity, compounding, color, oxidation, etc.

High viscosity mineral oil has slightly more oiliness than low viscosity mineral oil, but if great oiliness is required it is better to mix a percentage of fixed oil with low viscosity mineral oil, rather than use a higher viscosity oil. When a straight mineral oil with a maximum oiliness is required then, of course, the only thing to do is to use as high a viscosity oil as the cooling requirements will permit. High viscosity means that less oil spray will be formed, therefore less oil wasted by splashing (or leakage).

High viscosity in a cutting oil, speaking generally, is, however, undesirable, as the oil is inclined to hold metal chips in suspension.

It adheres in great quantities to the swarf and is difficult to remove. High viscosity also means diminished cooling properties. The rapidity with which the oil removes heat and radiates the absorbed heat afterwards is probably in direct proportion to the fluidity of the oil.

Low viscosity is nearly always desirable. The oil does not hold metal chips in suspension, but is easily clarified by gravity or by filtration. Comparatively little oil adheres to the swarf and is easily removed in the separator. Low viscosity is demanded, when the oil must have good cooling properties.

Low viscosity oil is particularly required for aluminium, as otherwise the aluminium dust floats and settles out only with great difficulty. A mixture of 50 per cent. cutting oil (more or less compounded) +50 per cent. kerosene has given good results for aluminium—also cutting emulsions, which have even lower viscosities.

Compounding.—A high percentage of compound gives the oil great oiliness and is therefore required where good lubricating properties are needed, *i.e.*, for severe cutting in tough material and particularly where a perfect "finish" is required, which cannot be accomplished unless the chips move away smoothly over the well lubricated tool face.

The most exact requirement as regards "finish," such as reaming and rifling of rifle barrels, can only be met by using pure animal or vegetable oils, such as lard oil, sperm oil or olive oil.

Where the finishing cut on hard materials is very fine, mixtures of fixed oils with kerosene have given good results, such as 50 per cent. lard oil and 50 per cent. kerosene, or 12.5 per cent. castor + 37.5 per cent. cleaning oil (.860–.890) + 50 per cent. turpentine substitute (.760–.780), etc.

Color and Acid.—As cutting oils used in circulation systems are exposed to heat and the oxidizing action of air, pale colored oils should always be preferred, as they produce less carbon than dark colored oils, and therefore give cleaner results.

It has already been indicated that tinged lard oil, when it is excessively acid (and dark in color) is more easily decomposed and leads to the formation of gummy dark deposits, whereas pale colored lard oil low in acid contents, say below 6 per cent., is rather free from this objection.

Other chemical or physical tests are of little use in judging cutting oils, except in so far as they disclose characteristics of the oils which would condemn them from a general quality point of view, such as presence of moisture, glue, dirt and impurities, etc. It is, however, conceivable that some kind of oxidation test by blowing air through the heated oil (see page 590) may prove useful in comparing the gumming tendency of different oils.

The open flash point, as long as it is above 300°F. need not be considered. Of course, mixtures with kerosene and turpentine substitute have very low flash points and precautions must be taken to minimize the risk of fires.

In Table 32 is given a fairly complete line of cutting oils, together with a rough guide as to their uses.

TABLE NO. 32

Cutting oil	Per cent. of compound	Nature of compound	Saybolt viscosity at 104°F., min.	Acidity in terms of oleic acid, per cent.	Recommended for		
					Speed	Cutting	Material
[1]No. 1	50	Cottonseed or rape	160–200	Below 6	Slow	Heavy	Tough
No. 2	50	Extra No. 1 lard	100–120	Below 3	High	Medium and heavy	Tough
No. 3	30	15 per cent. extra No. 1 lard; 15 per cent. tinged lard	120–140	Below 2	Moderate to high	Medium and heavy	Tough
No. 4	12.5	Tinged lard or No. 1 pale whale	120–140	Below 1.5	Moderate to high	Light and medium	Tough
No. 5	6	Tinged lard or No. 1 pale whale	100–120	Below 1.0	Moderate to high	Light	Tough or brittle
[2]No. 6	Nil		100–120	Nil	Moderate to high	Light or medium	Brittle
[2]No. 7	Nil		160–200	Nil	Moderate to high	Medium or heavy	Brittle

[1] No. 1 Cutting oil must not be used in circulation systems.

[2] Nos. 6 and 7 are also recommended for cutting tough and hard material in machines, such as the Gridley automatics in which compounded oils are particularly inclined to gum and carbonize.

Pure lard oil or sperm oil is recommended for reaming and rifling rifle barrels or similar operations on tough material, where a perfect finish is imperative, when the "Finishing Cut" (usually a very fine one) is taken.

Sperm oil is a better coolant than lard oil on account of its low viscosity, but is not quite so "oily" as lard oil.

A mixture of 50 per cent. *lard oil and* 50 per cent. *kerosene* is recommended for the finishing cut on guns or other hard material; it can also be used, but is usually unnecessarily expensive, for cutting aluminium.

A mixture of 50 per cent. *cutting oil No.* 3 + *and* 50 per cent. *kerosene* is recommended for cutting aluminium, but the danger of fire must not be overlooked.

SOLUBLE OILS AND COMPOUNDS

Soluble oils are prepared by dissolving a soap (usually less than 20 per cent.) in a mixture of mineral oil (usually less than 70 per cent.) and saponifiable oil (usually more than 15 per cent.).

The saponifiable oils used in making the soap are of either animal or vegetable origin such as lard oil or other olein from animal fat, linseed oleic acid, light wool grease, castor oil, sulphonated or hydrolyzed castor oil, rape oil, cotton seed oil, rosin, rosin oil, etc., and the oils are saponified by means of caustic soda or caustic potash.

Soluble compounds are made on lines similar to soluble oils except that they contain 10 per cent. to 70 per cent. of water and are in a semi-solid and semi-emulsified condition.

Cutting oils are sometimes *used as soluble oils*, for example, Cutting oil No. 3 when it contains at least 5 per cent. free fatty acid will be capable of forming an emulsion with water to which has been added soda ash or borax in the right proportion. The finished mixture must have only a small excess of alkali, but it should be alkaline to prevent separation and formation of deposits.

An average mixture is as follows:

40 gals. of water + 1.5 lbs. of soda ash; mix the oil with this alkaline water to the required strength, ranging from 1 gal. to 6 gals. of cutting oil.

It is important that soluble oils or compounds be completely and easily soluble in water, as nearly neutral as possible, do not produce deposits, have rust preventing properties and possess as much oiliness as possible.

Solubility.—Soluble oils are easily dissolved in lukewarm water (say not below 70°F. and preferably not above 120°F.) by mild agitation and are therefore usually preferred, as soluble compounds are more or less difficult to dissolve. Many manufacturers incorporate a high percentage of water in their compounds, as much as 50 per cent. to 70 per cent. which makes it easier to dissolve them, but the customer often pays dearly for the water in such *diluted compounds*.

When emulsions are made from soluble compounds in small quantities, the mixing can be done by hand in an old barrel or the like. When large quantities are to be made, good practice is to make a rich emulsion, say 60 per cent. of compound to 40 per cent. of water in a smaller top tank, allowing the creamy emulsion when formed during, say, three days, to run into a large bottom tank, in which it is diluted to the proper strength. Both tanks are fitted with submerged paddlemixers with vertical, slowly revolving axles. If the paddles are not submerged or if the speed is too high, the emulsions become aerated and froth vigorously, whatever germs there may be in the air being thus introduced into the emulsion, which is an excellent germ feeder, particularly in hot weather. The addition of a sterilizing medium like Lysol is very desirable under these conditions.

Ammonia soaps are very easily emulsified, so that they are frequently present in soluble oils or compounds. Both alcohol and ammonia cause the emulsion to form readily.

Occasionally soluble oils after some time in storage become deficient in solubility; they may, for example, separate into layers, or the entire contents of the barrels may solidify into a gelatinous mass. This latter condition may arise from an excess of alkali.

The separation or decomposition of the oil is the result of defective preparation. Evaporation of the alcohol or free ammonia, or decomposition of ammonia soaps at ordinary temperatures, or exposure to low temperatures may bring about separation or other changes in the oil, which will affect its solubility.

When separation is due to cold the oil will in many cases be restored to its normal condition by warming. The soluble oils must not contain too much mineral oil, preferably not more than 65 per cent., if the emulsions are to remain stable, and it is important that the remainder of the oil contain suitable proportions of soap and fixed oils with a resultant neutral or slightly alkaline reaction.

The presence of rosin soaps helps to make the emulsions stable, possibly because of their high specific gravity. When rosin soaps form part of the soluble oil, the presence of ammonia soap is desirable, to make the oil easily soluble.

Acids and Alkalies.—Excess acidity causes the cutting emulsion to become unstable and separation takes place. Excess alkalinity tends to produce scum and deposits, and appears to reduce the oiliness of the liquid and to attack metal surfaces; excessive wear of the tool edges is often observed with excess alkalinity. The endeavor must therefore be to have the emulsions as near neutral as possible with only a very slight *excess of alkali*.

Under no consideration must the emulsion be acid. Carbolic acid must therefore not be used as a disinfectant as it makes the oil less soluble; it encourages separation, and in attacking some of the alkaline ingredients produces a troublesome tenacious deposit, which is apt to clog the pipes. Lysol or similar disinfectants may be used for sterilizing emulsions without any ill effects.

Deposits.—The contents of rosin or rosin oil must not exceed 10 per cent., as otherwise the emulsion formed will be inclined to throw down a gummy deposit, probably as a result of air oxidation.

With cutting emulsions made from some grades of soluble oils containing ammonia the ammonia volatilizes under severe conditions of service, and a scum is produced on the surface of the emulsion which is objectionable, as it tends to clog the pipes in the circulation system.

The fatty oils used must be of good quality, as if they are of a highly gumming (drying) character, the emulsions formed from such oils will oxidize and throw down deposits.

Rusting.—The presence of some rosin or rosin oil appears to be desirable as it makes it possible to use weak solutions on steel parts without danger of rusting.

Certain grades of oil containing alcohol have shown a marked tendency to cause rusting, but it is not certain whether the alcohol was the direct cause, or the unusually large percentage of mineral oil (70 per cent. and more) present in those particular oils. Free alcohol is easily oxidized exposed to heat; it may eventually be transformed into acetic acid, which would immediately cause rusting.

The use of a stronger emulsion will nearly always be a cure for rusting, but there is a great difference between different oils in this respect. Some soluble oils containing rosin soaps can be used in emulsions as weak as 40 : 1 without rusting steel parts; others cannot be used weaker than 10 : 1.

Oiliness.—Oils possessing high lubricating power, as castor, rape and lard oil, are excellent ingredients to use in soluble oils, and give the emulsions a comparatively great oiliness. The lower the percentage of mineral oil, and therefore the greater the percentage of saponifiable oils, the more oily will the emulsions be.

To have great oiliness, cutting emulsions must contain only a small percentage of mineral oil, and the emulsions should be rich, *i.e.* used in proportions of 4 : 1 to 6 : 1. Such oily emulsions may be used for very severe conditions of high cutting speed and heavy cuts, where great oiliness and excellent cooling properties are required.

The formulæ for soluble oils and compounds are innumerable and mostly trade secrets. If, however, the points mentioned above are studied, some little experimenting and experience will enable chemists to work out their own formulæ, making use of the raw materials available.

Much depends on the care exercised in mixing and preparing the soluble oils, if they are to remain stable without losing their solubility, separating into two or more layers or becoming gelatinous.

CHAPTER XXXV

STATIC ELECTRICAL TRANSFORMERS AND OIL FILLED SWITCHES

STATIC ELECTRICAL TRANSFORMERS

The economical distribution of electrical energy for power or lighting purposes has only been made possible through the development of electrical transformers, which are now built in sizes up to 20,000 k.w. and operating with voltages of 150,000 volts or more.

Transformers either transform electrical energy from high voltage into low voltage—"step-*down*" transformers—or from low voltage into high voltage—"step-*up*" transformers. The latter are used at large power stations for producing high tension current for long distance distribution service. The step-down transformers are used at sub-stations and receiving centres for local distribution of low tension current.

Fig. 222 shows diagrammatically the design of a transformer for 3-phase alternating current. The thin high tension coils (1) are wound around an iron core (2) and the thick low tension coils (3) are placed outside the high tension coils with a slight space intervening; there are three sets of cores and coils, one set for each phase; the iron cores are connected top and bottom to form a magnetic circuit.

In this transformation of energy a certain percentage ranging from 1 per cent. to 2 per cent. is lost consisting chiefly of *magnetic losses* in the iron core and *copper losses* in the copper coils. The loss is converted into heat which must be carried away; otherwise the coils become hot and the insulation breaks down, causing a short circuit.

Fibrous insulation is almost universally employed and if it is not to suffer must not be heated to a temperature exceeding 85°C. to 100°C.

Air Cooled Transformers.—The cooling in transformers below 33,000 volts can be done by air, either by natural draught with small transformers or by an air blast (1.5 oz. air pressure) of approximately 150 cu. ft. per minute per k.w. loss. This will give a temperature rise of the air entering and leaving of about 15°C. This method is used for transformers up to 1,000 k.w. or in even greater sizes, but such transformers are not suitable for out-door work, as they must be cased in, and they are likely to have their insulations destroyed by condensation or dust from the air.

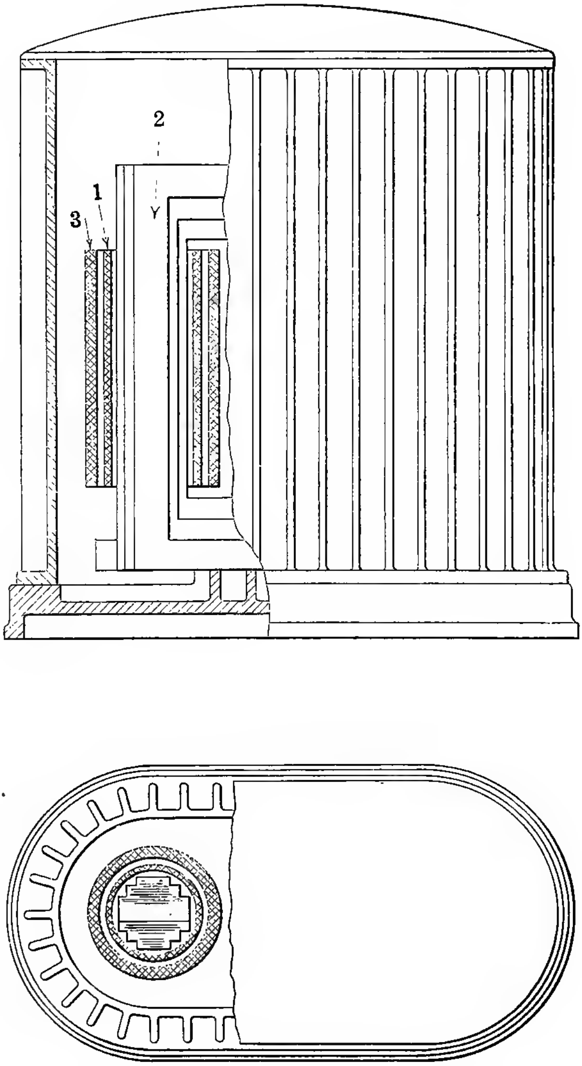

Fig. 222.—Transformer.

Oil Cooled Transformers.—Practically all transformers nowadays are oil cooled. The coils and core are immersed in the oil, which acts as a heat conveying medium between the coils and the surrounding transformer casing. In addition the oil has a dielectric strength about 15 times greater than air; it therefore helps to increase the breakdown resistance of the insulation and tends to "heal" it in case of a puncture.

The use of oil in a transformer as compared with air results in more rapid dissipation of heat, a lowering of the core temperature and longer life of the transformer. The dissipation of heat is increased by making the transformer case with deep vertical corrugations which largely increase the radiating surface. The corrugated steel sheets forming the sides of the transformer tank are welded together and are cast into the base and the top rim. Such self-cooled transformers are limited to about 500 k.w. capacity and in order to increase the capacity it becomes necessary to increase the efficiency of the oil cooling arrangements.

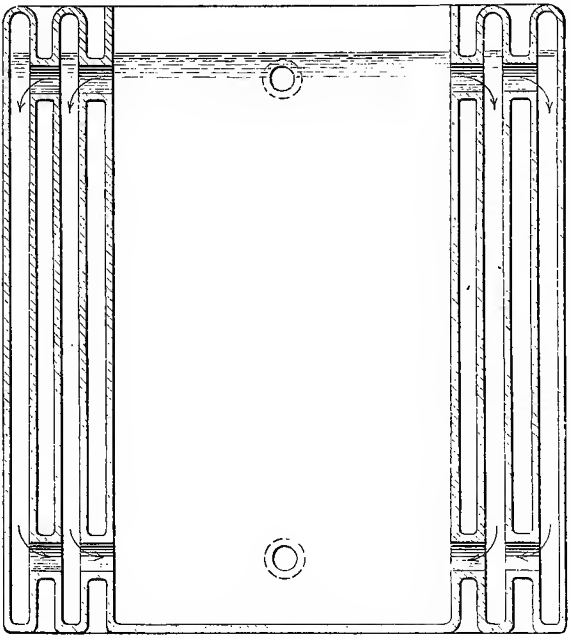

FIG. 223.—Jacketed oil cooled transformer.

This may either be done by further increasing the radiating surface or by the introduction of a cooling coil in the upper part of the transformer through which is passed a slow stream of cold water. Fig. 223 illustrates a jacketed transformer tank which can be employed up to 2,000 k.w. capacity. The transformer tank proper is surrounded by one or more jackets connected to the main tank at the top and bottom by tubular openings through which the hot oil at the top flows into the jackets and on being cooled sinks slowly down through the jackets, re-entering the transformer tank through the bottom connections. There will be a rapid circulation of air up through the space between the jackets and between the jackets and the tank, which serves to remove quickly the heat from the hot oil.

A further increase in the radiating surface is obtained in the construction illustrated Fig. 224. Several radiators are distributed in radial fashion around the transformer tank, being connected to the latter by tubes top and bottom, through which the oil enters the radiators at the top and re-enters the tank at the bottom. The radiators must be so designed that there are no "pockets." Such transformers have been constructed up to a capacity of 8,000 k.w.

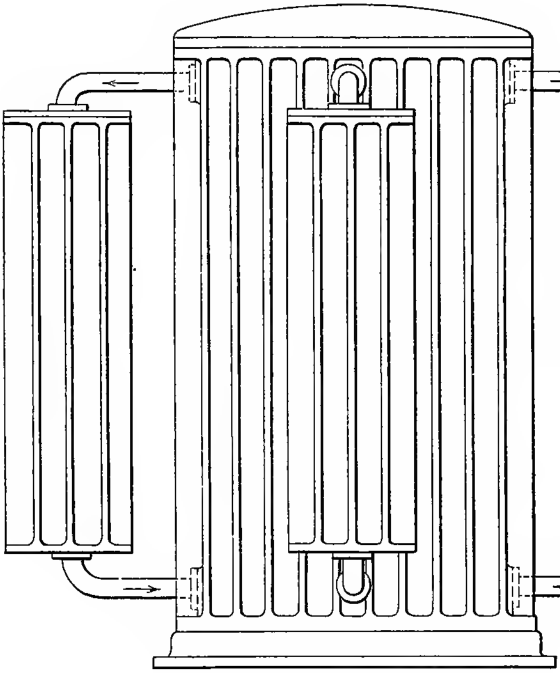

FIG. 224.—Transformer with radiators.

Both in this construction and the jacketed tank construction all joints are thoroughly welded to make them absolutely oil tight and to provide a strong mechanical construction.

In very large transformers or in transformers which are subject to occasional heavy overloads the cooling of the oil by means of a water cooling coil, as illustrated in Fig. 225, has been successful for indoor work and also for such outdoor work where the conditions permit of cooling coils being employed. These cooling coils are made of seamless copper tubing in order that, there may be no leakage of oil into the transformer.

The cooling coils must be kept entirely immersed in the oil, as otherwise sweating will occur and the water will contaminate the oil. The coils may be so arranged that the water can be entirely drained off to prevent freezing when the transformer is out of use

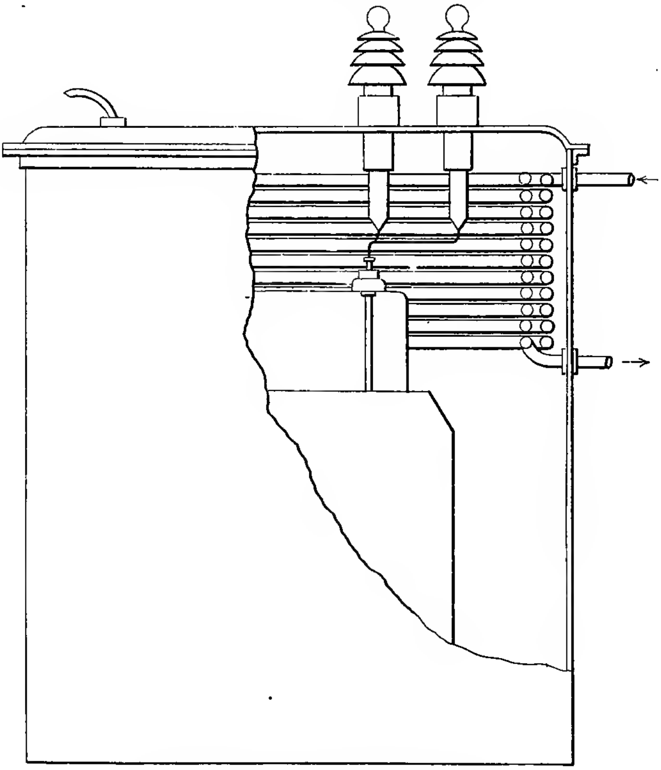

FIG. 225.—Water cooled transformer.

and exposed to low temperatures. When the cooling water enters and leaves through the cover, it is important to wrap the short pieces of cooling coil not immersed in the oil with layers of tape to prevent condensation.

The cooling coils are usually from 1 inch to 2 inches in diameter, the length depending upon the amount of heat to be carried away and the difference in temperature between the oil and the water. Current practice is to have a cooling surface in contact with the oil, ranging from 500 to 1300 square inches per k.w. of total transformer loss.

The cooling coil is made large enough to permit lifting the transformer from its case without disturbing the coil or its connections.

The cooling coils must not be used under low or medium load, as the result may be a lowering in temperature of the transformer oil below that of the surrounding air, which would cause the transformer to sweat. Some water cooled transformers are provided with a special thermometer, so arranged that in case the temperature exceeds the permissible limit an electrical alarm is operated. It would seem equally desirable to operate automatically the alarm when the temperature becomes too low (danger of sweating). It might even be advisable to put the cooling coils out of action automatically when the temperature becomes too low and into action when the temperature reaches a certain point, leaving the alarm to come into play when the temperature, notwithstanding the cooling coils, reaches the danger limit.

Water cooled transformers have been made as big in size as 40,000 k.w. capacity. Adding a water cooling coil to a transformer designed as a self-cooling unit may enable the transformer to carry a 50 per cent. greater load.

Placing a self-cooling transformer above an air pit may enable it to carry a 30 per cent. bigger load, as the rapid currents of air past the casing appreciably increase the heat radiation from the tank. Transformers may also be cooled by circulating the transformer oil through a cooler independent of and separate from the transformer. This system is occasionally used in transformers above 1,000 k.w. capacity. The heated oil is drawn from the top of the transformer and after cooling is forced to enter the ducts in the transformer windings and core at the bottom. In order to direct the course of the cold oil, the lower end of the transformer is enclosed and the only outlet for the oil is upward through the ducts.

For a 10,000 k.w. unit there may with this system be a saving in cost of the complete transformer equipment of as much as 25 per cent. whereas the advantages practically disappear for units in the neighborhood of 1,000 k.w.

An advantage with forced oil circulation is that in case of a leakage no trouble occurs, because the oil is under pressure, whereas with a cooling coil immersed in the transformer tank itself a leak will mean the entrance of water into the transformer oil.

As *exceptional systems of cooling* may be mentioned, that cooling water has been forced through the magnetic core or even through the low tension coils themselves, which have been made in the form of heavy copper tubes, the heat thus being removed from the very point where it is generated.

Oil Temperatures.—The satisfactory dissipation of heat in an oil immersed transformer depends upon two factors, *i. e.*, the coil radiation and the tank radiation. The coils and core must have sufficient surface to give up the heat to the surrounding oil and to the oil passing up through the ducts. The transformer tank, radiators and cooling coils, must be capable of removing or radiating this heat from the hot oil.

The temperature of the oil is always below the temperature of the coils or core and in most transformers certain parts are inclined to heat more than others. These "hot spots" are therefore the weakest part of the transformer and it is the temperature of these parts which should be recorded, by means of a resistance thermometer rather than taking the oil temperature by an ordinary thermometer.

Of course the temperature of the oil taken a few inches below the level is always of importance and should be recorded in the daily log, but it would be very advisable if transformer users would insist upon knowing which are the tender parts of their transformers, so that they might arrange for the temperatures of these parts to be regularly recorded.

As the temperature of the insulation must not exceed, say, 185°F., the temperature of the oil must obviously be less to give the necessary margin of safety from the point of view of the insulating material. Probably an oil temperature of 170°F. should be considered an absolute maximum. Most transformers in continuous service have oil temperatures ranging from 120°F. to 160°F. and a great many transformers operate with an oil temperature of 120°F. or less.

Transformer Oils.—In 1913 the Institution of Electrical Engineers formed a Research Committee of which the author is a member, with a view to standardizing the tests on insulating oils. An interim report was published in the January, 1915 issue of the Journal of Institution of Electrical Engineers which gives a great deal of useful information.

In the following chapters the author gives his personal and other views on this subject, which may not necessarily be endorsed by the above Committee; yet he has endeavored to present the information and ideas in such a manner as he hopes will not meet with objection from any quarter.

In order to judge the value of a transformer oil the following properties must be determined:

(1) Insulating Value.
(2) Sludging Tendency.
(3) Thermal Transference Value.
(4) Flash Point and Loss by Evaporation.
(5) Cold test.
(6) Freedom from such acid, sulphur or other materials likely to act detrimentally on the windings or the metals used in the construction of the transformer or casing.

1. Insulating Value.—When discussing insulating value of oil there are two terms which must not be confused, viz. specific resistance and dielectric strength.

Specific Resistance. The specific resistance per cubic cm. is the electric resistance of the oil as measured between two metal discs of known areas. It is a simple test to carry out and an important one. Tests have proved that the specific resistance decreases rapidly at high temperatures and becomes very low for all oils in the neighborhood of 200°F.

The specific resistance ought normally to be at least 5,000,000 megohm at 60°F. and 1,000,000 megohm at 100°F. If the oil contains small quantities of moisture or other electrically conductive impurities, such as metallic dust, acid, alkali or salts, which may be suspended or dissolved in the oil, the specific resistance is much affected and in this way the presence of even traces of such impurities can be readily detected.

Dielectric Strength. The dielectric strength is the number of volts required to puncture a transformer oil between electrodes of stated shapes and dimensions immersed in the oil and placed a certain distance apart, usually .15 inch. There are many apparatus designed for this test and some of the important things to keep in mind when designing a suitable apparatus are the following:–

(1) The quantity of oil required to make a test should be as small as possible.

(2) The electrodes should be readily interchangeable so that various shapes (balls, discs or needle points) can be fitted as desired.

(3) The distance between the electrodes should be capable of easy and accurate adjustment to any desired distance.

(4) It should be easy to clean both the vessel and the electrodes after each set of tests, so that there will be no danger of contaminating the next oil to be examined.

The dielectric strength when tested between various shapes of electrodes varies considerably, and sufficient tests have not been carried out to give a close specification at various standard temperatures and between various standard electrodes.

The use of two needle points is not to be recommended because of the small volume of oil subject to electric stress. When using a needle point and disc or two discs a fairly large amount of oil is subjected to electric stress and the electric spark has many paths to choose, so that if the oil contains dust or moisture or salts in solution the test will be more searching than with two needle points.

Spherical electrodes are now often used and the actual size does not appear to be of any particular importance. J. L. Langton informs the author that when carrying out tests at 100°C., using spheres with a gap of .15 in. he finds scracely any difference between .393 in., .5 in. and 1 in. diameter. He found a difference of only 6 per cent. between 1 in. and .5 in. sphere, the former giving the higher value.

When the oil is moist the dielectric strength will be low, so that when testing for dielectric strength it is customary to heat and dry the oil before carrying out the test, unless the object of the test is to detect the presence of moisture.

The dielectric strength of an oil increases with rise in temperature, the increase found by various investigators ranging from .1 kilovolts to .3 kilovolts per °F. The dielectric strength is, however, highest when the oil is congealed by freezing, probably because small specks of dust and moisture then are incapable of moving into line, which would facilitate the formation of a spark.

J. L. Langton makes the following remarks, which show the effect of the presence of moisture, all tests being carried out between spherical electrodes and with a gap of .15 in.:

> "Generally oils at a temperature of 100°C. give a value of 60 kilovolts. A falling off in the break down voltage is noticed as the oil cools, which I think is either due to condensation into larger drops of tiny moisture or steam particles locked up in the oil even after heating at 100°C. to 120°C. or else due to actual breathing action of the oil absorbing moisture from the air.
>
> The break down voltage at 20°C. varied between 20 and 30 kilovolts, (say 25 kilovolts) for most of the transformer oils after cooling (*i.e.*, and therefore also after absorption or condensation). I think one should expect a break down voltage of 27 kilovolts on a *fairly dry oil*. The ave age on a *very dry good oil*, when tested immediately after prolonged heating and allowed to cool in an oven to normal temperature is 40 kilovolts.
>
> Actually on account of moisture in most of the oils received, I obtained an average of 16 kilovolts."

With transformer oils of good quality the dielectric strength when tested after drying the oil should be not less than the following values when determined at 100°F.

Electrodes placed .15 in. apart	Dielectric strengtn in volts
Two ¾-in. balls.	20,000 volts.
Needle point and ½-in. disc.	11,000 volts.

"Some experiments were carried out by Messrs. T. Hirobe, W. Ogawa and S. Kubo of the Electric Technical Laboratory of Department of Communications, Tokio, (Report No. 25 of the 3rd Section of the Laboratory) as a result of which they suggest that the increase in dielectric strength usually observed when heating transformer oil may be due to the partial drying of any fibrous hygroscopic substance present in the oil. They also consider that the *effect of moisture is slight as long as dust is absent.*

Oil dissolves very little water, only about 0.01 per cent.; with greater amounts of water, oil forms emulsions, the particles agglomerating sooner or later, and if such water particles settle on the insulators, *e.g.*, on a high tension coil immersed in oil, their effect may be disastrous.

Dust particles, especially when fibrous, absorb moisture; such fibres readily bridged the electrode gap in the dielectric strength testing apparatus and caused breakdown. Thus the breakdown voltage of a good oil occurred at from 90 down to 60 kv. (using ½-in. ball electrodes with a gap of .15 in.) as the moisture increased; when the electrodes were "cleaned" by being rubbed with a dry cotton cloth a similar curve was obtained, but the breakdown occurred at from 35 down to 15 kilovolts. In a high tension transformer the dust is attracted towards the high tension coil and accumulates on it. Fortunately, filtering through a proper filter press removes both moisture and dust, and it is recommended to keep the oil of high tension transformers in constant circulation."

Apart from the influence of temperature on dielectric strength, it is quite certain that small percentages of moisture decrease the dielectric strength appreciably. It is very difficult to determine small percentages of water with any degree of accuracy, which explains why the figures quoted by different investigators differ considerably; but the following results being the average from various sources will indicate the serious effect of moisture.

Moisture in percentage	Dielectric strength in percentage
Nil.	100 per cent.
.01 per cent.	65 per cent.
.02 per cent.	50 per cent.
.10 per cent.	25 per cent.

As oil in time may absorb .01 per cent. of moisture when exposed to the atmosphere, it may be concluded that where transformer casings are not hermetically sealed one cannot reckon on a dielectric strength of more than half or two-thirds of the value for dry oil.

When the cooling coils inside the transformer have sweated or when they have cooled the oil below the temperature of the atmosphere, the condensation may have further reduced the dielectric strength of the oil.

Dust, especially if metallic, is as effective as water in reducing dielectric strength. Dust will enter the transformer casing when it is not hermetically sealed, and the amount of dust will of course depend on the cleanliness of the air in the transformer room. When transformers are being stored out of their tanks, great care must be taken to prevent dust accumulating on the windings and any dust present must be carefully removed before the transformer is again put into service.

Dust may also be introduced with the transformer oil. In one case the oil was found to contain a very fine steel dust which had come from the inside of the steel drums in which the oil was shipped. The dust was so fine that it kept more or less in suspension in the oil and had to be removed by careful filtration in a filter press before the oil was fit for service.

In view of the above it will be realized that it is of the greatest importance before putting the transformer oil into use that the oil be carefully dried and filtered.

The oil must be tested for dielectric strength not only before use but also periodically during service. Oils which are badly refined often show low dielectric strength. This is due to the presence of alkali acid or salts. It is therefore important that transformer oils be most carefully refined, so as to remove as nearly as possible all traces of alkali, acid, or salts.

While the presence of *free* sulphur is said to have an effect on the dielectric strength of oil, the greater danger lies in the fact that even in minute quantities it vigorously attacks copper. In some oils small amounts of sulphur exist in strong chemical combination. Such sulphur compounds have not been proved to be deleterious, probably because it is so difficult to decompose them.

2. Sludging Tendency.—The question of sludging in transformer oils has during recent years become very prominent.

Transformers used to deal chiefly with electric lighting loads which allowed them to have a rest and cool down in between the peak loads, but transformers are now worked continuously at high loads owing to the large amount used for power purposes. Increased competition creates a desire on the part of transformer makers to make the transformers as small as possible, which in turn means higher oil temperatures. High oil temperatures therefore now prevail and it is the high oil temperatures which through oxidation bring about the formation of sludge.

Sludge usually contains a large volume of oil and is soft and slimy. Occasionally it may be of a more solid nature, of dark chocolate color and much resembling the deposits produced in turbine oil systems caused by oxidation. The sludge clings to the sides and bottom of the transformer, and what is more serious it settles on the windings and chokes the ventilating ducts, thus obstructing the heat flow into the oil. In water cooled transformers the water cooling coils seem to attract the sludge, which in fact always seems to settle out where there is a sudden fall in temperature. The formation of sludge is accompanied by an increase in acidity, viscosity, and specific gravity, a slight lowering of the flash point and a considerable darkening in color.

Sludge is always very acid, much more so than the transformer oil. The acids are weak petroleum acids which do not appear to affect the insulation or attack the metals of which transformers are usually made. Transformer oil having an acidity as high as 0.3 per cent. in terms of SO_3 has not shown any ill effects.

Before sludge is actually produced in a transformer the oil darkens considerably in color. The darkening in color cannot be used as an accurate guide as to when sludging does occur, but it is distinctly a sign of warning, showing that the oil is beginning to oxidize and break down.

The mere heating of oil does not produce deposit. Oils have been heated for long periods to temperatures approaching their flash points and when such heating has taken place without the access of air, no deposit has formed. In the same way heating oil in the presence of an inert gas like carbonic acid or nitrogen does not appear to have any effect.

It has been suggested that sludging may be caused by electrostatic stress, the hydrocarbons decomposing as mentioned under turbine oils. A discharge of current through the oil will bring about such decomposition. It is generally agreed, however, that this cause cannot be responsible for the many frequent cases of sludging now met with.

Practically all sludge developed in transformers when analyzed will be found to contain a considerable percentage of oxygen. Dr. A. C. Michie reports the following composition of a typical deposit:

Carbon	74.3 per cent.
Hydrogen	6.6 per cent.
Oxygen	19.1 per cent.

Dr. Michie has shown that deposits of very similar characteristics are produced when transformer oils are oxidized by passing a current of air, ozonized air or oxygen, through the oil heated to a temperature ranging from 100°C. to 150°C. The percentage of sludge formed will, of course, depend on the oxidizing medium and the temperature. The percentage of sludge formed is increased several times in the presence of metallic copper which acts as a catalyst. Since Dr. Michie in 1913 published the results of these very important experiments his theory as to the formation of sludge in transformer oil has been widely accepted and all indications point to oxidation of the transformer oil as being the chief cause of sludge formation.

When a transformer is put under load the temperature increases and the oil expands. Later on when the load is reduced the temperature decreases and the oil level falls. As a result of the oil alternately expanding and contracting "breathing" takes place, the air being expelled from the top of the casing or again drawn in, assuming that the casing is not hermetically sealed. Such breathing continuously introduces new volumes of air together with dust, impurities and moisture.

Ozone may be produced in the transformer and will accelerate the oxidizing effect of the air on the oil. Most dust from the air is very thinly coated with a layer of ozone which assists in accelerating oxidation of the oil. It would appear that to largely minimize or entirely overcome the oxidation effects, it will be necessary to prevent the air having access to the transformer casing or one must be content to operate with lower oil temperatures.

Some modern transformers are therefore now made with hermetically sealed tanks having an expansion chamber in which the oil can expand or contract, but in which *no new air* is introduced during the normal operation of the transformer.

A combination relief and vacuum valve is fitted to prevent excess pressure, which would burst the tank, or excess vacuum, which would cause the tank to collapse. The lids may be made very weak or arranged to blow off quickly in case of abnormal pressure caused by a short circuit. Other transformers have breathers attached to the transformer tanks which are provided with traps to extract the moisture from the air which is inhaled as the transformer cools and the oil shrinks.

Sub-way transformers which are particularly exposed to dust and high temperatures are practically always made with airtight covers and rather large air spaces above the oil level to take care of the expansion of the oil under heat without creating undue pressure. Provision should be made to prevent excess pressure (caused by heavy overloads) by fitting a pressure relief valve or other safety device. A simple device, apart from those mentioned, is to put a float on top of the oil. The oil at the bottom and sides is already out of contact with the atmosphere, and with a properly fitted float which will rise and fall with the oil very little air can get to it.

It is difficult to say at what temperatures sludging can be absolutely prevented. The temperature at which sludging takes place depends largely on the condition of the transformer, *i.e.* whether the air has free access to the tank or whether it is more or less sealed; and it also depends very largely on the quality of the transformer oil. Non-sludging transformer oils have been produced during recent years which have only a very small tendency to oxidize as shown when subjected to the following oxidation test, which is the original test proposed by Dr. Michie.

"One hundred c.c. of the oil is placed in a 200 c.c. flask and maintained at 150°C. for 45 hours, during which period dry air is passed slowly through the oil at the rate of 0.066 cu. ft. per hour, a piece of copper with a total surface area 4½ sq. in. being placed in the oil."

Most transformer oils, when not particularly well refined, will produce 1 per cent. of deposit or more when subjected to his test. So-called "non-sludging" oils, whether of American or Russian make, do not produce any deposit by this test when the temperature is maintained at 120°C. but at 150°C. most oils, even the best, produce some deposit, say 0.05 per cent. or less. Pale oils generally produce less deposit than dark colored oils. "Non-sludging" oils are water white or almost water white in color, particularly the Russian oils. It is difficult to remove the last trace of color from American oils.

Obviously, when transformers are hermetically sealed and using "non-sludging" transformer oil a very much higher operating temperature can be permitted with safety, say 160°F., than when transformers are not hermetically sealed and placed in dirty surroundings, in which case the temperatures ought never to exceed, say, 120°F.

Deposits have also been due to the oil attacking the insulating compounds, as a fair number of deposits have been found to contain lead and manganese.

3. Thermal Transference.—The transference of heat through the oil usually takes place by convection circulation of the oil. The oil in contact with the transformer windings absorbs heat and rises to the surface, while the oil near the inside of the transformer casing cools and sinks to the bottom. The circulaton of the oil is due to the change in specific gravity caused by the difference in temperature between the oil in the centre and the oil at the outside.

Fig. 226 illustrates diagrammatically an apparatus suggested by the author for testing the thermal transference of transformer oils. The oil is heated in the thin tube (1) and cooled in the wide tube (2) the idea being that the thin tube will correspond to the vertical ducts in the centre of the transformer and the wide tube to the descending columns of oil near the inside of the casing. The National Physical Laboratory made some theoretical calculations based on this apparatus and arrived at the following formula for the thermal transference:

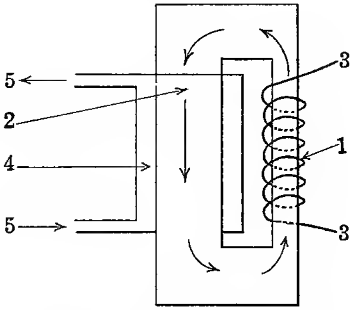

Fig. 226.—Thermal transference.

Thermal Transference = $S \times D \times E/V$.

S = The specific heat of the oil at the mean working temperature.
D = The density of the oil at the bottom of the transformer.
E = The coefficient of expansion.
V = The viscosity of the oil at the mean working temperature.

In comparing transformer oils made from paraffin base crudes and transformer oils made from Russian crudes, it is found that paraffin base oils have approximately 10 per cent. higher specific heat and 10 per cent. lower specific gravities than Russian oils. The coefficient of expansion is approximately the same, so that if the above formula gives a correct indication, it would appear that the thermal transference of different transformer oils is inversely related to their viscosity.

Russian transformer oils are higher in viscosity than paraffin base transformer oils, but the difference is not so marked at the working temperature of the transformers as will be seen from the following table:

	Saybolt Viscosity	
	@120°F., in.	@170°F., in.
Typical Russian White Transformer Oil	100	52
Typical American Pale Transformer Oil	56	41

The thermal transference value of American transformer oils might therefore be expected, speaking generally, to be higher than the thermal transference value of Russian oils, but it must not be overlooked that it is extremely difficult to produce non-sludging transformer oils from paraffin base crudes and that the sludging tendency is a very important factor in comparing the value of two oils. If one oil produces even a small amount of sludge compared with another oil which is non-sludging, preference should be given to the latter, notwithstanding its higher viscosity. Sludge is a bad conductor of heat and will easily cause the temperature of the coils to increase appreciably, which in turn means increased electrical loss, as the electric resistance of metals increases with rise in temperature.

If the sludging tendency of the two oils is the same, the one having the lower viscosity should be preferred, as it will produce quicker circulation of the oil and a more rapid transfer of heat to the casing. As the heat eventually radiated from the casing will be approximately the same with the two oils, it necessarily follows that the temperature of the casing itself will not be very different, but the more viscous of the oils will be somewhat higher in temperature than the lower viscosity oil, so that the maximum temperature of the windings and core will also be higher.

A low viscosity oil has the further advantage over a viscous oil of separating more easily from impurities, such as dust and water.

4. Flash Point and Loss by Evaporation.—Transformer oils must be of low viscosity and therefore have low flash points, but the flash points must not be too low, as if the oils are very volatile, they will lose a great deal by evaporation during service.

The lowest flash point oils used for transformer service are mineral seal transformer oils which are really high flash point burning oils having a closed flash point of about 265°F. These oils are used only for water cooled transformers where the temperature is under absolute control and kept low, say not exceeding 120° F.-130°F.

Transformer oils usually have closed flash points somewhat above 300°F. (320°F to 350°F.) and with such flash points the loss by evaporation will be found to be reasonably small at normal transformer temperatures, say, less than 0.25 per cent. when heating 70 grammes of oil for 6 hours at 100°C. in a beaker 4 in. high, 2½ in. in diameter in a hot oven.

5. Cold Test.—Where transformers are used in cold countries, transformer oil should preferably have a good cold test. This point is, however, not of supreme importance, except with very low temperatures, as during the working of the transformer the oil soon becomes warm and fluid. It is customary to use oils having a cold test of about 15°F.

Treating Transformer Oils.—Various means are employed for dehydrating and cleaning transformer oils. Oil will dissolve about .01 per cent. of moisture, but it may contain as much as .75 per cent. in emulsion or in suspension, which will separate out only with difficulty. Any water in excess of .75 per cent. will separate out when the oil is heated to a temperature of 80°C. and can be drained away.

Some makers have made use of chemicals such as calcium chloride or calcium oxide (unslaked lime). The oil is forced through a receptacle containing these chemicals and afterwards forced through dry sand. These methods are antiquated and not to be recommended if used alone. Other makers remove moisture from the oil by heating it to a temperature preferably not exceeding 80°C. and either under atmospheric pressure or assisted by a partial vacuum.

The dehydration will be much accelerated by allowing dry air to bubble slowly through the oil. The air should be freed from moisture by first passing through calcium chloride or unslaked lime.

Samples of oil should be removed from time to time and tested electrically or by immersing into the oil a ¼-in. iron rod heated to a dull red heat. If any water is present there will be a crackling noise, whereas if the oil is dry, it merely fumes without noise; .01 per cent. of water will be readily detected in this manner.

Transformer oils should preferably be shipped in steel drums, as they are then better protected from moisture than when shipped in wooden barrels. The wooden barrels have the further disadvantage that glue from the inside of the barrels may be dissolved in the oil and thus destroy its value for transformer purposes.

Steel drums or barrels used for transformer oils should be washed with naphtha to remove oil and drained, then washed again with clean naphtha under strong agitation. The drums should then be placed in a hot room, say, heated to 200°F., and kept in this room with the bung holes down for 24 hours. They may then be blown by hot air to remove any trace of vapor, after which dust and loose sediment should be removed by a vacuum pump. The drums should then be bunged and transferred to the filling room.

The transformer oil before being filled into the drums should be heated to 80°C. and forced through a filter press before it is delivered to the steel drums. The steel drums must be kept warm before filling to prevent condensation and must be lead sealed directly after filling. The oil barrelled in this manner will be free from moisture and dust. If the drums are not effectively sealed air will be sucked into the drum, owing to expansion and contraction of the oil following upon temperature changes, and the air introduces moisture.

Filter Presses.—A typical filter press is made up of a number of grids and chambers. Five sheets of dried and oiled filter paper are placed between each filter plate and the adjacent frame, and the whole compressed tightly together. The filter paper should be dry, soft, white blotting paper, made principally from wood pulp and free from coloring matter, chemicals and other foreign substances.

The oil is pumped by means of a rotary multi-stage centrifugal pump under a pressure of 25 to 100 lbs. per square inch through the blotting paper and discharged into the receiving tank. The blotting paper allows the oil to pass, but retains all moisture and impurities. The water will be retained in the paper because of its greater capillary attraction. This fact may be illustrated by making the following experiment:

Take 2 beakers, one filled with water and the other filled with oil, place a strip of dry blotting paper in each, interchange the slips when saturated. In about three minutes the oiled strip will be thoroughly saturated with water and the oil driven out. The strip which was soaked in water will, however, not be affected in any way by being immersed in the oil.

Most of the solid impurities in the transformer oil will be caught by the first filter paper, and when the first paper is saturated with water the water will collect in the second layer of filter paper and so on, until finally the pressure required to force the oil through the press rises considerably, indicating that the filter papers must be changed. After one filtration the oil will be practically free from water, but fine sediment and slime may need more than one filtration to be entirely removed.

The dielectric strength of the oil should be taken at frequent intervals to determine when the filter papers should be removed. Such filter presses are made complete with electric motor, pump, reservoirs, etc., in portable form, so that they can be connected to any transformer or transformer oil storage tank. They can be applied to transformers during service. In that case the oil is taken from the bottom of the transformer (Fig. 227), passed through the filter press and returned to the top of the transformer tank, being kept in circulation until completely purified and until tests have shown that the dielectric strength or specific resistance is satisfactory. The first sheet of papers should be renewed once every half-hour when the oil is wet and dirty, while for fairly dry and clean oil, once an hour is sufficient. The oil is circulated at the rate of from 6 to 20 gallons per minute, according to the size of the outfit.

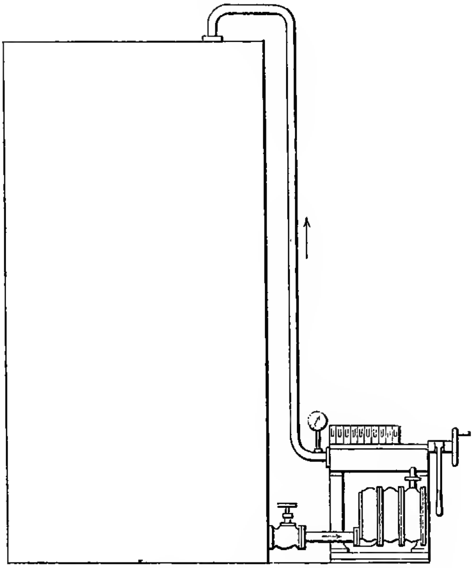

Fig. 227.—Purifying transformer oil.

Where transformers are not sealed the oil will in time become charged with hygroscopic moisture and more or less dust, and a certain amount of sludging may occur due to oxidation of the oil or to action of the oil on the insulating material.

For these reasons it is good practice to empty the transformer at least once every twelve months, to clean it thoroughly from sludge or deposit and carefully dry and filter the oil, preferably by means of a filter press.

Starting a Transformer.—Before a transformer is put into its case it is important that the windings or insulating material shall not contain any moisture or air. A satisfactory method of attaining this end is to place the transformer inside a cylindrical shell which can be hermetically sealed. The temperature of the interior of the shell is raised by steam heating coils to about 250°F. so as to evaporate any moisture which may be in the windings. At the same time a vacuum is produced which will cause any air bubbles or pockets in the insulation to swell and expand, the air being finally removed by the vacuum pump.

After sufficient time has passed to ensure the removal of all moisture and air, the tank is allowed to fill completely with the insulating compound under pressure. When all parts of the insulation are thoroughly impregnated, the insulating compound is drained out and the windings dried.

Coming back to the erection of the transformer, the first thing to do when the transformer is placed inside its case is to have it dried out properly at a temperature of 80°C. to 90°C. by heating the transformer case, in order that every trace of absorbed moisture may be removed.

When recording the temperatures during the drying out process, care should be taken not to break the thermometers, as drops of mercury might remain between the windings and cause a short circuit.

The transformer oil should be poured in through four or five thicknesses of cheese cloth (or through layers of unsized cambric). In this way any coarse scale that may have been loosened from the steel barrels in which the oil has been shipped will be kept back.

Transformer Explosions.—Explosions of transformers are fortunately very rare, but care should always be taken when examining the transformer and removing the cover not to have naked lights, as if the transformer has been overheated the oil may have given off vapors forming an explosive mixture with the air above the oil. Cases have been known where violent explosions of such vapors have occurred, ignited by a naked light.

Fires in transformers may result from a short circuit or from lightning or extreme overloading, causing parts of the windings to overheat, charring the insulation, and vaporizing the oil. A spark will be produced by contact between the windings, and the oil is ignited. A short circuit in a transformer will not set fire to the oil unless the arc is near the surface of the oil, so that the surface may be broken and the mixture of vaporized oil and air ignited.

In case of fire the transformer itself may be destroyed or, if the burning oil escapes from the tank, even more serious damage may occur. Fire extinguishers should therefore always be provided.

Fires have been caused by leakage of oil from the transformer casing until parts of the coils were above the oil level and therefore overheated. It is in order to guard against such leakage that all joints in a transformer tank are usually welded, but leakage has also been known to occur by syphoning, the oil rising by means of capillary attraction between the strands of the cable. The presence of oil on the cable outside the transformer tank can nearly always be detected by stickiness or the presence of oily dust and dirt on the floor.

As oil has a destructive effect upon the rubber insulation, destroying its mechanical as well as its dielectric strength, syphoning of the oil must be avoided. One method is to solder the strands of the cables together for ½ in. or more above the oil level, leaving a smooth surface.

OIL SWITCHES

Oil filled switches have come much into prominence during recent years, one reason being that the contacts if cleaned before the oil is poured in will keep clean and in a condition of maximum efficiency. The main feature from the oil point of view in all switches is that every time the contacts are broken an electric spark is produced which pierces the oil, burns it and produces a certain amount of oil carbon and gas. The gas contains a large portion of hydrogen and is highly explosive when mixed with air, so that the accumulation of gas is a point which must be kept in mind when designing oil switches, particularly for use in coal mines.

The majority of oil switches are employed for A.C. current, but they are not infrequently used for D.C. current, although in such switches a great deal more carbon is formed than in A.C. switches.

Some interesting experiments were carried out by Messrs. W. Pollard Digby and D. B. Mellis, and recorded in a paper given by them before the Manchester Section of the Institution of Electrical Engineers, March 22nd, 1910. They showed that in low viscosity transformer oils the carbon particles quickly agglomerated and settled to the bottom, whereas with viscous oils, the carbon kept floating in the oil.

It is therefore important that a switch oil should have a low viscosity, so that the carbon may separate out quickly. Also the more fluid the oil the quicker will the arc be quenched and the less carbon will be formed. Switch oils should be as free from sulphur and sulphur compounds as possible, as sulphur will attack the copper contacts.

The oil level should be kept high in the switch case covering the contact points to a sufficient depth, so that when breaking even the strongest current, there is no chance of the spark breaking through the surface and igniting the gases that are usually present above the oil.

In order to minimize the danger of an accumulation of gas, there are two ways open, either to ventilate the switch case effectively, so as to give the gas a chance to become diluted and get away from the switch case, or to enclose the switch case entirely and allow the gas to create a pressure within the switch case, which is prevented from becoming excessive by means of a pressure relief valve.

If the space above the oil is filled with the gas undiluted by air, the gas cannot possibly explode. The switch case, however, must be of sufficient strength to withstand the pressure. When switch cases are enclosed in this manner the entrance of dust and water is prevented, which is very desirable. The presence of moisture in particular may give rise to violent arcing and extremely heavy carbonization. In one case a violent explosion in a 10,000 volt switch case took place in consequence of the Attendant throwing in the switch unphased, a powerful arch thus being immediately formed. The flames leapt 8 ft. high and the switch casing was twisted all out of shape. The oil was thrown violently about and was found running all over the iron girders in the neighborhood of the switch casing and burning. The oil on examination was found to contain an appreciable percentage of moisture. The water during the period of arcing would immediately turn into steam and atomize the oil, so that a considerable amount of oil spray or oil fog would be formed, thus accelerating the violence of the explosion.

SPECIFICATIONS FOR TRANSFORMER AND SWITCH OILS

In formulating specifications for transformer and switch oils the following schedule embodies the principal points, given in their order of importance:

(1) The oil must be a highly refined, *pure mineral oil* containing *no free sulphur*, *no resinous*, *animal* or *vegetable matter*, and *no unstable sulphurous compounds*.

(2) It must contain only the *merest trace of acid, alkali or salts.*

(3) It must be *dry and well filtered,* containing *no dust* or other *solid impurities.*

(4) The *dielectric strength* must not be less than kilovolts when tested between electrodes at °F.

(5) The *specific resistance* must be not less than million megohms at °F. and not less than million megohms at °F.

(6) The *percentage of sludge* must not exceed per cent. when the oil is subjected to (here follows description of the oxidation test).

(7) The *viscosity* as measured by the instrument must not exceed " at °F.

(8) The *closed flashpoint* must not be less than °F.

(9) The *loss by evaporation* must not exceed per cent. when heating grammes of oil for hours at °C. in a beaker " high and " in diameter in (here follows description of heating apparatus).

(10) The *cold test* must not be higher than °F. when tested by (here follows description of apparatus).

The following test applies only to switch oils:

(11) When exposed to heavy sparking in (here follows description of apparatus) c.c. of oil must not deposit more than grammes of *carbon* at °C. and the carbon should *quickly agglomerate and separate from the oil.*

(12) The sulphur contents must be as low as possible and must not exceed per cent.

The information given in the preceding chapters will give an indication of the approximate figures which may be specified under the different headings, but in view of the fact that the Insulating Oil Committee of the Institution of Electrical Engineers, when it has completed its various researches will formulate specifications for transformer and switch oils, the author refrains from making his recommendations more definite.

A good quality transformer oil will always prove to be a good switch oil, although there is no apparent reason why this should be the case. The most important points in the specification as far as switch oils are concerned appear to be:

Freedom from moisture (3);

High insulating value (4 and 5);

Low carbon formation (11), which appears to be more or less related to sludging tendency (6);

Low viscosity, to quickly quench the arc (7);

Reasonably high flash point (8).

APPENDIX

SKIN DISEASES PRODUCED BY LUBRICANTS

(By Dr. J. C. Bridge)

1. Oil rashes are, generally speaking, of two kinds—the first is due to plugging of the small glands at the root of the hairs on the arms and legs of workers, the second to mechanical injury to the skin produced by metallic particles suspended in the cutting lubricant.

(*a*) *Plugging of the Glands of the Hair Follicles.* Primarily this is purely mechanical; a mixture of oil and dirt blocks the minute openings of these glands and sets up inflammation round the hair (folliculitis). The inflammation commenced in this way may lead on to suppuration or abscess formation (a boil). If many hairs are affected the arm presents an appearance of a crop of raised red spots (papules) with a black spot as a centre, or, if the inflammation has gone as far as suppuration (abscess formation), a yellow head.

(*b*) *Mechanical Injury to the Skin by Metallic Particles.* Minute metallic particles suspended in the cutting lubricant may produce injury to the skin. This occurs chiefly on the hands, where two surfaces are rubbed together, *e.g.* the skin between the fingers. Injury to the skin may also be produced on any part of the hands and arms by wiping with a cloth or rag while the hands or arms are coated with a film of fluid in which metallic particles are suspended. Injury to the skin allows germs to enter and causes septic infection.[1]

2. Prevention.—(*a*) *Cleanliness of the Worker.*—Washing accommodation for workers in contact with oil must be on a liberal scale. Hot water, soap and scrubbing brushes are essential. Workers should be instructed not to wipe their hands on rags, etc., before washing and to avoid washing their hands in the cutting compounds.

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[1] *Author's Note.* Blood poisoning has also been caused by bacteriological infection of gluey moisture present in the cutting oil.

Barrels after exposure have got soaked with moisture which spread the infected glue throughout the oil (objectionable odor) so that wherever this oil afterwards came in contact with the workers (hands, arms, thighs), even including the storesman, blood poisoning set in.

Ether soap, which dissolves oil, has been found useful in preventing inflammation of the hair follicles. Dusting the arms with a powder containing equal parts of starch and zinc oxide before commencing work prevents the action of the oil on the skin.

(*b*) *Cleanness of the Lubricant.* Care must be taken in the handling of the constituents before blending that they have not undergone changes (*e.g.*, formation of free fatty acid).

Constant removal of metal particles is necessary to avoid injury to the skin. Filtration, such as is provided on the machines, and centrifugal action, are insufficient to remove the minute metal particles which may injure the skin. Where cutting oils (straight oils) are used, their viscosity can be diminished by heat sufficiently to allow the particles to sink without affecting their value as lubricants. This operation completely removes all metal particles. In other lubricants where such a procedure is impossible it is necessary constantly to change and renew the cutting lubricants.

(*c*) *Cleanness of the Machines.* Frequent cleaning of the machines with the removal of all the old lubricant from all parts of the machine is essential.

3. Addition of Disinfectants or Antiseptics to the Lubricants.—Various antiseptics, carbolic acid (1 per cent. to 2 per cent.) being the most common, have been added to the lubricant to prevent rashes, and in the case of cutting emulsions 0.5 per cent. of disinfectants soluble in water have been used for this purpose. The results obtained have not been altogether satisfactory, and reliance cannot be placed upon such a method to prevent skin rashes.

4. Sterilization by Heat.—It has been suggested to heat the cutting oil to 300°F. for a short period with a view to sterilizing it as well as to increase its antiseptic or germicidal action.

Laboratory experiments in America have shown that used oil possesses rather marked germicidal effects, and in view of the fact that the used oil becomes heated during use attempts were made to determine whether heating new oil would also bestow upon it germicidal powers. Apparently, heating does produce such a change, but the temperature required is upwards of 125°C. The actual temperature rquired to produce this germicidal action in the oil has not yet been determined, but it has been recommended to mix new oil with the used oil before filtering and heating, so that the new oil would possess to some extent the germicidal power of the used oil.

5. Removal of Workers with Septic Infection of the Hands.—Workers whose hands become the seat of septic infection should not be allowed to work on machines, as they are liable to infect the oil with germs and so infect other workers.

6. Treatment. (*a*) *Folliculitis Produced by Blocking of the Glands.*—As a general rule, frequent washing with soap and hot water is sufficient to produce a rapid cure. The skin may be subsequently dusted with zinc oxide and starch powder.

It has been found that where this is insufficient a mild antiseptic applied on lint has relieved the irritation and given good results.

(*b*) *Septic Infection of the Skin due to Cuts.*—Septic infection should be treated on general principles by the application of suitable antiseptic dressings.

7. Susceptibility.—Certain individuals appear to be particularly susceptible to the action of lubricants.[2] Such persons when found should be removed from contact with oil.

Author's Note.[2] Bad health, weakness following upon illness, delicate skin, etc.

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