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LUBRICANTS AND LUBRICATION

LUBRICANTS AND LUBRICATION

BY

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PREFACE

This book is essentially practical. It is for buyers, sellers, and users of lubricants and for those who design and operate machinery. It is the outgrowth of the author's experiences in the industry and in teaching the subject to engineering students. The author realizes that it is not so comprehensive as might be desired by many. But material that is to be found in standard works on certain specialized phases of the subject has been purposely avoided or minimized. The production and refining of crude oil and the mathematical theory of lubrication, for example, are fully covered by several available good books.

It is the author's opinion, however, that, in order to select, apply, use, and care for lubricants properly, it is necessary to possess at least a fair knowledge of the source, production, refining, and theory of lubrication. In consequence, such subjects are discussed more fully than has been done in previous books of this general sort.

The first eleven chapters are devoted to the fundamentals of lubricants and lubrication and apply to all types of machinery and industry. The next six chapters cover in detail the lubrication of steam turbines, steam engines, air compressors, refrigerating machines, and all types of internal-combustion engine—machines that are universally used in all types of industry. The general principles and practices of the first eleven chapters are here applied to specific machines. The last chapter points out general principles and proper practices for storing and handling lubricants. The desirability and the necessity of proper supervision and keeping records are also emphasized. In the Appendix are a table and charts of considerable practical value for making volume and gravity corrections and viscosity index determinations.

Man as a thinking individual has existed for 27,000 years or more, but he has probably used lubricants for only 7000 years. Until less than a century ago, his lubricants consisted entirely of animal and vegetable fats and oils. Petroleum, which constitutes the bulk of all lubricants today, was first used in 1845,

when it was mixed with sperm oil to form an excellent lubricant for cotton-mill spindles in use at that time. From this simple and unpretentious experiment has developed in less than a century one of the world's largest and most indispensable industries.

Although the development of the refining and application of petroleum lubricants advanced rapidly from the very beginning, yet the methods employed until recently were mainly empirical. The last decade, in particular, has witnessed the infusion of many highly scientific methods and practices. Refinery procedures and laboratory research have been closely coordinated and put on a highly scientific basis. Equipment builders and refiners work cooperatively to solve their mutual lubricating problems by the coordination of petroleum research with refinery procedure and industrial requirements. As a result, where formerly equipment and lubricants were manufactured with little regard for each other, now they are closely synchronized for their mutual benefit. Consequently, where formerly the characteristics of lubricants depended chiefly on the crude, now many lubricants are "tailor-made" to meet certain specific requirements. It can be safely predicted that further advances in this respect will come in the near future. This development will probably justify a revised edition of this book within a few years; in the meantime, it is hoped that this effort will serve a useful purpose.

A complete list of those who have helped in various ways with this work would be impossible to compile. The material of Chaps. IX and X has appeared in *Power* at various times during the past two years. For permission to re-use this material, the author expresses his appreciation. Thanks are due also to the several equipment builders who have permitted the use of their data and illustrations, credit for which is given in the text. Particularly helpful have been various booklets and bulletins published by different oil- and lubricating-equipment manufacturers. The author wishes to express especially his appreciation to Mr. F. A. Annett, associate editor of *Power*, for his encouragement and advice throughout the preparation of this book.

JAMES I. CLOWER.

BLACKSBURG, VA.,
July, 1939.

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LUBRICANTS AND LUBRICATION

CHAPTER I

CRUDE PETROLEUM

The bulk of lubricating oils today are made from petroleum, which is an inflammable, oily liquid varying in appearance from transparent light yellow to opaque black. It consists essentially of the elements carbon and hydrogen, which are chemically combined to form compounds called *hydrocarbons*. The word *petroleum* is derived from the two Latin words *petra*, a rock, and *oleum*, oil. Hence, petroleum is sometimes called *rock* oil but more frequently *mineral* oil since it is one of many minerals secreted in the earth's crust.

1. Origin of Crude Petroleum.—A number of theories as to the origin of crude petroleum have been advanced by geologists and other scientists, but there is still much uncertainty as to its origin. The theories so far advanced, however, may be grouped into two general and diametrically opposed sets: (1) the inorganic or mineral set; and (2) the organic or living matter set.

The inorganic set of theories hold generally that the elements of hydrogen and carbon in the rocks of the earth have been brought together under high temperature and pressure conditions such that they combined to form petroleum hydrocarbons. One of the inorganic theories holds that the primary reaction was between water and metallic carbides, such as iron, sodium, and calcium. Unquestionably, at one time the earth's temperature was 4000°F. or higher, and it is known that iron carbides will form under such conditions. Thus, the iron carbides might have remained in an unoxidized state through many geological ages until reached by water to form petroleum.

A corollary of this theory is that the earth contains free alkali metals, particularly sodium, and that this metal and carbon

dioxide react under high temperatures to form acetylides, which, when contacted with water, produce acetylene and other hydrocarbons.

Still another inorganic theory holds that petroleum was formed during the solidification period of the earth by the action of great heat and pressure on the elements of carbon and hydrogen. This theory is strengthened by the presence of petroleum in volcanic materials.

The organic set of theories, which are more widely accepted than the inorganic set, hold generally that the hydrogen and carbon contained in the hydrocarbons of petroleum both came from remains of preexisting plant and animal life. According to this set of theories, plant and animal matter has been covered with an impervious layer of material, which excluded air and prevented rapid decay. Slow decomposition of this material occurred, however, through hundreds of thousands of years and converted it into crude petroleum and gas. In general, the organic material is considered to be the remains of microscopic marine and swamp life rather than of true land life.

Under the inorganic set of theories, no plausible explanation can be offered to account for the widely different characteristics of various crude petroleums. But under the organic set these differences are explained by the diversity of plants and animals. The organic theories are also strengthened by the fact that the oil fields of the world are graveyards of trillions upon trillions of animals and plants.

It is impossible to prove conclusively any theory, for geological time and the effects of earth temperature and pressure cannot be simulated in the laboratory. Unquestionably, the most plausible evidences favor the organic set of theories. No single theory is sufficiently broad to account for all known types of crude petroleum. Each theory is plausible within limits, and it is quite probable that the true origin of petroleum is accounted for to a certain extent by every one of them.

2. Antiquity of Petroleum.—History does not record when petroleum was first employed by man. His use of it probably dates back to Abraham. Vessels constructed in his time and containing bitumen have been found on the ancient site of Ur in Chaldea. It is known, also, that more than 7000 years ago the Egyptians made extensive use of bitumen for embalming pur-

poses. The word *mummy*, in fact, has been traced to the Egyptian word *mum*, meaning bitumen. It is also recorded that the Babylonians used bitumen as mortar for building walls. Five thousand years ago, the Phoenicians made long river journeys in round boats, which were waterproofed with gray-black asphalt. In the first century of the Christian era, the Roman historian Pliny, stated in his history of the world that oil obtained from Sicily was used in the lamps of the temple of Jupiter.

The peoples of ancient Japan, China, Judea, and Persia used petroleum in a primitive way centuries before the Christian era. As early as 221 B.C. "deep-well" drilling for petroleum was practiced in China. Japanese history also records the use at the court of the Emperor Tenchi as early as A.D. 668 of a marvelous liquid called *Moyuru mizu*, or inflammable water.

The Greeks are said to have destroyed a Scythian fleet by pouring "burning water" on the sea. Belisarius, a Roman general, in A.D. 533 taught the Vandals of North Africa about oil by smearing it on swine, lighting it, and then driving the blazing, squealing porkers against them.

Three hundred years ago, as today, a thriving oil industry existed in Baku on the Caspian sea. Noah's ark is said to have been caulked with bitumen, probably gathered from the shores of the Dead Sea. Job told of a rock that "poured me out rivers of oil." The Crusaders learned about the disastrous use of petroleum in the form of flame-throwers when they stormed the walls of Constantinople from A.D. 1096 to 1270.

The earliest recorded use of petroleum in the New World was about 1527 when the Spaniards, landing in Peru, used asphalt for caulking their boats. They found that the Incas were mixing it with sand and gravel and using it as mortar for building stone houses and roads.

It was at Cuba Lake, N. Y., 1627, that a missionary priest discovered the first oil pool known to the white man in North America. The existence of many oil springs was reported by explorers and missionaries later in the seventeenth century. When Europeans first came to the New World they found the Indians using crude petroleum for toothaches and headaches and sometimes internally. They are said to have regarded oil springs with religious awe and reverence. Throughout the

seventeenth and eighteenth centuries, petroleum continued to be found in small quantities in various parts of the American colonies.

It was not used for industrial purposes until the early part of the nineteenth century, when in 1815 the streets of Drohobycz, Poland, and Prague, Czechoslovakia, were lighted with petroleum lamps. In 1828, Pittsburgh, also, considered lighting its streets with oil lamps.

In 1829, while salt was being drilled for, the American well was drilled in Cumberland County, Ky. The oil from this well

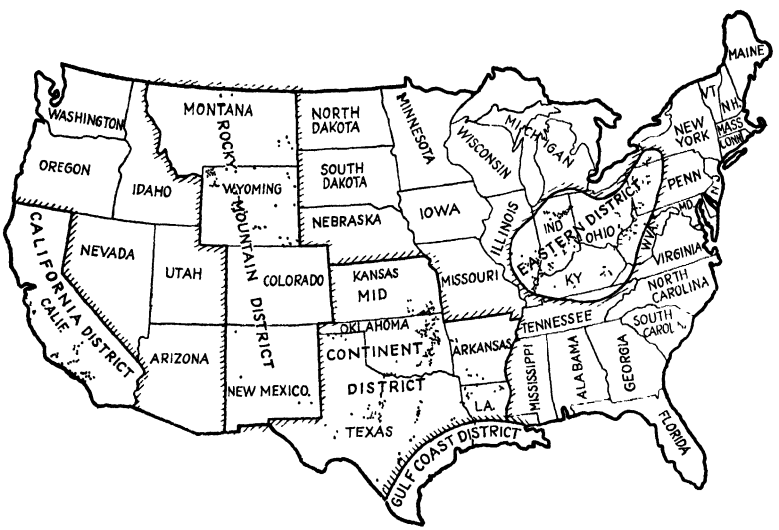


FIG. 1.—Principal oil-producing districts of the United States.

found its way into the Cumberland River and, having been set on fire, is said to have burned for a distance of more than 40 miles. Despite the abundance of oil from this well and other salt wells that yielded oil unexpectedly, it continued to be primarily a nuisance.

In 1845, however, oil was mixed with the expensive sperm oil, and the mixture was found to make an excellent lubricant for cotton machinery. The time was not ripe, and the vision of the men who were later to build a great industry had not matured; consequently, the widespread application of petroleum for industrial uses was delayed until the famous Drake well was drilled at Titusville, Pa., Aug. 27, 1859. With the bringing in

of the Drake well, the commercial importance of the oil industry was established and the manufacture of illuminants from coal was doomed, though the name of the product, *coal oil*, persisted for a long time.

3. Locating Crude Petroleum.—Petroleum has been found on every continent. It is not contained in underground lakes or pools but is always held in the pores of sand or rock, which are sometimes so small that they cannot be seen with the naked eye. It is always found in sedimentary sands or rocks, such as shales, limestones, and sandstones. These take their name from sedi-

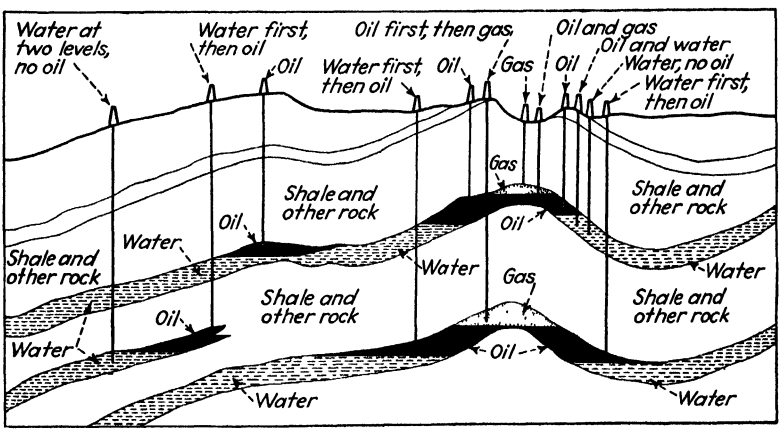


FIG. 2.—How oil is found and missed.

ment and were formed eons ago by the action of water, ice, or wind. Oil has never been found in igneous rock, *i.e.*, rock that once existed in liquid form and later solidified.

It is generally believed that oil will be found only when the following four conditions exist in the same place: (1) where there is a porous formation to serve as a reservoir for the oil; (2) where impervious, enclosing layers of earth or rock exist both above and below the oil-bearing formation; (3) where the geological structure is such that oil drains from a relatively large area to a pocket or pool; and (4) where plant or animal life, or both, could have existed in abundance millions of years ago.

Geologists generally believe that oil is indicated by the following four principal geological formations: (1) anticline, Fig. 3; (2) domes, Fig. 4; (3) fault, Fig. 5; and (4) sand lens, Fig. 6.

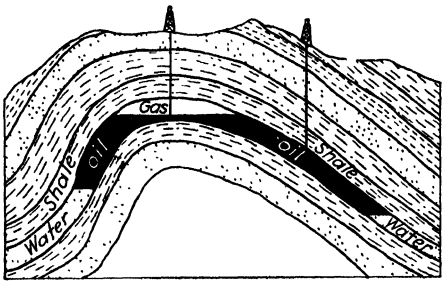


FIG. 3.—An anticline formation.

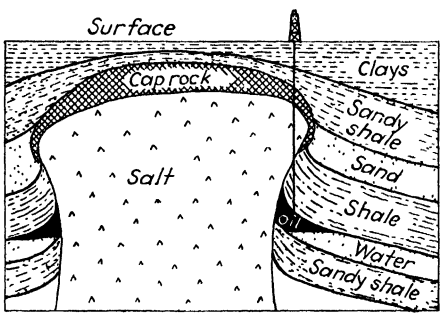


FIG. 4.—A dome formation.

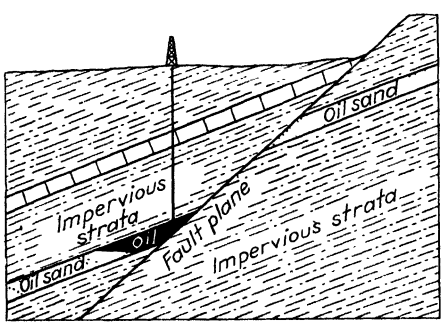


FIG. 5.—A faulted formation.

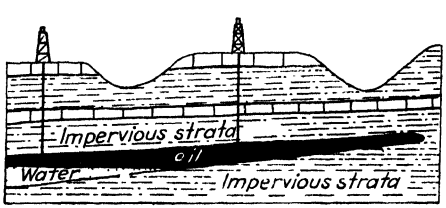


FIG. 6.—A sand-lens formation.

The old answer to the question Where is oil found? was: Oil is where you find it. This offered little consolation to those who expended large sums of money for drilling only to find "dry holes" (dusters). Costly disappointments caused prospectors to seek more reliable methods than the mere "hunch" of the early oil prospector, the "wildcatter." Consequently, although hunches are still followed, the modern search for oil is carried on by the application of the sciences of geology, paleontology, and geophysics. And vanished are those romantic days when prospectors used "oil witches," "divining rods," "wiggle sticks," or "doodlebugs." Today, the ground is carefully surveyed; the age and type of structures are identified; the ages and characteristics of the outcrops of rocks are determined; the character of the vegetation is noted; and sometimes the soil is analyzed, and aerial photographs are taken. Delicate geophysical instruments such as the magnetometer, torsion balance, and seismograph are used. Recently, electrical transient instruments have come into use.

These scientists, however, do not actually locate oil. They simply locate the position of formations that they believe favorable to oil accumulation. There is nothing definite or precise about locating oil. The old oil proverb "The only proof of oil production is in the drill" is still true.

4. Production of Crude Oil.—Undoubtedly, the first oil wells were hand-dug. In fact, oil wells were hand-dug in Burma, India, as late as 1889, some of which were 400 ft. deep. The spring pole superseded hand digging and was generally used by the pioneer drillers of Pennsylvania during the middle part of the nineteenth century. Drake, in 1859, employed equipment in principle the same as the spring pole but substituted steam for man power.

The contrast is sharp between a modern, oil-well-drilling rig and that used by Drake and others of his time. At the present time, there are two quite different methods employed: (1) the cable-tool or percussion method, Fig. 7; and (2) the rotary method or system, Fig. 8.

The cable-tool method consists in principle of a churning action produced by alternately lifting and dropping the "string" of drilling tools in the well. In principle, it is the same as the early spring-pole rig. The improvements that have been made are in the nature of increased size, weight, and strength. The

string of tools, roughly 50 ft. long, consists of a bit and stem, "jars," and rope socket. The bit itself may vary from a few inches to 36 in. in diameter.

The chief limiting favor of this method of drilling is the necessity of using casing to support the wall while drilling. In

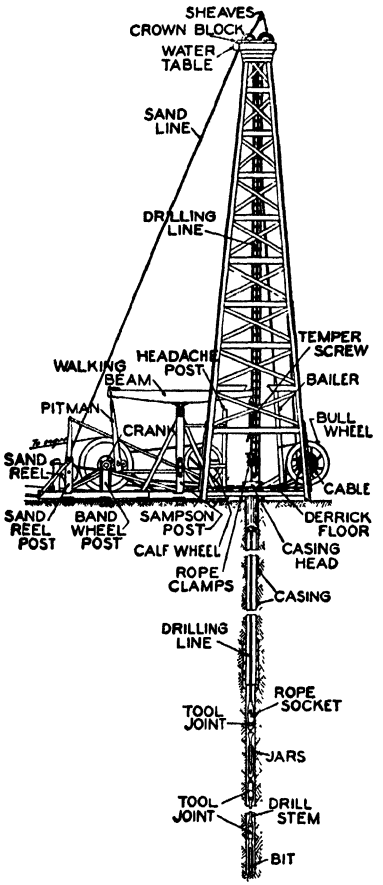


FIG. 7.—Cable-tool or percussion drilling rig.

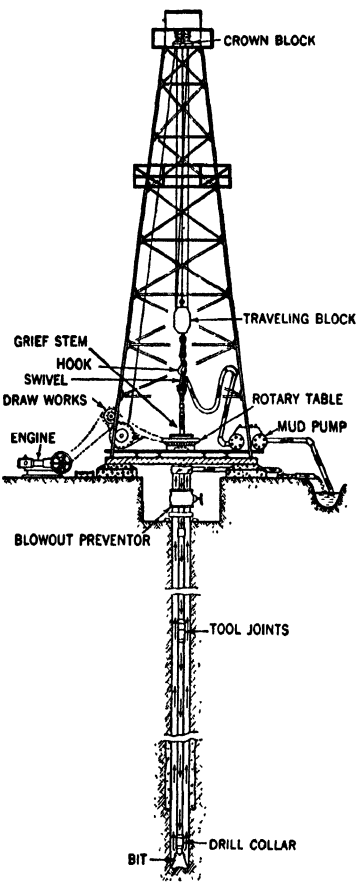


FIG. 8.—A rotary drilling rig.

drilling deep wells in soft formations, many sections of casing are required, which not only is expensive but also requires that the well should be started with a very large diameter and completed with a small diameter. Consequently, this system has been supplanted by the rotary system in most sections; it is still,

however, the most practical method for drilling hard rock formations.

The rotary method, introduced at Spindle Top, Tex., in 1901, operates on the same principle as a wood auger or steel bit. The bit is fastened to the bottom of several sections of drill pipe screwed together. As the well deepens, drill-pipe sections are added one at a time. Attached to the top of the string is a "grief stem" or "Kelly," which is a heavy, tubular forging having square, exterior sides. The grief stem extends through an opening in the center of the rotary table, which grips it. The grief stem is free to move up and down but is forced to rotate with the table, which is rotated by a steam engine, electric motor, Diesel engine, or some other type of internal-combustion engine.

The grief stem and drill pipe are hollow, and so-called *mud* is pumped down through them and out openings in the bit to remove cuttings from the well. The mud, under a pressure varying from 200 to 2000 lb. per sq. in., returns to the surface through the annular space between the drill pipe and the well wall, carries with it cuttings, and supports the wall of the well. For most formations, the rotary method is much faster and cheaper than the cable-tool method.

In the event oil is found in paying quantities, the string is removed from the well and the final or "oil" string of casing is set and sealed off with cement, or "packer." The well is then drilled in and completed. If oil flows naturally from the well without pumping, it is a "gusher" or flowing well, but if the oil has to be pumped it is a "pumper." In gushers, the natural pressure below the ground is sufficient to force the oil (usually mixed with gas and sometimes water) to the surface.

Frequently, when oil sand is reached, there is no flow of oil and "shooting" is resorted to. This consists of lowering to the bottom of the well a charge of nitroglycerin and exploding it. This increases the size of the well at the bottom and opens cracks in the sand, thereby making it possible for the oil to flow into the pocket at the bottom of the well. Frequently, apparently dry wells are converted into producers by shooting.

Various other artificial methods of making wells produce are employed when natural pressures decline. The *injection* method of forcing air or gas under pressure into the producing formation is commonly used. Waterflooding, which consists of pumping

water down a key well in the formation, thus forcing oil to adjacent wells, is extensively used in the Pennsylvania field.

5. Classification of Crude Petroleum.—In describing crude petroleum, it is common practice to refer to the *base* of an oil. Apparently, many of the pioneers of the industry considered crude petroleum similar in nature to medicinal salves and ointments, which consist generally of a base, a semisolid, fatty material (lard, lanolin, or petroleum), and an active medicinal agent carried by the base. Similarly, crude oils consist of a semisolid, nonvolatile base and a volatile portion, which can be distilled off to make gasoline, kerosene, etc.

Many crude oils, particularly those from the eastern district, deposit when slowly chilled a waxy material (paraffin). This undoubtedly is one reason for the use of the term *paraffin base* in referring to such oils. Almost all the petroleum first discovered in the United States was of this character; not until the industry was extended to California and along the Gulf Coast was petroleum found that contained no wax but apparently asphaltic material. Accordingly, these oils became known as *asphalt-base* oils. The use of this term, however, is unfortunate, because the better grade oils of this type contain little if any asphalt. A more descriptive, significant and preferable term is *naphthene base.* Other crude oils, especially those from the midcontinent district, possess properties intermediate between those of the so-called *paraffin* and *asphalt base.* Hence, the terms *intermediate base* and *mixed base* have been used to describe these oils.

Though approximately 85 per cent of crude oils fall definitely in the three classes—paraffin base, intermediate base, and naphthene base—yet certain crude oils yield light, volatile products that are paraffinic in character and other, less volatile products that are naphthenic in character, and vice versa. Such crude oils obviously do not logically belong to either of these three classes. To this extent this classification is incomplete. Other classifications have been suggested from time to time, but the most complete appears to be that of the *U. S. Bureau of Mines,* which classification is set forth in detail in *Report of Investigations* 3279, 1935. This classification is based on the study of the analyses of more than 800 crude oils from the principal producing fields of the world and is as follows:

Analysis	Class
A	*Paraffin base:* distillates paraffinic throughout
B	*Paraffin-intermediate base:* light fractions paraffinic; heavy fractions intermediate
C	*Intermediate-paraffin base:* light fractions intermediate; heavy fractions paraffinic
D	*Intermediate base:* distillates intermediate throughout
E	*Intermediate-naphthene base:* light fractions intermediate; heavy fractions naphthenic
F	*Naphthene-intermediate base:* light fractions naphthenic; heavy fractions intermediate
G	*Naphthene base:* distillates naphthenic throughout

There are two possible additional classes—*paraffin-naphthene base* and *naphthene-paraffin base*—but no crude oil has been found that would fall in either of these classes.

This classification is based on the distillation temperatures and gravities of two key fractions. "Key fraction 1" has a distillation temperature range at atmospheric pressure between 482 and 527°F., and "key fraction 2" has a distillation temperature range at 40 mm. absolute pressure between 527 and 572°F. If the gravity of no. 1 is 40°A.P.I. or lighter, the lower boiling fractions of the oil are paraffinic in character; if it is 33°A.P.I. or heavier, they are naphthenic; and if it is between 33 and 40°A.P.I., they are intermediate.

Similarly, if the gravity of no. 2 is 30°A.P.I. or lighter, the higher boiling fractions of the oil are paraffinic in character. They are naphthenic if no. 2 is 20°A.P.I. or heavier and intermediate if the fraction is between 20 and 30°A.P.I.

In the foregoing classification no mention is made of the presence or absence of wax. The U.S. Bureau of Mines states that there is no evidence to show that wax is a necessary part of any crude oil. In general, oils whose heavy fractions are paraffinic or intermediate in gravity will be found to contain wax. Samples of these two oils, however, are occasionally found to be wax-free. Some samples of intermediate-naphthene, naphthene-intermediate, and naphthene oils are wax-free, whereas others are wax-bearing. The naphthene and naphthene-intermediate oils are generally wax-free, whereas in the intermediate-naphthene class both wax-free and wax-bearing oils exist.

As already pointed out, the classifications *paraffin base, intermediate base,* and *naphthene base* are used extensively by the

TABLE I.—CHARACTERISTICS AND YIELDS OF TYPICAL CRUDE OILS

Characteristics and yield	Paraffin-base (wax bearing) W. Va., Ritchie Co., Lost Run field	Paraffin-intermediate-base (wax bearing) Okla., Lincoln Co., Chandler field	Intermediate-paraffin-base (wax bearing) La., Webster Parish, Cotton Valley field	Intermediate-base (wax bearing) Okla., Seminole Co., Seminole field	Intermediate-naphthene base (wax bearing) Wyoming Park Co., North Sunshine field	Naphthene-intermediate base (wax bearing) Tex., Austin Co., Racoon Bend field	Naphthene-base (wax-free) Tex., Refugo Co., Refugo field
Specific gravity	0.781	0.829	0.879	0.827	0.964	0.879	0.910
A.P.I. gravity	49.7°	39.2°	29.5°	39.6°	15.3°	29.5°	24.0°
Sulfur, per cent	Less than 0.1	0.28	0.32	0.33	3.84	0.16	0.14
Viscosity, S.U.S. at 100°F	34 sec.	41 sec.	120 sec.	39 sec.	4000 sec.	47 sec.	55 sec.
Pour point, °F	Below 5	Below 5	40	Below 5	40	Below 5	Below 5
Color	4 N.P.A.	Greenish black	Greenish black	Green	Brownish black	Greenish black	Green
Carbon residue, per cent	0.2	1.5	2.5	1.6	10.6	1.9	0.6
Gasoline and naphtha, per cent	45.2	32.0	5.8	38.6	2.9	21.3	1.1
Kerosene distillate, per cent	17.7	17.2	.....	4.9	4.5		
Gas oil, per cent	8.3	10.6	27.8	17.3	10.6	34.6	55.5
Nonviscous lubricating distillate, per cent	9.8	10.9	20.4	9.4	8.6	10.4	14.2
Medium lubricating distillate, per cent	3.4	5.2	9.2	6.3	6.7	7.0	4.7
Viscous lubricating distillate, per cent	.....	.....	.....	.....	6.4	4.7	11.6
Residuum per cent	14.7	23.5	36.4	22.1	58.4	21.4	12.7
Distillation loss, per cent	0.9	0.6	0.4	1.4	1.9	0.6	0.2

petroleum industry of the United States. The fact is, however, that all crude oils are complex mixtures of various series of hydrocarbons. Consequently, these terms should not be interpreted to mean that a crude oil consists wholly or even predominantly of any one family of hydrocarbons.

The characteristics and yield of typical crudes of the seven classes are shown in Table I.

6. Composition of Crude Petroleum.—Crude petroleum is a complex mixture of various classes of hydrocarbons containing small amounts of impurities, such as oxygen, nitrogen, and sulfur. In fact, it is such an intricate mixture that chemists have been able to isolate and identify only a very few of these hydrocarbons.

Hydrocarbons are composed of the elements hydrogen and carbon, which are chemically united in various proportions and arrangements. It is of interest to note that although hydrogen is a gas and carbon is a solid they unite chemically in the case of petroleum to form a liquid. If a barrel (42 gal.) of crude oil were broken up into these two elements, there would result approximately 8000 cu. ft. of hydrogen and 300 lb. of carbon.

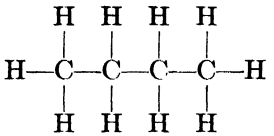
The chemical and physical properties of hydrocarbons depend on: (*a*) the *proportions* of hydrogen and carbon atoms;[1] and (*b*) the *arrangements* of the atoms that make up the molecule.[2] Actually, the variation in hydrogen content of different types of oils is very small, ranging from about 11 to 15 per cent. It is, therefore, the manner in which the carbon and hydrogen atoms are arranged in the molecule that mainly characterizes the differences in crude oils.

The significance of the molecular arrangement is emphasized by the fact that the molecules of thousands of hydrocarbons are identical except that the atoms composing them are arranged differently; consequently, they differ both in physical and in chemical properties. Such hydrocarbons are called *isomers*. The effect of changing the molecular arrangement of hydrocarbons is similar to rearranging letters of the alphabet to give different words. For example, the word *s-o-i-l* may be rearranged as *o-i-l-s*, a word of totally different meaning and pronunciation. Similarly, the hydrocarbons butane and isobutane are composed

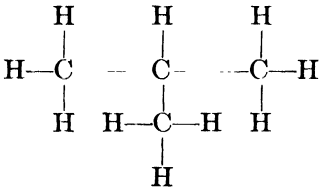
[1] The atom is considered the smallest possible particle of an element.

[2] The molecule is the smallest possible particle of a compound and is made up of atoms.

of the same number of carbon and hydrogen atoms, but their molecular arrangements are very different, as shown by the following structural formulas:



butane (C_4H_{10})

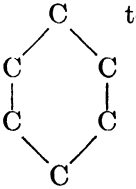


isobutane (C_4H_{10})

These are known as *structural, graphic,* or *constitutional* formulas and show not only the number of atoms in the molecule but also the plan or structure of the molecule. As previously stated, it is this plan or arrangement of the molecule that determines chiefly the physical and chemical properties of hydrocarbons.

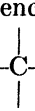
Atoms of different elements possess different capacities for holding other atoms in combination. This combining power of atoms is called *valence* and is measured in terms of the number of hydrogen atoms uniting with one atom of each element. The dashes or links shown in the foregoing formulas are called *valence bonds.* The valence of hydrogen as a standard is 1 (monovalent), that of oxygen is 2 (divalent), that of nitrogen is usually 3 (trivalent), and that of carbon is usually 4 (quadrivalent).

Atoms of carbon may be combined one after another, thus: C—C—C—C—C—C to form *chain compounds.* They may also combine in ring fashion, thus:

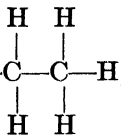


to form *ring compounds.*

These are the two general types of compound, but others exist as combinations of these two. In compounds, of course, atoms of other elements are linked in various ways to the carbon atoms.

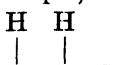
Since the valence of carbon is four a carbon atom may be represented, thus:  . Then if two carbon atoms are united, thus: —C—C—, two valence bonds are used in linking them together.

If the two carbon atoms are thought of as possessing four hands each, two hands clasp and there remain six unattached hands or valence bonds. Atoms of any other elements may be attached to the remaining valence bonds. Six atoms of hydrogen being attached, thus:



the hydrocarbon ethane is formed.

Any other monovalent element might have been attached to the free valence bonds of the carbon, entirely different compounds being thereby formed. It is not, however, necessary that there should be only one valence bond holding two carbon atoms together. There may be two or even three in some instances. For example, the structural formula of the hydrocarbon ethylene is



and that of acetylene is H—C≡C—H.

Compounds such as these, containing double and triple bonds, are called *unsaturated compounds.* The double bond represents two pairs of joined bonds, and the triple bond, three pairs. But one pair is sufficient to hold two atoms together; therefore, every double bond includes a pair of valence bonds that are free to combine with something else. Similarly, each triple bond represents two pairs of valence bonds that are free to combine with something else. On the other hand, a compound in which all valence bonds are completely satisfied is called a *saturated compound.*

Saturated hydrocarbons are chemically more stable than unsaturated ones, because all valence bonds are satisfied. Unsaturated hydrocarbons have a decided tendency to combine with other elements, particularly oxygen, nitrogen, sulfur, chlorine, and bromine. Saturated hydrocarbons will also combine with these elements and others under certain conditions but not so readily. When a saturated hydrocarbon combines with oxygen, for example, it does so by releasing hydrogen, whereas unsaturated hydrocarbons absorb oxygen. Such a replacement of hydrogen by another element, atom for atom, is called *substitution.*

There are innumerable organic compounds, which generally are divided into two groups: (*a*) aliphatic compounds, and (*b*) aro-

matic compounds. The hydrocarbons found in petroleum oils are derived from both of these groups as well as an intermediate third group, the naphthenes. On the aliphatic side there are three important hydrocarbon series; the paraffin, the olefin, and the acetylene. On the aromatic side the benzene series is the most important.

All aliphatic hydrocarbons are of the chain type, and those of the aromatic and naphthene groups are of the ring type. The paraffin and naphthene series are saturated whereas the olefin, acetylene, and benzene series are unsaturated.

The longest and best known of the hydrocarbon series is the paraffin or methane series, some members of which are shown in Table II. The general chemical formula for this series is C_2H_{2n+2}, and the names of all members end in *-ane*. They are the most stable of all the hydrocarbons, being indifferent to most chemical reagents except chlorine and bromine. They are not easily

TABLE II.—PARAFFIN HYDROCARBONS

Name	Formula	Physical state	Boiling point, °F.	Specific gravity
Methane	CH_4	Gas	−263.0	0.415 at boiling point
Ethane	C_2H_6	Gas	−135.4	0.446 at 32°F.
Propane	C_3H_8	Gas	− 34.6	0.536 at 32°F.
Butane	C_4H_{10}	Gas	33.1	0.601 at 32°F.
Pentane	C_5H_{12}	Liquid	97.3	0.631
Hexane	C_6H_{14}	Liquid	156.2	0.660
Heptane	C_7H_{16}	Liquid	209.1	0.684
Octane	C_8H_{18}	Liquid	256.3	0.707
Isooctane	C_8H_{18}	Liquid	240.8	0.704
Nonane	C_9H_{20}	Liquid	303.4	0.718
Decane	$C_{10}H_{22}$	Liquid	345.2	0.747
Undecane	$C_{11}H_{24}$	Liquid	386.6	0.741
Dodecane	$C_{12}H_{26}$	Liquid	420.8	0.768
Tridecane	$C_{13}H_{28}$	Liquid	453.2	0.757
Tetradecane	$C_{14}H_{30}$	Liquid	486.5	0.765
Pentadecane	$C_{15}H_{32}$	Liquid	518.9	0.772
Hexadecane	$C_{16}H_{34}$	Solid	549.5	0.775
Heptadecane	$C_{17}H_{36}$	Solid	577.4	0.778*
Octadecane	$C_{18}H_{38}$	Solid	602.6	0.777*
Nondecane	$C_{19}H_{40}$	Solid	626.0	0.777*
Eicosane	$C_{20}H_{42}$	Solid	401.0	0.778*

* Under 15 mm. pressure.

oxidized at low temperatures but are readily oxidized at higher temperatures. The pure compounds all have a pleasing odor and are colorless and only slightly soluble in water. They are present probably to a limited extent in all petroleum, particularly the paraffin-base crude oils.

The olefin series is closely related to the paraffin series. As shown in Table III, the first and lightest member is ethylene, and consequently this series is often called the *ethylene series*. The series has the general chemical formula C_nH_{2n}; therefore, each molecule contains two less hydrogen atoms than its corresponding molecule of the paraffin series. Being unsaturated, the members of this series are much more reactive than the paraffins, readily absorbing nitrogen, chlorine, oxygen, and sulfur and reacting with sulfuric and nitric acids. They are present to a more or less degree in practically all crude petroleum, even in the paraffin-base oils.

The acetylene series has the general chemical formula C_nH_{2n-2} and is believed to form a part of most light lubricating oils. The best-known member of this series is acetylene, from which a number of important substances are produced. Since these hydrocarbons are unsaturated, they are very reactive, acetylene itself being exceedingly explosive, especially when compressed.

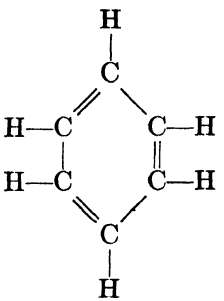
The benzene series is a member of the aromatic group of organic compounds. Members of this series are unsaturated and, hence,

TABLE III.—OLEFIN HYDROCARBONS

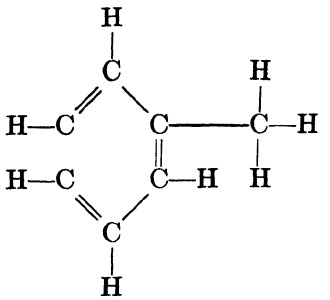
Name	Formula	Physical state	Boiling point, °F.	Specific gravity
Ethylene (ethene)	C_2H_4	Gas	−154.8	0.566
Propylene (propene)	C_3H_6	Gas	− 52.6	0.609
Butylene (butene)	C_4H_8	Gas	23.0	0.668
Isobutylene	C_4H_8	Gas	21.2	0.666
Amylene	C_5H_{10}	Liquid	97.5	0.651
Hexylene	C_6H_{12}	Liquid	154.4	0.682
Heptylene	C_7H_{14}	Liquid	203.0	0.703
Octylene	C_8H_{16}	Liquid	255.2	0.722
Nonylene	C_9H_{18}	Liquid	307.4	0.743
Decylene	$C_{10}H_{20}$	Liquid	341.6	0.763
Octadecylene	$C_{18}H_{36}$	Solid	354.2*	0.791
Melene	$C_{30}H_{60}$	Solid	716.0	0.890

* Under 15 mm. pressure.

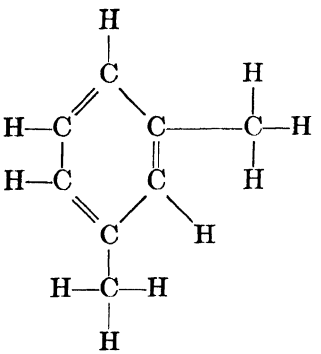
very reactive and unstable. They are formed not by adding more carbon atoms to the ring but by adding straight chains to one or more of the carbon atoms, thus:



benzene (C_6H_6)



toluene (methyl benzene) (C_7H_8)



xylene (dimethyl benzene) (C_8H_{10})

The hydrocarbon groups attached as above to the ring are called *radicals*. Thus, OH is the hydroxyl radical; CH_3, the methyl radical; C_2H_5, the ethyl radical; C_3H_7, the propyl radical; C_4H_9, the butyl radical; C_6H_5, the phenyl radical; COOH, the carboxyl radical; etc.

The naphthene series is also called the *cycloparaffin* and *polymethylene series*. Its members are related to those of the benzene series in that they have a ring structure, but they possess many of the characteristics of the paraffins and olefins. They are saturated and, therefore, comparatively stable. The general chemical formula is the same as that of the olefin series, C_nH_{2n}. The first member of the series is cyclopropane, Table IV, which has a ring of only three carbon atoms. When cyclohexane and a ring of six carbon atoms are reached, most of the other members of the series

are formed by the addition of side chains as in the benzene series. Most petroleums, particularly the Russian, California, and Gulf Coast oils, contain large proportions of these hydrocarbons. Some of the high-boiling-temperature members appear to contain more than one ring and are represented by general formulas such as C_nH_{2n-4}, C_nH_{2n-6}, and C_nH_{2n-8}.

TABLE IV.—NAPHTHENE HYDROCARBONS

Name	Formula	Physical state	Boiling point, °F.	Specific gravity
Cyclopropane	C_3H_6	Gas	−29.9	0.720
Cyclobutane	C_4H_8	Gas	55.4	0.703
Cyclopentane	C_5H_{10}	Gas	121.1	0.754
Cyclohexane	C_6H_{12}	Liquid	176.5	0.779
Cycloheptane	C_7H_{14}	Liquid	244.6	0.811
Cyclooctane	C_8H_{16}	Liquid	303.1	0.839
Cyclononane	C_9H_{18}	Solid	341.6	0.773

TABLE V.—PETROLEUM PRODUCTS, 1933–1937
(Thousands of barrels, unless otherwise indicated)

Products	1933	1934	1935	1936	1937
Crude production, world	1,441,000	1,521,445	1,654,688	1,801,786	2,040,500
Crude production, U.S.	905,656	908,065	996,596	1,099,687	1,277,653
U.S. proportion, per cent	63	60	60	61	63
Gasoline, U.S.	407,932	432,801	468,021	516,266	570,979
Kerosene, U.S.	48,977	53,855	55,813	56,082	65,308
Gas oil and fuel oil, U.S.	316,439	335,353	360,061	413,874	456,867
Lubricants, U.S.	23,775	26,373	27,853	30,927	35,321
Wax, thousands of pounds	469,560	468,720	450,240	472,920	521,360
Yield of gasoline, per cent	43.7	43.4	44.2	44.1	43.9
Value of crude at well, U.S., thousands of dollars	608,000	904,825	961,440	1,199,820	1,530,000
Average price per bbl. at well	$0.67	$1.00	$0.97	$1.09	$1.20
Producing wells, U.S.	326,850	330,070	340,990	349,452	351,206
Wells completed, U.S.	8,068	12,512	15,108	17,800	22,143
Refineries, U.S.	591	631	632	572	583
Crude-oil capacity of refineries, U.S.	3,918	4,059	4,117	4,295	4,376

The fact should not be lost sight of that all mineral oils are complex mixtures of the various hydrocarbon series, not only of those and their derivatives mentioned here but also probably of many others. Comparatively few pure hydrocarbons have been isolated and identified so far as oils are concerned. Very

little information is available regarding the heavier hydrocarbons of petroleum, particularly those of the naphthene series.

7. Petroleum Statistics.—The total estimated petroleum reserves of the world as of Jan. 1, 1937, were approximately 20,000,000,000 barrels, and those of the United States were 14,753,515,046 barrels. For the past 4 or 5 years the annual production and new discoveries in the United States have been approximately equal. The oil industry is the third largest industry in the United States, there being about 14 billion dollars invested in it.

Some statistics of the oil industry are shown in Tables V and VI.

TABLE VI.—DOMESTIC DEMAND FOR LUBRICATING OILS
(Thousands of barrels)

Year	Automotive				Industrial	Grand total
	Passenger cars	Trucks	Busses	Total		
1929	9,754	2,010	188	11,952	11,657	23,609
1930	9,899	2,004	213	12,116	9,473	21,589
1931	9,782	1,965	221	11,968	8,100	20,068
1932	8,780	1,739	216	10,735	5,879	16,614
1933	8,516	1,757	212	10,485	6,667	17,152
1934	8,920	1,920	227	11,067	7,417	18,484
1935	9,098	2,043	241	11,382	8,279	19,661
1936	9,721	2,270	255	12,246	10,077	22,323
1937	10,111	2,444	270	12,825	10,549	23,374

CHAPTER II

PETROLEUM REFINING

Crude petroleum is one of the world's most valuable resources, mainly because of the many essential commercial products that are made from it. It is the job of the refiner to prepare these products for commercial use.

1. Variety in Refining Processes.—Although there are only three general types of crude petroleum, *viz.*, paraffin base, naphthene (asphalt) base, and mixed base, yet few crudes can be definitely assigned to any one particular type, because many have such intermediate properties that they are misfits in any one type. Because of this wide difference in crudes, refining processes, also, vary widely. No two refineries employ exactly the same processes. Fundamentally, the method of processing employed is the one that will produce from the available crude the most profitable commercial products at the least cost. The selection of the process depends mainly on: (*a*) the value and accessibility of the crude, (*b*) the value and marketing possibility of the finished products, (*c*) yield of products, and (*d*) cost of processing.

Differences in refining processes, however, are largely a matter of detail. Space does not permit a discussion of the various details; hence, only the basic principles of refining will be outlined.

2. Classification of Refineries.—Refineries may be divided into four major groups, as follows:

1. *Topping plants*, which are employed primarily for the production of fuel oil. Only the light, low-temperature boiling fractions are removed from the crude.

2. *Skimming plants*, which are used mainly for the production of gasoline, naphtha, kerosene, gas oil, and fuel oil. Gasoline is the principal product, and fuel oil is made from the residuum. Some skimming plants, however, use high-grade crude occasionally and dispose of the residuum as untreated cylinder stock instead of as a fuel oil.

TABLE VII.—MAJOR REFINING PROCESSES

- Refining processes
  - 1. Distillation
    - Fire distillation
    - Steam distillation
    - Vacuum distillation
      - Topping or skimming
        - To cylinder stock
      - Complete distillation
        - To flux
        - To coke
      - Redistillation
        - Gasoline
        - Kerosene
        - Lubricating oils
  - 2. Absorption
    - Percolation
    - Contact
    - Clay treatment
      - Liquid-phase process
        - Fuller's earth
        - Bone char
        - Silica gel
        - Proprietary clays
      - Vapor-phase process
        - Activated charcoal
  - 3. Cracking
    - Liquid phase
      - Tubestill
      - Cross
      - Dubbs
      - Holmes-Manley
      - Tube-and-tank
    - Vapor phase
      - Gyro
      - DeFlorez
      - Pratt
  - 4. Crystallization
    - Nonsolvent
      - Filtering and sweating
      - Cold settling
      - Centrifuging
    - Solvent
      - Acetone-benzol
      - Propane
      - Bari-Sol
  - 5. Chemicals
    - Acid treatment
    - Doctor treatment
    - Hypochlorite treatment
    - Inhibitors and addition agents
    - Solvent extraction and deasphalting
      - Liquid sulfur dioxide (Edeleanu process)
      - Carbolic acid (phenol process)
      - Furfuraldehyde (furfural process)
      - Beta beta dichlorocthylether (Chlorex process)
      - Nitrobenzene
      - Propane-cresylic acid (Duo-Sol process)
      - Aluminum chloride (Alchlor process)
  - 6. Polymerization
    - Catalytic process (phosphoric anhydride)
    - Thermal process
      - Unitary
      - Multiple coil
  - 7. Hydrogenation
    - Low temperature (660–795°F.)
    - High temperature (932–1112°F.)

3. *Cracking plants* are utilized to convert by thermal decomposition (cracking) heavier fractions, such as gas oil, into gasoline. The cracking plant is sometimes used in conjunction with the skimming plant, but more often it is an adjunct to a complete refinery.

4. *Complete refineries* are equipped to process crude completely. Gasoline, kerosene, fuel oil, lubricating oils, waxes, asphalts, and, frequently, many specialties are simultaneously produced.

3. Refining Processes.—Crude petroleums are refined, and finished products are manufactured, by employing in succession one or more of the seven major processes: (*a*) distillation, (*b*) absorption, (*c*) cracking, (*d*) crystallization, (*e*) use of chemicals, (*f*) polymerization, and (7) hydrogenation, as shown in Table VII.

4. Distillation.—Distillation is employed in all cases as the first process of refining. From the lightest hydrocarbon gases to

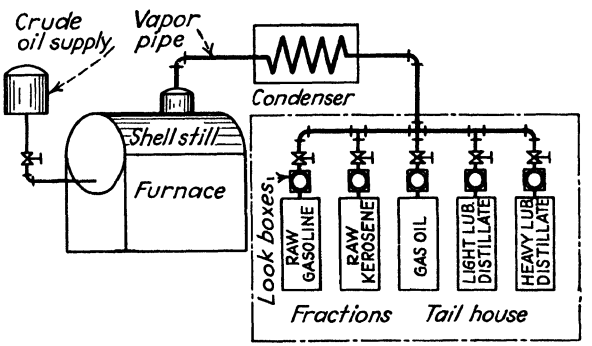


FIG. 9.—Schematic diagram of batch distillation unit.

the heaviest refinery sludges, separation of crude into various fractions is accomplished by distillation and subsequent condensation. The separation of crude into fractions is based on the fact that all crudes are mixtures of many complex hydrocarbons, all having different boiling temperatures.

The oldest but least used and simplest method by which fractionation is accomplished is the *intermittent* or *batch system*, which employs only a shell still and condenser, as in Fig. 9.

In this system, batches of crude oil are charged into the shell still and heat is applied. The fraction having the lowest boiling-temperature range is first vaporized and subsequently condensed. The heat is then increased, and the fraction having the next low-

est boiling-temperature range is vaporized and condensed, etc., until all fractions have been removed, except a residue known as *bottoms* or residuum. These bottoms are drained from the still, which is then charged with another batch of crude, and the process is repeated.

The intermittent system of distillation is little used at present, having been superseded by one of several *continuous systems.* There are three principal methods for continuously distilling crude oil with the shell still. First, as in Fig. 10, the still is charged continuously with crude oil and the vapors are passed through a series of condensers, each of which is automatically maintained at a constant temperature but each at a different

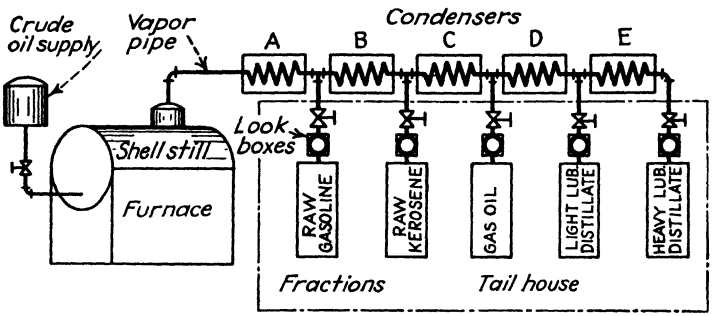


FIG. 10.—Schematic diagram of continuous distillation unit.

temperature. The first condenser is maintained at the highest temperature, and each succeeding one at a lower temperature. The fraction having the highest boiling-temperature range is condensed first, that having the second highest is condensed next, etc., in order, to the last condenser in the series where the fraction having the lowest boiling-temperature range is condensed. This is known as *fractionation by condensation.*

The second way for continuously distilling crude is by means of a battery of shell stills arranged in series. Each still is maintained at a constant but different temperature. The temperature in the first still is the lowest, and that in the last still is the highest, the intermediate still being maintained at intermediate temperatures. The lowest boiling-temperature-range fraction is, of course, vaporized in the first still, and the second lowest in the second still, etc., in order. This system obviously requires a still for each fraction. The method is known as *fractionation by*

distillation. In some instances, batteries of these stills are arranged on hillsides; the oil then flows from one still to the next by gravity, the necessity for pumping being thus eliminated.

The third method of continuously distilling crude oil by utilizing shell stills is to employ a combination of the first and second methods.

Shell stills may be grouped into three divisions: (*a*) fire still, (*b*) steam still, and (*c*) vacuum still.

All shell stills are cylindrical in shape, somewhat like a boiler, and are made of strongly riveted, heavy boiler plates. They vary greatly in size and may be as much as 40 ft. in length and 14 ft. in diameter. On the top of all horizontal stills there is a cylindrical dome usually equipped with safety devices and to which is attached the "vapor pipe."

The first still is externally heated by direct fire, and it usually operates at atmospheric pressure but may operate as a pressure still, *i.e.*, above atmospheric pressure. In the true steam still the oil is heated by a combination of open steam sprays and a closed steam coil placed in the bottom and submerged in the oil. The more common practice, however, is to heat the oil by a combination of direct external fire and steam, which is introduced into the body of the oil through a perforated pipe coil at the bottom of the still.

The use of direct steam results in three important benefits: (1) It lowers the distillation temperature by reducing the partial pressure of the oil, thereby minimizing cracking of the crude. (2) It maintains the bottom of the still cleaner and agitates the oil, thus increasing the efficiency and life of the still. (3) The agitation of the oil by the steam increases the capacity of the still and also permits closer boiling-temperature fractions to be produced.

The vacuum still, as the name indicates, operates below atmospheric pressure, thus permitting the distillation of the crude to occur at a lower temperature than it would if a higher pressure were used. It also minimizes cracking of the crude and is frequently used for the highest grade of lubricating oil.

Since in both the vacuum and steam stills the crude is not heated to so high a temperature as in the fire still, the amount of condensing surface and cooling equipment is less than that required for the fire still.

Many shell stills are in use yet, but they are rapidly being displaced by the pipe still, especially for primary distillation purposes. The pipe still, as in Fig. 11, consists of a large number of tubes or pipes connected by return bends, which are heated in a proper furnace. The crude oil is pumped through the pipes at a very high velocity, and its temperature is increased as it flows through the pipes.

Pipe stills are much more efficient and flexible than shell stills, and they may be used for all types of oil-refining processes that involve the heating of crude oil or its fractions. When crudes contain emulsified water, there is a tendency for them to foam in shell stills, which is not the case when they are distilled in a pipe

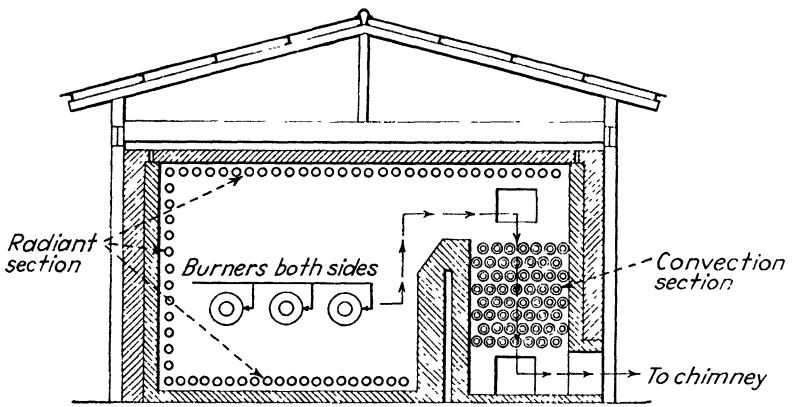


FIG. 11.—Pipe still for distilling and cracking services.

still. Another advantage of the pipe still is the ease with which an integral steam superheater can be installed for supplying high-temperature steam for distillation purposes. This steam is usually the exhaust steam from pumps.

Like shell stills, pipe stills may be operated either above, below, or at atmospheric pressure.

From the foregoing description of distilling methods and equipment, it might be supposed that fractionating crude oils is a comparatively simple process. Such is not the case; for when a liquid consisting of a mixture of complex hydrocarbons is distilled by the methods outlined, some of the heavier, high-boiling temperature hydrocarbons evaporate along with the lighter, low-boiling-temperature ones, and vice versa. By these methods, therefore, it is not possible to obtain very close boiling-tempera-

ture fractions, and it is necessary to redistill many of the fractions before making them into finished products.

In order to minimize this difficulty, the modern refinery uses a fractionating *column* or *tower*, which is a vertical steel cylinder. These towers are connected to a tube type of still, in which the crude is vaporized, the oil vapor passing from the still into and up through the tower. The basic action inside a fractionating tower results from the fact that the tower is cooler than the still and that its temperature varies from high to low from bottom to top. Consequently, the heavy, high-boiling-temperature hydrocarbons are condensed at or near the bottom of the tower, whereas the light, low-boiling-temperature ones are condensed at or near the top.

The earlier fractionating towers were known as *packed towers* and were filled with some material, such as crushed stone or broken tile, that presented a large amount of surface to the ascending vapor. The packed tower was followed by *baffle-plate and perforated towers* which, in turn, have been largely displaced by the so-called *bubble tower.*

Although these various types of fractionating towers vary in details, they all operate on the same basic principle, which may be explained by referring to Fig. 12. If hot-oil vapor is introduced beneath the surface of the cooler liquid in vessel *A*, it will be slightly cooled as it bubbles through the liquid and a large percentage of the heavier hydrocarbons will be condensed and remain in *A*, and the vapor leaving *A* and entering *B* will be lighter and will have a somewhat lower boiling-temperature range than that which entered *A*. Consequently, as the vapor passes through *B*, *C*, and *D* in succession, it becomes progressively lighter until finally, when it possesses the desired boiling range, it is led to condenser *E* and collected in receiver *F*. If, as is done, connections were made to each vessel *A*, *B*, *C*, and *D* and vapors were removed and subsequently condensed at these points, fractions having different boiling-temperature ranges would be secured.

To secure closer fractionation or separation of vapors a counterflow of the condensate from condenser *F* is provided. Consequently, a portion of the liquid is returned from *F* to vessel *D* and from *D* to *C*, etc., as shown. The action inside all fractionating towers is thus a washing or scrubbing process, in which rising

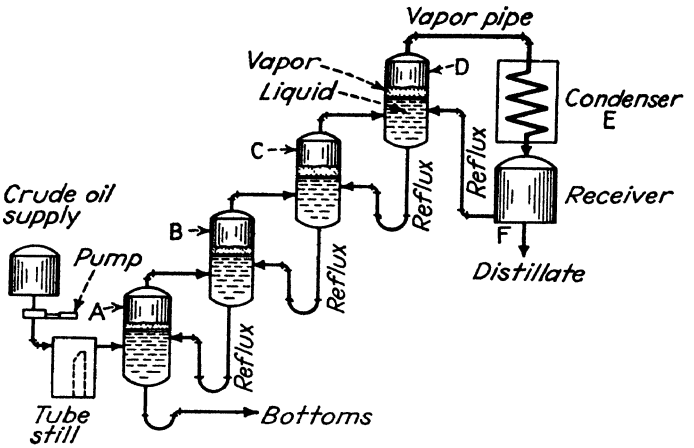


FIG. 12.—Principle of fractionating tower.

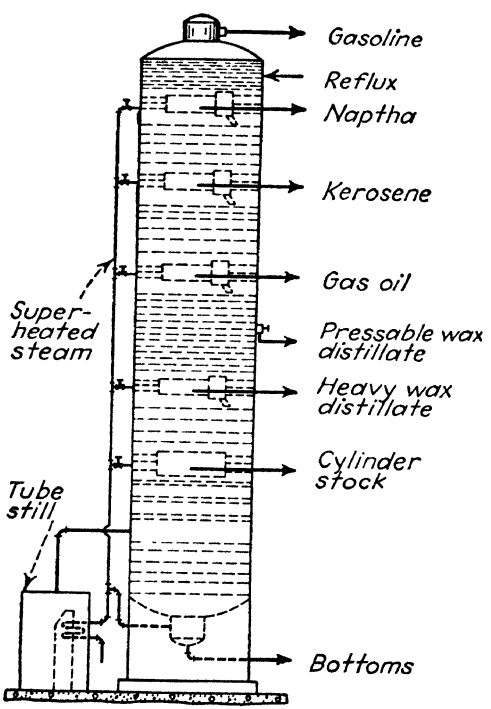


FIG. 13.—Fractionating tower.

vapors flow through descending streams of liquid called the *reflux*. The ratio of the weight of reflux to the weight of the product is known as the *reflux ratio*. The greater this ratio, other things being equal, the closer the fractionation.

Actually, fractionating towers are constructed as an integral unit and divided into sections by means of steel or cast-iron trays or plates, as in Fig. 13. The number of sections depends on the number of fractions desired, and the number of trays per section depends on the size of the tower. Shown in Fig. 14 is a diagram-

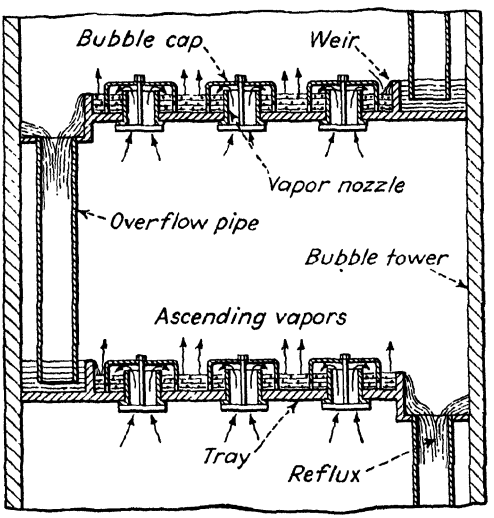


FIG. 14.—Section of bubble tower.

matic section of a bubble tower. The bubble caps effect a more intimate contact between the ascending vapors and descending liquid.

5. Absorption.—This is a secondary refining process to which some stocks are subjected for certain purposes; it may be defined as the *adherence* of a film of substance to a surface. Although the exact mechanism of absorption is not well understood, it may be said that the absorbent material exerts an attraction for certain molecules of a liquid or gas. This molecular attraction is always accompanied by an increase in temperature, which is caused by the *heat of moistening*.

Two general absorption methods are used to refine petroleum products: (*a*) the percolation method, and (*b*) the contact method.

The percolation method has been in use for many years, but the contact method has come into general use in recent years.

The percolation method is carried out in large, vertical steel cylinders called *filters*, which vary from 15 to 30 ft. in height and from 5 to 15 ft. in diameter. The absorbent material is supported on a false bottom, either perforated or of open construction covered with canvas. These filters are usually constructed to withstand pressures of 40 to 50 lb., in order to provide sufficient strength for air blowing and steaming.

In operation, filters are filled with an absorbent material, usually fuller's earth, and the charging oil stock is pumped in at the top under 5 or 6 lb. pressure until it "shows through." The filter is left standing or "soaking" then for 12 to 24 hr. to eliminate the danger of the absorbent material from channeling. The pressure is then increased to approximately 15 lb. The oil first through or "off" has less color than that desired, but as filtration progresses the oil off becomes darker until the blend finally possesses the desired color.

When the oil off becomes too dark, pumping of the charging stock is discontinued and air is applied under pressure, which forces most of the oil remaining through and out of the filter. Light naphtha is then pumped through the absorbent material to flush out the absorbed matter, after which steam is introduced to displace the naphtha. The absorbent material is then dumped; and the filter is inspected, closed, and refilled with either a fresh or a regenerated charge of the absorbent material, after which it is ready for another run.

The contact method of absorption consists of agitating together the charging stock and absorbent material at some temperature favorable to maximum efficiency, after which they are separated by means of a cell type filter press. In practice, the charging stock and clay are mixed and agitated in tanks and pumped to a pipe heater. The temperature of the mixture at the outlet of the heater depends on the nature of the oil and clay, but usually it is between 350 and 600°F. The mixture is then cooled, and, if not too viscous, may be filtered at temperatures from 200 to 300°F. If too viscous, however, it is diluted with naphtha before filtering.

The efficiency of the contact method is much greater than that of the percolation method, varying from three to twenty times as

great. A disadvantage, however, is that the clay is of little use after one application, whereas the clay used in the percolation method may be regenerated by burning and re-used as many as eighteen to twenty times.

Absorption refining has the effect of removing to a considerable extent the asphaltic and resinous constituents as well as of reducing distinctly the color and to a slight degree the gravity and viscosity of the oil.

6. Cracking.—This is also a secondary refining process used to convert by thermal decomposition (cracking) heavier fractions, such as gas oil, into lighter more volatile fractions, such as gasoline. Hydrocarbons, suddenly heated to a high temperature above their boiling points, subjected to either high or low pressures, and not given time to distill in the ordinary manner, crack or decompose into simpler hydrocarbons having lower boiling points.

Although gas oil is the most common charging stock, kerosene, heavy residual oils, and even crude oils are used. The type of charging stock used is mainly an economic question. The products obtained from the cracking plant are fixed gases, gasoline, coke, and sometimes Diesel and furnace oils. Approximately 50 per cent of the gasoline used at the present time in the United States is of the cracked type. From the standpoint of antiknock characteristic, cracked gasoline is superior to other types, except polymer gasoline.

Since gasoline produced by the cracking process is superior, it is now common practice to reform by cracking other gasolines low in antiknock value. This process is known as *re-forming.*

As indicated in Table VII, commercial cracking processes are broadly classified as *liquid phase* and *vapor phase.* Of the two, the liquid-phase processes are more generally used.

7. Crystallization.—This is a secondary refining process used to extract waxes mainly from *wax distillates* and *residual oils,* chiefly cylinder stocks.

The waxes found in wax distillates and in residual oils are quite different in character and are known, respectively, as *paraffin wax* and *petrolatum.* It was formerly thought that paraffin wax was crystalline in structure and that petrolatums had an amorphous or a noncrystalline structure. But it is now thought that both waxes have a crystalline structure and that the difference is

mainly in the size of the crystals, those of petrolatum being very small comparatively. In coking processes a third type of wax, called *slop wax* or wax tailings, is encountered. It is stringy and brittle and is of little commercial value.

As indicated in Table VII, lubricating oils are dewaxed by two general processes: (1) the nonsolvent or mechanical process, and (2) the solvent process.

The nonsolvent process may be carried out by either of three methods: (*a*) filtering and sweating, (*b*) cold settling, or (*c*) chilling and centrifuging.

A typical nonsolvent process of filtering and sweating is shown in Fig. 15; it consists of chilling the wax distillate and then passing

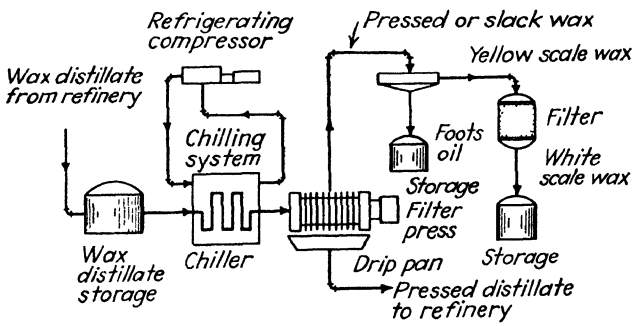


FIG. 15.—Simplified diagram of nonsolvent dewaxing process.

it through the filter press, where the wax is filtered out. The oil pressed from the wax is known as *pressed distillate* and is further refined by filtration or by distillation and filtration, after which it is called *filtered neutral*, which is used as a blending stock to make various lubricating oils. The *pressed* or *slack wax* is removed from the filter press to the sweat pan, where additional oil (foots oil) is sweated out; then known as *yellow-scale wax*, it is further refined by filtering and sometimes treated with a dilute solution of soda, washed, blown dry, and then filtered. The finished wax ready for the market is known as *white-scale wax*.

The filtering and sweating method is generally applied to wax distillates, but it has also been recently applied to cylinder stocks through the use of a filter aid, which makes it possible to filter out the minute wax crystals of petrolatum. Residual cylinder stocks, however, are generally dewaxed by either cold settling or centrifuging.

Cold settling is a gravity settling process and is usually carried out as follows: First, the stock is diluted with 60 to 70 per cent naphtha in order to hasten separation of the wax and oil. The mixture is then charged into tank settlers, which are provided

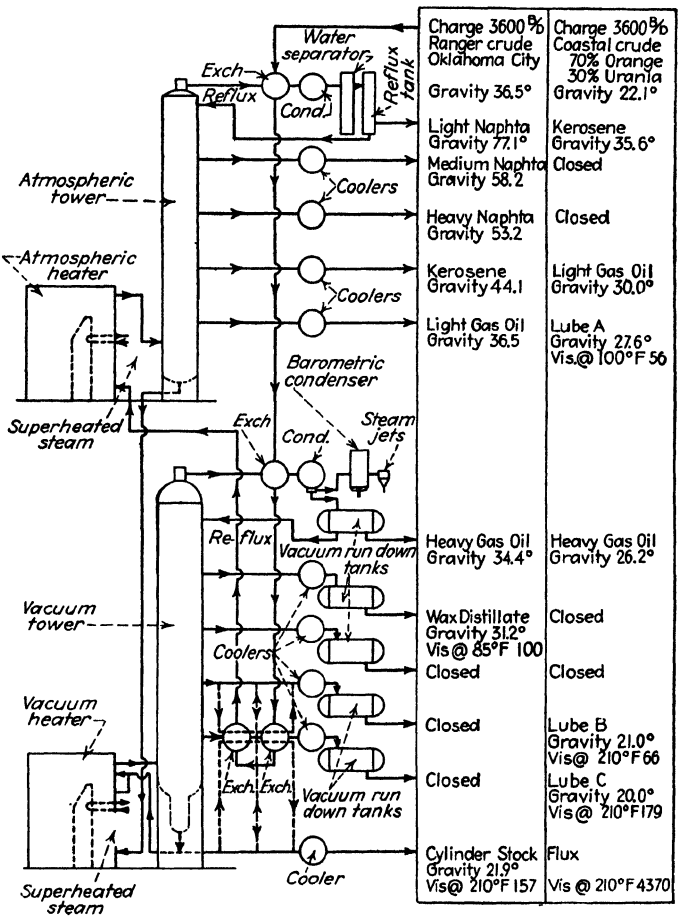


FIG. 16. – Two-stage atmospheric and vacuum distillation unit.

with cooling coils, and gradually cooled to 8 or 10°F., when refrigeration is stopped. The mass is allowed to settle for 24 hr., during which time the petrolatum settles and accumulates at the bottom. The oil-naphtha solution, called *bright-stock solution*, is then pumped off and run to a still, where it is separated into bright stock and naphtha. After filtering, the bright stock is

ready for blending with distillates to make various finished lubricating oils.

The centrifuging method of dewaxing is now generally used to separate petrolatum and cylinder stock. The essential difference between this method and cold settling is that the separation is effected by means of a centrifuge. The stock is diluted with naphtha, is chilled to the necessary temperature to produce the desired pour point, and is then fed continuously to a centrifuge, which discharges oil-naphtha solution from one outlet and petrolatum from another. The resulting products are then given treatments similar to those employed in the cold settling method.

The advantages of this method are continuous operation, lower cold test for the dewaxed oil, greater yield of dewaxed oil, higher uniformity of product, and higher quality petrolatum.

Since the foregoing methods of dewaxing are not commercially applicable to all types of wax-bearing stocks, considerable efforts have been made from time to time to develop a single method by which all wax-bearing stocks can be dewaxed. As a result of these efforts, the solvent process of dewaxing has come into commercial use in recent years. Many different solvents have been proposed as diluents for dewaxing purposes, but still only three—acetone benzol, propane, and Bari-Sol—have achieved commercial success at the present time.

In both the acetone benzol and Bari-Sol processes, chilling is accomplished by indirect ammonia refrigeration at a relatively high rate. This is one important difference between these processes and the conventional method of dewaxing by centrifuging where the rate of chilling is not greater than 4 or 5°F. per hr. Propane dewaxing uses the diluent (propane) direct as a refrigerant. In the acetone benzol and propane processes the wax is separated from the oil-solvent solution by means of a stationary batch, rotary batch, or continuous rotary type filter, whereas, in the Bari-Sol process, separation is by means of a special centrifuge. The acetone benzol and Bari-Sol processes are continuous, and all steps in the propane process are continuous except that of chilling.

The products of these processes are further treated in the same manner as in the conventional dewaxing methods.

The advantages of the solvent dewaxing processes over conventional dewaxing methods may be summarized as follows:

1. Greater yield of lubricating oil from same charging stock.
2. Oil contains less wax, consequently has lower pour point.
3. Oil can be dewaxed without first filtering to color, the cost of filtering the wax thus being saved.
4. Both paraffin and petrolatum types of waxes can be removed by one process, the cost of dewaxing thus being lowered.
5. Charging stock may be run to specifications in primary distillation unit, the costs of rehandling and redistillation thus being saved.

8. Refining by Use of Chemicals.—Chemicals are used in petroleum-refining processes for two purposes: (1) to remove objectionable foreign substances such as sulfur compounds, tars, gums, resins, and carbon; and (2) to separate the hydrocarbons on the basis of their chemical activity and structure. The distillation process separates the molecules of petroleum according to their size only. But petroleum contains many molecules which are approximately of the same size but which chemically are quite different. For example, an oil may and usually does contain paraffin, olefin, naphthenic, aromatic, and other hydrocarbons. Although the molecules of the various hydrocarbons may be of the same size, yet their chemical activity and structures are widely different, as pointed out in Chap. I.

Chemicals, as employed in refining processes, act in two very different ways: (1) chemically with certain constituents of the oil; and (2) physically as solvents for certain undesirable constituents.

At the present time, four major processes are used, in which the chemicals react directly with certain undesirable constituents of the oil, and one major process, in which the chemical acts physically. The pure chemical processes are: (1) acid treatment; (2) doctor treatment; (3) hypochlorite treatment; and (4) addition-agent treatments. The single use of chemicals in a physical sense is the solvent-extraction process, which is subdivided into several methods depending on the solvent employed, as in Table VII.

The acid treatment employed today is essentially that suggested by Silliman in 1855. It is the oldest of all chemical treatments and is still very generally used. It is employed for treating practically all types of petroleum products, such as gasoline, kerosene, and some of the lubricating oil stocks and waxes. It consists essentially of first treating the stock in a batch agitator or a continuous system with concentrated sulfuric acid, then neutralizing with an alkali, usually sodium hydroxide (NaOH), and finally washing with water. During both the acid and alkali

treatments, the charge is usually agitated by means of compressed air or a recirculating system. In the case of lubricating oil stocks, the water wash is generally followed by blowing with air to remove any water that may be present. This procedure is known as *blowing bright.* The concentration of the acid used varies from 75 to 98 per cent; 93 per cent finds the most general use. The degree of refinement effected depends on the concentration of the acid, quantity of acid used, temperature at which the treatment is conducted, and time of contact, all of which are varied, depending on the stock in question.

The acid treatment, in general, improves color and reduces asphaltic-, sulfur-, nitrogen-, and gum-forming compounds and odors to a certain extent.

The doctor treatment is a so-called *sweetening* treatment used to remove elementary sulfur and mercaptans (sulfur alcohols) from light distillates, which substances cannot be effectively removed by the acid treatment. Mercaptans give a foul odor to distillates and in the presence of elementary sulfur cause the distillates to be corrosive. The process consists of agitating the distillate in question with a little sulfur and with an alkaline sodium plumbite solution. The concentration of the sodium hydroxide solution varies from 8 to 24 per cent and is saturated with litharge (lead oxide) before it is mixed with the distillate. Both the continuous and batch methods of treatment are used.

The hypochlorite treatment is also a sweetening process that is extensively used for treating natural and straight-run gasolines. The hypochlorite solutions generally used are sodium (NaOCl) and calcium ($Ca(OCl)_2$). In preparing these solutions an excess of alkali is used.

Improvements in the quality and suitability of petroleum products may be accomplished not only by removing undesirable constituents and impurities and by changing the chemical structure of others but also by adding to them various agents. These addition agents or inhibitors were first used in gasolines to minimize, during storage, deterioration in color, octane value, and gum content. The deterioration of gasoline in storage is primarily caused by oxidation; hence, gasoline inhibitors or antioxidants, such as alpha naphthol, catechol, hydroquinone, and para-hydroxyphenyl morpholine, are substances that retard oxidation.

More recently, agents have been also added to lubricating oils, particularly the automobile and aircraft lubricants, not only to retard oxidation while in service, but also to improve viscosity index, pour point, oiliness, load-carrying capacity or film strength, corrosion characteristics, and color. Some of these agents have been in use for a long time, whereas others have been employed only recently. For example, the use of animal and vegetable oils and fatty acids to improve the oiliness of mineral oils has been practiced from the very beginning of the lubricating-oil industry. Recently, the esters of chlorinated aliphatic acids and monohydric alcohols have come into use as oiliness agents.

At present, a proprietary product Exanol (also called *Paratone*) is widely used as a viscosity-index improver. This is a heavy, resin-like, synthetic material prepared by polymerizing the light ends of refinery gasoline.

Many substances, including benzyl chloride, aluminum stearate, zinc and magnesium hydrostearate, and esters of cholesterin, have been suggested as pour-point depressants. The two best known, however, are the proprietary agents Paraflow and Santopour. Paraflow is a condensation product of chlorinated wax and naphthalene in the presence of aluminum chloride. Santopour is also a condensation product, prepared by first condensing phenol and chlorinated wax in the presence of aluminum chloride and then further condensing the product of this reaction with phthalyl chloride.

For increasing the film strength of lubricating oil intended for certain purposes, lead soaps, sulfur, and chlorides have been used alone and in various combinations.

Corrosion inhibitors include compounds of phosphorus, arsenic, and antimony and organic compounds of chromium, bismuth, mercury, and other metals.

Oxidation inhibitors include phenolic derivatives, naphthols, naphthylamines, aniline derivatives, elementary sulfur, disulfides, chlorine, phosphorus, arsenic, antimony, selenium, and tellurium.

Many of the agents used for imparting color to lubricating oils are petroleum derivatives, but a number of synthetic organic dyes are also used.

The major undesirable constituents of crude oil are generally considered to be asphaltic substances, wax, and low-viscosity-

index or chemically unstable hydrocarbons. The old, conventional refining methods employing sulfuric acid, sodium hydroxide, and clay as the principal reagents are quite capable of removing the asphaltic compounds and the chemically unstable hydrocarbons. But the action of sulfuric acid on oil is apparently both physical and chemical. By modifying the conditions of acid treatment, it is possible to control to a certain degree the predominance of these two major actions of sulfuric acid, but it is not possible to eliminate either completely. For this reason, acid-refined oils may contain certain substances produced during the course of refining, such as products of polymerization and condensation and sulfonated bodies. The problem of disposing of the acid sludge and the loss of oil in the sludge are also undesirable features of the acid-refining process. These shortcomings of the acid-refining process has led to the solvent-extraction process, which is purely physical in action and permits the recovery of both the desirable and undesirable constituents in their original state. The solvent method, however, is not effective in removing the asphaltic compounds. It is, therefore, necessary to employ a deasphalting treatment whenever the solvent-extraction process is used. Thus, two distinct refining processes are substituted for the acid treatment.

Dewaxing of petroleum oils has always been and continues to be a distinct refining process.

From the foregoing discussion, it is evident that the present modern methods of refining consist of: (1) distillation, (2) solvent extraction, (3) deasphalting treatment, and (4) dewaxing.

This division is not well defined in practice, for some of the reagents employed may exercise two or more actions on the oil. For example, certain deasphalting agents, such as propane, may also act as a dewaxing agent, and certain solvent-extraction agents may remove in part the asphaltic compounds, etc.

If two liquids are mixed, they may act in one of three possible manners: (1) They may blend perfectly to form a single homogeneous liquid, *i.e.*, they may be perfectly miscible. (2) They may not mix or blend at all, one settling to the bottom and the other rising to the top, thus being perfectly immiscible. (3) They may in part be mutually soluble, forming two separate phases, one consisting predominantly of one of the liquids and the other consisting predominantly of the other.

In the refining of petroleum oils by the solvent-extraction method, it is the last of the three foregoing cases that provides refining action. Certain hydrocarbons of the oil must be soluble to a limited but appreciable extent in the solvent in order to bring about solvent extraction. In other words the system must be two phase in order that it may be operative.

Three methods are employed in applying the solvent to the oil: (1) single batch extraction, in which the solvent is applied to the oil in a single dose; (2) multiple batch extraction, in which the solvent is applied to the oil in several doses each of which consists of fresh solvent; and (3) countercurrent extraction, in which fresh solvent is mixed with the oil leaving the extraction system and partially spent solvent is mixed with the incoming oil containing many impurities.

In general, all commercial solvents have a stronger affinity for the aromatic type of hydrocarbons than for the paraffin type; hence, the undesirable aromatic type is removed in the extract and the desirable paraffinic type remains in the raffinate. Most solvents have also a certain selective action toward the lower molecular-weight paraffinic type hydrocarbons. In some cases, these hydrocarbons may be more soluble than the aromatic compounds of higher molecular weight.

The selectivity and solubility of various solvents are affected by: (1) nature of the solvent used, (2) quantity of solvent used, (3) temperature of extraction, (4) time of contact between oil and solvent, (5) time of settling, (6) method of contacting the oil with the solvent, and (7) nature of the oil extracted.

A number of chemical compounds are capable of exerting preferential solvent action toward the various constituents of petroleum oils. Of these compounds, liquid sulfur dioxide, Chlorex, furfural, nitrobenzene phenol, propane-cresylic acid, aluminum chloride, and sulfur dioxide benzol and others are used commercially.

Deasphalting by use of solvents depends on the ability of certain solvents to precipitate the asphaltic compounds when mixed with asphalt-bearing petroleum stocks. Certain liquefied hydrocarbon gases, notably propane, and aliphatic alcohols are the most generally used commercial solvents for this purpose.

9. Polymerization.—This is a process by which two or more molecules of a substance are caused to combine to form a larger

molecule of a new substance known as the *polymer*. In petroleum refining, the polymerization process is chiefly used to convert cracking still gas, uncompressible refinery gas, and natural gas to gasoline. The most easily polymerizable gas is the cracking still gas formed when oils are cracked in the vapor phase. Paraffin gases, such as butane, propane, and ethane, are first converted to unsaturated compounds by dehydrogenation, or pyrolysis, or by cracking, and are then polymerized to form gasoline, whereas the polymerization of olefin gases may occur under the influence of heat alone or in the presence of a catalyst.

Because of the chemical structure of the hydrocarbons formed by polymerization processes, polymer gasoline has a very high octane value and a low sulfur content. Polymer gasolines having an octane number from 75 to 100 are being commercially produced. It has been estimated that more than 1 billion gallons of 95-to-100 octane gasoline and 8 billion gallons of 80-to-83 octane gasoline are potentially available in the United States each year from polymerization of hydrocarbon gases. In 1937, however, there were approximately 100 million gallons of polymer gasoline produced, most of which was used in the aviation industry.

Not only is this method of producing gasoline of great importance in salvaging much gas that is now largely wasted, but it is also of special importance in the aviation industry because of its effect on aircraft performance.

As shown in Table VII, there are two chief methods by which polymerization is accomplished: (1) catalytic action, and (2) thermal action.

As the name indicates, the catalytic process makes use of a catalytic agent (phosphoric anhydride) to bring about polymerization of the gases. The process may be carried out to produce gasoline from either olefin or paraffin gases.

The Unitary or Polyco thermal process is noncatalytic, and gasoline can be produced from either paraffin or olefin gases. The products are gasoline and gas oil.

The multiple-coil or Pure Oil thermal process is likewise noncatalytic, and is quite flexible. The products are gasoline, fuel oil, and tar.

10. Hydrogenation.—This is a process by which undesirable constituents may be changed chemically in the presence of a

catalyst to desirable ones. It is possible to apply it to processing a wide variety of petroleum oils. Crude oil can be converted almost entirely to gasoline, and various fractions can be improved to the desired quality without large losses. Briefly, the process is carried out by adding hydrogen, in the presence of a catalyst, under a pressure of approximately 3600 lb. and 700°F. to the stock.

Less is heard of hydrogenation now than a few years ago. It holds, however, a strong position as a potential refining operation. It is not being used extensively at present, mainly because of unfavorable economic conditions.

CHAPTER III

PETROLEUM PRODUCTS

Crude petroleum is the most versatile of the world's natural resources. Hundreds of products are made from it. They include products for almost every field of commerce and art. With the exception of printing, the petroleum industry has probably affected civilization more than any other single industry. Today, practically every human activity is dependent in one way or another on petroleum and its products. It is the major fuel for transportation on land, upon and under the sea, and in the air. It is the source of lubricants upon which the operation of machinery and radio, telegraph, and telephone communication depend. It is the base of most of the insecticidal sprays that are daily becoming more and more important and necessary in fighting the insect menace. In the field of medicine, it finds wide usage as anesthetics and internal medicine and as the major ingredient in ointments and salves. Many foods are wrapped in paraffin-wax-treated paper, and jars containing foods are often paraffin-wax-sealed. The use of petroleum and its products in every phase of our daily life is almost incredible.

1. Primary Products.—Over 400 primary products and thousands of derivatives are made from petroleum. A partial list of the major primary products is shown in Table VIII. It is beyond the scope of this book to describe all these primary products. Brief mention only will be made of gasoline, illuminating oils, fuel and Diesel-engine oils, insulating oils and waxes. Lubricating oils, however, are described in detail.

2. Gasoline.—The term *gasoline* is used to describe a petroleum fuel that comes within certain commonly accepted volatility limits. Like all petroleum products, it is a mixture of many different complex hydrocarbons. In general its distillation range is approximately 80 to 420°F. From the standpoint of commercial use, it is classified as (1) motor gasoline, and (2) aviation gasoline. Motor gasoline is further classified as (*a*) premium grade, (*b*) regular grade, and (*c*) third grade. Aviation gasoline

is generally classified according to its octane number. At present, 73, 80, 87, 90, 95, and 100 octane aviation gasolines are widely marketed. From the standpoint of refining, gasoline is commonly divided into the following six classes: (1) straight-run gasoline; (2) natural gasoline; (3) cracked gasoline; (4) casing-head gasoline; (5) polymer gasoline; and (6) blended gasoline.

Aviation gasoline differs chiefly from motor gasoline in greater volatility and higher octane number.

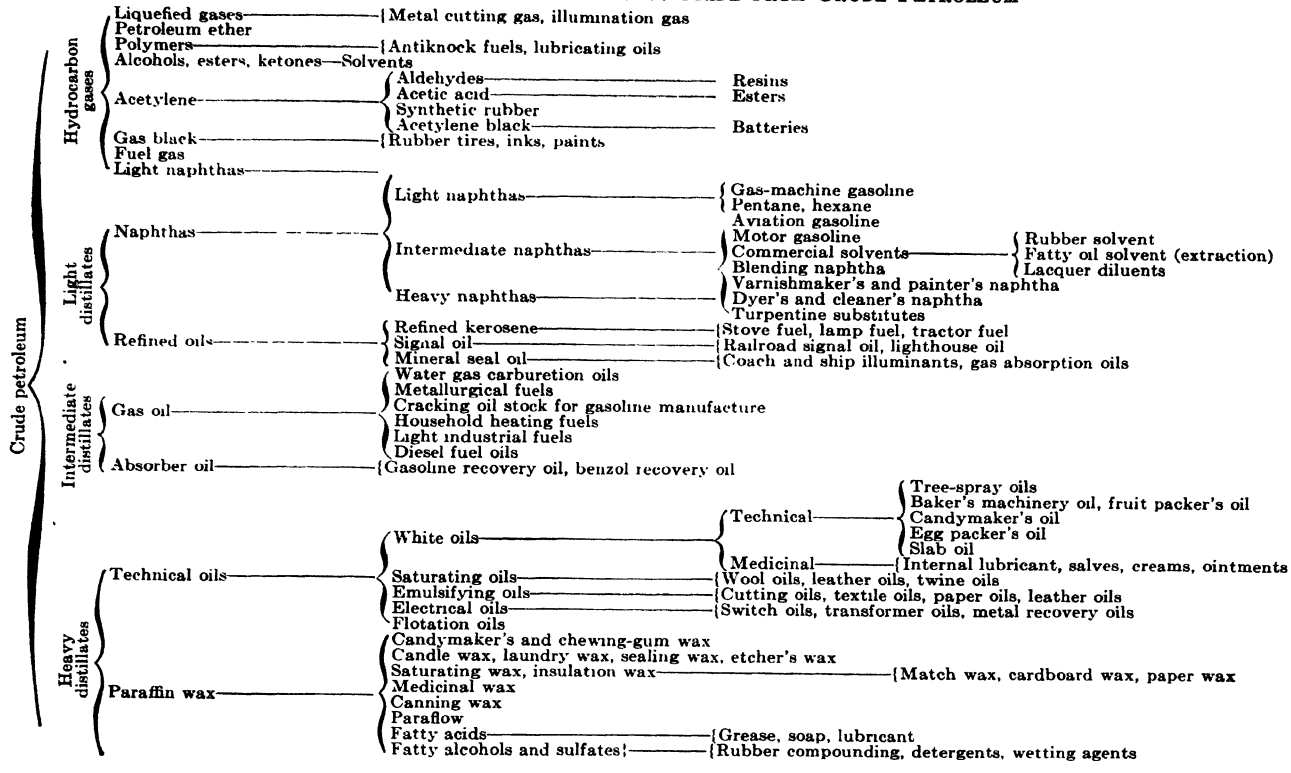
3. Illuminating Oils.—Products of this group include kerosene, signal oil, and mineral seal oil, which is also known as *mineral colza* and 300 *fire-test oil.* Kerosene, the best known of this group, is less volatile than gasoline, having a distillation range of approximately 340 to 550°F. Its gravity generally falls between the limits of 38 and 50°A.P.I. It is intended primarily for burning in wick burners for the production of heat and light, although it is used to a limited extent as a fuel, particularly as a tractor fuel.

Mineral seal and signal oils are less volatile than kerosene. They are used chiefly in lamps of railroad semaphores, switches, lighthouses, harbors, and similar places, where steady burning and only small illumination are required. Signal oil is prepared by compounding mineral seal oil with various fatty oils such as sperm, peanut, and prime lard in order to produce a more persistent flame. Whereas the fire test of kerosene usually varies from 100 to 160°F., that of these heavier illuminating oils is about 300°F., and their gravity ranges from 34 to 42°A.P.I.

4. Fuel and Diesel-engine Oils.—These terms are used to describe any liquid or liquefiable petroleum products burned for the generation of heat in a furnace or firebox, or for the generation of power in an engine, exclusive of oils with a flash point below 100°F., as determined by means of the Tag-closed tester, and oils burned in cotton- or wool-wick burners. Fuel and Diesel oils may be broadly classified as (1) residuals; (2) distillates; (3) crude petroleums and weathered crude petroleums of relatively low commercial value; (4) blended oils, which are mixtures of two or more of the three preceding classes. In general, there are five numbered and three lettered grades of fuel oil.

The distilled oils are chiefly made from gas oil, which is a fraction intermediate between the kerosene and lubricating-oil fractions. *Gas oils* are so called because they were originally made for the carburetion of water gas.

TABLE VIII.—PRINCIPAL PRODUCTS MADE FROM CRUDE PETROLEUM



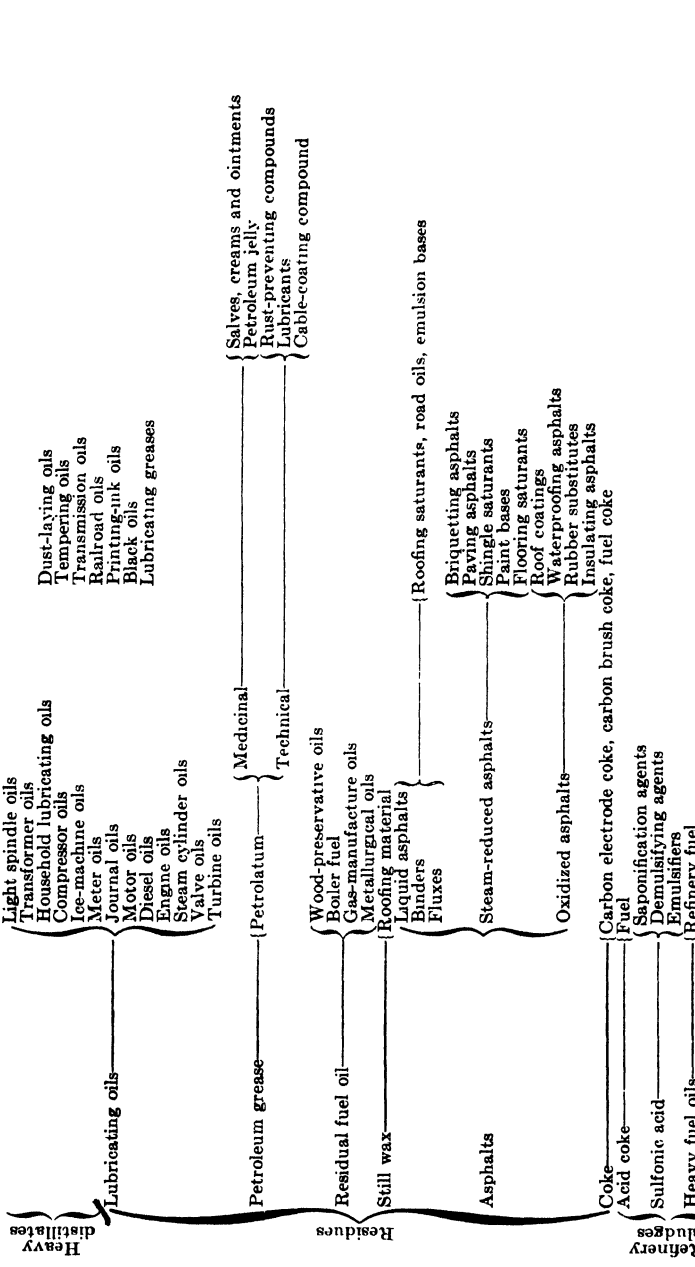


Table prepared by Standard Oil Development Co.

These fuel oils have served not only as fuel oils but also as fuels for Diesel engines. The trend today, however, is toward specification fuels for Diesels. Consequently, Technical Committee C on Fuel Oils of the American Society for Testing Materials has developed the classification shown in Table XLVII. As in the past, it is quite probable that fuel-oil stocks will be the basis of Diesel fuel oils. It is generally recognized that Diesels, especially high-speed units, require cleaner, more uniform, and higher ignition-quality products than furnace burners.

5. Insulating Oils.—Petroleum oils are employed to insulate transformers and switches by immersion, to saturate fibrous and other insulating materials, and as an ingredient in certain insulating paints and varnishes. Desirable characteristics of these oils are: high resistivity and dielectric strength; low viscosity; high flash point; chemically neutral toward metals and insulating materials; freedom from water, sediment, and impurities; and chemical stability under local high temperatures. In general, these oils are of the nonviscous type, having a flash point of not less than 300°F. and a viscosity of 80 to 140 S.U.S. at 100°F.

6. Waxes.—In general, four types of waxes are known to the petroleum industry: (1) paraffin wax, (2) petrolatum, (3) slop wax, and (4) rod wax. Paraffin wax is obtained from light wax distillates, petrolatum from residual stocks, slop wax from high-viscosity wax distillates, and rod wax from crude oil. Paraffin wax and petrolatum are the only two of these waxes that are of commercial importance. Slop wax or wax tailings is encountered when wax-bearing crudes are "run to coke." It is stringy and generally considered nonpressable. Rod wax separates from the crude oils around the pump sucker rods.

It was formerly thought that paraffin wax was crystalline in structure and that petrolatum had an amorphous or a noncrystalline structure. But most authorities now believe that all waxes are crystalline in structure but that petrolatum and slop waxes contain certain impurities which act as inhibitors and prevent the formation of crystals. It may be said that at this time the exact chemical nature of these waxes is not known.

The crystals of paraffin wax are definitely known to be of three different forms: (1) plate crystals, (2) needle crystals, and (3) mal-crystalline. Although other factors may be of influence, the rate of cooling is known to affect both the size and the kind of

crystals formed. Paraffin wax, in general, has a melting point ranging from 100 to 150°F. and a specific gravity varying from 0.88 to 0.92. It is very stable with respect to acids and alkalies at ordinary temperatures but readily absorbs odors. It is used for making candles, waxing paper, electrical insulating material, impregnating matches, in floor and shoe polish, as a sealing medium, etc.

Petrolatum is slightly sticky and is more dense and ductile than paraffin wax. Its melting-point range is, in general, from 145 to 165°F. It is obtainable in three grades, amber, light yellow, and yellow. Its specific gravity is usually between 0.82 and 0.87. Its dielectric properties are exceptionally good, and it has found wide use in the manufacture of certain classes of electrical equipment. Different petrolatums have found wide use as a base for salves, ointments, and many cosmetic preparations.

7. Lubricating Oils.—There have been many proposed systems for classifying lubricating oils, but none has been accepted as standard. The simplest method, used for many years by the federal government, was based on viscosity and made use of such vague terms as *light*, *medium*, and *heavy*. These were later modified to include *extra light* and *extra heavy*. The most logical classification would appear to be one based on some specific property or a combination of two or more properties. Many, however, prefer a classification based on commercial use and/or refining process and/or base of crude oil from which the finished products are made. Consequently, lubricating oils will be discussed and classified from the standpoint of: (1) the base of the crude, (2) the refining processes, (3) commercial use.

8. According to Base of Crude.—In the following discussion the broad classification of paraffin base, naphthene base (asphalt), and mixed base will be adhered to, rather than the more complete classification of crudes given in Chap. I.

Paraffin-base Oils.—These are oils made from paraffin-base crudes, especially those made from crudes of the eastern district. In general, oils of this class are considered to be of high quality and suitable for all sorts of machines, such as automobiles, airplanes, steam engines and turbines, Diesel engines, air compressors, and ice machines. These oils are composed predominantly of the saturated hydrocarbons, probably of the paraffin and naphthene series.

Naphthene-base Oils.—These include any oil made from the so-called *naphthene-base* crudes, particularly those made from crudes of the California and Gulf Coast districts. Until the solvent-extraction method of refining was developed, it was difficult to make high-grade lubricating oils from this type of crude, especially for services where a high viscosity index was advantageous, such as for automobile use. Since oils of this type contain practically no wax, they are especially suitable for ice machines and other services that require a low-pour-point oil. The untreated distillates and residues of this type of oil are composed predominantly of unsaturated hydrocarbons, probably of the olefin, aromatic, and acetylene series. In the finished oils, however, these unsaturated hydrocarbons are practically all removed or converted to saturated hydrocarbons.

Mixed- or Intermediate-base Oils.—These include any oil made from crude that is not predominantly paraffinic or naphthenic in character, especially those made from crude of the midcontinent and Rocky Mountain districts. Modern refining methods have made it possible to produce high-quality lubricating oils of this class. The bulk of lubricating oils are produced from the so-called *mixed-base* crudes. These oils are suitable for all types of machines.

9. According to Refining Process.—All lubricating oils may be broadly divided into (*a*) distillates, and (*b*) residuals.

Distillates.—Any oil that has been vaporized and subsequently condensed in the refining process is rightly called a *distillate.* Distillates comprise the bulk of lubricating oils now on the market. They vary in viscosity from about 60 to 600 S.U.S. at 100°F. They are used as straight-cut oils or are blended with residual oils to make finished oils of different viscosities.

Residual Oils.—These are any oils that have not been vaporized and subsequently condensed in the refining process. Notably of this class are the steam cylinder oils, made from paraffin-base crude, and the dark lubricating oils.

Pressed Distillates.—These are distillates made from wax-bearing crudes (paraffin and mixed base chiefly) that have been dewaxed. They constitute the bulk of the low- to medium-viscosity lubricating oils.

Bright Stock.—This is not usually sold in the retail market as such but is widely used as a blending stock to make various

lubricating oils of different viscosities. The term was originally used to describe a residual cylinder-oil stock that had been steam-refined, dewaxed, and filtered, but not acid-treated. The modern bright stock is not always a residual product and may be acid-treated. It is, however, dewaxed and filtered. It is characterized by a low pour point, sulfur content, carbon residue, and small amounts of impurities. Its viscosity is usually 100 or more S.U.S. at 210°F. It may be sold under a trade name in the nonblended state for such services as tractors, airplanes, and other machines requiring a very heavy oil.

Neutral Oils.—This term is practically obsolete; originally, however, these were pressed distillates, initially steam-refined, and not acid-treated, the color being reduced by filtering. Today, the term applies to any distillate of low or medium viscosity, even if made from mixed- or naphthene-base crudes. The viscosity may range from 65 to 300 S.U.S. at 100°F. They are generally considered to be high-quality oils suitable for circulating systems of steam turbines, compressors, and other services that require oils of exceptionally high chemical stability.

Viscous Neutral Oils.—This term originated from the practice of reducing by distillation the neutral fraction to obtain an overhead and a bottom, the bottom being designated as the *viscous neutral.* Roughly, these oils vary in viscosity from 125 to 300 S.U.S. at 100°F. They are frequently blended with bright stock to make finished oils of various viscosities.

Nonviscous Neutral Oils.—This term was originally used to describe the overhead product obtained by distillation of the neutral fraction. In general, the viscosity of these oils varies from 45 to 125 S.U.S. at 100°F. They are often used in the nonblended state as spindle and light machine oils, such as textile or household oils, and, also, they are often used to blend with more viscous oils for other purposes.

Filtered Oils.—Any oil that has been subjected to a filtering process during its manufacturing is called a *filtered oil.* Practically all lubricating oils except dark cylinder oils and dark lubricating oils are of this class.

Nonfiltered Oils.—Any oil that has not been filtered during the course of its refining is termed a *nonfiltered oil.* Dark cylinder oils, dark lubricating oils, and some of the poorer quality lubricating oils are of this class.

Red Oils.—These oils were originally the residual fraction obtained by fire-distilling pressed distillates. They were acid-treated but not filtered. The term is used at present to describe any oil of red color, regardless of the refining process by which it was made. The bulk of the so-called *red engine oils, bearing oils,* and *machinery oils* are of this class. They may be considered as an intermediate grade of lubricating oil for general purposes.

Paraffin Oils.—Originally, this was a term used to describe products that were obtained as the overhead fraction from fire-distilling pressed distillates. They were acid-treated but not filtered. Today, paraffin oils are refined by various processes, and some of the better grades may be filtered and not acid-treated. The viscosity ranges from that of heavy kerosene to 300 S.U.S. at 100°F. The lighter grades are sometimes used as spindle oils in place of the more expensive nonviscous neutrals, and the heavier grades may be used as general machinery oils, loom oils, etc. Many of the tree-spray oils are of this class. They are also frequently used as cutting oils either alone or, more generally, mixed with fixed oils or soaps.

Pale Oils.—This term originally was used to differentiate between the overhead fraction obtained by fire-distilling pressed distillates that were filtered and those not filtered, those not filtered being the paraffin oils and those filtered being termed *pale oils.* The term is now used in a much broader sense to describe any oil of a lemon or pale color, irrespective of how it was refined. Originally, pale oils were considered to be intermediate in quality between the paraffin oils and the neutrals.

Dark Lubricating Oils.—These oils are made from the undistilled residues of crudes or from the residues resulting from the redistillation of various lubricating-oil stocks. Thus, they may be either a residual or a distilled oil. In viscosity they range from about 300 to 2200 S.U.S. at 100°F., the less viscous grades being prepared by blending with a low-quality lubricating oil, such as the so-called *paraffin oil.* They are low-quality oils suitable only for rough machinery, such as foundry, quarry, construction, mine, and dredging equipment.

Fire-distilled Oils.—Any oil that was initially distilled in a fire type still at or above atmospheric pressure is called a *fire-distilled oil.*

Steam-distilled Oils.—An oil is said to be *steam-distilled* or *-refined* whenever steam is used in the initial distillation process to lower the partial pressure of the oil. Most of the higher quality lubricating oils are steam- or vacuum-refined.

Vacuum-distilled Oils.—Oil vaporized or distilled in a still operated below atmospheric pressure is said to be *vacuum-distilled* or *-refined.* The bulk of the higher quality lubricating oils are vacuum- or steam-distilled.

Solvent-refined Oils.—Oils that have been solvent-treated during the refining process are said to be *solvent-refined.* Most of the automobile, airplane, Diesel-engine, steam-turbine and other high-quality lubricating oils are now solvent-refined.

Hydrogenated Oils.—Any oil subjected to the process of hydrogenation is said to be *hydrogenated* or *hydrorefined.* Only a relatively small portion of lubricating oils are so treated at present.

Compounded Oils.—Any oil composed of a mixture of mineral oil and fixed oil (animal or vegetable) is termed a *compounded oil.* The quantity of fixed oil in the mixture is designated as the percentage of compound. Steam cylinder and marine oils are notable examples of compounded oils. The amount of compound seldom exceeds 20 per cent.

Blended Oils.—*Blended oils* are mineral-oil mixtures of two or more fractions or cuts of widely different boiling ranges. For example, a medium-viscosity oil prepared by blending a viscous residual oil with a relatively low viscous distillate is a blended oil. Most lubricating oils are blends.

Straight-cut or -run Oils.—A straight-cut oil is any oil consisting of a single fraction or cut and whose boiling temperature range is relatively narrow.

White Oils.—Any oil that has been treated with fuming sulfuric acid or otherwise decolorized completely is called a *white oil.* White oils are easily made from Russian crudes and are widely used in bakeries and other food-preparation plants. They are seldom made from paraffin-base crudes as it is very difficult to remove all coloring matter from these oils.

Bloomless Oils.—*Bloomless oils* are usually made from the so-called *neutral* oils by filtration and sun bleaching. They are never acid-treated but are frequently treated with nitronaphthalene or similar chemicals. They are light in color and of light

viscosity. Their chief use is as adulterants in edible oils, but they are also used in the preparation of the so-called *stainless* loom and spindle oils.

Voltol Oils.—These are mineral, animal, or vegetable oils, or mixtures of these, that have been subjected to a silent electrical discharge, under specific conditions, which greatly increases the viscosity but is said to cause little change in flash point, acidity, or asphalt content. They are said to be very satisfactory for airplane engines and other machinery that requires high-viscosity oil. They are also said to function as pour-point depressors and viscosity-index improvers.

10. According to Commercial Uses.—Space does not permit even a complete listing of all of the terms used in industry to describe the many different oils. Consequently, only the more common and important industrial oils will be given consideration. It will be realized that all the oils described under this heading fall into at least one of the classes discussed above. Throughout the following discussion the terms *low quality, intermediate quality,* and *high quality* are used, but in a very broad sense. They do not refer to any specific property or properties but are used to describe very broadly the general characteristics of the different oils. Generally, oil companies market at least three grades or lines of lubricating oils. These are usually referred to by the oil companies as *first-, second-,* and *third*-line or -grade products, commanding, respectively the highest, intermediate, and lowest prices. High, intermediate, and low quality are not necessarily synonymous with high, intermediate, and low price, for high-quality products are sometimes sold at a very low price because of competition, overproduction, market conditions, etc.

Moreover, the relative terms *light body, medium body,* and *heavy body* are used broadly to classify the different grades of oils according to viscosity. These terms are vague, and obviously their interpretation depends on the individual. They are arbitrarily used here, however, to indicate roughly viscosity ranges as follows: light bodied, up to 200 S.U.S. at 100°F.; medium bodied, 200 to 1000 S.U.S. at 100°F.; heavy bodied, 1000 and over S.U.S. at 100°F.

Air-compressor or Compressor Oils.—These oils are generally high-quality distillates of pale color and range in viscosity from about 300 to 500 S.U.S. at 100°F. For turbo blowers and com-

pressors a light-bodied oil is generally recommended. For multi-stage reciprocating compressors and wet vacuum pumps, a medium-bodied oil containing about 1 per cent compound is frequently recommended.

Airplane-engine Oils.—These are usually heavy-bodied, high-quality oils ranging in viscosity from about 70 to 140 S.U.S. at 210°F. They may be (1) pure mineral oils, or (2) mineral oils to which various agents have been added. They are generally produced from the so-called *bright stock* by the solvent-extraction process.

Automobile-engine Oils.—These are medium-bodied, usually blended oils that vary from low to high quality. Many of the present automobile oils contain addition agents such as those described in Chap. II. They are classified usually according to the Society of Automotive Engineers classification numbers, as in Table IX.

TABLE IX.—S.A.E. VISCOSITY CLASSIFICATION NUMBERS*

S.A.E. viscosity number	Viscosity range, S.U.S.					
	At 0°F.		At 130°F.		At 210°F.	
	Min.	Max.	Min.	Max.	Min.	Max.
10W†	5,000	10,000				
S.A.E. 10	.....	.....	90	120		
20W†	10,000	40,000				
S.A.E. 20	...	....	120	185		
S.A.E. 30	...	..	185	255		
S.A.E. 40	...	...	255	...	...	80
S.A.E. 50	...	.....	...	...	80	105
S.A.E. 60	.....	.....	...	..	105	125
S.A.E. 70	.....	.....	...	...	125	150

* The S.A.E. viscosity numbers constitute a classification of crankcase lubricating oils in terms of viscosity only. Other factors of oil quality or characters are not considered.

† These are comparatively new oils intended for winter use, but have not as yet been adopted as S.A.E. numbers. Many of the S.A.E. 10 and S.A.E. 20 oils fall within these classifications and may be used as 10W and 20W.

Bearing Oils.—Generally these are medium-bodied, medium-grade oils of the so-called *paraffin* and *red engine oil* types described above. The name is used in a very broad sense and consequently is practically meaningless.

Car-journal Oils.—These are usually still residues from crudes that were originally unsuitable, or were rendered so by treatment, for use in steam cylinder stocks. They are used for lubricating the journals of railroad cars and are made usually in summer and winter grades of viscosity ranges, respectively, of 80 to 100 and 60 to 65 S.U.S. at 210°F. In general, they belong in the low-quality class.

Crankcase Oils.—These oils were originally made for use in the crankcases of steam engines, especially for the Westinghouse; but today the term is frequently used in a very broad sense to describe any oil used in the crankcase of any machine. Specifically, this oil is a high-quality, heavy-bodied, pure mineral residual oil having a viscosity of about 100 S.U.S. at 210°F.

Crusher Oils.—This is a generic term to describe lubricating oils used for a variety of crushers. Crusher oils include pure mineral and compounded cylinder oils, dark lubricating oils, medium-bodied, high-quality lubricating oils, and crankcase oils. The viscosity varies widely, depending on the make, type of crusher, and service.

Diesel-engine Oils.—These are usually high-quality, medium- and heavy-bodied lubricating oils varying in viscosity from about 600 to 1600 S.U.S. at 100°F. Some contain various addition agents and are frequently solvent-refined.

Dynamo or Electric-motor Oils.—These are light-bodied and usually high-quality but sometimes medium-quality oils that range in viscosity from 125 to 200 S.U.S. at 100°F. Steam-turbine oils are frequently used for this service.

Engine Oils.—This term is used broadly to describe lubricating oils for the external bearings of steam engines. In general, these are medium-quality, light- and medium-bodied oils ranging in viscosity from about 130 to 500 S.U.S. at 100°F. They are not as a rule suitable for use in splash and circulating systems.

Elevator Oils.—These oils have no definite specifications and vary from low to high quality, depending on the parts for which they are used. Dynamo and turbine oils are frequently used for the motor bearings, steam cylinder oils for the gears; and engine and dark lubricating oils for the ropes.

Gas-engine Oils.—These are usually high- or medium-quality oils of medium body, varying in viscosity from about 300 to 700 S.U.S. at 100°F. For wet- or dirty-gas conditions generally, oils

containing from 1 to 2 per cent compound are recommended. They are used for lubricating both the cylinder and external parts.

Gear Oils.—This term is used in a very general way to describe any oil used for lubricating gears. Gear oils vary from low to high quality and from light to heavy body, depending on the type of gear, method of lubrication, and operating conditions. Dark lubricating oils, steam cylinder oils, and various grades of other lubricating oils are used.

In addition to the ordinary gear oils and greases there has comparatively recently come on the market the so-called *extreme pressure* (E.P.) lubricant. The trend in gear design has been toward the use of smaller gears having higher tooth pressures and rubbing velocities. This is particularly true in the automobile industry, where the hypoid type of gear is widely used in differentials. Such gears require special lubricants having extreme-pressure characteristics, for ordinary gear lubricants will not prevent galling and scoring.

Several ingredients are used alone and in combination to impart extreme-pressure characteristics to oils. The most effective and widely used are sulfur, chlorine, and lead soap. It is common practice to classify these lubricants as *mild*, or conventional, and *powerful* extreme-pressure lubricants. The powerful type usually contains more than one ingredient, usually sulfur and lead soap, and is recommended for hypoid gears. The mild type is commonly used for heavily loaded spiral and worm gears.

Hydraulic Oils.—This term is used to describe oils used as a power-transmission medium in various hydraulically operated machines, such as milling and broaching machines. They are usually high-quality, light- and medium-bodied oils such as steam-turbine oils.

Ice-machine Oils.—These are high-quality and light- to medium-bodied, pure mineral oils having a pour-point range from 0° to −40°F. They usually vary in viscosity from 130 to 350 S.U.S. at 100°F. Frequently they are straight-cut distillates.

Loom Oils.—Because of the character of the work done by looms and the different types of loom, these oils vary from light to medium bodied and from medium to high quality. Very light spindle and light engine oils of the so-called *paraffin* and *neutral* types are used. Frequently, they are of the so-called *stainless* type which is compounded with 5 to 20 per cent of fixed

oils, such as neat's-foot oil, lard oil, or olive oil. The viscosity range is usually from 65 to 900 S.U.S. at 100°F.

Machinery Oils.—This is a term used to describe general-purpose oils, which are usually of medium quality and vary from light to medium body. They are frequently engine oils, bearing oils, and similar medium-quality oils.

Marine Oils.—Although the term *marine oil* used in its broadest sense includes all types of lubricating oil used on board ship, it generally denotes a medium-quality, medium-bodied oil containing 10 to 25 per cent of compound, usually rapeseed oil. In general, such an oil varies in viscosity from 350 to 600 S.U.S. at 100°F.

Medicinal White Oils.—These are prepared from the white oils described above by filtering and/or chemical treatment to remove all odors and taste. They are used as internal medicine and are sold under a great many different brand names.

Mineral Castor Oils.—These oils are sometimes also referred to as *castor machine oils* and *nonsplattering oils.* They are generally light-bodied lubricating oils that contain 2 to 5 per cent aluminum soap.

Oil-engine Oils.—These oils have the same general properties as Diesel- and gas-engine oils. They are medium bodied, usually having a viscosity from 300 to 700 S.U.S. at 100°F.

Penetrating Oils.—These are usually very fluid oils, such as paraffin and light spindle oils, and are heavily compounded, which reduces the surface tension and gives excellent penetrating ability. They are used chiefly to loosen all sorts of tight metal fits.

Spindle Oils.—These are light-bodied distillates such as paraffin and nonviscous oils. They are of medium and high quality and range in viscosity from about 60 to 350 S.U.S. at 100°F. They are used for light, high-speed machinery, such as small electric motors, grinders, and spindles of ring-spinning frames, and for office equipment and household appliances.

Stainless Oils.—These are spindle oils that are compounded with about 50 per cent of fixed oils. They are widely used in textile mills because they are alleged to be more readily removed from fabrics than the pure mineral spindle oils. The fixed oils most generally used as compounds are sperm, lard, olive, cottonseed, and neat's foot, alone or in combination.

Steam Cylinder Oils.—These are generally residual, heavy-bodied oils. They may be filtered or nonfiltered and usually contain 5 to 15 per cent of compound; the compounds most generally used are acidless tallow, lard, and *degras* oils. For certain operating conditions, however, pure mineral oils are used. As noted above, they are usually of two classes, filtered and non-filtered or dark cylinder oils. Paraffin- and mixed-base crudes are the most suitable for making cylinder-oil stocks.

Steam-turbine Oils.—These are usually high-quality, solvent-refined oils and vary in viscosity from about 150 to 350 S.U.S. at 100°F. They are never compounded. For certain ring-oiled units, other oils, such as mineral steam cylinder oils, may be used.

Tractor and Motorcycle Oils.—These are the heavier bodied automobile oils, as these machines require heavy-bodied oils because of the high operating temperatures. They usually range in viscosity from 65 to 150 S.U.S. at 210°F.

Transmission Oils.—These oils vary widely in viscosity and quality. Steam-turbine oils, engine oils, cylinder oils, dark lubricating oils, heavy, viscous, tacky residual oils are used for various purposes, depending on the type, design, method of lubrication, and operating conditions. The so-called *extreme-pressure* type of oil is widely used in the automobile industry for transmissions and differentials.

Valve Oils.—This term is sometimes used to describe steam cylinder oils, especially the lighter bodied, heavier compounded ones.

CHAPTER IV

FIXED OILS AND FATS

Oils and fats are obtainable from all animals and from many of the seeds and fruits of plants and vegetables. These oils and fats are sometimes called *fatty* oils, or *saponifiable* oils; but more frequently they are referred to as *fixed* oils and fats because they cannot be distilled without decomposition. Not only do they differ in this respect from mineral oils but also in that they contain 9.4 to 12.5 per cent oxygen.

Although animal and vegetable oils and fats are obtained from very dissimilar sources, they form a well-defined and homogeneous group of fatty substances that vary in consistency from very fluid oils at low temperatures to hard solids that melt at about 125°F. From a chemical point of view there are no essential differences between an oil and a fat. It is customary, however, to regard any fatty substance that is fluid below 68°F. as an oil and any fatty substance that is solid above this temperature as a fat.

1. Number of Fixed Oils and Fats.—The number of these oils and fats known is very large. To deal with all of them is beyond the scope of this book. Consequently, only those which are used as lubricants and in the preparation of lubricants will be described. Many of the best quality ones, such as margarine, cooking fats, and salad oils, are for edible purposes. In industries, aside from the oil industry, they are used for soapmaking, candle manufacturing, leather dressing, paint making, linoleum manufacturing, etc. Certain oils, such as castor, curcas, chaulmoogra, lard, and olive, are widely used in the medical and drug professions.

2. Physical Properties.—The most significant properties of fixed oils and fats from the standpoint of lubrication are shown in Table X. All fixed oils are practically insoluble in water and, with the exception of castor oil, are insoluble at normal temperatures in alcohol. Exclusive of castor oil they are com-

TABLE X.—CHARACTERISTICS OF FIXED OILS AND FATS

Name	Type	Specific gravity	Open flash point, °F.	Iodine no., %	Saponification no.	Free fatty acid, %	Pour point, °F.	Viscosity S.U.S.	
								100°F.	212°F.
Castor oil	Nondrying	0.960–0.970	530–560	82– 92	176–187	0.1– 6	0– 10	1200	95
Rapeseed oil	Semidrying	0.913–0.917	530–560	94–102	168–179	0.3– 3	15– 30	250	57
Blown rapeseed oil	Semidrying	0.960–0.985	430–460	47– 73	195–216	3 – 8			
Cottonseed oil	Semidrying	0.921–0.926	560–625	100–120	191–197	0	30– 40	170	50
Peanut oil	Nondrying	0.918–0.925	540–620	90–102	186–197	1 – 5	27– 37	210	51
Olive oil	Nondrying	0.915–0.918	475–600	79– 88	185–196	3 –20	20– 50	210	51
Soybean oil	Semidrying	0.924–0.927	540	122–134	189–193	2	10– 20	165	54
Coconut oil	Nondrying	0.925–0.930	530	8– 9	189–197	2 –20	40– 70	145	43
Rosin oil	Nondrying								
	Semidrying	0.961–1.02	320–360	25–115	70– 80	3 –40	20– 25	1500	
Lard oil	Nondrying	0.914–0.918	500–600	65– 75	192–198	3 –25	32– 60	210	51
Tallow oil	Nondrying	0.913–0.918	540–600	55– 60	193–198	1 – 5	55– 60	....	56
Neat's-foot oil	Nondrying	0.914–0.917	470–480	65– 75	193–204	0.2–25	0– 40	210	51
Sperm oil	Nondrying	0.878–0.882	455–505	80– 94	120–140	0.5– 3	32	100	38
Porpoise oil	Nondrying	0.916–0.927	415–495	22– 48	195–270	.....	5– 10	150	
Wool grease	Nondrying	0.944–0.960	450	15– 30	100–102	50– 60	100–125	....	135
Tallow fat	Nondrying	0.925–0.950	550–590	34– 48	193–198	2– 10	100–125	....	55
Palm oil	Nondrying	0.922–0.925	450	50– 56	196–202	10 –60	80–110	221	56

pletely soluble in ether, carbon disulfide, chloroform, carbon tetrachloride, petroleum ether, benzol, and mineral lubricating oils. Clear mixtures of castor oil and mineral oils can be prepared by the addition of a third fixed oil, such as rapeseed, tallow, or lard. They have no well-defined melting or solidifying point. They are devoid of bloom, except rosin oil, and each variety has generally a distinctive odor, by which it can be identified.

The viscosity of fixed oils and fats is affected less by both temperature and pressure than is that of mineral oils. For example, Hersey and Shore found that an increase in pressure of 14.2 to 56,900 lb. per sq. in. caused the viscosity of lard oil to increase about 17.4 times and that of mineral oil 112 times, both viscosities being determined at the constant temperature of 212°F. Furthermore, the viscosity of lard oil was found to be only 29 times greater at 32 than at 212°F., whereas the viscosities of two mineral oils having viscosity indexes of 100 and 0 were respectively 71 and 103 times greater at 32°F. than they were at 212°F.

Fixed oils and fats are generally considered to possess greater oiliness or greasiness than mineral oils. Other things being equal, a lubricant of greater oiliness will cause less heat in use and, to this extent, conditions will be favorable for reducing wear and preventing seizure. Moreover, rubber is not decomposed by fixed oils and fats as it is by mineral oils.

3. Chemical Properties.—Fixed oils and fats are composed chemically of an alcohol radical and a fatty acid radical. The most common alcohol radical is glycerin ($C_3H_5(OH)_3$). It is found in all vegetable and in most of the animal oils and fats. There are many fatty acids found in fixed oils and fats. The three most important and widely distributed acids are, however, stearic ($HC_{18}H_{35}O_2$), palmitic ($HC_{16}H_{31}O_2$), and oleic ($HC_{18}H_{33}O_2$). The fatty acids do not exist, to any appreciable extent, in these oils and fats in the free state but are chemically combined with glycerin to form glycerides. The corresponding glycerides of stearic, palmitic, and oleic acids are, respectively, stearin ($C_3H_5(C_{18}H_{35}O_2)_3$), palmitin ($C_3H_5(C_{16}H_{31}O_2)_3$), and olein ($C_3H_5(C_{18}H_{33}O_2)_3$). Stearin and palmitin predominate in the solid fats, and olein predominates in the fluid oils. The nature of the fatty acid radical, therefore, largely determines the character of the fatty compound.

If any fixed oil or fat is treated with an alkali, such as caustic soda (NaOH) or caustic potash (KOH), and is heated, it separates into glycerin and soap, as shown by the following action of caustic soda on palmitin:

$$\underset{\text{palmitin}}{C_3H_5(C_{16}H_{31}O_2)_3} + \underset{+\text{ caustic soda}}{3NaOH} = \underset{\text{glycerin}}{C_3H_5(OH)_3} + \underset{\text{soda soap}}{3NaC_{16}H_{31}O_2}$$

The soda has combined with the fatty acid to form the soap. This splitting up of the oil or fat into glycerin and soap is called *saponification*. All fixed oils and fats are capable of being saponified, while mineral oils are not. This characteristic of saponification of fixed oils and fats is often used to determine the percentage of fixed oil or fat in a compounded oil.

Fixed oils and fats differ also from mineral oils in that they absorb oxygen and iodine readily. Some oils, such as linseed, absorb oxygen or are oxidized very easily, dry and thicken quickly, and form solid elastic substances. Such oils are known as *drying oils*. Other oils, such as rapeseed, whale, and cottonseed, oxidize at a more moderate rate and are said to be *semidrying oils*. Still other fixed oils, such as castor, olive, sperm, and lard, oxidize relatively slowly and are termed *nondrying oils*. From a lubrication standpoint, only semidrying and nondrying oils and fats are of any value.

The drying properties of a fixed oil or fat are dependent largely on the relative amount of hydrogen in the fatty acid of the oil or fat. The less hydrogen the oil contains, the more readily it oxidizes and the more iodine it will absorb. Some fatty acids, such as stearic and palmitic, which have the general formula $C_nH_{2n}O_2$, do not absorb iodine directly. Such acids are called *saturated fatty acids*. Consequently, the corresponding glycerides, stearin and palmitin, which predominate in fats, do not readily oxidize. Other fatty acids, such as oleic, which have the general formula $C_nH_{2n-2}O_2$, absorb iodine directly and are readily susceptible to oxidization. Such are called *unsaturated fatty acids*. Since the glyceride olein predominates in the fatty oils, the oils are more susceptible to oxidization than the fats.

4. Refining.—The sources from which fixed oils and fats are obtained are numerous and widely different. Consequently, many methods are employed for extracting them. Basically, however, three processes only are used for removing them from the

tissues of animals and plants, *viz.*: (1) rendering or melting out, (2) expression by means of pressing, and (3) extraction by means of solvents.

Most animal and fish oils and fats are obtained by rendering, which consists of removing the fatty matter from the tissues by means of heat. Heating causes the fatty matter to expand and as a result bursts the enveloping tissues, thus liberating the fatty matter. Heating may be by means of direct heat, by boiling in water, or by steam under pressure.

Some oils, particularly those obtained from seeds, are obtained by either hot or cold expression. The husks are first removed from the seeds, after which the seeds are crushed and then pressed. Oils of higher grade are obtained by cold expression rather than by hot expression, but the yield is lower.

All fixed oils and fats are soluble in organic liquids such as ether, carbon disulfide, benzol, and carbon tetrachloride. This property is widely utilized for removing fixed oils and fats from the tissues of animals and plants. The fatty matter is treated with the solvent in a closed vessel, after which the mixture is run into a still or retort, where the solvent is distilled off by steam. The fat remains in the still, while the solvent is recovered and re-used. Usually, the extracted oil or fat is high grade, as practically all coloring and gummy and other undesirable substances are removed.

As crude vegetable oils and fats come from the press, they are usually cloudy, contain coloring matter, moisture, resins, and gums, and possess undesirable odors. For many purposes, therefore, it is often necessary to refine them further, which is usually done by treating them with sulfuric acid, caustic soda, or filtration through fuller's earth or by agitation with steam or air. The sulfuric acid treatment removes extraneous vegetable matter, whereas the caustic soda treatment not only removes this matter but also neutralizes any free fatty acid and removes resins, gums, and coloring matter. Filtration through fuller's earth exerts a bleaching action and removes impurities in suspension and, to a certain extent, odor.

5. Blown Oils.—Oils, such as rapeseed and whale and various fish oils, are frequently artificially thickened by blowing a current of air through them. The process is carried out in a tall, iron vessel. The oil is first heated by means of steam coils to a tem-

perature of 170 to 190°F. or higher, and then the steam is shut off and air is blown through the oil. Oxidation occurs and sufficient heat is produced not only to maintain the temperature but also to increase the temperature of the oil. The blowing process requires 18 to 48 hr., according to the oil being processed, the product desired, and the conditions of processing.

The specific gravity of oils thus treated increases and generally ranges from 0.955 to 0.985. The viscosity also increases and may be ten to twenty times greater at ordinary temperatures than that of the untreated oil. Blown oils have a peculiar, characteristic odor and are slightly soluble in alcohol but not soluble in all proportions in mineral lubricating oils. The flash point is lowered considerably, and they usually contain a higher percentage of free fatty acid than do untreated oils.

6. Uses of Fixed Oils and Fats.—These oils and fats were probably man's first lubricants. Beef and mutton tallows were used for lubricating the axles of chariot wheels before 1400 B.C., and these, as well as many other fixed oils and fats, continued, until the discovery of mineral oils and until the art of refining them was developed, to be the principal source of lubricants. Today, however, they are rarely used alone as lubricants. Their chief use at present is as a compounding agent in mineral oils and in the manufacturing of greases. Tallow, lard, neat's-foot oil, and *degras* are commonly used in steam cylinder oils. And rapeseed and its cheaper substitutes are frequently used in engine, textile, and many other lubricating oils. Lard oil is used widely, alone and in combination, with various mineral oils as a cutting oil. The blown oils, especially rapeseed, are used mainly for compounding marine engine oils and other engine and bearing oils.

Although fixed oils and fats possess some very excellent properties as lubricants, yet certain objectionable features have practically eliminated them for this purpose. They have been discarded chiefly because: (1) They are more expensive than mineral oils. (2) They oxidize much more easily than mineral oils, and, as a result, harmful gums, resins, and acids are readily formed in use and storage. (3) They are not obtainable in so wide a range of viscosity or in such close viscosity steps as are mineral oils.

CHAPTER V

SOLID LUBRICANTS

A few solid minerals, particularly graphite, mica talc, and soapstone, possess lubricating properties. In general these solids possess to a certain degree the property of unctuousness and are capable of resisting high pressures and temperatures.

Some of these solid lubricants possess a tough, flaky structure, which enables them to resist pressure without crumbling. Others are easily crushed into a fine powder when subjected to heavy pressure. Some are prepared so finely divided that they are able to be suspended in colloidal form in a liquid. The colloidal graphite preparations Aquadag and Oildag are examples of colloidal graphite suspended in water and oil, respectively.

1. Natural Graphite.—Graphite is by far the most important of the solid lubricants. It is found in nature and is also prepared in the electric furnace. Natural graphite—also known as *plumbago* and *black lead*—is found in almost every country of the world and is produced commercially in a score of countries. The bulk (85 per cent), however, comes from Czechoslovakia, Austria, Chosen, Germany, Madagascar, and Ceylon. It is a black, lustrous mineral with a greasy feel. It is found in amorphous and crystalline forms. In fact, all graphite is crystallized carbon, the crystals of the so-called *amorphous graphite* being so small as to be indistinguishable to the naked eye. Depending on the manner of occurrence and on the shape of the particles, crystalline graphite is further separated into vein and flake graphite. The vein form is found in more or less well-defined veins and is produced commercially almost exclusively in Ceylon. The flake variety is the most desirable for lubricating purposes and is secured mainly from Madagascar. It has a tough, flaky, scaly structure and a decided luster; the flake structure is retained even after it is ground into a very fine powder. It is obtainable in several degrees of fineness.

It may be used for lubrication purposes either in the dry form or mixed with oil or grease. It cannot, however, be used in an

admixture of oil in ordinary lubricators or lubricating systems, because of its high specific gravity (2.0 to 2.5), which causes it to settle and plug oil pipes, ducts, and grooves. As it is obtained from the mine, it contains some impurities, chiefly silica, alumina, and ferric oxide.

2. Manufactured Graphite.—By the Acheson process, this graphite is produced in the electric furnace from anthracite coal and petroleum coke. It has a soft, greasy, noncoalescing nature and is almost chemically pure. The grades produced for lubrication purposes are guaranteed to contain not less than 99 per cent pure carbon. They are ground to 200 mesh and deflocculated by treatment with a water solution of tannin, the amount of tannin being 3 to 6 per cent by weight of the graphite treated. As a result of this treatment, the so-called *colloidal graphite* is produced, whose particles are said to be within the colloidal dimensions of 0.1 to 1 millionth of a micron.

The colloidal graphite is obtainable for commercial use dispersed in distilled water, mineral lubricating oil, glycerin, and phenol-formaldehyde varnish under the proprietary names of Aquadag, Oildag, Castordag, Glydag, and Varnodag, respectively.

These commercial products are prepared in concentrated form and are usually diluted before being used. Oildag, Castordag, and Glydag contain approximately 10 per cent by weight of colloidal graphite dispersed, respectively, in mineral lubricating oil, castor oil, and glycerin. Aquadag contains approximately 22 per cent by weight of graphite dispersed in distilled water.

Perhaps the chief advantage of graphited oils and greases is their ability to form films of graphite on the bearing surfaces of mechanical devices. These films are closely bonded to the metal and possess a low coefficient of friction.

At ordinary temperatures, graphite is not affected by acids, alkalies, or the halogens. It does not combine with oxygen until a temperature of about 1100°F. is reached, when it is converted to carbon dioxide. It has a hardness of 1 on the Mohr scale and varies in specific gravity from 2.0 to 2.5, depending on its source.

3. Mica.—This term is used to describe a group of widely distributed rock-forming minerals having a specific gravity varying from 2.7 to 3.1 and a hardness from 2 to 3 on the Mohr scale. Members of this group are characterized by a very easy cleavage in one direction, a high degree of flexibility and tough-

ness, and are more or less elastic. The different kinds of mica vary from perfectly colorless and transparent, through shades of yellow, green, and red, and black and opaque. They are poor conductors of heat and electricity.

All 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. The most common micas are muscovite and biotite.

Mica is prepared for the market by splitting the rough blocks into plates or sheets, which are cut into the required shapes by means of shears. The refuse mica from the splitting and cutting operations is finely ground and is used for lubricating purposes.

4. Talc.—Talc is a hydrogen magnesium silicate that is characterized by a soapy or greasy feel. It contains water, and its specific gravity ranges from 2.6 to 2.8. It consists of broad, flat, smooth plates, which are flexible but not elastic, thus differing from mica.

Steatite is a term used to describe a massive variety of talc, and soapstone is an impure form of steatite. French chalk is powdered talc or steatite.

The hardness of talc ranges from 1 to 4 on the Mohr scale and varies in color from silvery white for the best and softest varieties to grayish or greenish for the harder steatite varieties. It is strongly resistant to acids, alkalies, and heat.

5. Uses of Solids as Lubricants.—Solids are used as lubricants either in the dry, powdered form or mixed with oil, water, or grease. In the dry form, they are used to a very limited extent, being restricted to certain parts of lacemaking, food-preparation, and similar machines where an oil or a grease is undesirable because of the possible damage that may occur to the product.

Oil-graphite and water-graphite mixtures are used for certain high-temperature conditions such as baking- and enameling-oven chains, furnace- and kiln-car bearings, bearings and sliding surfaces of die-casting machines, arc lamps, typesetting machines, and glassmaking machinery.

Oil-graphite mixtures are also used for "running-in" new and reconditioned machines, for fire-alarm boxes, telephone equipment, radio parts, household appliances, and automobile leaf springs.

Water-graphite mixtures are used frequently where a combustible lubricant would be dangerous, such as for lubricating the dies for drawing tungsten and molybdenum.

From 2 to 20 per cent of graphite is frequently added to cup grease. Such grease is especially suitable where the grease is likely to be washed away by water, oil, or chemical solvents. Hydraulic rams, plungers, slides, and bearings, exposed to water, are typical examples of parts for which graphite grease is used.

Mica grease is especially suitable for wood gears and bearings. Talc, soapstone, mica, and other solids are also frequently added to axle and other comparatively cheap greases as fillers.

In conclusion, oil-solid mixtures are found to be advantageous under the three following conditions: (1) for heavily loaded and low-speed bearings where the formation of a complete fluid oil film is impossible; (2) wherever bearings, gears, etc., are practically inaccessible and for this reason are likely to receive scant attention; and (3) wherever it would be dangerous to use a combustible lubricant because of the extremely high temperature.

There are certain drawbacks in the use of solids as lubricants. The color of graphite and its staining qualities are sometimes objectionable. Also, practically all solid lubricants, with the possible exception of colloidal graphite, tend to separate from the oil, even while in service.

CHAPTER VI

GREASES

The early greases of which there is knowledge were simple mixtures of lime soap and mineral oil and were used mainly for greasing cart and wagon axles. They were prepared by hand mixing crude petroleum and rosin oil in an open kettle over a coal fire and then, when the temperature was thought to be about right, stirring in a solution of milk of lime until the batch began to thicken. These early greases were frequently adulterated by additions of talc, chalk, alba, graphite, and excess water.

1. Definition.—The word *grease* comes from the early Latin *crassus* and the late Latin *grassus* meaning fat. The word has been used rather loosely to describe practically all sorts of fatty and oily substances. It is commonly applied to all lubricants that are more or less solid at ordinary temperatures, and even to some heavy viscous liquid lubricants, regardless of their composition. Grease manufacturers are prone to classify all lubricants sold by the pound as greases.

Grease, however, is defined by the A.S.T.M. as "*a combination of a petroleum product and a soap or a mixture of soaps, suitable for certain types of lubrication.*" Thus, strictly speaking, it is a soap–mineral-oil mixture. In the broader sense of the word, however, it includes products such as mineral oil to which solids such as graphite, talc, mica, chalk, soapstone, sulfur, resin, etc., have been added, and blends of residuum, waxes, uncombined fats, rosin oils, and pitches.

2. Modern Greases.—Early machinery could be lubricated satisfactorily with comparatively few and simple greases, because speed and temperature requirements were easily satisfied. But, today, operating conditions are, in the main, quite exacting. Modern machinery is frequently composed of highly specialized mechanisms accurately made and timed to perform complex motions. This development in the mechanical field has brought about many specialized greases, each specially made to fulfill

individual requirements. So exacting have the requirements become that many of the larger grease manufacturers make over 300 different varieties and consistencies of grease under as many as 100 different brand names.

They are made in all sorts of forms; some contain horsehair or strands of wool or yarn. In consistency, they vary from extra hard greases that must be cut with a heavy knife to liquid grease that may be poured easily from a container. There are cooling sticks, grease blocks, grease rats, and many other forms. Cooling sticks are about 8 in. long and are used for relieving overheated journals, especially hotboxes, of locomotives and cars. Grease blocks or bricks are extensively used on hot necks of rolling mills, and grease rats, which are long intertwined strands of grease-soaked wool, are used to wrap around open bearings.

Other special greases contain abrasive materials. Usually, these are block or brick greases used to polish aluminum wares and other similar products. Oddly enough, the abrasive generally used is aluminum oxide. Another special grease contains phenyl dichlorarsine, a deadly poisonous substance. This grease is used to treat wood and destroys termites and other wood-boring insects.

Some greases are scented to cover up rancid odor or to prevent the development of rancid odors. Oil of mirbane (nitrobenzene ($C_6H_5NO_2$)) is frequently used as a perfume but is rapidly giving away to synthetic deodorants. Sassafras oil is also used to a limited extent.

Many makers also use artificial coloring materials in their greases. Coloring is usually not for the purpose of covering up the ingredients, but rather employed to help those who cannot understand or read ordinary instructions in identifying grade and application. Moreover, since it is rather difficult to control manufacturing so accurately that each batch produced is of the same color, by using coloring materials all batches may be brought to a uniform color. Various aniline dyes are generally used as the coloring ingredient.

3. Manufacture.—The manufacture of a grease has long been considered an art. Through the years grease makers have been associated with handicraftsmen such as the old-time cobbler, cabinetmaker, smith, watchmaker. The handicraft was passed from father to son. From 4 to 5 years were generally required

for an average apprentice to learn the trade sufficiently well to make even the simpler greases. Usually, 10 to 15 years were required to develop a finished grease maker capable of making good grease from a variety of formulas. But, like most handicrafts, with the introduction of scientific temperature-measuring and control instruments, improved weighing and measuring devices, and easily regulated steam-heated kettles, grease making has become less of an art and more of a science. More often than not, manufacturing processes are controlled now from the chemist's laboratory, and less dependence is placed on the judgment and experience of the maker. With modern equipment,

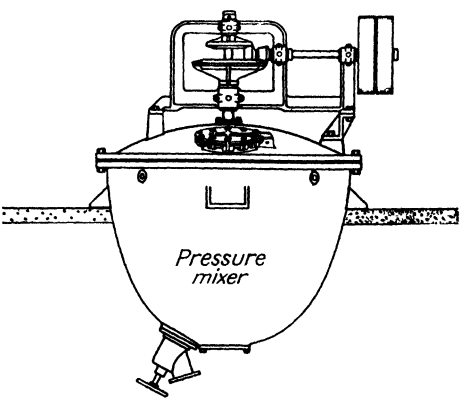


FIG. 17.—Closed steam-heated pressure kettle. Charged into this kettle are measured amounts of (1) a fat, which is to be saponified; (2) the saponified agent, usually made into a cream with oil or water; (3) water, if needed; and (4) all of the lubricating oil required to make the finished grease. (*Courtesy Sowers Mfg. Co.*)

once the correct ingredients have been selected and the procedure has been established, it is possible to produce batch after batch of grease of standardized characteristics, even by relatively inexperienced grease makers. In some grease plants today, observation glasses are not provided for the express purpose of preventing the operator from being influenced by the appearance of the batch.

4. Materials.—In virtually all cases, three ingredients are used in the manufacture of grease: (1) the saponifying agent or metallic base, such as calcium hydroxide, sodium hydroxide, or aluminum hydroxide; (2) the saponifiable fat, such as tallow, horse fat, or palm oil; (3) the mineral oil, which is the lubricating agent. In

general, the procedure is to heat the fat in contact with the saponifying agent until the saponification is complete, or nearly so, and then slowly work into the hot soap solution the proper quantity of mineral oil to give the desired consistency.

From the standpoint of manufacturing, greases may be classified as boiled or cooked greases, cold sett greases, and residuum greases, as in Table XXIII.

5. Cooked Greases.—By far the bulk of greases manufactured are cooked or boiled. This method is used in preparing lime-base, soda-base, aluminum-base, lead-base, and mixed-base greases.

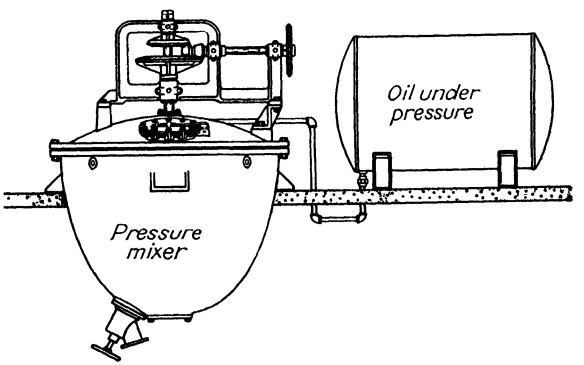


FIG. 18.—Closed steam-heated kettle with oil under pressure. This is a modification of the method described in Fig. 17. Here the soap base is made under pressure without mineral oil, which is added later under pressure and is thoroughly worked into the soap base before the pressure is released. (*Courtesy Sowers Mfg. Co.*)

Greases manufactured by cooking are, in general, superior to those manufactured by other methods.

Lime-base Greases.—Lime-base greases are usually manufactured by one of the following methods:

METHOD 1.—In an open kettle heated by means of steam, hot oil, or other hot fluids, oil, coke, coal, or electricity.

METHOD 2.—By a two-stage process in which a soap base is prepared first and later dissolved in mineral oil to form grease.

METHOD 3.—In a closed steam-heated kettle (Fig. 18) under pressure.

METHOD 4.—In a closed steam-heated kettle under pressure and subsequently finished in an open steam-heated kettle.

When direct fire with oil, coke, or coal is employed in the manufacture of lime-base greases, greater difficulty is experienced

in controlling temperatures. Considerable care must be exercised to avoid burning the contents of the kettle.

The chemistry of preparing the lime soap for use in manufacturing grease may be carried out by one of three methods, as follows:

1. Direct saponification:

$$\underset{\text{tristearin}}{2C_3H_5(O\cdot CO\cdot C_{17}H_{35})_3} + \underset{\text{+ hydrated lime}}{3Ca(OH)_2} = \underset{\text{glycerin}}{2C_3H_5(OH)_3} + \underset{\text{calcium stearate}}{3Ca(C_{17}H_{35}COO)_2}$$

This is the usual method.

2. Indirect saponification:

$$\underset{\text{tristearin}}{C_3H_5(O\cdot CO\cdot C_{17}H_{35})_3} + \underset{\text{+ caustic soda}}{3NaOH} = \underset{\text{glycerin}}{C_3H_5(OH)_3} + \underset{\text{sodium stearate}}{3Na(C_{17}H_{35}COO)}$$

$$\underset{\text{calcium chloride}}{CaCl_2} + \underset{\text{sodium stearate}}{2C_{17}H_{35}COONa} = \underset{\text{calcium stearate}}{Ca(C_{17}H_{35}COO)_2} + \underset{\text{sodium chloride}}{2NaCl}$$

3. Direct neutralization:

$$\underset{\text{stearic acid}}{2C_{17}H_{35}COOH} + \underset{\text{+ hydrated lime}}{Ca(OH)_2} = \underset{\text{calcium stearate}}{Ca(C_{17}H_{35}COO)_2} + \underset{\text{water}}{2H_2O}.$$

This third method is usually referred to as the *cold process*, as the reaction is usually brought about at a temperature of 120 to 150°F. Boiling is unnecessary to produce saponification and, in many cases, is detrimental to the finished grease.

Soda-base Greases.—The making of soda-base grease follows closely the procedure used in preparing lime-base grease, caustic soda, of course, being substituted for the lime in preparing the soap base. Broadly speaking, soda-base greases may be divided into two groups: (1) those containing free water; and (2) those practically dehydrated. Those containing free water are emulsions of the type of *oil in water*, whereas those that are practically dehydrated are *intimate mechanical mixtures of soap and oil.*

Usually, soda-base greases are manufactured by one of the following methods:

METHOD 1.—Direct-fired open kettle with agitators, as in Fig. 19.

METHOD 2.—Steam-jacketed open kettle with agitators, as in Fig. 20.

METHOD 3.—Steam-jacketed closed pressure kettle in combination with steam-jacketed open kettle, as in Fig. 21.

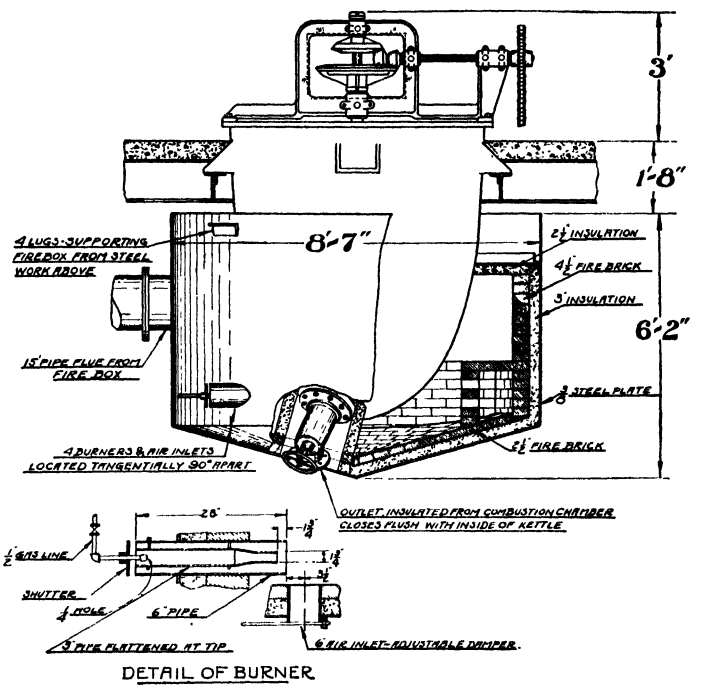


FIG. 19.—Direct-fired, open kettle with agitator. (*Courtesy Sowers Mfg. Co.*)

The general, chemical reactions that occur in the formation of soda soaps may be represented by the following equations:

METHOD 1.—When oils or fats are saponified with caustic soda:

$$\underset{\text{fat}}{C_3H_5(O\cdot CO\cdot R)_3} + \underset{\text{caustic soda}}{3NaOH} = \underset{\text{glycerin}}{C_3H_5(OH)_3} + \underset{\text{soda soap}}{3R\cdot COONa}$$

METHOD 2.—When direct neutralization of a free fatty acid is accomplished with caustic soda:

$$\underset{\text{fatty acid}}{R\cdot COOH} + \underset{\text{caustic soda}}{NaOH} = \underset{\text{water}}{H_2O} + \underset{\text{soda soap}}{R\cdot COONa}$$

METHOD 3.—When direct neutralization of a free fatty acid is accomplished with sodium carbonate:

$$\underset{\text{fatty acid}}{2R\cdot COOH} + \underset{\text{sodium carbonate}}{Na_2CO_3} = \underset{\text{soda soap}}{2R\cdot COONa} + \underset{\text{water}}{H_2O} + \underset{\text{carbon dioxide}}{CO_2}$$

In these equations R represents the radical of the fatty acid used. For example, for oleic acid R = $C_{17}H_{33}$, and for stearic acid R = $C_{17}H_{35}$.

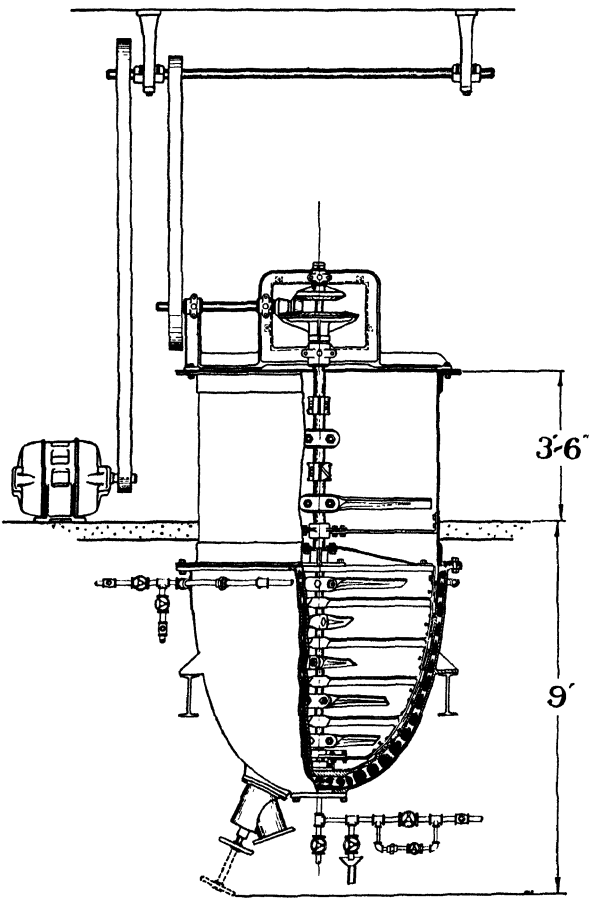


FIG. 20.—Steam-jacketed kettle for making soda-base greases. (*Courtesy Sowers Mfg. Co.*)

Aluminum-base Greases.—The double-decomposition method is generally used in preparation of aluminum-soap greases. The aluminum soap, which is later dissolved in mineral oil, is usually prepared by the action of a water-soluble alkaline soap, such as

soda soap, on a solution of aluminum sulfate or alum. The precipitated soap is washed free of impurities and is then dried or dissolved immediately in the mineral oil.

The rate of cooling, method of dissolving soap, rate of heating, the maximum temperature to which the soap and oil are heated, chemical composition of the soap, presence or absence of free fat, and the character of the mineral oil—all have an important influence on the texture, consistency, and stability of the finished grease.

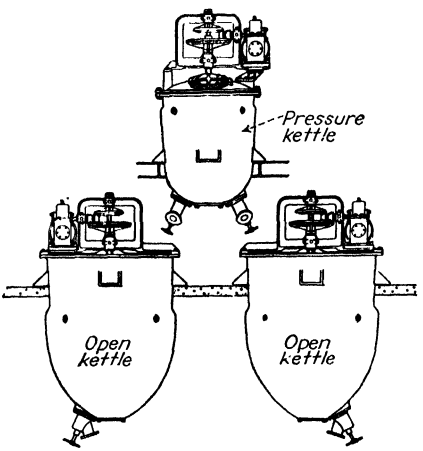


FIG. 21.—Usual arrangement of pressure and open kettles. The soap base is prepared in the pressure kettle without mineral oil, finishing being carried out in the open kettles. Since saponification and finishing are carried out separately, they may be carried on simultaneously, one pressure kettle supplying soap base alternately for two or more open kettles. (*Courtesy Sowers Mfg. Co.*)

The double-decomposition method of preparing an aluminum-soap base may be represented by the following chemical reactions:

STEP 1.—

$$\underset{\text{oleic acid}}{C_{17}H_{33}COOH} + \underset{\text{caustic soda}}{NaOH} = \underset{\text{sodium oleate}}{C_{17}H_{33}COONa} + \underset{\text{water}}{H_2O}$$

STEP 2.—

$$\underset{\text{sodium oleate}}{6C_{17}H_{33}COONa} + \underset{\text{aluminum sulfate}}{Al_2(SO_4)_3 \cdot 18H_2O} = \underset{\text{aluminum trioleate}}{2Al(C_{17}H_{33}COO)_3} + \underset{\text{sodium sulfate}}{3Na_2SO_4} + \underset{\text{water}}{18H_2O}$$

Lead-base Greases.—Lead-base greases are usually manufactured by direct saponification, or double decomposition.

In the direct-saponification method, usually an open gas-fired kettle is charged with the fat or fats and litharge (lead monoxide), and saponification occurs at a temperature of approximately 500°F. When saponification is complete, the required amount of mineral oil is added.

This method invariably produces an objectionable amount of uncombined lead oxide, which tends to settle out in service.

In the double-decomposition method, a soap (usually soda soap) is prepared in an aqueous solution in the usual manner. To this soap solution a solution of a water-soluble lead salt (usually lead acetate) is slowly and carefully added. Double

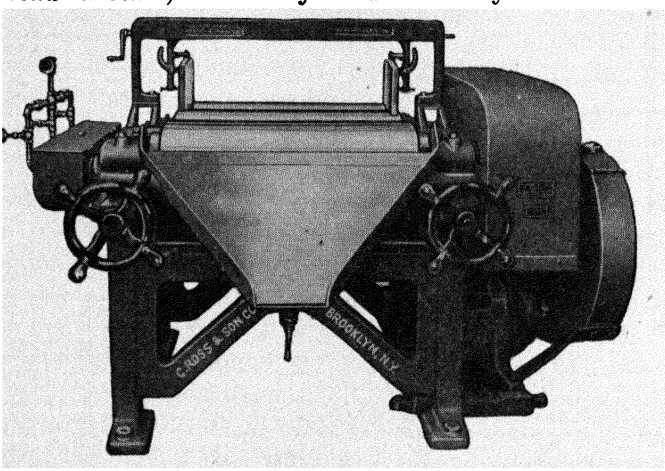


FIG. 22.—Water-cooled, motor-drive three-roller grease mill. This type of mill is sometimes used for working fillers, such as graphite and mica, into greases, and for reducing lumps. (*Courtesy Charles Ross and Son Co.*)

decomposition occurs, and the water-insoluble lead soap is purified by washing with hot water, after which the excess water is removed. The lead soap thus prepared is removed and used at once, or else it is completely dehydrated and stored for future use.

The grease is finally prepared by dissolving the correct amount of lead soap in a selected mineral oil. Lead-base greases prepared in this manner are entirely free from suspended solids. Not all mineral oils, however, are suitable for preparing lead-base greases, for the lead soap is not entirely soluble in all mineral oils. Cheap black oils of low viscosity are decidedly unsuitable. The purity of the lead soap, the type of fat used, and the suitability of the mineral oil not only with respect to its lubricating qualities, but

also as to its ability to hold the lead soap in solution, are all factors of prime importance in making good lead-base grease.

Mixed-base Greases.—It is not unusual to find greases having a mixed-soap base. Combinations of lime soda, lime potassium, lime lead, lime aluminum, soda lime, soda lead, soda aluminum, etc., are used.

These greases are usually manufactured by one of any of the following three methods:

METHOD 1.—By first preparing each soap separately, according to any one of the methods previously discussed, and then mixing the soaps and adding the mineral oil in the usual way.

METHOD 2.—By preparing both soaps simultaneously in the same kettle and then adding the mineral oil in the usual manner.

METHOD 3.—By double-decomposition process of a mixed-soap base, and subsequently dissolving it in the mineral oil in a similar manner to that employed in preparing lead- and aluminum-base greases.

6. Cold Sett Greases.—Cold sett greases are made by mixing while cold or at a temperature less than 150°F. mineral oil, rosin oil, and sett. This sett is usually an emulsion containing light mineral oil, water, hydrated lime, and a small amount of rosin oil. The rosin oil reacts with the lime to form a small quantity of lime soap, which stabilizes the emulsion. The final mixture solidifies in a few minutes, and the resulting grease is insoluble in water. If proper care is exercised in selecting the raw materials and if the mixing has been thorough and the correct proportions have been used, the resulting grease will have a satisfactory consistency and be free from lumps.

For special purposes or for other reasons, solids such as flake and powdered graphite, soapstone, gypsum, mica, and similar fillers are sometimes incorporated. Also, occasionally, other fats or fatty acids may be added. In such cases, there is formed the lime soap of both the fatty material and the rosin oil. Some makers also use small amounts of caustic soda in their sett greases, especially where a grease is required to adhere tenaciously to wet or moist metal surfaces.

7. Residuum Greases.—So-called *residuum greases* are manufactured in two ways: (1) by simply blending heavy, dark oils with the residues or bottoms from crude-oil stills, and (2) by mixing various fatty oils with blends of residuum and heavy black

oils. In the strict sense of the word, neither of these products is a grease, the first being simply a blended oil, and the second a compounded oil. Both types of these so-called greases are made in a wide range of consistencies, varying from products that flow freely at ordinary temperatures to those that are so viscous that they must be heated before they can be applied by means of a paddle or swab.

8. Grease Tests.—It is the intention to give here, not specific instructions as to grease-testing procedures, but only sufficient information to enable one to understand in a general way how the tests are made and, specifically, the significance of the various tests, especially from the standpoint of the user.[1]

Grease-testing procedures, however, have not been standardized to the same extent as those for oils and many other substances. This is doubtless because greases often contain such a variety of ingredients that it is difficult to establish procedures that will give consistent results for all types. In most cases, much must necessarily be left to the judgment and ingenuity of the analyst, especially in the case of chemical tests, which should be undertaken only by an expert chemist who has had considerable experience in grease testing.

Grease tests may be conveniently divided into three major divisions and several subdivisions, as follows:

1. Physical tests:
   - *a.* Melting and dropping points. ✓
   - *b.* Consistency or hardness.
   - *c.* Flash point.
   - *d.* Stability in storage and use.
   - *e.* Color and odor.
   - *f.* Texture and elasticity.
2. Chemical tests:
   - *a.* Determination of ash.
   - *b.* Determination of fillers, soap, fat, petroleum oil, and unsaponifiable matter.
   - *c.* Determination of free alkali and free acids.
   - *d.* Determination of water content.
   - *e.* Corrosion.
   - *f.* Emulsibility.
3. Mechanical tests.

[1] Those who are interested in specific test procedures will find invaluable the bulletin *A.S.T.M. Standards on Petroleum Products and Lubricants*, published by the A.S.T.M., Philadelphia, Pa.

9. Physical Tests.—Though chemical tests in general serve to detect undesirable ingredients that might render a grease unsatisfactory to the user, and may indicate contamination or cheap manufacturing methods, yet physical tests are generally considered more important to the user. They, as a rule, indicate the qualities a lubricant possesses for rendering specific services to a greater extent than do chemical tests. Moreover, they do not in general require highly specialized and expensive laboratory apparatus, nor do many of them require a trained laboratory technician.

Melting and Dropping Points.—These two terms are frequently used synonymously; yet regardless of the apparatus or method of procedure employed, identical results are not obtained. Usually the melting point is a few degrees less than the dropping point; the results of both tests are usually expressed in degrees Fahrenheit. Some tests are designed to obtain the melting point, whereas others give the dropping point. In general, the dropping point is more easily determined (hence, is more frequently run) and is often reported as the melting point.

Greases, in general, are highly complex mixtures of many substances, and the temperature of incipient melting, at which some portion of the mixture becomes fluid, and the temperature at which the whole is completely melted are not as a rule the same. The melting and dropping points of a grease may be modified considerably by heating and cooling, the rate of heating, mass of test sample, and the physical dimensions of the apparatus. In consequence, the temperatures recorded as melting and dropping points by various observers using different methods of preparation and procedures of tests, unfortunately, in general do not agree. It should be clearly understood that greases do not have definite melting and dropping points as a rule but gradually soften as the temperature is increased. The melting and dropping points depend chiefly on the quantity and kind of soap base (lime, soda, etc.), the kind of fat employed in making the soap base, the characteristics of the mineral-oil content, and the amount and state of water, if present. In the case of lime-base greases, however, the melting point increases less rapidly than it does for soda-base greases as the percentage of soap base is increased. The majority of lime-base cup greases have melting points in the region of 200°F., when determined by the

Ubbelohde method, whereas the soda-base sponge greases vary from 250 to 300°F. Completely dehydrated soda-base greases are produced with melting points from 350 to 450°F.

It will be realized that consistency and melting point are interrelated and that melting points depend largely on the methods by which they are determined.

The melting point of a grease is of value to the user in selecting grease for any type of service, particularly for conditions where operating temperatures are 100°F. and up. It is one of the major factors in determining the rate of consumption in a given case. Obviously, if the operating temperature of a bearing is, say 250°F., a grease having a melting point of 200°F. should not be used.

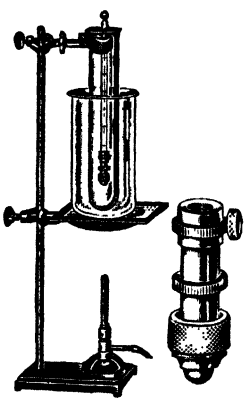


Fig. 23.—A.S.T.M. dropping-point apparatus. (*Courtesy Precision Scientific Co.*)

Conversely, the fact that two greases may have the same melting point does not indicate that they are suitable for the same service. The melting point is also of value to both the user and manufacturer in checking the uniformity of the product.

Some of the more commonly used methods for determining the melting point or dropping point, as the case may be, are as follows:

1. A.S.T.M. Proposed Method of Test for Dropping Point of Lubricating Greases.—This method employs the apparatus shown in Fig. 23. The apparatus comprises a grease-cup assembly composed of four brass parts suspended at the bottom of a thermometer, test tube, beaker, supports, and burner. As the temperature increases after the apparatus is properly assembled and the oil bath is heated, grease will gradually protrude through the orifice of the grease cup. The dropping point is that temperature at which the first drop of grease falls.

This test yields data as to the temperature at which greases soften under the conditions of tests but does not give information on the performance of greases in actual service.

A modified form of this method is known as the *Penola method*, developed by Penola, Inc., Pittsburgh, Pa. Figure 24 gives details of the apparatus.

2. CAPILLARY-TUBE METHOD.—This method consists primarily of using a capillary tube about 6 in. long open at both ends. One end is dipped into the melted grease until enough has risen to fill about ½-in. of the tube, which is then permitted to cool for several hours, preferably overnight, until the grease has solidified and regained its normal melting point. The tube is then supported in a vertical position a certain distance from the bottom

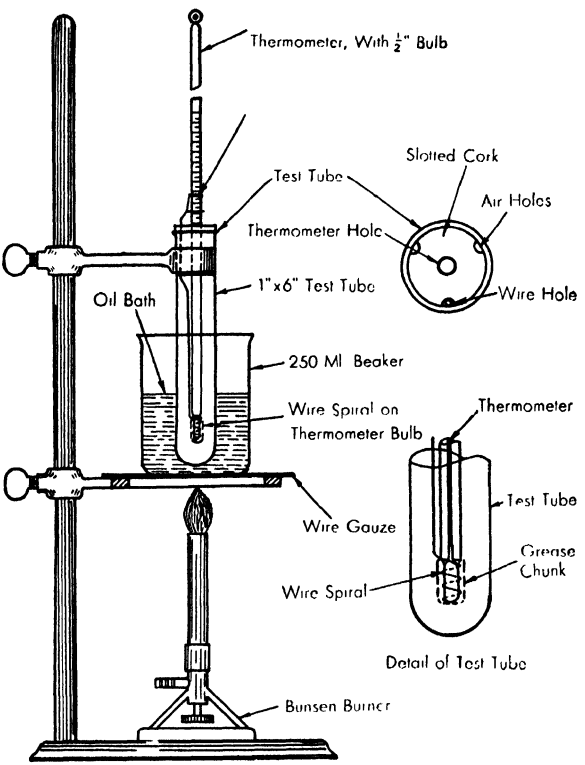


FIG. 24.—Penola melting-point apparatus.

of a beaker of water or oil. A thermometer is placed in the bath near the tube and in such a position that the center of the bulb is at the lower end of the tube. The bath is then slowly heated and continually stirred, and the temperature at which the grease melts and rises up the capillary tube is recorded. The average of two or three determinations is taken as the melting point of the grease. It has been found that the temperature of melting varies with the diameter of the capillary tube.

3. Slip or Plug Method.—This method employs a piece of open glass tubing, about 8 cm. long and 0.4 cm. internal diameter, which is stuck into the grease so that a plug 1 cm. long is left in the tube. The tube is then attached by means of a rubber band to a thermometer so that the grease plug is even with the bulb. The whole is then immersed in a suitable bath so that the bottom of the plug is 5 cm. below the surface of the bath. The bath is heated at the rate of 4°F. per min. When the melting point of grease is reached, the plug, which is under a pressure of 5 cm. of liquid, slips upward in the tube. This is sometimes called the *Guillett method.*

4. Ubbelohde Method.—This is one of the most commonly used methods. It consists of a thermometer surrounded by a metal ring, having an opening at the bottom. At the bottom of the metal ring is a glass tip 10 mm. long and having an opening at the bottom 3 mm. in diameter. The cup is filled with grease, care being taken to avoid the inclusion of air bubbles. The apparatus is then fastened by means of a cork in a test tube, which is 4 cm. in diameter. The whole is then immersed in a beaker or wide-mouth tube containing glycerin, white oil, or other suitable fluid, and the temperature of this bath is raised at the rate of 1°F. per min. The temperature at which arching at the bottom begins is the melting point; the dropping point is the temperature at which the first drop falls from the cup.

5. Miscellaneous Methods.—Other methods include those in which a steel ball of definite weight is placed on a definite volume of grease and the temperature noted at which the ball sinks into or through the grease.

Another method used by many manufacturers and especially suitable for hard greases is to place a $\frac{1}{16}$-in. cube of grease on the surface of clean mercury in a 25-cc. porcelain crucible and to heat it until the cube begins to melt down. The melting point is noted on a thermometer, the bulb of which is in the mercury.

Still another method sometimes employed is to put grease in a capillary tube closed at one end and to note the temperature at which the grease becomes transparent when heated in a suitable bath.

Dalican's *titer test,* which was devised for the valuation of tallow by determining the solidifying point, is also sometimes applied to greases. It is expressed in degrees centigrade and as

indicated measures the solidifying point rather than the melting point.

Consistency.—With liquids such as oils, when the flow is streamline a simple relation exists between pressure and rate of flow. If the pressure causing flow is increased or decreased, the flow will be proportionally increased or decreased and, no matter how small the pressure, some flow will occur and at a rate proportional to the pressure. Because of this simple relationship between pressure and flow, a viscosity determination may be made at any convenient pressure such as atmospheric, as is the case with commercial viscosimeters of the Saybolt and Redwood type. Thus, a single determination permits calculating the rate of flow not only through the same instrument under pressure, but also through anything from a capillary tube to a pipe line.

As regards consistency, greases are of two types: (*a*) plastic solids, and (*b*) plastic liquids. Plastic solids are not deformed by small forces but flow if any considerable pressure is applied. For example, at a small pressure, such as atmospheric, flow may not occur with a certain grease but if the pressure is gradually increased a pressure will eventually be reached at which flow will start, and from this pressure on, the rate of flow will rapidly increase.

Plastic liquids are substances intermediate between plastic solids and viscous liquids. They are similar to liquids in that they seek their own level and in time obliterate deformation of their surface. They resemble plastic solids in that their rate of flow increases more rapidly than directly proportional to the applied pressure. Examples of such substances are rubber cement and the so-called *fluid* and *semifluid* greases, which are in reality soap-thickened oils. Consequently, to obtain the relation between pressure and rate of flow for greases, determinations must be made at more than one pressure. A determination at a single pressure does not permit predicting the rate of flow at other pressures.

As indicated, an oil is a viscous liquid such that the smallest pressure or stress (shearing force) causes a constantly increasing change of form. Conversely, greases of the plastic solid type are characterized by requiring a certain starting pressure before flow starts, and by the fact that no continuous change of form is produced by stresses up to a certain minimum value. This

minimum value was first mentioned by Bingham and was termed by him *internal friction.* Later, Wilson, Baxter, and Mackenzie suggested the term *yield point.* If the stress exceeds this minimum value, flow will occur at a rate proportional to the excess shearing stress above the minimum value required to start flow. If the excess stress only is considered, therefore, the same relation between stress and flow will exist for greases as for oils. For oils this relation between flow and stress is defined by *viscosity,* or its reciprocal *fluidity;* for greases, it is defined by *mobility.*

The term *consistency* is sometimes used to include related factors which might more properly be described as differences in texture (*smooth, fibrous, spongy*), elasticity (*tacky, rubbery*), or ductility (*stringy, short, cheesy*). Very little work has been done to evaluate these properties of greases, but they can sometimes be controlled approximately by describing the general composition.

Obviously, many factors have a bearing on the consistency of greases. The chief ones are: (*a*) character and percentage of soap base, (*b*) percentage of free fat in the finished grease, (*c*) percentage of free alkali in the finished grease, (*d*) rate of cooling, (*e*) drawing temperature, (*f*) method of manufacture, (*g*) temperature in storage, (*h*) the extent of kneading or "working," (*i*) final water content.

In general the consistency of greases may be considered to be a measure of the soap content. This is especially true of greases of the same series; the harder the consistency, the greater the percentage of soap present.

The nature of the fatty oil employed has a tremendous effect on the consistency. Some fatty oils make greases of harder consistency than others, which accounts for the fact that some greases having the same consistency do not contain the same percentage of soap. Such factors as rate of cooling, method of manufacture, and drawing temperature have a pronounced effect on the consistency, but usually these may be easily controlled.

The rate at which a grease is cooled has a very pronounced effect on the consistency. For example, a cup grease can be manufactured to a consistency of no. 3, or, by cooling rapidly, it can be brought to a no. 1 consistency.

From a practical standpoint, consistency is one of the most important properties of a grease, for effective lubrication and minimum consumption depend on it to a great extent. It is of

great importance in connection with the use of grease in compression cups and in grease guns, and in estimating the flow characteristics of grease in centralized systems. To a great extent, it determines the bearing friction, the heat produced, and the rate of flow through the bearing. If the consistency is too high, the grease may channel and, in consequence, the surfaces requiring lubrication may suffer from lack of lubrication or, because of excessive internal friction, overheating may occur, as frequently happens in the case of antifriction bearings. On the other hand, if the consistency is too low, excessive losses may occur, due to leakage; or the consistency may be too light to withstand the temperature and load conditions prevailing, excessive wear and, in extreme cases, seizure of the bearing surfaces thus resulting.

Any handling of grease after it has set or any remelting will change its consistency. The original consistency also changes to some extent on standing, more rapidly during the first 48 hr. and only slowly thereafter. Consequently, in reporting consistency, it is necessary to indicate whether or not the sample was worked before making the test. Most tests in the past have been based on the original or unworked consistency; this consistency rarely bears any relationship to the worked consistency, which is generally of more practical importance for cup and most other greases. Grease has almost invariably reached its maximum softness at the time it is applied for lubrication purposes. As a rule, therefore, consistency should be made on a worked basis. Moreover, it is practically impossible to determine the unworked consistency when the sample has to be taken from a drum, barrel, or can.

Conversely, for very hard greases, such as railroad and some mill greases, the original or unworked consistency is generally the property of practical importance and should be the object of the test.

No standard unit has as yet been adopted for expressing consistency of greases. Considerable progress, however, has been made in recent years in devising apparatus and methods for determining flow-pressure curves of greases at different pressures through capillary tubes. Undoubtedly, methods of this type are the best so far devised to give a comprehensive picture of grease under varying temperature and shear conditions. These instruments are, in general, time-consuming and require using two or

three variables to describe the consistency. For these reasons, they have not been found practical for control test work or specifications. For these and other reasons, it has not been found possible to devise one instrument that is satisfactory for all types of greases. Consequently, many different instruments are used, some especially suited to measure the consistency of the harder greases and others more suitable for the fluid and the semifluid greases.

The common method of specifying consistency of the plastic solid greases is by arbitrary numbers that bear a certain relation to the penetration as determined by the A.S.T.M. penetrometer. Klemgard in his book *Lubricating Greases* gives for cup greases the following relationship between A.S.T.M. worked penetration and the commercial grade numbers:

Commercial Grade Number	A.S.T.M. Penetration, Mm.
0	35.0
½	32.5
1	30 0
1½	27 5
2	25 0
2½	22 5
3	20 0
3½	17 5
4	15 0
5	12 5
6	10.0

Certain grease manufacturers give the relationships shown in Tables XI and XII between their commercial grade numbers and the A.S.T.M. penetration.

Though most manufacturers indicate the degree of hardness or solidity by numbers in the ascending order, yet some manufacturers use the numerical system in the reverse order. For example, one firm designates cup-grease consistencies as follows: no. 0, extra hard; no. 1, hard; no. 2, medium; no. 3, soft; no. 4, extra soft. Frequently, manufacturers describe grease consistencies with such adjectives as *double extra hard, extra hard, hard, medium, soft, extra soft, fluid,* and *semifluid.* Obviously, such terms are meaningless, for it is doubtful if any two manufacturers agree on the use of such terms. It will also be noted from these data that there is quite a variation between the commercial grade

TABLE XI.—GRADE NUMBERS OF COMMERCIAL GREASES

Commercial grade number	A.S.T.M. penetration, mm. at 77°F.		
	Cup greases (worked)	Sponge greases (unworked)	Fiber greases (unworked)
00	.....	38.0 or over	Over 400
0	37.0–39 0	....	39.0–40.5
1	33.0–35.0	32.5–34.0	34.0–35.5
2	29.5–31.5	27.0–28.5	30 0–31.5
3	25.5–27.5	21.0–22.5	26.0–27.5
4	21.5–23.5	15.5–17.0	21.0–22.5
5	18.0–20.0		
6	14.0–16.0		

TABLE XII.—GRADE NUMBERS OF CUP GREASES

Commercial grade number	A.S.T.M. penetration, mm. at 77°F.	
	Manufacturing 1 (unworked)	Manufacturing 2 (worked)
00	30.0–36.0	
1	24.0-28 0	37 5–39.0
2	. . ..	30.0–33 0
3	18.0–22.0	21 5–24 5
4	15 0–17 0	18 5 -20 5
5	10.0–14 0	12.5–15.5

numbers and the A.S.T.M. penetration numbers as reported by different manufacturers. There is undoubtedly a great need for some uniform system of designating grease consistencies similar to the S.A.E. number system of classifying automobile crankcase oils.

Instruments commonly used for determining the consistency of greases may be divided into five broad groups as follows:

1. Penetration instruments:
   a. A.S.T.M. penetrometer.
   b. Abraham consistometer.
   c. Sinclair-Knopf consadometer.
2. Torsion instruments:
   a. MacMichael viscosimeter.
   b. Stormer viscosimeter.

3. Pressure instruments:
   a. Sinclair pressure viscosimeter.
   b. National Bureau of Standards pressure viscosimeter.
4. Capillary-tube instruments:
   a. Saybolt-Furol viscosimeter.
5. Miscellaneous instruments:
   a. Gardner mobilometer.
   b. Karns-Maag consistometer.

PENETRATION INSTRUMENTS.—Of all these instruments, the A.S.T.M. penetrometer is the most commonly used. The general arrangement of this instrument is shown in Fig. 25. It consists essentially of a cast base, which supports a vertical rod carrying the penetrometer dial, releasing mechanism, and plunger. Fastened to the lower end of the plunger is the penetration cone of standardized dimensions and weight. The penetrometer dial is graduated into 380 units representing a penetration of 38 mm. in 0.1-mm. divisions. In making a test, the sample is brought to 77°F. ± 1°F. The surface is cut level and very smooth with a knife and then placed on the penetrometer table. The cone is lowered until the tip just touches the surface, the scale is then set to zero, and the plunger released for exactly 5 sec. The penetration is read from the dial, the units being tenths of a millimeter.

This instrument is very well suited for determining the consistency of the solid plastic type of grease but is not adapted to the so-called *fluid* and *semifluid* products.

The Abraham consistometer consists of a spikeshaped plunger, which is forced through the sample of lubricant at a uniform velocity. The force required to cause penetration is applied by means of a handwheel and screw, the force being transmitted from the wheel to the screw by a spiral spring. The elongation of this spring is indicated by means of a pointer on a scale, which is graduated to read metric units of force. The rate of penetration is indicated by a hand, which is constrained to turn 1 revolution for each centimeter of penetration. The spike plunger thus penetrates at the rate of 1 cm. per min. Plungers having areas of 0.01, 0.1, 1.0, and 10 sq. cm. are used, as well as different sizes of springs. Results are reported as the cube roots of the pressures and are known as the *Abraham hardness numbers* or *Abraham consistencies.*

This instrument may be used for a very wide range of consistencies, varying from semifluid transmission to hard railroad

greases. It is, however, expensive and requires careful manipulation to obtain accurate results.

The Sinclair-Knopf consadometer is similar to the Abraham consistometer. It consists essentially of a spike-head plunger,

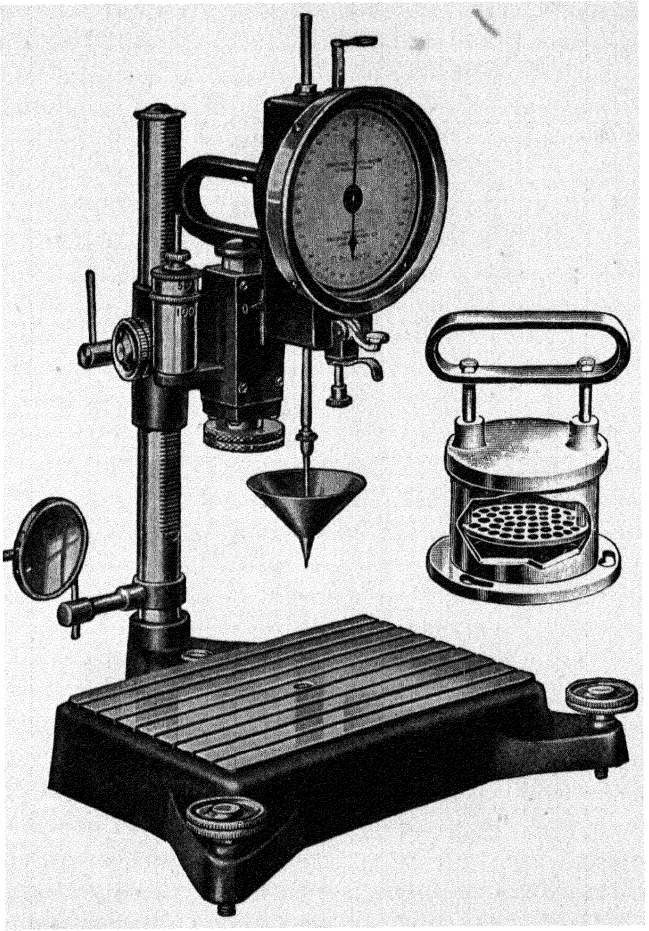


FIG. 25.—A.S.T.M. penetrometer and grease worker. (*Courtesy Precision Scientific Co.*)

which is forced through the sample at a constant speed, the force being read on a spring scale. Actually, the grease sample is raised on a platform by means of a constant-speed motor at a constant rate of 8.9 in. per min. against the fixed plunger. The viscidity is defined as the *average resistance* offered by the grease

to the passage of the plunger through it. The resistance or viscidity is usually expressed in ounces.

TORSION INSTRUMENTS.—The general arrangement of the MacMichael instrument is shown in Fig. 26. It consists essentially of a plunger of standard dimensions suspended by a torsion wire of exact length from the top of the instrument. The test sample

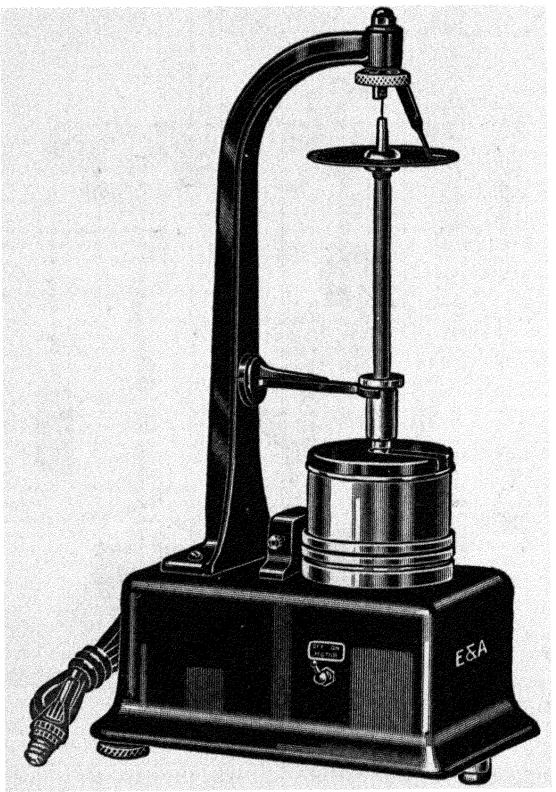


FIG. 26.—MacMichael torsion-type viscosimeter. (*Courtesy Eimer and Amend.*)

is placed in a cup, which is turned at a constant speed by a motor mounted in the base. The twist of the wire depends on the viscosity or consistency of the lubricant and is read on a graduated disk attached to the spindle, to the bottom of which the plunger is fastened. The graduations on the disk are in arbitrary degrees *M* ($\frac{1}{300}$ of a circle). However, by standardizing against solutions of known viscosity or consistency, the results can be expressed

in absolute units or any arbitrary units, such as Saybolt-Furol seconds. The sample cup is placed within an outer cup, which serves as a water or oil bath for controlling the temperature of the sample.

This instrument is widely used for determining the consistencies or viscosities of the fluid or semifluid greases. It gives satisfactory results over a wide range of viscosity, from that of light lubricating oils to the semifluid greases.

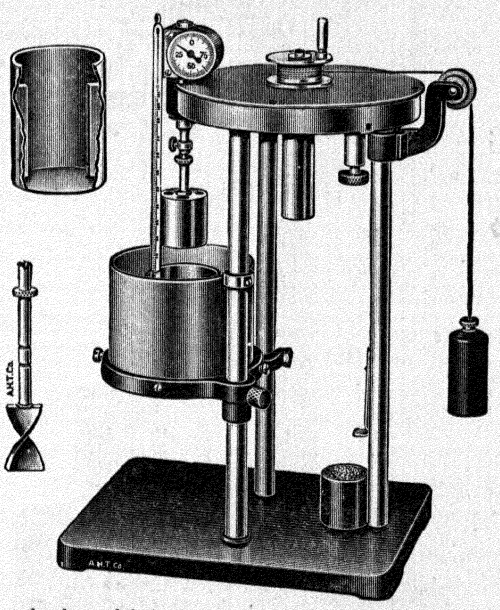


FIG. 27.—Standard model Stormer viscosimeter. The propeller-type rotor (lower left) is used in place of the cylindrical rotor (shown on the spindle) for measurements of oils and fluid greases. (*Courtesy Arthur H. Thomas Co.*)

The Stormer viscosimeter is shown in Fig. 27. Consistency determinations are made with this instrument by measuring the speed attained by a cylinder, which is caused to rotate in a test cup by means of a weight acting through a spindle, gear, and pinion. The cup is immersed in a suitable bath to maintain the desired temperature. A revolution counter is connected to a spindle, which supports the cylinder. The number of revolutions of the cylinder in distilled water and in the lubricant under test forms a basis for determining the consistency of the lubricant.

This instrument, or a modified form of it, is used for determining the viscosity of fluid and semifluid greases. One advantage of the torsion-type viscosimeter is that results secured are independent of specific gravity of the lubricant. In general, however, it is difficult for different operators to obtain concordant results on different instruments because of the many variables involved.

PRESSURE INSTRUMENTS.—The Sinclair pressure viscosimeter consists of a nickel-plated steel cylinder (2 by 8 in.), the top cap of which is connected to a 0.75-in. pipe, communicating with a constant-pressure air tank. Accurate and convenient control of air pressure is accomplished by two needle valves or by an automatic pressure regulator. A stop-and-waste valve makes it possible for pressure to be applied to the lubricant in the tube for any desired period of time or to be cut off and instantaneously released from the tube. The pressure is read on a calibrated gage. The whole is enclosed in a well-insulated cabinet and provided with heating and refrigeration facilities. A circulating fan is also provided within the cabinet.

About 0.50 to 0.75 lb. of the sample is placed in the tube, care being taken that no air pockets are formed. After bringing the sample to the desired temperature, air pressure is applied and maintained constant until approximately 50 g. of the sample are extruded into a receiving cup. The time of efflux is the time that the lubricant is flowing, or it is the time during which the orifice is uncovered until the pressure is released. The sample is weighed to the nearest tenth gram and the pressure viscosity calculated by means of the formula developed by Parsons and Taylor:

$$\text{Pressure viscosity} = \frac{525 \times \text{seconds flowing} \times \text{pressure, pound per square inch}}{\text{grams discharged}}$$

Usually, two pressures are employed for known greases, but three or four pressures should be used for greases not previously tested. If the rate of shear is sufficiently high, it is said the results will check within 1 or 2 per cent, even though the pressures differ considerably. The minimum reading is taken as the correct value, which usually checks one or more other readings.

The National Bureau of Standards pressure viscosimeter is a new type, in which the test material may be passed successively back and forth through a capillary tube, thereby giving con-

sistency readings that show whether or not the grease is changing under stresses.[1]

The advantage of the pressure type of instrument lies in the fact that a flow-pressure diagram may be obtained of a grease, *determining* the degree of plasticity and the behavior of the lubricant under different shearing stresses being thereby determined.

CAPILLARY-TUBE INSTRUMENTS.—There are a number of this type of instrument used, but the Saybolt-Furol is by far the more commonly used instrument. It is similar in every respect to the Saybolt universal instrument, except that the orifice through which the grease flows is larger than it is in the universal model. The diameter of the orifice is 0.1765 cm. in the universal model and 0.315 cm. in the Furol model. A bath of suitable liquid surrounds the test tube, in the bottom of which the orifice is located. The bath may be electrically, steam, or gas heated to any desired temperature. By removing a cork, the lubricant flows under gravity from the test tube into a 60-ml. flask. By means of a stop watch, the time required for the 60-ml. flask to run full is determined. This time expressed in seconds is the Saybolt-Furol viscosity.

This instrument is suitable only for greases that are liquid at reasonably low temperatures.

MISCELLANEOUS INSTRUMENTS.—The Gardner mobilometer consists of a brass tube, in which the grease to be tested is placed. A circular line on the inside of the tube indicates the height to which it should be filled. A plunger of standardized dimensions and weight carries a disk at its lower and a scale pan on its upper end. The time required for the plunger to descend through the grease is measured by means of a stop watch. A sharp click is heard when the plunger strikes the bottom of the tube. Three standard disks are used; no. 1 is solid, no. 2 has a series of small holes, and no. 3 has four large holes. The no. 1 disk is used for greases of very soft consistency and disks 2 and 3 for those of soft consistency. A wide range of greases can be tested by employing different disks and adding different weights to the scale pan.

The Karns-Maag instrument is so constructed that by pressing a trigger a set of jaws opens and permits a ball of definite weight

[1] A complete description of this instrument may be found in the *National Bureau of Standards Research Paper* 188, July, 1930.

and diameter to fall a specified distance into the center of a standard cylinder containing the grease to be tested. The depth that the ball penetrates into the grease is measured in millimeters by means of a depth gage and recorded as the consistency, or degree of solidity, of the grease.

For lubricants too hard to be determined in this manner, the ball falls on a pin, which is held by a disk in the standard cylinder centrally above the sample of hard grease contained in a small cylindrical cup. The depth in millimeters that the pin penetrates into the grease is recorded as its consistency. Scale *S* denotes consistency determined by the ball or sphere and scale *H* that determined by the pin.

This instrument obviously cannot be used for determining the consistency of greases that are liquid at ordinary temperatures.

Flash Point.—The flash point of a lubricant is the lowest temperature, expressed in degrees Fahrenheit, at which sufficient vapors are given off to form, with air, an inflammable mixture that will burn momentarily when a small flame is applied. The flash point of a lubricant varies with the apparatus and procedure employed in making the test. Hence, it is necessary always to specify apparatus and method when reporting flash-point values. The A.S.T.M. Cleveland open-cup tester is more commonly used than any other instrument. This instrument has been standardized by the A.S.T.M. for lubricating oils.

The flash point gives an idea of the grade of mineral oil used in the grease without actually extracting the oil. In general, the lower the viscosity of the mineral oil, the lower will be the flash point. However, the flash point bears no direct relationship to suitability. It serves the user as a check on the uniformity of the grease. Often an experienced grease chemist is able to detect certain ingredients in the grease by the odors given off during a flash-point test.

Stability in Storage and Use.—Stability of grease in storage and especially in service is of the utmost importance to the user.

Stability depends primarily on the quality of the ingredients used and the thoroughness of the manufacturing process. Greases containing poor-quality or unsuitable fats are likely to turn rancid in storage and use or to oxidize and change color. Excessive amounts of free fats or free fatty acids in the finished grease are likely to promote this action. Conversely, excessive

quantities of free lime will cause separation of the soap and mineral oil during storage of cup greases. It is of the utmost importance that any grease subject to centrifugal action does not separate—as, for example, ball- and roller-bearing and universal joint greases.

No standard test for determining stability has been developed. The Norma-Hoffmann test, however, is widely used for predicting

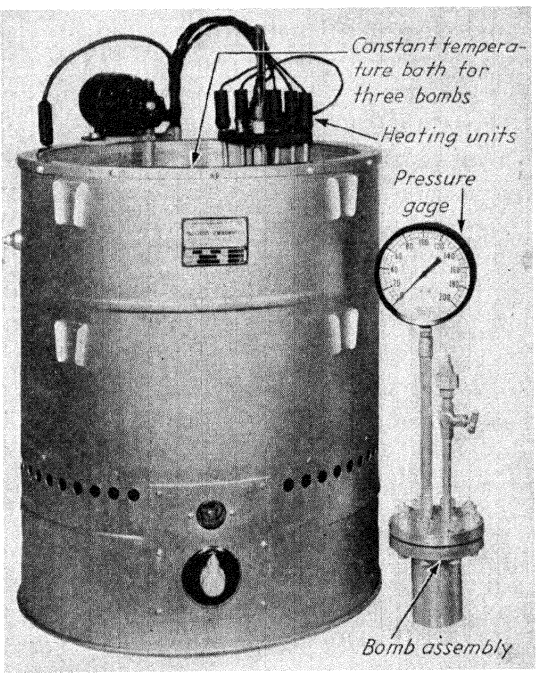


FIG. 28.—Norma-Hoffmann grease stability apparatus. (*Courtesy Precision Scientific Co.*)

the storage life of soda-base greases. The apparatus, shown in Fig. 28, consists essentially of a steel bomb immersed in a constant-temperature bath. Each bomb is fitted with a suitable valve for flushing and filling with oxygen and also with a pressure gage to indicate drops in pressure resulting from the absorption of oxygen by the sample of grease.

This test makes it possible to specify definite storage-stability characteristics of greases, either in terms of the number of hours for the induction period or the rate of oxygen absorption in

cubic centimeters per hour during the induction period. This method permits a reasonably rapid check on shipments for uniformity between batches, which is one of the important considerations in providing the best possible lubricant for antifriction bearings.

Color and Odor.—The natural color of greases depends solely on the color of the fats and mineral oil used and on methods of manufacture. The color, therefore, indicates to a certain extent the quality of the ingredients used. The lubricating quality of a grease should not, however, be judged by its color, as there is no relationship whatsoever between color and lubricating value. High-viscosity cylinder stock or black lubricating oils are generally used in the black or dark-colored greases, whereas light, pale, and neutral oils, and red engine oils are used in the more common yellow-colored greases. Greases of the same grade will have uniform colors if the method of manufacture has been carefully carried out. It is possible to produce a very dark grease by employing excessive temperatures during the manufacturing process, even though the mineral oil is a light-colored one. Some commercial greases are colored by means of aniline dyes, which give them a distinctive appearance and make them readily identifiable. The color of all fats is likely to vary from time to time, which may alter the depth of color in the finished grease, unless artificial coloring material is added.

Greases may change color during storage because of oxidation and evaporation of free moisture if present. The majority of greases will bleach if exposed to strong light, so that a sample of some age is likely to be lighter in color than the freshly made grease.

No standard test has yet been devised for determining the color of greases. The only method used is that of observation.

Most fats used in grease manufacture have objectionable odors. Even after fats are saponified, they may be detected at times in the finished grease. There are several reasons why scenting substances in the lubricating greases are used. The chief value to the user is that particular greases may be easily identified. Moreover, natural odors are sometimes objectionable in establishments such as bakeries and candymaking plants. From the standpoint of the manufacturer, objectionable odors of such ingredients as tars and unrefined lubricating oils used in inexpen-

sive greases should be masked or altered. Conversely, highly scented, ordinary, general-purpose greases should be looked on with suspicion, because the scenting may have been done to cover up rancid fats or low-grade, disagreeably smelling oils. Rancid fats should not be used in greases because of their general instability and rapid deterioration, which generally result in the development of higher acidity.

Oil of mirbane (nitrobenzene) is frequently used but is giving way rapidly to the so-called *synthetic deodorants*. Sassafras oil is also used, to a limited extent, because of its cheapness and strong odor.

Texture and Elasticity.—*Texture* refers to the structure of the grease and is described by such adjectives as *smooth, fibrous,* or *spongy*. It depends mainly on the basic constituents of the soap but does not depend on the quantity of soap present. *Elasticity* is the ability of a grease to absorb energy and return it elastically. It is described by such terms as *rubbery, stringy, short,* and *cheesy*.

Although the service value of greases depends to a large degree on these properties, practically nothing has been done toward developing methods of measuring these characteristics.

10. Chemical Tests.—A complete chemical analysis of a grease is, in general, a long and complicated process. It is often necessary, however, in order to obtain a general idea as to major constituents and main characteristics of a grease. Usually, it is advisable to make a brief examination first, to determine the best method of approaching the analysis. In making an analysis, it is of particular importance to differentiate between greases made of soaps and mineral oils, such as cup greases, which are usually not difficult for an experienced grease chemist to analyze, and those made from combinations of pitches and mineral oils and, perhaps, soaps, fats, and fillers as well.

An analysis of a substance as complex as a grease requires considerable skill and experience on the part of the chemist, and in general the results achieved are not nearly so accurate as for inorganic materials.

Moreover, the interpretation of the results obtained in terms of lubricating value in service is even more difficult. Two greases of practically the same chemical analyses may show marked differences in lubricating value in service and stability in storage and use. The kind of fatty oils used in making greases may be

determined with reasonable certainty where only one kind of fatty oil is used; but if a mixture of fatty oils has been used, the identification becomes much more difficult and less certain.

The chemical analysis of a grease is more useful to the manufacturer than to the user, because the manufacturer depends mainly on chemical analyses for controlling the various steps in the manufacturing process. To the user, its chief value is to determine whether or not a grease is of the general type specified, such as lime or soda base, and to make sure that the differences between various lots of the same grade and brand are not greater than are reasonable.

Fillers include finely divided solid substances, such as chalk, talc, mica, asbestos, or gypsum, insoluble and dispersed in the grease. Most fillers are adulterants added to increase the weight, since greases are generally sold by the pound. Some, such as graphite and mica, however, have definite lubricating value and increase the cushioning power and reduce the noise of the operation. It is necessary, therefore, to know for what service a grease was manufactured before the presence of filler is condemned or approved.

A grease expert is capable of telling much about a grease by noting its color, odor, texture, especially during a determination of its flash point. The presence of tallow, rosin, and rosin oil and of certain other oils may often be detected by the odor given off when the grease is warm, provided that a scenting material has not been added. Very pale greases usually contain low-viscosity mineral oils, whereas dark and black greases generally contain heavy dark lubricating oils. Greases completely soluble in ether or gasoline contain no soap; and water, if present in appreciable quantities, is indicated by the turbidity of the solution. The presence of soap may also be detected easily by burning a little of the grease on a platinum crucible lid or in a crucible. If any ash remains, soap is present, and the kind of soap (lime, soda, lead, etc.) may be found by testing the ash in a flame on a platinum wire with hydrochloric acid.

Two general methods of procedure for determining the constituents of a grease have been standardized by the A.S.T.M. and have been approved as the American standard by the American Standards Association (A.S.A.).

One method of procedure is provided for light-colored greases, including fiber, sponge, and axle greases, which, because of their high "asphalt" content, give troublesome emulsions if the first procedure is employed. Because of its simplicity, the first procedure is preferable wherever it can be applied. Relatively speaking, both methods are complicated and highly chemical; but briefly they consist of extracting the various constituents by means of solvents, then determining the quantity and character of these constituents by various chemical and physical tests.

Neither method provides for a determination of the nature of the oils or fats used in preparing the soap base of the grease. By a careful examination, however, of the extracted fats and the determination of certain of their physical and chemical properties, an experienced chemist can determine fairly accurately the nature of the fats used.

Corrosion.—The A.S.T.M. does not provide a standardized method of determining the corrosive properties of greases. The U.S. Bureau of Mines (method 530.4) has devised a simple test, however, which requires that a small portion of the grease be placed on a clean, polished copper strip which is placed under a watch glass at room temperature for 24 hr. Any development of green color in the grease or of brown stain on the copper strip is considered indicative of corrosion.

Emulsibility.—There is no standardized test for determining the emulsibility of a grease; however, a simple method is to mix a small amount of grease with a little warm water and observe whether or not the grease absorbs the water to form a lather, at the same time changing to a lighter, creamy color.

11. Mechanical Tests.—It has long been realized that, although chemical and physical tests do to a limited extent produce results of value as regards lubricating properties, yet they indicate very little, if anything, as to the friction-reducing and film-forming characteristics of a lubricant—both of which are of great practical importance. Stability during storage and use depends partly on the type of ingredients and partly on proper manufacture, neither of which can be accurately determined by analytical methods. Nor do analytical methods indicate the quality or degree of refinement of the various ingredients used in manufacturing the grease. In consequence, many efforts have been made to devise a mechanical test that will rate lubricants in the

same order of merit as actual service tests, which are obviously both time-consuming and expensive.

Manifestly, the mechanical testing of a lubricant should be effected in a machine that reproduces, as closely as possible, the conditions under which the lubricant is subsequently required to work. The success that has been achieved in this effort has not been marked, for in practice there are usually many influencing factors that make it most difficult to design a laboratory machine that will simulate all conditions.

The older machines were designed mainly for determining the frictional resistance or coefficient of friction of the lubricant. These machines as a whole were very cleverly designed and constructed and undoubtedly have contributed a great deal to our present knowledge of the science of lubrication. Usually, they contain only one test bearing or pair of gears having highly polished rubbing surfaces and operated under conditions of pressure, speed, and temperature quite different from those of practical service. Among the notable ones are the Thurston, Goodman, Riehle, Deeley, Daimler-Lanchester, Stanton, and Kingsbury. In general, these machines are capable of evaluating the friction-reducing ability of a lubricant under the specific conditions of the test. On the other hand, they are not capable of producing results that indicate the lubricating value of a lubricant when employed under different conditions of service.

In the past few years, however, considerable progress has been made in perfecting laboratory machines, and three machines have been designed that are widely used at the present time. These machines are: (1) the Almen extreme-pressure lubricant-testing machine, (2) the Timken wear and lubricant tester, and (3) the S.A.E. extreme-pressure lubricant-testing machine. A brief description of each of these machines is given in Chap. VII.

12. Grease vs. Oil.—Although there are conditions under which it is obvious that a grease is a more suitable lubricant than an oil, or vice versa, yet there are many cases where the choice is more or less immaterial. If all factors influencing the selection, however, are taken into account and given their respective proper weight, there are only a few, if any, cases where the choice is unimportant.

From the standpoint of lubrication alone, *i.e.*, to reduce frictional power losses, minimize wear, and prevent abrasion, it is

questionable whether a grease can ever be said to be a better lubricant under any operating condition than oil. Greases in general are less stable than oils. They tend to separate under high-temperature and -speed conditions. Because of their heavier body or consistency, they offer greater internal friction than oils and therefore are not so suitable as oils for high-speed conditions or other conditions where frictional power loss is an important consideration. The disadvantages of grease may be considered the outstanding advantages of oil.

The design of the equipment, operating conditions, and the various requirements of the process in which the machinery is used—all must be given careful consideration before an intelligent decision can be made as to whether a grease or an oil is the more suitable lubricant for the case in hand. Greases, however, are generally more practical than oil:

a. When required to supply lubrication under dirty atmospheric conditions. Grease seals the ends of the bearing, preventing dust and dirt from entering the bearings. This is especially important in the case of ball and roller bearings, as these bearings are quickly ruined by a small amount of dirt.

b. For the bearings of inaccessible machinery, such as hoists, cranes, or elevator motors. Grease as a lubricant generally requires less attention than oil. Moreover, grease will ensure some lubrication even when a bearing is neglected for some time.

c. Where freedom from dripping and spattering is an important consideration, *e.g.*, in bakeries, paper mills, laundries, candy-making plants, textile mills, etc.

d. Where operating conditions are extremely severe, such as at high temperatures, extreme pressures, and low speeds, for shock loading, or when bearings are operating intermittently or reversing.

e. Where running clearances are excessive owing to wear or rough machine work, for example, for cast-iron bearings of some farm machinery, construction and road-building equipment, and coal-mine and quarry machinery.

f. Where seats or retainers are badly worn or are lacking and where frequent attention cannot be given.

13. Specifications.—In general, grease manufacturers discourage the use of specifications, because they are frequently drawn up by persons inexperienced in grease manufacturing

methods and procedures. In consequence, specifications often contain close numerical limits, frequently based on a particular grease, that cannot be met by many manufacturers and yet that do not ensure that the consumer will obtain a satisfactory grease for his particular requirement.

Large quantities of grease are bought and sold annually, however, on the basis of specifications, and no doubt this practice will increase as time passes and the fund of information on the subject grows. The federal government, as well as many state and municipal governments, railroads, and other large consumers, buys greases on this basis. Doubtless, the specifications drawn up by the federal government are as accurate and as adequate as it is feasible to make them considering our present knowledge. Some of the more recent federal specifications are substantially as follows:

Mineral Lubricating Grease

(Federal Specification VV-G-681)

General Requirements.—Mineral lubricating grease shall be a smooth homogeneous mixture of mineral oil and pure odorless lime soap made from animal or vegetable fats or oils or fatty acids, completely saponified with hydrated lime, and shall be suitable for the lubrication of such parts of motor equipment and other machinery as are lubricated by means of compression cups, and for use in ball and roller bearings.

Mineral lubricating grease shall contain no fillers such as rosin, rosin oils, talc, wax, powdered mica, sulfur, clay, asbestos, or other undesirable or deleterious impurities.

Mineral lubricating grease shall possess only a slight odor of mineral oil and may be rejected if it has any other distinct odor.

Specification Limits.—Mineral lubricating grease shall comply with the specifications shown in Table XIII.

Graphite Lubricating Grease

(Federal Specification VV-G-671)

General Requirements.—Graphite lubricating grease shall be a smooth homogeneous mixture of mineral oil, graphite, and pure odorless lime soap made from animal or vegetable fats or oils, completely saponified with hydrated lime.

Flake graphite shall be used that is free from grit and that contains at least 82 per cent of graphitic carbon.

TABLE XIII.—SPECIFICATIONS OF MINERAL GREASES

Test	Grade			Test methods (A.S.T.M.)
	Soft	Medium	Hard	
Grease:				
Penetration	300–355	240–290	190–230	D 217-33T
Mineral-oil content, per cent (min.)	85	80	75	D 128-27
Water content, per cent (max.)	1.5	2.0	2.0	D 95-30
Ash as sulphates, per cent (max.)	5.0	6.0	8.5	D 128-27
Uncombined CaO, per cent (max.)	0.10	0.10	0.10	D 128-27
Insoluble matter, per cent (max.)	0.10	0.10	0.10	
Corrosion*	Nil	Nil	Nil	
Mineral-oil constituent:				
Viscosity at 130°F., S.U.S. (min.)	125	125	125	D 88-33
Flash point, °F. (min.)	340	340	340	D 92-33
Fire point, °F. (min.)	370	370	370	D 92-33

* U.S. Bureau of Mines, method 530.4.

TABLE XIV.– SPECIFICATIONS OF GRAPHITE GREASES

Test	Grade			Test methods (A.S.T.M.)
	Soft	Medium	Hard	
Grease:				
Penetration	300–355	240–290	190–230	D 217-33T
Mineral-oil content (min.)	85	80	75	D 128-27
Water content, per cent (max.)	1.5	2.0	2.0	D 95-30
Graphite content, per cent	2–3	2–3	2–3	D 128-27
Uncombined CaO, per cent (max.)	0.10	0.10	0.10	D 128-27
Corrosion*	Nil	Nil	Nil	
Mineral-oil constituent:				
Viscosity, S.U.S. at 130°F. (min.)	125	125	125	D 88-33
Flash point, °F. (min.)	340	340	340	D 92-33
Fire point, °F. (min.)	370	370	370	D 92-33

* U.S. Bureau of Mines, method 530.4.

Graphite lubricating grease shall contain no fillers such as rosin, rosin oils, talc, wax, powdered mica, sulfur, clay, asbestos, or other undesirable or deleterious impurities.

Graphite grease shall possess only a slight odor of mineral oil, and may be rejected if it has any other distinct odor.

Specification Limits.—Graphite lubricating grease shall comply with the specifications of Table XIV.

Driving-journal Lubricating Grease

(Federal Specification VV-G-661)

General Requirements.—Driving-journal lubricating grease shall be a smooth, homogeneous mixture of soda soap and well-refined cylinder-stock mineral oil and shall be suitable for the lubrication of driving journals on locomotives provided with grease cellars.

Driving-journal lubricating grease shall be green or greenish in color.

Specification Limits.—Driving-journal lubricating grease shall comply with the specifications of Table XV.

Table XV.—Specifications of Driving-journal Greases

Test	Limit, %	Test methods (A.S.T.M.)
Soap content (min.)	45	D 128-27
Free alkali	0.5–2.5	D 128-27
Water content	*	D 95-30
Glycerin content	*	D 128-27
Impurities	*	D 128-27

* The sum of the percentages of water, glycerin, and impurities present shall not exceed one-third of the dry-soap content.

Crankpin and Rod-cup Lubricating Grease

(Federal Specification VV-G-651)

General Requirements.—Crankpin and rod-cup lubricating grease shall be a smooth, homogeneous mixture of soda soap and well-refined cylinder-stock mineral oil, and shall be suitable for the lubrication of cranks and rods on locomotives provided with grease cups.

Crankpin and rod-cup lubricating grease shall be slightly yellowish in color.

Specification Limits.—Crankpin and rod-cup lubricating grease shall comply with the specifications of Table XVI.

TABLE XVI.—SPECIFICATIONS OF CRANKPIN AND ROD-CUP GREASES

Test	Limit, %	Test methods (A.S.T.M.)
Soap content (min.)	40	D 128-27
Free alkali	0.5–2.5	D 128-27
Water content	*	D 95-30
Glycerin content	*	D 128-27
Impurities	*	D 128-27

* The sum of the percentages of water, glycerin, and impurities present shall not exceed one-third of the dry-soap content.

CHAIN- AND WIRE-ROPE LUBRICANT

(Federal Specification VV-L-751)

General Requirements.—Chain- and wire-rope lubricant shall be a petroleum oil without the admixture of fatty oils, fatty acids, resins, soaps, talc, or other nonhydrocarbon materials, and shall be suitable for the lubrication and protection of all heavy equipment.

Specification Limits.—Chain- and wire-rope lubricants shall comply with the specifications of Table XVII.

TABLE XVII.—SPECIFICATIONS OF CHAIN- AND WIRE-ROPE LUBRICANTS

Test	Limit	Test methods (A.S.T.M.)
Viscosity, at 210°F., S.U.S.	900–1100	D 88-33
Protection test, days	30	*

* Federal Specification Board Test 400.1.

TABLE XVIII.—CLASSIFICATION, COMPOSITION, AND USES OF GREASES

Classification	Class name	Composition			Remarks and recommendations
		Alkali	Fat	Mineral oil	
	Lime base	Calcium hydroxide (slacked lime) ($Ca(OH)_2$)	Horse, hog, bone, wool, fats; fish, rapeseed, castor, palm, neat's-foot, cottonseed, soybean, sperm, rosin oils; beef, mutton, vegetable tallows; esters of stearic, palmitic, and oleic acids	Various lubricating oils ranging from light spindle to heavy, dark residuum oils, depending on the purpose for which the grease is made	General-purpose greases containing usually from 70 to 90 per cent mineral oil; widely used in compression grease cups, gear boxes, etc., in industrial plants. Not suitable where operating temperatures exceed 175°F. or where they are subject to high speeds or churning action, because high centrifugal force incident to high speeds tends to separate the water and soap-oil mixture, thereby permitting the mineral oil and soap base to separate. Not suitable for antifriction bearings that operate at high speed and temperature conditions. They are water-repellent
	Sodium base	Sodium hydroxide (caustic soda) (NaOH)	Same as for lime-base greases	Same as for lime-base greases	Suitable for high-temperature and -speed conditions as they do not contain water as a binding agent. Not recommended for use in the presence of water because they readily emulsify with it. Suitable for antifriction bearings operating at high-speed and -temperature conditions, for plain bearings and in centralized-pressure lubrication systems where a light product of nonseparating characteristics is required to avoid clogging of the supply pipes. Suitable for wheel bearings, universal joints, steering gear, and spring shackles of automobiles
According to soap base	Aluminum base	Generally, sodium or potassium hydroxide used with oleic or stearic acid to form sodium oleate or stearate which in turn is combined with aluminum sulfate to form aluminum trioleate or tristearate	Oleic and stearic acids, acidless tallow, castor oil, and sodium naphthenate	Various lubricating oils, ranging from light spindle oils to cylinder stocks	Combine some of the advantages of both lime- and sodium-base greases. Are water-repellent; withstand high temperatures; do not separate when agitated or used in centralized-pressure greasing systems. Usually, brilliant and transparent in appearance; often referred to as solidified oils or transparent cup and pressure gun greases. Used where operating temperatures and speeds are high. For example, rocker arms of airplane motors, high-speed gears, and many other applications where grease is applied by means of a pressure grease

					gun. They are nonspattering and are used where such a lubricant is demanded
	Lead base	Lead acetate, lead monoxide (litharge), sodium hydroxide	Oleic and stearic acids; fish, whale, castor, rosin, neat's-foot, nut, linseed oils; naphthenic acids; etc.	Specially selected lubricating oils. Heavy black oils are not suitable	These greases are usually classified as *extreme-pressure* lubricants because of their ability to withstand high pressures. They are sometimes used as a compound in transmission greases, especially those intended for use in worm and Hypoid sets. They do not emulsify or dissolve in water but tend to settle out in the presence of water when in dilute solution in mineral oil
	Zinc base	Zinc oxide, zinc acetate, sodium hydroxide	Sodium oleate and sodium stearate	Same as for lime-base greases	These greases are water-repellent and are frequently used for lubricating the plungers of hydraulic elevators, and the piston rods of water pumps and as a slushing compound for preventing the rusting of wire cables that operate in water. These are frequently referred to as *hydraulic* greases
	Mixed base	Calcium hydroxide + sodium hydroxide, potassium hydroxide +calcium hydroxide, aluminum hydroxide +sodium hydroxide	Same as for lime-base greases	Same as for lime-base greases	Used where conditions do not permit using lime- or sodium-base greases, such as high-speed bearings in the presence of moisture. Mixed-base greases combine to a certain degree characteristics of the individual soaps used in the admixture
According to manufacturing methods	Cooked or boiled	Same as for lime-, sodium-, aluminum-, lead-, zinc-, and mixed-base greases	Same as for lime-base greases	Same as for lime-base greases	The bulk of greases are manufactured by cooking or boiling. Cup, sponge, fiber and many other greases are made by this method. In general, all the better grade greases fall under this classification. They are used for a wide variety of services, as indicated above
	Cold sett	Calcium hydroxide	Rosin acid	Usually, dark lubricating oils	These greases in general are of the cheaper grade. They are commonly used to lubricate rough machinery in steel mills, coal mines, skids, launching ways, track curves, etc. They should never be used on brass bearings, as they cause corrosion
	Residuum	None	Generally none	Dark, heavy oils, residuum or bottoms, and sometimes cylinder stocks	Sometimes, an animal or vegetable oil is added as well as tar, rosin oils, etc. Made in a wide range of consistencies; very adhesive and tacky. Used for lubricating wire cables, open gears, steel-mill roll necks, etc. Generally applied hot by swab or brush

TABLE XVIII.—CLASSIFICATION, COMPOSITION, AND USES OF GREASES.—(*Continued*)

Classification	Class name	Composition			Remarks and recommendations
		Alkali	Fat	Mineral oil	
	Fluid no. 0	Usually, same as those listed above under aluminum-base greases	Same as for lime-base greases	Generally, light- and medium-viscosity lubricating oils	Many of the so-called *solidified, dripless,* or *nonspattering* greases fall into this class. Such products are generally mineral oils thickened with usually less than 5 per cent aluminum soap. Used where nonspattering characteristics are desired, such as in textile mills, bakeries, food-preparation establishments and for chain drives, speed reducers, cranes, circulation systems of gyratory rock crushers, woodworking machinery
	Very soft no. 1	Same as for no. 3	Same as for lime-base greases	Various lubricating oils (see lime-base greases above)	Recommended for conditions similar to those appropriate for soft greases but where temperatures are lower and speeds generally higher. Soap content is usually very low
According to consistency	Soft no. 2	Same as for no. 3	Same as for lime-base greases	Various lubricating oils (see lime-base greases above)	Used for light-duty line-shaft bearings, ball and roller bearings, gearboxes, and in general where application is by means of grease cups and pressure guns
	Medium no. 3	Sodium, calcium, aluminum hydroxides alone and in combination; also, lead and zinc alkalies	Same as for lime-base greases	Various lubricating oils (see lime-base greases above)	This consistency is widely used in many different plants and industries. Under certain operating conditions, it is suitable for ball and roller bearings, line-shaft bearings, pumps, crushers, grinders, farm machinery, elevators, excavating machinery, machine tools, ceramic machinery, etc.
	Hard no. 4	Usually, sodium or calcium hydroxide	Same as for lime-base greases	Various lubricating oils (see lime-base greases above)	Recommended for bearings in heavy duty such as coal conveyors, cranes, hoists, excavating machinery, shears, punch presses, etc.
	Very hard no. 5	Usually, sodium or calcium hydroxide	Same as for lime-base greases	Generally, dark lubricating oils or cylinder stocks	Some of these greases have melting points as high as 450°F. Used for very high temperature conditions, such as paper driers, cement-mill kilns, tube mills, coolers, ball and rod mills, and laundry calenders, mangles, and ironers

Cup greases	Usually, calcium hydroxide	Same as for lime-base greases	Same as for lime-base greases	Usually, lime-base greases contain 80 to 90 per cent mineral oil and 10 to 20 per cent saponified fat. Water generally present from traces up to 1 per cent. Melting point varies from 120 to 200°F., depending on the soap content. General-purpose greases used in a wide variety of services but not suitable for high speeds and temperatures above 175°F. These are water-repellent greases
Graphite greases	Calcium hydroxide	Same as for lime-base greases	Same as for lime-base greases	Usually, cup greases to which has been added from 2 to 20 per cent flaked, powdered, or colloidal graphite. Especially suitable where the lubricant is likely to be washed away by water, oil, or chemical solvents. Hydraulic rams, plungers, slides and bearings exposed to water, and elevator cables and slides are typical examples of where these greases are used. Not suitable for ball and roller bearings unless graphite is in colloidal form. Obtainable in five consistencies
Fiber and sponge greases	Sodium hydroxide	Same as for lime-base greases	Same as for lime-base greases	Called *fiber* or *sponge* greases because of their peculiar fibrous or granular structure. Melting point varies from 200 to 400° F. Cannot be used in the presence of water as they readily emulsify and are easily washed from the bearing surfaces. If of good quality can be melted and cooled again without altering their consistency. Contain no filler of any kind. Especially suitable for ball and roller bearings, automobile-wheel bearings, universal joints, spring shackles, stearing gears, etc. Obtainable in five consistencies
Ball and roller-bearing greases	Calcium, sodium and aluminum hydroxide and lead oleate, as well as various mixed alkalies	Same as for lime-base greases	Generally, high-grade lubricating oils	Soft greases, composed of petroleum jelly, or mixtures of this with mineral oils; or soft cup greases containing 12 to 15 per cent soap and mineral oil having a viscosity of 400 to 500 sec. Saybolt at 100°F.; or sodium-base grease containing 16 to 20 per cent soap and mineral oil having a viscosity of 500 to 600 sec. Saybolt at 100°F.; or aluminum-soap greases and mixed-base greases of lime and sodium. Generally, lime-base greases are not recommended where temperatures are above 150°F. Greases

TABLE XVIII.—CLASSIFICATION, COMPOSITION, AND USES OF GREASES.—(*Continued*)

Classification	Class name	Composition			Remarks and recommendations
		Alkali	Fat	Mineral oil	
					are not generally recommended for these bearings where temperatures exceed 200°F. and speeds over 10,000 r.p.m. Essential features of these greases are that they should be practically free of moisture, should be neutral, and should contain no filler other than colloidal graphite
	Axle greases	Calcium hydroxide	Generally, rosin acid	Various lubricating oils	Usually, made from lime and rosin oil, with or without addition of mineral oils. Lime combines with rosin acid, forming soap, which thickens the oil. Usually, more lime used than necessary to combine with rosin acid, excess remaining as filter. Mica, talc, soapstone, etc., frequently used as fillers. Suitable for rough service, such as cast-iron bearings of farm machinery
	Gear greases	Sodium, calcium, aluminum hydroxide or none	Same as for lime-base greases or none	Various lubricating oils; residuum oils; and cylinder stocks	Gear greases may be residuum, lime-, sodium-, or rosin-base. Frequently contain dark cylinder oil as a softening ingredient, usually possess strong adhesive properties, and are capable of absorbing shock loads. Outside-gear greases usually are heavy, viscous residuum grease, which requires heating before applying. Made in a wide variety of consistencies
	Wool and yarn greases	Generally, calcium hydroxide or none	Same as for lime-base greases or none	Same as for lime-base greases	May be cup, sponge, or residuum greases containing strands of wool, cotton yarn, or horsehair. When the last is used, the grease is generally termed *elastic wool yarn grease.* Used for lubricating journal bearings fed through packed or open boxes, such as crane, mine car, and certain types of heavy-duty electric-motor bearings
	Mine-car greases	Calcium and sodium hydroxides	Same as for lime-base greases	Various lubricating oils	These greases are usually cup, sponge, or fiber greases used for lubricating plain and antifriction bearings of mine cars and motors. Usually obtainable in four consistencies
	Wire-rope greases	Calcium hydroxide or none	Generally, rosin acid or none	Heavy residuum oils and various lubricating oils	Generally cheap; either of the rosin-base or residuum type. Generally, very heavy, sticky, and adhesive. Usually, nonfluid at

					ordinary temperatures and applied hot by means of brush or swab. Obtainable in five or more consistencies. See *Federal Specifications*, p. 105
	Hydraulic greases	Calcium hydroxide, zinc alkalies, or none	Same as for lime-base greases or none	Residuum oils, dark lubricating oils, and cylinder stocks	Usually, lime-base, zinc-base, or residuum greases. Usually, dark, viscous products extremely adhesive and resistant to the washing action of water. Suitable for plunger-pole lubricants in mines where water is present. Obtainable in five consistencies
	Block or brick greases	Sodium hydroxide	Same as for lime-base greases	Dark lubricating oils and cylinder stocks	A very hard grease having a melting point as high as 450°F. Often supplied in blocks or bricks shaped to fit open cavities of high-temperature bearings of cement, paper, and tube mills, laundries, coolers, locomotives, etc. Considerable clearance should be allowed between the "brick" and cavity to prevent "bridging" of the grease. Usually, obtainable in three or four consistencies
According to commercial uses	Cold- and hot-neck greases	Sodium or calcium hydroxide or none	Same as for lime-base greases	Dark lubricating and residuum oils and cylinder stocks	May be block greases of sodium or calcium base made with heavy dark lubricating oils or residuum oils. Frequently contain graphite. Used for lubricating the roll necks of steel mill stands having plain bearings requiring a block grease. Obtainable in four or more consistencies packed in 440-lb. barrels or 90-lb. boxes
	Calender greases	Sodium hydroxide	Same as for lime-base greases	Dark lubricating oils and cylinder stocks	High-melting-point soda-base greases, similar to block greases. Sometimes packed in canvas bags to apply as pads to calender-roll bearings
	Launching greases	Generally, none	Generally, mixed fats	Cheap dark lubricating oils or cheap cylinder stocks	Tallow substitutes, composed of mixed fats and possibly some soap, are cheap, and not suitable for lubricating bearings
	Antirust, rust-preventives, or slushing greases	Generally, none	Generally, none	Light- and heavy-bodied lubricating oils	Seldom do these so-called *greases* contain a soap thickener. In general, they are pure mineral oil or mixtures of cylinder stock and petrolatum. The former type is commonly used to rust-proof razor blades, needles, hand tools, and instruments, and the latter type is used to provide a protective coating for machine tools, engines, etc., while in storage or transportation.

TABLE XVIII.—CLASSIFICATION, COMPOSITION, AND USES OF GREASES.—(*Continued*)

Classification	Class name	Composition			Remarks and recommendations
		Alkali	Fat	Mineral oil	
	Curve and track greases	Calcium hydroxide or none	Rosin acid	Usually, heavy, dark cylinder stock blended with a lighter body neutral oil	Generally made by the cold-sett process. Similar to cheap axle and launching greases; sometimes contain graphite or other fillers. Used for lubricating car tracks on curves, skids, etc. Obtainable in summer and winter consistencies
	Locomotive driving-box and rod-pin greases	Usually, sodium hydroxide, but sometimes calcium hydroxide	Generally, tallow or palm oil	Heavy lubricating oils and cylinder stocks	Both of these greases are exceedingly hard. Driving-box grease usually has a melting point above 400°F., and that of the rod-pin grease is about 360°F. In general, there are three types of these greases: (1) the so-called *sett* type made cold by the reaction of caustic soda with fat in the presence of heavy cylinder stock; (2) the fibrous soda-soap type, which is only partially dehydrated; (3) the completely dehydrated and melted soda-soap type (see *Federal Specifications*, pp. 104 and 105)
	Automobile-chassis greases:				
	Wheel-bearing grease	Calcium or sodium hydroxide	Same as for lime-base greases	Various lubricating oils	Most automobile and bearing manufacturers recommend a short-fiber soda-base grease containing a mineral oil of not less than 300 sec. Saybolt viscosity at 100°F. for wheel bearings. In the past, cup greases have been extensively used for this purpose.
	Universal-joint grease	Sodium hydroxide	Same as for lime-base greases	Various lubricating oils	To lubricate the universal joint effectively a grease must have strong adhesive and cohesive properties, as the high centrifugal force tends to pull the grease out of the joint. Usually, the best grease for this service is a long-fiber soda-base type.

TABLE XVIII.—CLASSIFICATION, COMPOSITION, AND USES OF GREASES.—(*Continued*)

Classification	Class name	Composition			Remarks and recommendations
		Alkali	Fat	Mineral oil	
	Stearing-gear grease	Calcium, sodium, or aluminum hydroxide	Same as for lime-base greases	Various lubricating oils	Many grease companies do not market a special grease for this service, but recommend regular gear or pressure-gun greases. These products render fairly satisfactory service if the housing is tight enough to hold such fluid greases. Stearing-gear greases usually contain 5 to 6 per cent of calcium soap and a very heavy-bodied lubricating oil. Extreme-pressure compounds are also frequently added
	Water-pump grease	Calcium hydroxide	Same as for lime-base greases	Various lubricating oils	Usually, this is a hard calcium-soap grease containing 20 to 25 per cent soap and having a melting point above 200°F.
	Pressure-gun grease	Calcium, sodium, or aluminum hydroxide	Same as for lime-base greases	Various lubricating oils	These greases are primarily intended for the lubrication of spring shackles of automobiles. They are frequently used for other purposes where application is by means of a pressure gun.

CHAPTER VII

LUBRICATING-OIL TESTS

The physical and chemical properties, factors of safety, and limitation of most engineering materials as determined by laboratory tests correlate fairly closely with actual service performance. Consequently, many believe that the lubricating value and suitability of lubricating oils can readily be determined by laboratory tests. It is true that the physical and chemical properties of oils can be determined with a fair degree of accuracy in the laboratory, but it is also true that these values often bear little or no relation to the actual service performance of an oil. The lack of correlation between service performance and laboratory testing has long been and, to a lesser extent, still is a deterrent to satisfactory oil specifications.

1. General Significance.—Many of the physical, chemical, and mechanical tests that are applied to lubricating oils have been standardized by the federal government, the A.S.T.M., and the A.S.A. Some tests are of importance in connection with refining processes and control; some indicate the history and source of an oil; and some, more or less, indicate the suitability of an oil for a particular service. A few are an outgrowth of competitive selling and are virtually worthless. A few others are holdovers from earlier days, when faulty significance was attached to them, and are now of little value.

Chemical tests serve to detect in general the presence of adulterants and undesirable constituents, such as resin, water, sulfur, or oxygenated compounds of an acid and phenolic character.

Because the utility of lubricating oils depends mainly on their physical rather than on their chemical properties, physical tests are more widely used. Many physical tests are of value to the oil refiner for controlling the manufacture of lubricating oils during distilling, refining, blending, and compounding operations. To the consumer, some of these tests give definite information as to the usefulness of an oil for a particular purpose, and most of

them are very valuable as a guide for checking the uniformity of an oil. Mechanical or machine tests deal mainly with friction-testing machines, tests on engines, motors, and machinery in general. These tests are less standardized than the chemical and physical ones because of the many difficulties encountered in constructing laboratory testing apparatus that will give results comparable with those obtained by long-time service tests on actual machines. There is a great variety of these machines, mainly for testing bearing and gear lubricants, and they have been extremely valuable in establishing and verifying important laws of friction and in comparing the efficiency of different systems of lubrication. The results of such tests have been of much value to designers, lubrication engineers, oil consumers, and oil manufacturers.

The following discussion of lubricating-oil tests is divided into three divisions: (1) chemical tests, (2) physical tests, and (3) mechanical tests. No attempt has been made to give the detailed test procedures.[1] Consequently, the emphases in the following discussion are placed on the significance of the tests, especially as to their value to the consumer.

CHEMICAL TESTS

2. Acidity or Alkalinity.—There are two types of acids that may be found in lubricating oils: (*a*) inorganic or mineral acids; and (*b*) organic acids, consisting mainly of *petroleum*, or naphthenic, acids and fatty acids. In some refining processes, sulfuric acid is used to remove undesirable compounds from the distillates. The oil is then washed, and the acid is neutralized with caustic alkali; then the alkali is washed out. A straight mineral oil when properly refined should show no acidity.

A compound oil is a mixture of a mineral oil and an animal or a vegetable oil. All animal and vegetable oils contain organic acids, the principal one found being oleic acid. The amount present varies with the kind of oil, its degree of refinement, and its age.

Petroleum, or naphthenic, acids are present in untreated straight mineral oils and usually develop when any kind of

[1] Anyone desiring such details is referred to *A.S.T.M. Standards on Petroleum Products and Lubricants*, published by the A.S.T.M., and *Federal Standard Stock Catalog*, Sec. IV, Part 5.

petroleum oil is subjected to high temperatures in the presence of moisture and air.

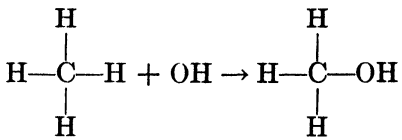
The A.S.T.M. tentative test (D 188-27T) for measuring acidity is made by determining the neutralization number of the oil. The *neutralization number* is the weight in milligrams of potassium hydroxide (KOH) required to neutralize 1 g. of the oil and expresses the total amount of mineral acid and of the organic compounds having acid characteristics. The test is made by first dissolving the acid contained in the oil in alcohol and then measuring the potassium hydroxide required to neutralize it, phenolphthalein being used as indicator to tell when neutralization has been accomplished.

The composition of the various acids is complex and difficult to determine. Acidity in oils, however, is not always harmful under all conditions. The chief dangers arise when high temperatures and exposure to moisture and air are encountered. These dangers are: (*a*) the corrosion of metals; and (*b*) the formation of sludges, emulsions, and deposits in circulatory systems. Organic or fatty acids become very active and corrode metals rapidly at high temperatures. The weight of acid (expressed as equivalent milligrams of potassium hydroxide) required to neutralize the alkali content of 1 g. of oil is called the *alkali neutralization number.*

Generally, when the acid test is made on a new mineral oil, it shows the degree of refinement; when made on used oil, it shows the extent of deterioration of the oil.

3. Oxidation.—All lubricating oils, when in contact with air, tend to oxidize. This process is generally believed to occur in four steps or stages, which result in the formation of three important families of compounds containing carbon, hydrogen, and oxygen. The presence of these compounds in lubricating oils is usually objectionable and harmful as they are generally of a gummy, resinous, asphaltic, and acid character. Their formation is accelerated by intimate mixture at high temperature with air and solid particles, especially metals which act as catalytic agents. These conditions often prevail in internal-combustion engines, steam turbines, and other machines equipped with circulating oiling systems. Resistance to oxidation is, therefore, an important property of many oils.

The principles of oxidation may be best shown by considering the simple hydrocarbon methane (CH_4). The first step of oxidation converts this hydrocarbon to methyl alcohol, thus:

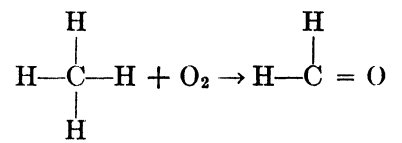


$CH_4 + OH \rightarrow CH_3OH$

methane + radical → methyl alcohol

By the principle of substitution, a hydrogen atom is liberated and its place taken by the hydroxyl radical. The first step in the oxidation of all aliphatic hydrocarbons occurs in this manner, and various alcohols are formed. Similarly, when aromatic hydrocarbons are oxidized, phenol compounds are formed; these are by structure alcohols but differ markedly in properties because of the nature of the benzene ring.

The second step in the oxidation of hydrocarbons is to replace two hydrogen atoms by one oxygen atom, thus:



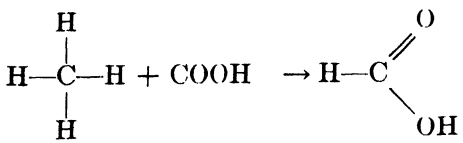
$CH_4 + O \rightarrow HCHO$

methane + oxygen → formaldehyde

Hydrogen is released as in the first step. This second step also gives rise to two closely related families of compounds called *aldehydes* and *ketones*. The aldehydes are characterized by the C:HO radical and the ketones by the C:O radical. Formaldehyde is the simplest of the aldehydes, which have characteristic odors and relatively low boiling points and are reactive. Formaldehyde is a gas; the others formed from higher hydrocarbons than methane are liquids and white solids.

The ketones have a more pleasant odor, but they are still pungent and in many respects resemble the aldehydes. Acetone ($(CH_3)_2C:O$) is one of the most generally used ketones. Cane sugar and starches are examples of other aldehydes and ketones.

Step 3 in the oxidation of hydrocarbons is the substitution of the carboxyl radical (COOH) for three hydrogen atoms on any single carbon atom, thus:



$$CH_4 + COOH \rightarrow HCOOH$$

methane + COOH radical → formic acid

This results in the formation of the important family of organic acids, called *fatty* acids because they occur in nature combined with glycerin as fats. Many of these are insoluble in water, but those that are soluble in water ionize and exhibit all the properties of typical acids. The first nine of the chain type of fatty acids are colorless liquids; the others are white acids resembling fats. The liquids have penetrating, characteristic odors. The second member of the family, acetic acid (CH_3COOH), is well known as a constituent of vinegar and is formed from ethyl alcohol by fermentation (oxidation) in the presence of air.

The fourth step in the oxidation of hydrocarbons destroys completely the hydrocarbon, thus:

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

methane + oxygen → carbon dioxide + water

Carbon dioxide and water are the ultimate products of oxidation (combustion) of all hydrocarbons (oils).

Another important family of compounds, esters, are formed by the interaction of fatty acids and alcohols. For example, acetic acid + ethyl alcohol = ethyl acetate + water.

Esters are volatile liquids and solids of pleasing, fragrant odor. The flavor and odor of many fruits and flowers are due to the presence of esters.

It should not be concluded from the foregoing that oil oxidation is well understood, for the oxidation of the complex hydrocarbons of oil is very complicated and very little is really known about the process.

The chemical stability of many oils, however, is of prime importance. Accordingly, there are in use a number of laboratory-accelerated methods to determine the resistance of an oil to

oxidation. The two most generally used tests are the Sligh oxidation method (Federal Specification Bureau no. 340.1) and the Indiana oxidation test.

The Sligh test consists in placing a 10-g. sample of the oil in a special oxidation flask and displacing the air in the flask with oxygen at atmospheric pressure. The flask is then immersed for

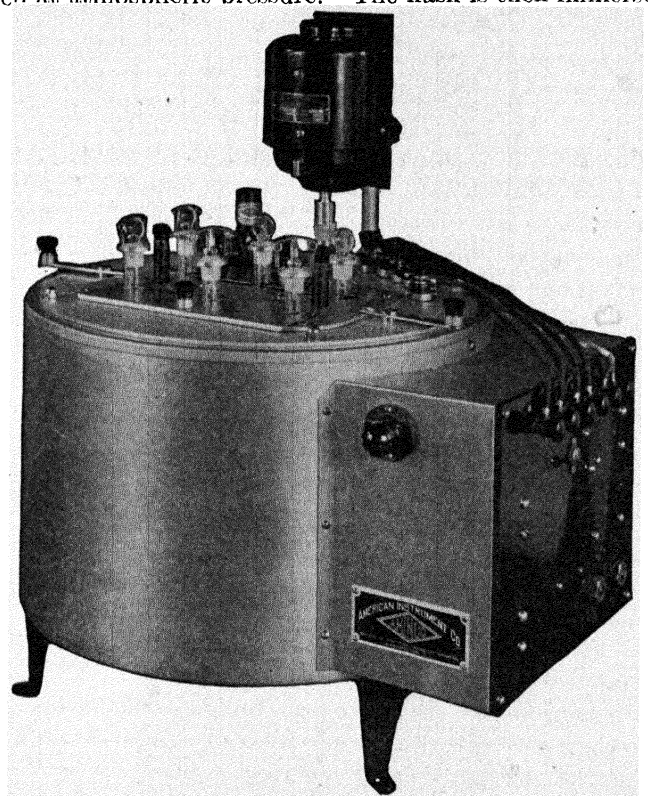


FIG. 29.—Sligh oxidation apparatus. (*Courtesy American Instrument Co.*)

2½ hr. in an oil bath, maintained at 200°C., removed, cooled, diluted with petroleum naphtha, and allowed to stand for 1 hr. at 25°C. The precipitate is then filtered, washed, dried, and weighed. The weight, expressed as a percentage of the weight of sample used and multiplied by 100, is taken as the Sligh oxidation number.

In the Indiana test, specified test tubes, each containing 300 ml. of the oil under test, are inserted in a constant-temperature

oil bath so that the oil level in the tubes is below the oil level in the bath. Air passing through a flow meter is delivered into the oxidation tubes at a rate of 10 l. per hr. Periodically, depending on the oxidation characteristics of the oil, 25 ml. of oil are

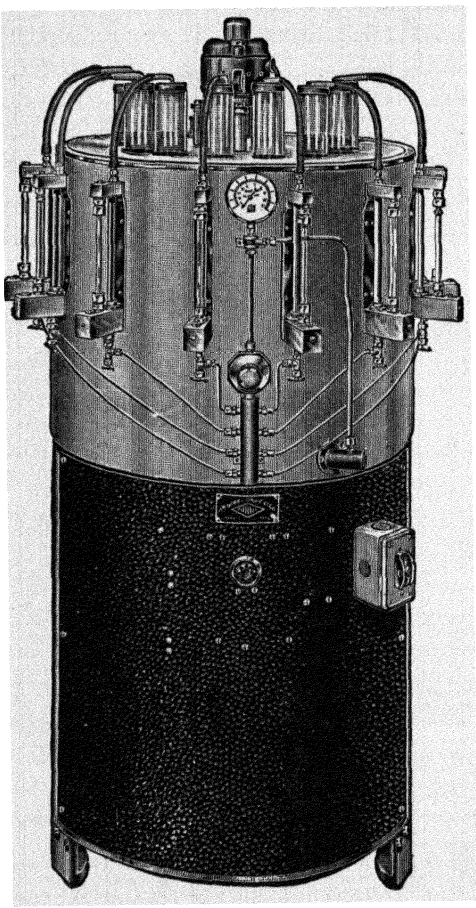


FIG. 30.—Indiana oxidation apparatus. (*Courtesy American Instrument Co.*)

removed, 10 g. of which are immediately weighed. This portion is diluted with 100 ml. of petroleum naphtha and allowed to stand 3 hr. before filtering through a prepared Gooch crucible. The crucible containing the insolubles is washed with approximately 100 ml. of naphtha, after which it is dried ½ hr. at 300°F. and weighed.

The amount of insoluble is expressed in milligrams per 10 g. of oil, and a sufficient number of samples are taken for test to determine accurately: (*a*) sludging time, *i.e.*, the time required for 10 mg. of insolubles to form per 10 g. of oil; and (*b*) the 100-mg. point, *i.e.*, the time required for 100 mg. of insolubles to form per 10 g. of oil.

There is no doubt that oils having high oxidation numbers as determined by these tests are readily susceptible to oxidation and produce soluble pitchlike materials, commonly called *asphaltenes*, which are difficult to dissolve and are subsequently deposited in oiling systems as sludge. These two tests have been developed to such a degree that results obtainable are moderately reproducible, but others have not reached even the stage of yielding concordant results in the hands of a single operator. Moreover, the results of these two tests, as well as of others, have never been correlated with actual service results to such a degree as to make possible a standardized test for universal use.

The term *oxidation number* is meaningless unless the name and description of the method employed are given.

4. Precipitation Number.—The *precipitation number* is an indication of the amount of so-called *asphalt*, or *tar*, present in lubricating oil. The chemical composition of this asphaltic material is not known. It is, however, practically insoluble in petroleum naphtha, and this characteristic forms a basis for determining the precipitation number.

The A.S.T.M. method (D 91-35) consists of diluting 10 ml. of the oil to be tested with 90 ml. of petroleum naphtha of specified properties and separating the precipitate by centrifuging. The precipitation number of the oil is the volume in milliliters of the separated layer.

In general, asphaltic materials in lubricating oils are undesirable, although their effect upon the lubricating qualities of an oil is not definitely known. In new products the precipitation number is of importance in indicating the degree of refining and in classifying the several groups of residual oils such as steam-refined cylinder stocks and bright stocks, in which the asphalt contents vary. The so-called *black oils* frequently used for lubricating open gears, mine-car journals, wire ropes, etc., usually show moderately high precipitation numbers. In used

oils the precipitation number is significant where it is desirable to determine the amount of sludging or content of foreign matter.

5. Saponification Number.—*Saponification number* applies to only a fatty or a compounded oil. It is used to identify unmixed animal and vegetable oils and to measure the quantity of fatty material in compound oils. When carried out in accordance with the A.S.T.M. (D 94-36) method, it is the number of milligrams of potassium hydroxide required to saponify 1 g. of the oil. It is, therefore, a measure of both the free and combined fatty acids.

The saponification number is useful in determining the character and percentage of a fixed oil present in a compounded oil. When two or more grades of fixed oils are present, however, it is difficult to identify them with certainty. The saponification number serves to reveal the presence of fatty oils in mineral oils and to check the amount of compounding present in compounded oils. It is the best obtainable index of the percentage of fat or fatty oil in a given product.

6. Sulfur Content.—Sulfur may occur in lubricating oil as free sulfur, combined sulfur, or sulfonates. A small percentage of combined sulfur is found in practically every lubricating oil. Below certain small percentages, combined sulfur is inactive and does not affect the stability of an oil. Either through careless or improper refining or by actual addition, free sulfur may be present in lubricating oils. Free sulfur is corrosive in nature and impairs the stability of oil in service. The presence of sulfonates in oil indicates overtreatment of the oil with sulfuric acid or inadequate washing of the oil to free it of chemicals used during the refining process. Sulfonates are strong emulsifying agents and tend to promote sludge formation in circulatory oiling systems. It has been found, also, that lubricating oils containing high percentages of sulfur are more easily oxidized than those having a low sulfur content.

The A.S.T.M. bomb method (D 129-34) for determining sulfur content is complicated and should be undertaken only by an experienced chemist.

7. Carbon Residue.—Petroleum lubricating oils are complex mixtures of many hydrocarbons, which vary widely in their physical and chemical properties. Owing to these property differences, some oils may vaporize under atmospheric condi-

tions without leaving any appreciable residue, whereas other oils upon vaporization leave a nonvolatile carbonaceous residue. This residue when determined in accordance with the A.S.T.M. method (D 189-36) is termed *carbon residue.*

Carbon residue is the result of a partial decomposition of the oil by heat and is obtained by destructive distillation of the oil without air entering into the reaction. Many bearings operate at temperatures so high as to cause a chemical change in the oil, so-called *carbon deposits* being thus produced. This is especially

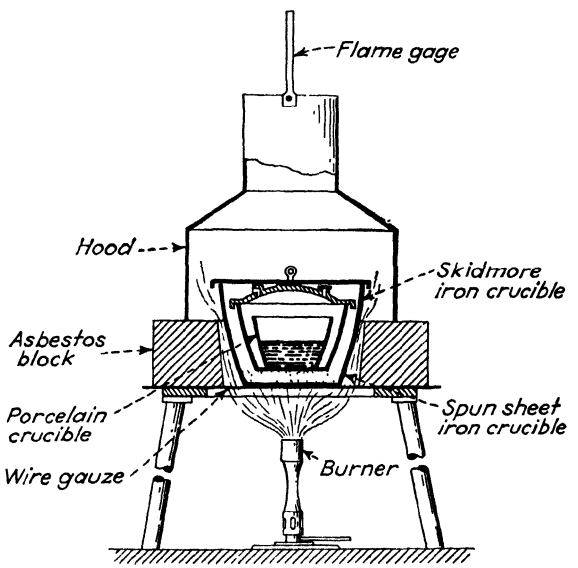


FIG. 31.—A.S.T.M. carbon-residue apparatus.

true in connection with internal-combustion engines, air compressors, textile calenders, paper-mill driers, and high-pressure steam engines. These deposits are detrimental, in general, wherever they form. They clog oil ducts and grooves, thus restricting and, in extreme cases, stopping the flow of oil. In steam, air, and gas cylinders fitted with pistons having rings, they form in piston-ring grooves, interfering with the proper functioning of the rings; they are a direct cause of blow-by and an indirect cause of film destruction and consequent severe wear. They interfere with valve operation, causing sticking and leakage and thus loss of power.

Chemical analyses of many carbon deposits show them to consist mainly of: (*a*) an oily portion soluble in gasoline; (*b*) a brittle asphalt, insoluble in gasoline, but soluble in other solvents, such as chloroform; (*c*) a coal-like portion more or less insoluble; and (*d*) ash. The ash content may vary from a small percentage to half or more of the deposit, depending on operating and mechanical conditions of the machine.

It is frequently stated that the quantity of carbon deposited in cylinders and on pistons is proportional to the carbon residue of the oil. Under ideal conditions, this may be true, but certainly it is not true under average operating conditions. For example, in the case of the gasoline engine the following eight factors are considered to be of major importance:

a. Engine running conditions, temperature, speed, and load.
b. Oil consumption.
c. Time since cleaning.
d. Amount of dust in air.
e. Air-fuel-mixture ratios.
f. Engine design and mechanical condition.
g. Characteristics of fuel.
h. Characteristics of oil.

The carbon-residue test does not show the relative amount of carbonization that will take place in an engine cylinder and the troubles that may develop from such carbonization. For example, if the carbon formed in a cylinder is dry, it will be carried away, causing no trouble; but if it is combined with oil, it sticks and forms a gummy mass. The carbon-residue test cannot determine this or other factors that may enter. Information on carbonization in the cylinder (or valves) can best be secured by actually running the engine or other machine with the oil in question as the lubricant and periodically examining the surfaces.

8. Corrosion.—Corrosion of bearing metals is nearly always due to moisture in the oil. Although it is possible for corrosion to occur from acidity in the oil, this is quite unlikely to happen unless moisture is also present. Certain tests have shown that lubricating oil containing varying percentages of oleic acid has no corrosive effect on polished steel balls unless moisture is introduced. The more moisture present, the faster the corrosive action in most cases. Therefore, to prevent corrosion it is important to eliminate moisture in the oil as far as possible.

This is especially true where high temperatures are encountered, for rate of corrosion is accelerated by high temperature.

The federal government method (F.S.B. no. 530.31) for corrosion test is to place a clean strip of pure polished copper in a sample of oil, the temperature being held at 212°F. for 3 hr. The strip is then rinsed with sulfur-free acetone and compared with a similar strip of freshly polished copper. Discoloration or pitting usually indicates corrosion. The presence of moisture in the oil may sometimes produce discoloration of the copper, which may be erroneously attributed to corrosion.

PHYSICAL TESTS

9. Cloud and Pour Points.—The A.S.T.M. *cloud point* (D 97-34) of an oil is the temperature at which paraffin wax or other solid substances begin to crystallize and separate from solution when oil is chilled under definitely prescribed conditions. Briefly, the cloud point is determined by placing a prescribed test jar in a cooling bath, which is not less than 15° or more than 30°F. below the expected cloud point of the oil, and noting the temperature at which cloudiness or haziness first appears. With some oils, wax separation does not occur prior to solidification; in others, wax separation is not visible. Obviously, in either case the cloud cannot be determined.

The *pour point* of an oil is the temperature at which it will just flow under prescribed conditions. It indicates the temperature at which an oil has practically lost its fluidity and below which channeling may be expected. The pour-point test was devised to determine the ability of oils to lubricate at low temperatures.

The cloud point is of value mainly when the oil is to be used in wickfeed cups or boxes exposed to low temperatures. The test, however, may give misleading results if moisture is present in the oil. The cloud point in general is of a more limited value and has a narrower range of application then the pour-point test.

The pour-point test is one of suitability rather than of quality. The pour point indicates the temperature below which it may not be possible to pour or draw oil from its container or below which it probably would be dangerous to use the oil in a gravity lubrication system, especially where the head tending to produce flow

is small. The size and shape of the container, the pressure exerted on the oil, and the nature of the physical structure of the oil, when solidified all have an effect on its tendency to flow. Pour point is not a true measure either of the ability of an oil to flow under high pressure, such as exists at the discharge side of an oil pump, or of the ease of starting an engine in cold weather, which depends mainly on the viscosity at the crankcase temperature. A low pour point is necessary, however, if the oil is required to flow to the sump of the pump by gravity.

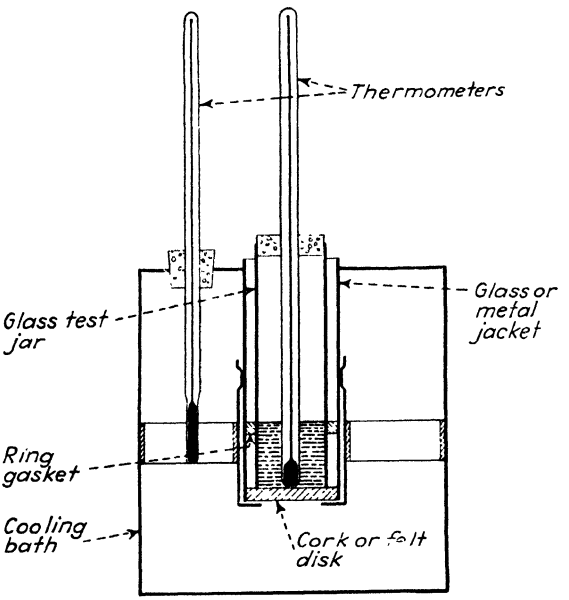


FIG. 32.—A.S.T.M. cloud- and pour-point apparatus.

10. Color Tests.—Both reflected and transmitted lights are used to describe and define the color of lubricating oils, the latter being the more generally used. The common commercial methods do not measure absolute color but are largely the result of adaptation and development of simple methods, which indicate relative color.

Color by transmitted light is determined by: (*a*) the depth of oil required to match a given color standard, and (*b*) the color standard required to match a given depth of oil.

Color is a generally accepted index of the uniformity of a given grade or brand of oil, but it does not necessarily indicate quality.

Many consumers believe that pale color indicates low viscosity. This is, of course, fallacious.

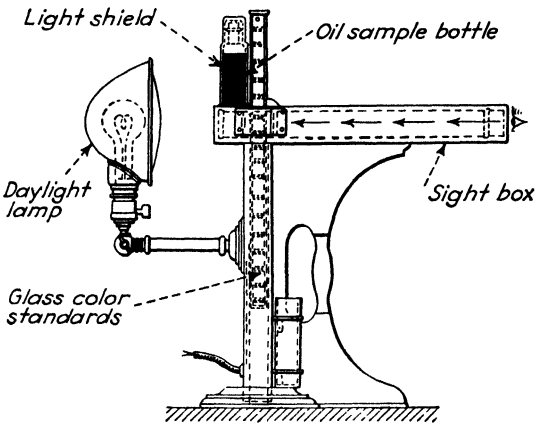


FIG. 33.—Union colorimeter.

Lubricating oils are made in a large variety of colors, ranging from the white oils, through the pale, golden, amber, and red,

TABLE XIX.—COLOR-SCALE COMPARISONS

A.S.T.M. color numbers	N.P.A. names	N.P.A. color numbers (1915)	Union Petroleum Company designations	Tag-Robinson colorimeter numbers	Lovibond analysis		
					Red 200 series	Yellow 510 series	Blue 1180 series
1	Lily white	No. 1	G	21	0.12	2.4	
1½	Cream white	No. 1½	H	17½	0.60	8.0	
2	Extra pale	No. 2	I	12½	2.5	26.0	
2½	Extra lemon pale	No. 2½	J	10	4.6	27.0	
3	Lemon pale	No. 3	K	9¾	6.9	32.0	
3½	Extra orange pale	No. 3½	L	9	9.4	45.0	
4	Orange pale	No. 4	M	8¼	14.0	50.0	0.55
4½	Pale	No. 4½	N	5	21.0	56.0	0.55
5	Light red	No. 5	O	3½	35.0	93.0	
6	Dark red	No. 6	P	2¼	60.0	60.0	0.55
7	Claret red	No. 7	Q	2	60.0	106.0	1.80
8		No. 8	R	1	166.0	64.0	
A	Extra light filtered	Cylinder oil	A	9	10.2	29.0	
D	Light filtered	Cylinder oil	D	5½	21.0	31.0	
E	Medium filtered	Cylinder oil	E	2	89.0	56.0	

to the reddish green, green, brown, and black oils. The commercial grades of oil do, in general, have distinctive colors. Color, therefore, is of some value in determining the commercial grade of an oil. For example, commercial grades are known as *pale-filtered, pale, red, bright-filtered, olive-green, dark-green,* and *black* oils.

There are several instruments for determining color, among the most widely used being the Tag-Robinson colorimeter, the Union colorimeter, and the Lovibond tintometer. Table XIX shows the relationship of one scale to another.

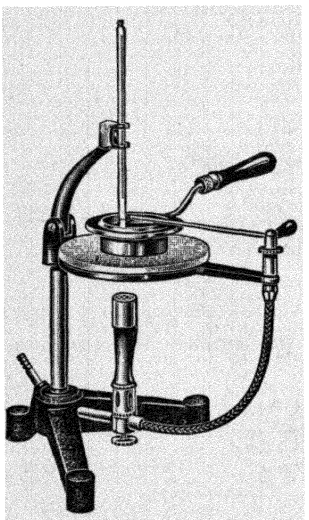


FIG. 34.—A.S.T.M. Cleveland open-cup flash- and fire-point apparatus. (*Courtesy Precision Scientific Co.*)

11. Flash and Fire Points.—The flash point of an oil as determined by the A.S.T.M. method (D 92-33) is the lowest temperature, in degrees Fahrenheit, at which sufficient vapors are given off to form an inflammable mixture with air that will burn momentarily when a small flame is applied. The fire point is the lowest temperature at which this inflammable mixture will burn continuously. The fire-point test is made with the same apparatus as that used for determining the flash point, the oil being heated beyond the flash point until the fire point is reached. The fire-point test is less frequently made than the flash-point test and adds little to the information supplied by the latter.

In general, the flash and fire points of a lubricating oil bear no direct relation to its suitability. These tests are useful to oil manufacturers in controlling refining processes. To the consumers they serve as a check on the uniformity of the product, thus indicating whether or not there has been any contamination with lower flash oils, or whether the distillation of the crude has been carried far enough.

The flash- and fire-point tests were originally developed for the purpose of determining the fire hazard involved in the transportation and storage of oils. These tests do indicate accurately the comparative inflammability of oils under atmospheric condi-

tions. But since practically all lubricating oils have flash and fire points considerably higher than the temperatures normally encountered in transportation and storage, these tests are of little value in this respect.

Unless the vapor is ignited from an outside source, an oil will not flash or burn spontaneously until it is heated to a temperature very much higher than its flash and fire points, and then only if a sufficient supply of oxygen is present. Lubricating oils can,

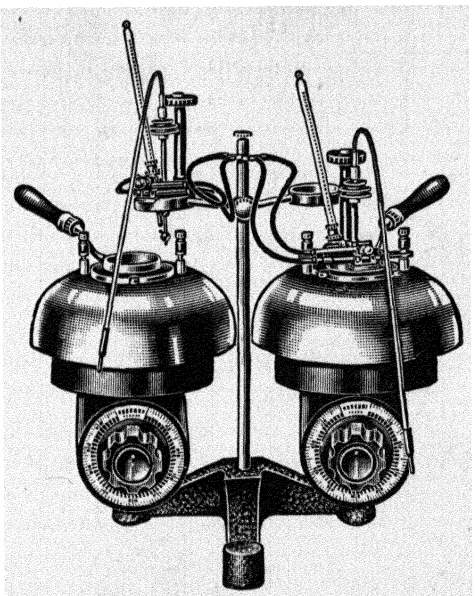


FIG. 35.—Twin-unit Pensky-Martens flash-point apparatus. (*Courtesy Precision Scientific Co.*)

therefore, be used at temperatures far above their flash and fire points and still retain their lubricating properties.

In some cases the flash and fire points have been taken as an index for measuring the rate of evaporation of an oil. The rate of evaporation of an oil is influenced by many factors, such as rate of heating, temperature, length of time the oil is exposed to heat, and rate of removing vapors. Two oils may have identical flash points and yet have different rates of evaporation at, say 200 and 400°F. The importance of flash- and fire-point tests is often overestimated. They are helpful undoubtedly in checking the uniformity of a product, whether or not it is in accordance with

specifications or in conformity with a sample, or whether it is contaminated; but as an index for determining the comparative rates of evaporation and of deterioration in service or the ability of an oil to reduce friction in a bearing or cylinder, the flash and fire points have no practical value whatever.

12. Dilution.—The A.S.T.M. dilution test (D 322-35) is a comparatively simple laboratory test for determining the percentage of unvaporized fuel that has worked past the piston into the crankcase oil and the light fractions that have been formed by "cracking" certain portions of the lubricating oil itself. From a lubrication standpoint, therefore, dilution is a factor to be

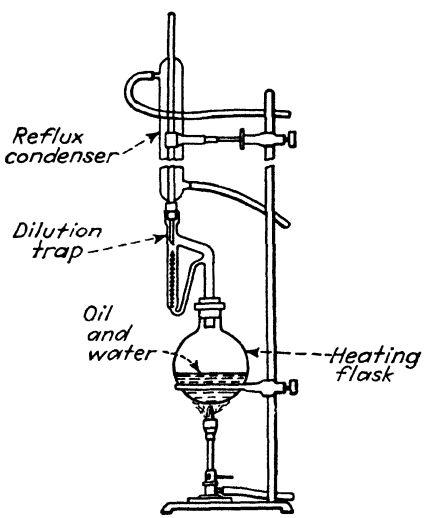


FIG. 36.—A.S.T.M. dilution apparatus.

considered only in connection with the lubrication of internal-combustion engines using a liquid fuel. The changes in viscosity, flash and fire points, pour point, and specific gravity that an oil undergoes while in service are mainly due to dilution. Consequently, the factors affecting dilution will largely determine these changes.

The extent of dilution is dependent mainly on: (*a*) volatility of the fuel used; (*b*) length of run of the car in question; (*c*) temperature of jacket water; (*d*) air-fuel-mixture ratio; (*e*) engine load; (*f*) temperature of crankcase oil; (*g*) mechanical condition of engine; and (*h*) operating conditions.

Dilution will, in general, show a gradual increase and decrease the viscosity of the oil for the first 50 to 200 miles of service, but the extent to which it occurs will vary within wide limits, depending on the foregoing influencing factors. Normally, a used oil will have between 3 to 10 per cent of diluent, but dilutions as high as 30 per cent are not uncommon, especially in the wintertime, when the choke is freely used.

The effect of dilution in decreasing the viscosity of an oil in service is partly counteracted by oxidation and evaporation of the light ends of the lubricating oil, both of which tend to increase the viscosity of the oil. An equilibrium viscosity is finally reached in service between these limiting factors. The presence of dilution has an appreciable effect in reducing the slope of the viscosity-temperature curves for oils that, when new, have steep curves but appears to change but little the slope of the viscosity curves of oils having relatively flat curves.

Dilution of crankcase oil is probably of minor importance. In the average automobile engine the volume of oil supplied to the bearings and the cylinder walls actually increases as viscosity decreases. Engines can be run apparently indefinitely on highly diluted oils, and there is no measurable difference in the rate of wear over a very wide range of viscosity.

Devices of various designs, such as crankcase ventilators, oil-temperature controls, and thermostatic jacket-water controls, are employed on automobile engines to reduce the amount of dilution present. From tests on these devices, however, it appears that they are more effective in maintaining a low water content than in keeping the dilution low.

13. Emulsification.—From a lubrication standpoint, an emulsion is an intimate mixture of oil and water, which on standing generally tends to separate into its different constituents. It is formed when an oil is thoroughly agitated with water, as is the case in many circulating systems. An emulsion promotes the collection of grit and foreign matter in the oil. When these particles are carried through the bearings, they act as abrasives and cause excessive wear.

If an emulsion breaks quickly, its harmful effects are reduced. Many substances, such as sulfonates, certain acids and alcohols, and finely divided earthy matter, will retard separation. A highly filtered and purified oil will separate quickly and, for this

reason, is in demand for use in circulating systems and in ring-oiled bearings where the oil is used over and over. The ease with which an oil will emulsify is found to increase with use.

Two different methods are widely employed for determining the tendency of oil to emulsify: the A.S.T.M. steam emulsion test (D 157-36); and the federal government method (F.S.B. no. 320.32), called frequently the *Herschel demulsibility test.*

The steam emulsion test is made by measuring the number of seconds required for an oil to separate completely from an emulsion prepared by passing steam through the oil in a standard

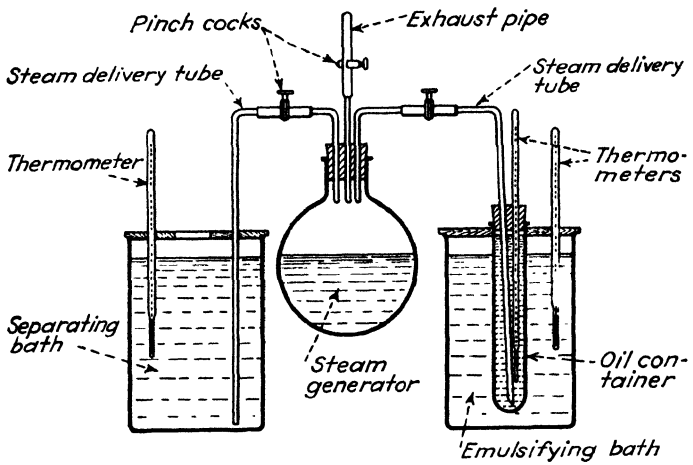


FIG. 37. A.S.T.M. steam-emulsion apparatus.

manner. This number of seconds is known as the *steam emulsion number* (S.E.number). Formerly, this time was taken in minutes and designated as the R.E.number. For example, an oil having an S.E.number of 180 would have an R.E.number of 3.

The federal government method consists in producing an emulsion of oil and water made up of 27 ml. of oil and 53 ml. of distilled water at either 130 or 180°F. and determining, after churning for 5 min. at constant temperature, whether the oil and water will separate within a period of 30 min. An oil is said to have perfect demulsibility when complete separation occurs within 1 min. The demulsibility number is calculated by the formula $D = (V \times 60)/t$ where D = demulsibility number, in milliliters, per hour; V = volume settled out, in milliliters; t = time since stopping paddle, in minutes.

An emulsification test is a very important measure of the suitability of an oil in steam-turbine and high-speed engines' lubricating systems. In these cases, it is considered next in importance to viscosity. For certain types of marine engine, it is desirable to use an oil that will separate very slowly, and the persistence of the emulsion is of prime importance. For oils intended for use in air compressors, internal-combustion engines, and machinery in general, the use of the emulsification test is a debatable question. It is sometimes included in specifications for such oil; but there is no general agreement as to its practical value, and, in general, it may be considered unnecessary.

14. Evaporation.—Close-cut oils are more resistant to evaporation than blended oils, though both may have the same flash point. The flash-point test is qualitative, whereas evaporation-loss determination is a quantitative test.

The flash-point test serves as an approximate index to the tendency of an oil to evaporate. An oil having a low flash point will, in general, evaporate at a greater rate than one having a high flash point. There is no evidence, however, that any simple relationship exists between the rate of evaporation of an oil and its flash point.

Many efforts have been made to devise an evaporation test to show the amount of evaporation that may be expected from an oil in service. The difficulty is that the rate of evaporation under one set of conditions is no indication whatever of what may be expected under another set of conditions. For example, two oils having the same rate of evaporation when heated in an open dish to a temperature of 150°F. for 2 hr., might have entirely different rates of evaporation when heated to 200°F. Any other change in conditions might also affect the relation between their rates.

The only practical method of comparing the suitability of two oils for a particular application, as far as their rates of evaporation are concerned, is to test them under identical service conditions. The results of any evaporation test indicate simply the presence of an excess of light oils.

15. Commercial Viscosity.—The *viscosity* or body of an oil is the measure of its resistance to flow. It may, therefore, be regarded as the *internal friction* of an oil, just as *friction* refers to the resistance of a solid body to motion when it is in contact with another solid body. It is one of the physical properties of an oil,

just as are density, color, pour point, and flash and fire point.

Unfortunately, there is no universal standard unit for measuring viscosity. In commercial work, viscosity is expressed in various arbitrary units, as follows:

Saybolt universal seconds (*S.U.S.*) are the number of seconds required for 60 ml. of oil to flow through the orifice of the Saybolt universal viscosimeter at a specified temperature.

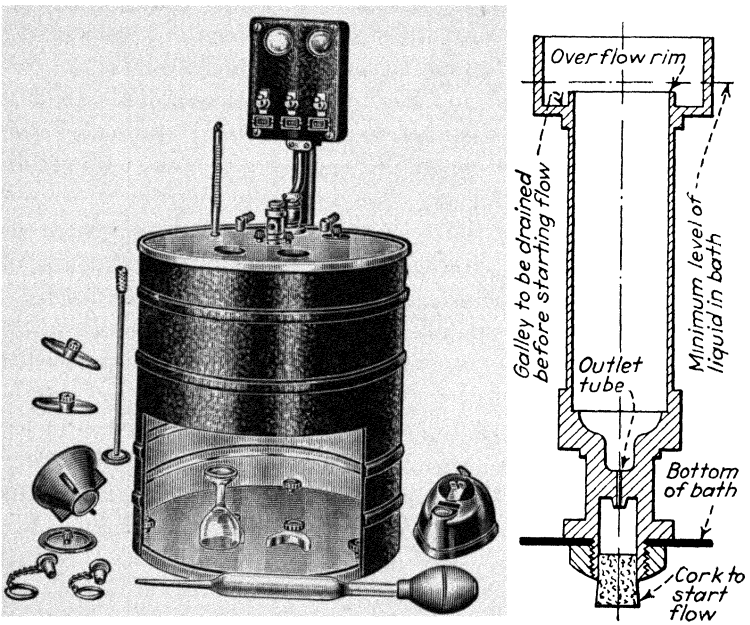


FIG. 38.—A.S.T.M. Saybolt viscosimeter. (*Courtesy Precision Scientific Co.*)

Saybolt-Furol seconds (*S.F.S.*) are the number of seconds required for 60 ml. of oil to flow through the orifice of the Saybolt-Furol viscosimeter at a specified temperature.

Redwood standard seconds (*R.S.S.*) are the number of seconds required for 50 ml. of oil to flow through the Redwood no. 1 viscosimeter at a specified temperature.

Redwood Admiralty seconds (*R.A.S.*) are the number of seconds required for 50 ml. of oil to flow through the orifice of the Redwood Admiralty viscosimeter at a specified temperature. This is also called the *Redwood no. 2 instrument.*

Engler seconds are the number of seconds required for 200 ml. of oil to flow through the orifice of the Standard Engler viscosimeter at a specified temperature.

Engler degrees are the Engler seconds divided by the time in seconds required for 200 ml. of distilled water at 20°C. to flow through the orifice of the Engler instrument. This time is approximately 51 sec. and must be between 50 and 52 sec.

Barbey fluidity is the milliliters of oil that flow through the orifice of the Barbey instrument in 10 min. at a specified temperature. This instrument measures fluidity, which is 1 divided by viscosity. The unit of fluidity in absolute metric units is the *rhe*.

The Saybolt universal and Saybolt-Furol instruments are the standard commercial viscosimeters in the United States. These instruments are highly developed and have been completely standardized by the A.S.T.M. The universal instrument is used for the determination of the viscosity of lubricating oils, whereas the Furol instrument is generally used for the determination of the viscosity of heavy fuel oils and liquid asphaltic road materials. For the universal instrument, measurements are usually made at 100 or 130°F. for the lighter oils and 210°F. for the more viscous oils. For the Furol instrument, measurements are generally made at 122°F., although 77, 100, and 210°F. are used, and for liquid asphaltic materials also 140 and 180°F. The outflow time for the universal instrument is approximately 10 times that of the Furol instrument for S.U.S. values from 300 to 5000 sec. For values between 300 and 100 S.U.S., the ratio varies from about 10 at 300 to 6½ at 100 S.U.S.

The Redwood no. 1 and no. 2 instruments are the standard commercial viscosimeters in England and cover, respectively, the same general range as the Saybolt universal and Saybolt-Furol instruments.

The Engler viscosimeter is used in virtually all of continental Europe and is the standard instrument in Germany. The Barbey is used to a limited extent in France, Spain, and a few other countries of Europe.

16. Absolute Viscosity.—In scientific work, viscosity is measured in the fundamental units of time, force, and mass. To distinguish between the commercial and scientific methods, the expression *absolute viscosity* is applied to observations expressed in

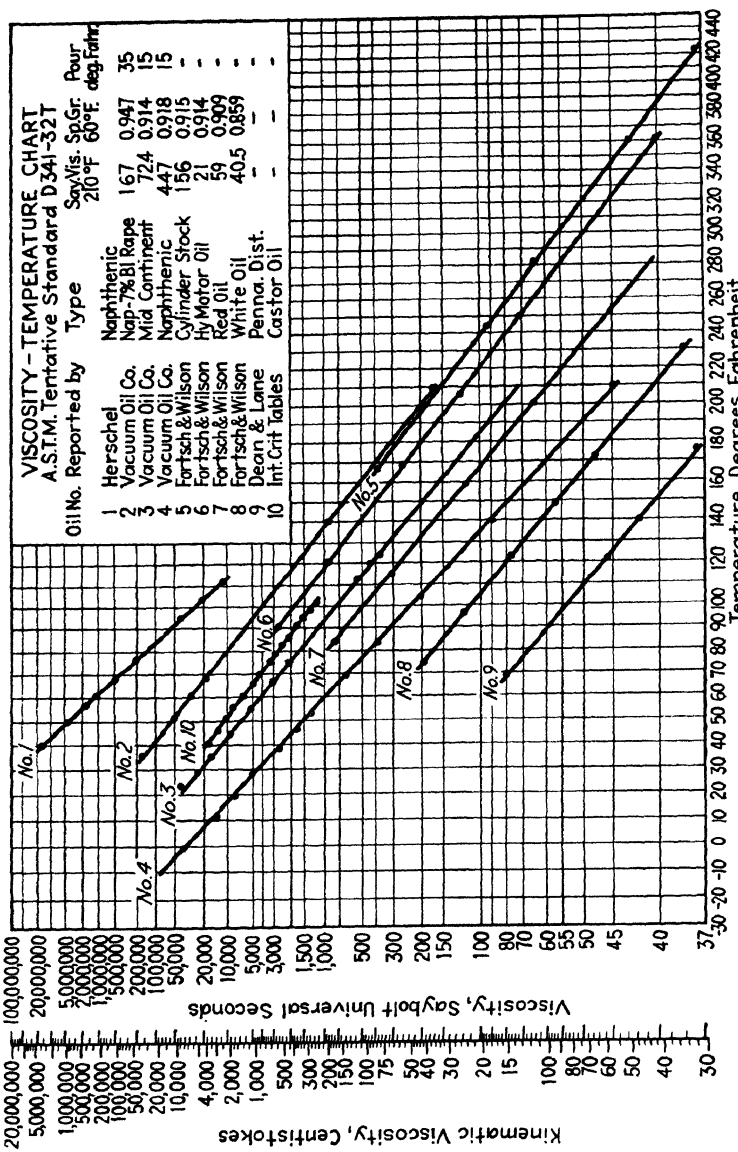


Fig. 39.—Viscosity curves of oils made from different crudes. (*Courtesy American Society for Testing Materials.*)

TABLE XX.—VALUES FOR CONVERTING K.V. TO S.U.S. VISCOSITY

K.V., centistokes	Equivalent S.U.S. viscosity at temperature of		
	100°F. (basic values*)	130°F.	210°F.
2	32.6	32.7	32.8
2.5	34.4	34.5	34.6
3	36.0	36.1	36.3
3.5	37.6	37.7	37.9
4	39.1	39.2	39.4
4.5	40.7	40.8	41.0
5	42.3	42.4	42.6
6	45.5	45.6	45.8
7	48.7	48.8	49.0
8	52.0	52.1	52.4
9	55.4	55.5	55.8
10	58.8	58.9	59.2
11	62.3	62.4	62.7
12	65.9	66.0	66.4
13	69.6	69.7	70.1
14	73.4	73.5	73.9
15	77.2	77.3	77.7
16	81.1	81.3	81.7
17	85.1	85.3	85.7
18	89.2	89.4	89.8
19	93.3	93.5	94.0
20	97.5	97.7	98.2
21	101.7	101.9	102.4
22	106.0	106.2	106.7
23	110.3	110.5	111.1
24	114.6	114.8	115.4
25	118.9	119.1	119.7
26	123.3	123.5	124.2
27	127.7	127.9	128.6
28	132.1	132.4	133.0
29	136.5	136.8	137.5
30	140.9	141.2	141.9
31	145.3	145.6	146.3
32	149.7	150.0	150.7
33	154.2	154.5	155.3
34	158.7	159.0	159.8
35	163.2	163.5	164.3
36	167.7	168.0	168.9
37	172.2	172.5	173.4
38	176.7	177.0	177.9
39	181.2	181.5	182.5
40	185.7	186.1	187.0
41	190.2	190.6	191.5
42	194.7	195.1	196.1
43	199.2	199.6	200.6
44	203.8	204.2	205.2
45	208.4	208.8	209.9
46	213.0	213.4	214.5
47	217.6	218.0	219.1
48	222.2	222.6	223.8
49	226.8	227.2	228.4
50	231.4	231.8	233.0
55	254.4	254.9	256.2
60	277.4	277.9	279.3
65	300.4	301.0	302.5
70	323.4	324.0	325.7
Over 70	Saybolt sec. = centistokes × 4.620	Saybolt sec. = centistokes × 4.629	Saybolt sec. = centistokes × 4.652

* To obtain the Saybolt universal viscosity equivalent to a kinematic viscosity determined at t°F., multiply the equivalent Saybolt universal viscosity at 100°F. by $1 + (t - 100)0.000064$. For example, 10 centistokes at 210°F. are equivalent to 58.8 × 1.0070 or 59.2 Saybolt universal seconds at 210°F.

absolute units, whereas the name of the instrument is used to designate the commercial method. Viscosity is scientifically defined in absolute metric units as the force required to move a plane surface 1 sq. cm. in area over another plane surface at a velocity of 1 cm. per sec. when the two surfaces are separated by a layer of the oil 1 cm. in thickness. Although absolute viscosity may be expressed in absolute metric units, absolute English units, gravitational metric units, or gravitational English units, it is usually given in the absolute metric units.

The absolute metric unit is correctly expressed in dyne-seconds per square centimeter, but it is often referred to simply as dynes per square centimeter. This unit is termed a *poise* after Poiseuille, who was the first to show experimentally that the volume of a liquid passed by a capillary tube is directly proportional to the pressure and to the fourth power of the radius of the tube and is inversely proportional to the length of the tube. In order to avoid decimals, the centipoise, the hundredth part of a poise, is commonly used. The viscosity of water at 68°F. is virtually 1 centipoise (1.005), and that of castor oil at the same temperature is 9.86 poises or 986 centipoises.

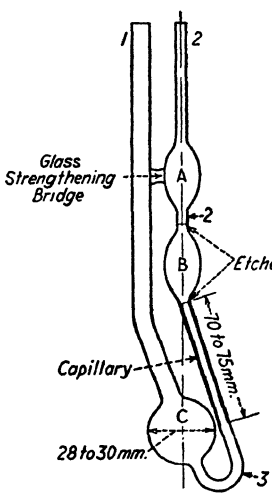


FIG. 40.—Modified Ostwald viscosimeter.

Constants necessary for converting absolute viscosity expressed in poises to any of the other systems of units are shown in Table XX.

17. Kinematic Viscosity (K.V.).—The *kinematic viscosity* is defined as the absolute viscosity divided by the density. The absolute metric units of kinematic viscosity are the *stoke* and *centistoke*, which correspond to the poise and centipoise. The kinematic viscosity is scientifically correct, since multiplying it by the density gives the absolute viscosity.

$$\text{K.V.} \times d = Z$$

The moving parallel-surfaces arrangement suggested in the definition of absolute viscosity is not a convenient or accurate

apparatus for measuring viscosity. The most accurate method is to measure the rate of flow of oil through a long, small-bore capillary tube, such as is shown in Fig. 40, the design of which is based on Poiseuille's equation

$$Z = \frac{\pi g d r^4 t h}{8QL}$$

where g = gravitational constant.
d = density of oil.
h = average head between upper and lower oil levels.
r = radius of bore of capillary tube.
t = time in seconds.
Q = volume of oil discharged in t seconds.
L = length of capillary tube.
Z = absolute viscosity.

Osborne Reynolds has shown that Poiseuille's equation is substantially correct when $rVd/Z < 700$, where V is the average velocity of flow through the capillary tube. This is known as *Reynolds' number*, and viscosimeters must be so designed as to conform to it for measuring absolute viscosities.

From experimental data, equations have been derived by which Saybolt, Redwood, and Engler viscosity determinations can be expressed in kinematic viscosity units.

For the Saybolt universal viscosimeter,

$$\text{K.V. in centistokes} = 0.226t - \frac{195}{t}$$

where t = 100 S.U.S. or less.

$$\text{K.V. in centistokes} = 0.220t - \frac{135}{t}$$

where t = more than 100 S.U.S.

For the Redwood no. 1 viscosimeter,

$$\text{K.V. in centistokes} = 0.260t - \frac{188}{t}$$

where t = R.S.S. seconds.

For the Engler viscosimeter,

$$\text{K.V. in centistokes} = 0.147t - \frac{374}{t}$$

where t = Engler seconds.

Relative and *specific viscosity* are terms sometimes used to express the viscosity of an oil in terms of some other arbitrarily chosen liquid. The viscosity of distilled water at 68°F. (20°C.) is most frequently used.

It should be emphasized that Saybolt viscosity seconds are not even approximately proportional to the absolute viscosities except in the range above 200 sec. As the time of flow decreases, the deviation becomes greater, and below 40 sec. the departure is so great that the use of Saybolt viscosity as an index of absolute viscosity is very deceptive. For example, an oil having a Saybolt viscosity of 35 sec. has approximately twice the absolute viscosity of one having a Saybolt viscosity of 32 sec. The most fluid liquids do not give Saybolt viscosities below 28 sec. This instrument, therefore, should preferably not be used on oils reading below 40 sec. and never on oils below 32 sec.

This limitation of the Saybolt instrument is due in part to the fact that the pressure forcing the oil through the orifice is produced by the column of oil above the orifice, *i.e.*, the head on the orifice, and this head is a function of the density of the oil, so that the density as well as the viscosity determines the time of flow. Furthermore, the pressure drop through the outlet tube of the Saybolt instrument is dependent on the absolute viscosity of the oil, whereas the entrance and exit losses are virtually independent of the absolute viscosity. The time of flow is, however, proportional to the kinematic viscosity.

The primary objects of lubrication are to minimize friction and wear of the moving parts of machinery. Friction and possibly wear are more dependent on the viscosity of the oil than on any of its other properties. In a bearing perfectly lubricated, *i.e.*, having an oil film separating completely the journal and bearing and operating under given load and speed conditions, the viscosity of the oil at the operating temperature determines the bearing friction, heat produced, and rate of oil flow through the bearing. The oil should have sufficient viscosity to maintain a complete film between the bearing surfaces in spite of the pressure tending to squeeze it out. A reasonable factor of safety is essential, but excessive viscosity means unnecessary friction and heat generated. Oil distribution is a function of viscosity, and the lower the viscosity, other things being equal, the quicker the oil is distributed to the rubbing surfaces, thus decreasing

friction at starting. That wear is most severe during the starting-up period is evidenced by the fact that machinery which is started and stopped frequently wears more rapidly than machinery which runs more continuously.

18. Viscosity Index.—From the standpoint of viscosity, the perfect oil has the same viscosity at all temperatures. No such oil exists; all thin out (have lower viscosity) at high temperature and thicken (increase in viscosity) at lower temperature. But changes in viscosity with temperature changes are not the same for all oils; some thin out more and thicken less than others for a given temperature change. The viscosity index (V.I.) is an arbitrary, numerical index used to indicate the relative change in viscosity of oils for a given temperature change. Specifically, the viscosity index indicates the relation which the Saybolt universal viscosity of an oil at 100°F. bears to the Saybolt universal viscosities of an average paraffin oil and average naphthene oil at that temperature, all three having the same viscosity at 210°F. The viscosity index of an average paraffin oil has arbitrarily been assumed 100, whereas that of an average naphthene oil has been assumed 0. The charts shown in Figs. 1, 2, and 3 of the Appendix have been prepared by the Standard Oil Development Co. and may be used for determining the viscosity index of oils.

An oil of high viscosity index does not become excessively thin when heated or excessively thick when cooled. For services where the oil is exposed to wide temperature variations, an oil of high viscosity index is usually desirable. An outstanding example of such service is that of the automobile engine in which the crankcase oil is frequently required to flow freely at 0°F. at starting and at the same time possess sufficient viscosity to render safe lubrication at 300°F. when operating.

Viscosity index serves not only to indicate viscosity changes with temperature but also to identify the base of the crude from which an oil is made, provided that a viscosity-index improver has not been used. The strictly paraffinic type oils have viscosity indexes of about 100, whereas the naphthenic type oils have viscosity indexes close to 0. Oils made from the intermediate-base crudes fall between these two limits. Commercial oils, especially refined and containing viscosity-index improvers, are now obtainable having viscosity indexes as high as 150.

19. Gravity.—The gravity of an oil is a numerical index that indicates the weight of a measured volume of the oil. In the petroleum industry there are two scales in general use, the specific-gravity scale and the A.P.I. (American Petroleum Institute) gravity scale.

The specific gravity of an oil is the ratio of its weight to that of an equal volume of water, both measured at 60°F. It is necessary to specify the temperature at which the weights are compared, because of the change in volume with temperature.

Two methods are employed for determining the specific gravity. The first is the constant-weight, variable-volume method in which a hydrometer is employed. This method is based on the principle of Archimedes, *viz.*, that when a body floats, it displaces a volume of liquid equal to its own weight. The second is the constant-volume variable-weight method, which involves weighing an accurately measured volume of oil in a special flask and comparing its weight to that of an equal volume of distilled water, both being weighed at the same temperature.

The A.P.I.-gravity and specific-gravity relationship is expressed by the following formula:

$$\text{A.P.I. degrees at } 60°\text{F.} = \frac{141.5}{\text{sp. gr. at } 60°\text{F.}} - 131.5$$

The figure 141.5 is termed the *modulus* of the A.P.I. scale.

It should be noted that the A.P.I. gravity varies inversely as the specific gravity. A high A.P.I. gravity means a low specific gravity; conversely, a low A.P.I. gravity indicates a high specific gravity.

The gravity test has several uses. To the experienced oil user, it indicates the type of crude from which the oil was made, thus indicating indirectly other characteristics of the oil. It is of value in converting Saybolt viscosity seconds to absolute viscosity. As oil is frequently sold on the basis of volume delivered corrected to 60°F., gravity is of use in making volume corrections.

The weight per gallon of a petroleum product can be quickly determined by multiplying its specific gravity by 50 and then dividing the product by 6.

To the refiner, gravity is very useful as it furnishes information for controlling refining operations and is easily and quickly

determined. To the user, it serves as a check on the uniformity of a product. In general, the specific gravity of paraffin-base oils is less than 0.90, that of intermediate base oils is between 0.90 and 0.91; and that of naphthene base oils is more than 0.91. Gravity bears no relationship to quality or usefulness of an oil, and its use in specifications should be avoided.

20. Water and Sediment.—Water and sediment are seldom found in oils when received from the refiner. They may and frequently do find their way into oil, however, before use owing to carelessness in handling or storing of the oil. Water gives all but the darkest oils a cloudy appearance, and its presence is, therefore, easily detected. When such an 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, the water will partly evaporate and partly separate at the bottom as visible drops.

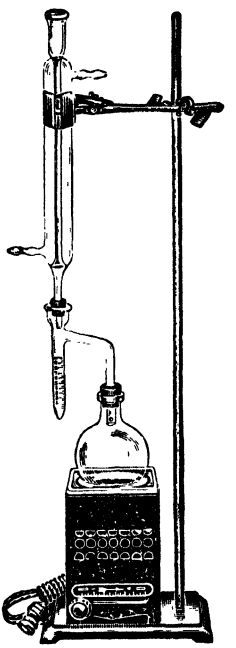


FIG. 41.—A.S.T.M. water-determination apparatus. (*Courtesy American Instrument Co.*)

Water is especially objectionable in oils used in wick-feed cups because it retards capillary action. Its presence in steam-turbine oils may cause corrosion of the journals and the formation of finely divided iron oxide, which acts as an emulsifying agent. If present in an internal-combustion engine crankcase, it will absorb sulfur dioxide from exhaust gases escaping into the crankcase and become oxidized to sulfuric acid, which may cause serious corrosion of the crankpins and other highly polished surfaces.

Sediment is easily detected when oil is transparent. It is more difficult to do so in the case of dark oils, such as steam cylinder oils and dark lubricating oils. Sediment generally consists of inorganic materials such as sand, silt, and iron rust. Its detrimental influence is mainly dependent on its character. If of an abrasive nature, it causes excessive wear; and if of a gluey or resinous character, it clogs oil-holes and -passages.

The determination of water and sediment is one of considerable importance. The three most important laboratory test methods are: (*a*) the A.S.T.M. centrifugal method (D 96-35) for both water and sediment; (*b*) the A.S.T.M. distillation method (D 95-30) for water; and (*c*) the extraction method (F.S.B. no. 300.2) for sediment.

Water and sediment by centrifuge is the percentage by volume of the water layer (including sediment and incomplete broken emulsion) separated when the oil under test is centrifuged under specified conditions. This test is confined almost entirely to crude oils, semirefined products, and heavy fuel oils. It is commonly known as the *B. S. and W.* (bottom, sediment, and water) *test.*

Water by distillation is the volume of water as determined by a specified distillation test. This test is practically independent of empirical factors and is convenient and accurate.

Sediment by extraction is the percentage by weight of insoluble materials that exist in particles of sufficient size to be retained by a porous filter of specified characteristics. This method, obviously, is highly empirical.

MECHANICAL TESTS

Many different oil-testing machines have been constructed, for physical and chemical tests do not generally indicate the lubricating values of oils. Nearly all of them have been so designed as to simulate, as closely as possible, the conditions met with in actual service.

21. Purpose of Tests.—The older machines were generally designed for studying friction; means were usually provided for controlling and measuring speed, load, temperature, and frictional torque, from which the coefficient of friction could be calculated. Chiefly, the following effects were studied:

1. Effects of viscosity on friction.
2. Effects produced by different loads.
3. Effects produced by different speeds.
4. Effects of temperature on friction.
5. Effects of different bearing metals on friction.
6. Comparative oiliness of various lubricants.

These machines have not been altogether satisfactory, for they usually had a single, highly polished bearing or pair of gears which

often operated under conditions of speed, load, temperature, and oil feed very different from those encountered in service. In practice there is such a great variety of bearings and gears, which operate under all sorts of conditions, that it is highly impracticable to simulate all, or even a small number, of them on a laboratory testing machine. They have served, however, to confirm many of the mathematical laws of lubrication.

The more recent machines have been designed, in general, for studying wear, scuffing, seizure, corrosion, and, also, oiliness. In the past, it has been customary to think of perfect lubrication, *i.e.*, a complete separation of the bearing surfaces by a full film of oil. This condition easily prevails in high-speed bearings, copiously supplied with oil and not loaded, say above 2000 lb. per sq. in. It is, on the other hand, known that such a condition does not exist in heavily loaded, low-speed bearings, gears, and sliding members. Pressure between the teeth of hypoid gears, such as those used in automobile differentials, are as high as 400,000 lb. per sq. in., with sliding velocities varying from zero to 300 ft. per min. Moreover, the convex surfaces of hypoid teeth are not conducive to oil-film formation and maintenance. Even the most viscous mineral oils and greases fail to form films sufficiently thick to prevent scuffing and seizure, especially when operating temperatures as high as 210°F. or more are reached, which is not unusual. In consequence, the most recent efforts have been to construct machines capable of evaluating lubricants in terms of wear, scuffing, seizure, galling, corrosion, and film strength.

22. Almen Machine.—The Almen extreme-pressure lubricant-testing machine, developed and manufactured by the General Motors Corporation was one of the first of the newer machines designed for evaluating lubricants for hypoid differential gears from the standpoint of film strength.

This is a small, portable machine employing a ¼-in. drill-rod journal and a ½-in. split bushing made of S.A.E. 2315 cold-drawn steel. The journal is polished; and the bushing, after splitting, is ground on the bearing surface with a formed wheel. A clearance of 0.007 in. is provided between the journal and the normal diameter of the bushing. Pressure is applied to the bushing by means of a hydraulic and mechanical loading system. The friction torque developed is indicated through a second hydraulic system by a Bourdon gage. It is operated at 600 r.p.m.

In conducting a test the oil container is first filled with oil to be tested (about 25 ml.), the test journal being thus submerged. The machine is started and run for 30 sec. at no load to ensure thorough lubrication of the journal and bushing. The load is then applied at the rate of 2 lb. every 10 sec. until seizure occurs or until 30 lb. have been applied. For timing the application of weights a bell is provided and so arranged as to ring at 10-sec.

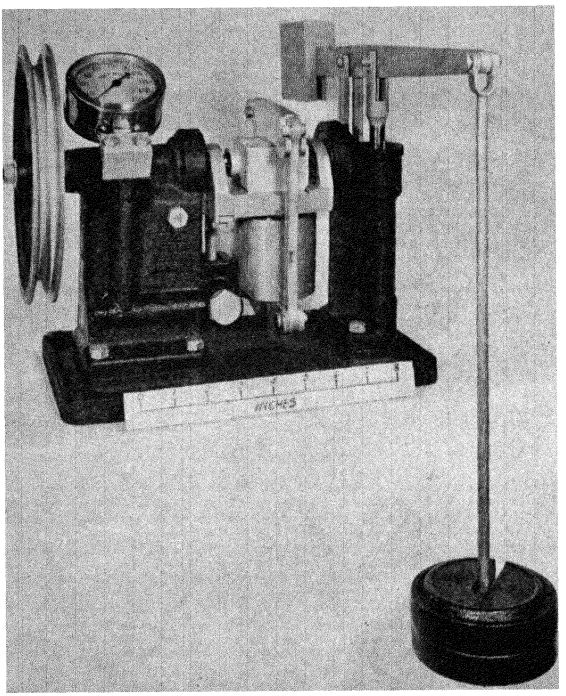


FIG. 42.—Almen E.P. testing machine.

intervals. Each 2-lb. weight produces a pressure of approximately 1000 lb. per sq. in of projected area on the test bearing.

23. Timken Machine.—Another machine developed about the same time as the Almen and for obtaining similar information on hypoid lubricants and lubricants for industrial roller bearings is the Timken wear and lubricant tester. This machine was developed and is manufactured by the Timken Roller Bearing Co. It is comprised essentially of a cast-iron base, which supports the testing mandrel, two levers, and a 2-gal. oil reservoir,

under which is an electric heater used to raise the oil to any desired temperature up to 210°F. The oil flows by gravity from the reservoir over the test block to the sump in the base. From the sump, the oil is pumped back to the tank. The test elements consist essentially of a hardened and ground steel ring, against which is forced a similar finished steel test block. The ring, which is a Timken bearing cup, is securely mounted on the

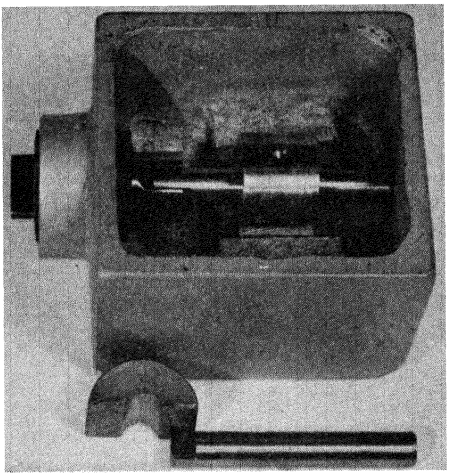


FIG. 43.—Cup, journal, and bearing for Almen machine.

end of the mandrel, and the block is carried by load lever. The test is carried out in accordance with the following procedure:

1. The usual speed for testing automobile rear-axle lubricants is 400 ft. per min. (800 r.p.m. of the spindle), and for light oils, such as freewheeling and crankcase oils, 200 ft. per min. (400 r.p.m. of the spindle).

2. A steady load is applied for a period of 10 min. The standard load is obtained by applying a total of 33 lb. on the lever arm. The lever is so pivoted that a load of 33 lb. produces a unit bearing load of approximately 20,000 lb. per sq. in.

3. Film failure is determined by a visual examination of the surface of the test block at the end of a run. If the surface shows signs of scoring or galling after a lever load of 33 lb. has been applied for 10 min., the lubricant is rejected. The friction torque developed during the run may be measured but is not a part of the standard test.

24. S.A.E. Machine.—From these two machines, much valuable information may be obtained about the load-carrying abilities of lubricants. They do not, however, rate lubricants always

in the same order and sometimes fail to rate them in the proper order as determined by actual service tests. The shortcomings of these machines are thought to be mainly due to the fact that the ratio of pressure to the applied load changes during the test run as a result of an increase in contact area because of wear. Consequently, a third machine, the S.A.E. extreme-pressure

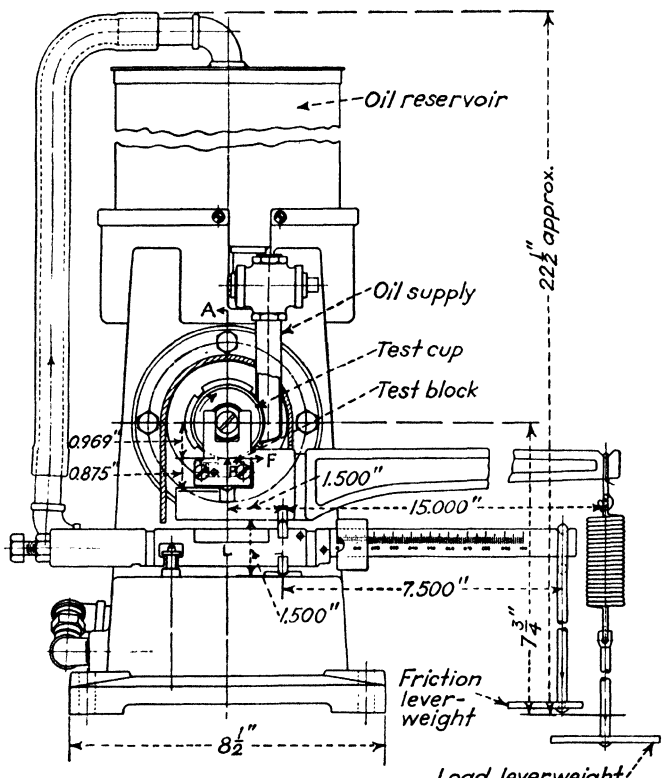


FIG. 44.—Timken E.P. lubricant- and wear-testing machine.

lubricant-testing machine, has been developed cooperatively by the National Bureau of Standards and the S.A.E. Extreme-pressure Lubricants Research Committee. This machine is essentially a device in which two cylindrical test specimens are rotated in line contact with each other and in opposite directions, with provision for controlling the speed of rotation, slipping velocity, and rate of applying pressure at the line of contact

between the two rotating cylinders. The test specimens are standard Timken test cup T-48651 and are bath-lubricated.

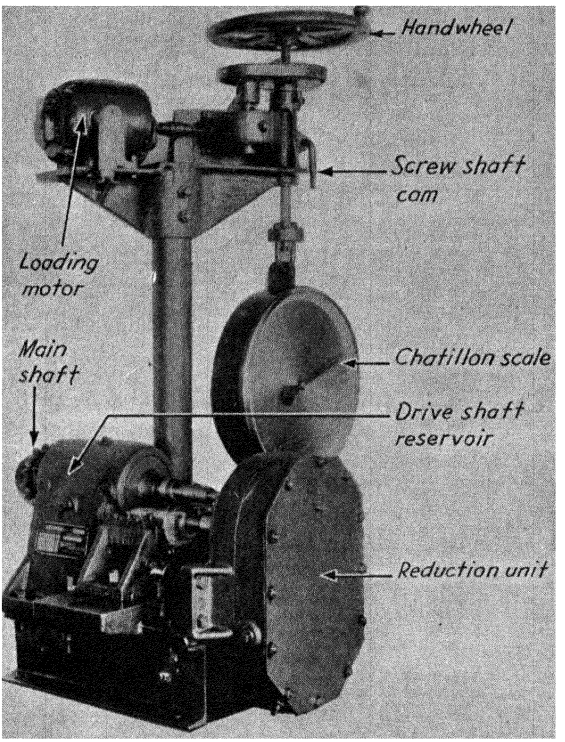


FIG. 45.—Society of Automotive Engineers E.P. lubricant-testing machine.

For evaluating extreme-pressure lubricants for use in automobile rear axles, the tentative method of test is conducted under the following operating conditions:

Main shaft speed	1000 r.p.m.
Rubbing ratio	14.6–1
Rate of loading	83.5 lb. per sec.
Initial temperature of testing machine, particularly the main shaft	100°F.

Analyses of the results obtained from this machine indicate that it is satisfactory as a go or no-go gage for the so-called *powerful* type of extreme-pressure lubricants and apparently evaluate them in the same order as actual service tests do in regard to their

scuff resistance. Whether or not it will satisfactorily rate the milder type of extreme-pressure lubricants is a matter for further research.

25. Herschel's Machine.—This machine was developed by W. H. Herschel, of the National Bureau of Standards, primarily

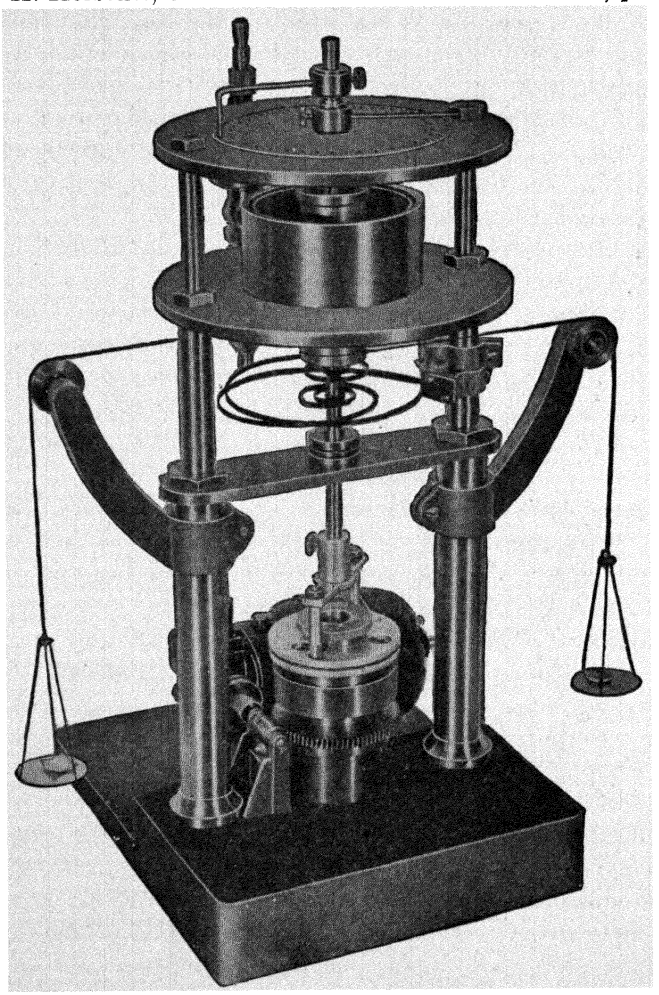


FIG. 46.—Herschel oiliness machine. (*Courtesy American Instrument Co.*)

for studying the oiliness of lubricants and the variation in frictional resistances produced by different combinations of bearing metals.

It is composed essentially of an aluminum slider, which is supported by three ½-in. commercial-steel balls resting on a motor-driven disk, the whole being submerged in the oil that it is desired to investigate. Means are provided for forcing the balls and disk together and for measuring and indicating the torque. When the disk is first rotated, the slider and pointer at the top of the vertical shaft rotate at the same speed as the disk: but when slipping occurs, the shaft winds up one of the two flat spiral springs and unwinds at the same time the other. The pointer moves over a graduated circle, and the springs are so adjusted that the reading of the pointer when slip first occurs is the static coefficient of friction.

It has been found that the static coefficient of friction is unreliable, presumably because it varies with chance irregularities in the smoothness of the disk and balls or with variations in the oil film. The preparation of the surface of the disk presents considerable difficulty; and, in order to obtain consistent results, a fair amount of experience with the machine is necessary. The surface of the disk must be ground under water, and every trace of abrasive must be removed.

26. Navy Work-factor Machine.—This is a laboratory machine for evaluating lubricating oils from the standpoint of their stability. Specifically, it is an accelerated endurance test that measures the changes that occur in carbon residue, viscosity, and neutralization number of an oil. It was developed by the U. S. Navy after making comprehensive tests of oil in service over an extended period of time. It was noted that during these tests certain definite physical and chemical changes regularly occurred in the oils that gave unsatisfactory service.

The test apparatus is essentially an oil-friction machine, having a $3\frac{13}{16}$- by 6-in. test journal revolving in a babbitt bearing and driven by a 3½-hp. variable-speed motor. By means of four calibrated helical springs, a nominal pressure of 150 lb. per sq. in. is applied to the test journal, which rotates continuously for 100 hr. at 2000 r.p.m. Five quarts of oil are used and are continuously circulated by means of a pump through the test bearing. No provisions are made for controlling the temperatures of the oil and bearing.

In order to calculate the work factor, it is necessary to determine the carbon residue, viscosity, and neutralization number of

the oil both before and after the 100-hr. duration test. The final work factor is the average of the individual work factors obtained for carbon residue, viscosity, and neutralization number. An oil to be acceptable must have an average work factor of not less than 0.60 and must not exceed certain established rejection points.

The final viscosity work factor is taken as the average of those obtained at 100, 130 and 210°F. The viscosity work factor is calculated as follows:

$$\text{Viscosity work factor} = \frac{\text{final viscosity} - \text{initial viscosity}}{\text{initial viscosity}} \times C$$

where $C = 4$ or 5, depending on the service for which the oil is to be used. The other work factors are calculated in a similar manner.

The final work factor is used to determine the service cost of the oil, as follows:

$$\text{Service cost per gallon} = \frac{\text{cost per gallon}}{\text{final work factor}}.$$

It is claimed that oils in service and oils in the work-factor test show comparatively the same changes as regards viscosity, neutralization number, carbon residue, and, sometimes, precipitation number. Furthermore, it is claimed that concordant results are obtained when oils are tested on different machines and by different operators and that the results are affected but little by changes in room temperature.

CHAPTER VIII

FUNDAMENTALS OF LUBRICATION

In order to select correct lubricants for machinery, certain lubrication fundamentals should be clearly understood.

1. Frictional Resistance.—When one body, whether solid, liquid, or gaseous, is moved over the surface of another, a resistance to motion is developed tangent to the surfaces in contact. This resistance or force, tending to oppose motion, is called *friction* or *frictional resistance.* It is present wherever motion exists or impends and always exerts a definite drag in opposition to motion.

Since it always opposes motion, it is undesirable in the operation of bearings, gears, and many other machine parts and, in such parts, is minimized as much as is practicable by the use of lubricants. Conversely, in other machine parts, such as brakes, clutches, and friction drives, it is very necessary and useful.

If friction between two bodies prevents relative motion, it is called *static friction,* whereas the friction between two bodies which move relative to each other is called *kinetic friction.*

2. Coefficient of Friction.—If force P, Fig. 47, is applied parallel to plane CD, on block A of weight W, the forces N and F are developed perpendicular to and parallel with the contacting surfaces, respectively. The ratio of F to N is called the *coefficient of friction.* The force F is the *frictional force,* N is the *normal pressure,* and their resultant R is called the *total reaction.*

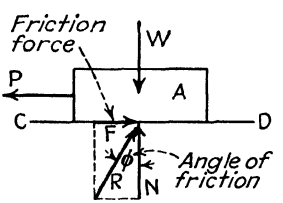


FIG. 47.—Frictional forces between block and horizontal plane.

If P is just of sufficient magnitude to cause motion of A to impend, the ratio of F to N is called the *static coefficient of friction.* On the other hand, if P is sufficiently great to cause A to move, the ratio of F to N is called the *kinetic coefficient of friction.*

3. Angle of Friction.—The *angle of static friction* for two surfaces is the angle between the total reaction and the normal pressure when motion is impending. Thus, if P, Fig. 47, is just large enough to cause motion of A to impend, the angle made by R and N is the angle of static friction and is denoted by ϕ. It is obvious from the figure that, if f represents the coefficient of static friction, $\tan \phi = f$. Also, from the definition of coefficient of friction, $f = F/N$. Therefore, $\tan \phi = F/N$; *i.e.*, the coefficient of static friction equals the tangent of the angle of static friction.

If the two surfaces move relative to each other, then the angle between R and N is called the *angle of kinetic friction*. Tan $\phi = f$ is also true for kinetic friction; the value f, however, for kinetic friction is usually less than that for static friction.

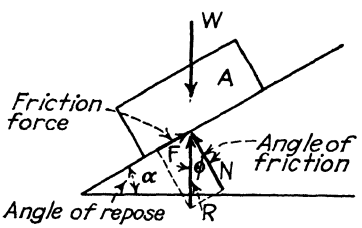


FIG. 48.—Frictional forces between block and an inclined plane.

4. Angle of Repose.—If a body rests on an inclined plane, Fig. 48, and is acted on by no other forces except its own weight and the reaction of the plane and if the inclination of the plane to the horizontal is such that motion of A impends down the plane, the angle α is the *angle of repose*. It is obvious that angles α and ϕ are equal. Hence, $f = \tan \alpha = \tan \phi$.

5. Friction of Circular Surfaces.—The normal pressure is not uniformly distributed over circular surfaces, such as those of journals and bearings. The distribution of pressure depends mainly on the clearance and the elasticity of the metals. For example, in Fig. 49, if a clearance exists between the journal and bearing, theoretically the surfaces make line contact; but practically, owing to the elasticity of the metals, the contact is over a very narrow, rectangular area, the intensity of pressure on which is not uniform. On the other hand, if no clearance exists, as in Fig. 50, the surfaces are in contact over a semicircular area on which the intensity of pressure also varies. In all such cases, because of the difficulty in obtaining the true area of contact and the distribution of the pressure over the area in contact, it is customary to define the coefficient of friction as the frictional resistance F at the surface of the journal divided by the total

load W normal to the axis of the journal. Denoting the coefficient of friction for circular surfaces by f_c, we have $f_c = F/W$ or $F = f_c W$.

Because the intensity of the normal pressure on circular surfaces is extremely difficult to determine accurately, it is customary to use the normal pressure as the intensity of pressure per square inch of projected area. That is, if D = diameter of the journal in inches, and L = length of bearing in inches, the intensity of pressure per square inch of projected area is $p = W/DL$.

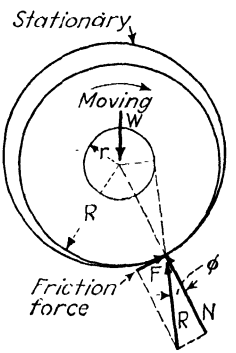


FIG. 49.—Frictional forces between rotating journal and bearing with clearance.

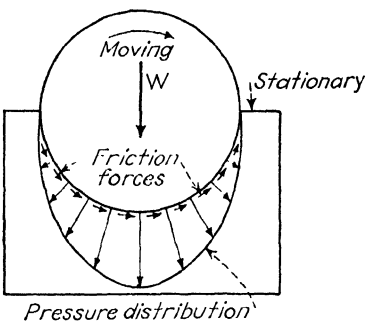


FIG. 50.—Frictional forces between rotating journal and bearing without clearance.

6. Rolling Friction.—The friction developed between flat and curved surfaces is commonly called *sliding friction*, whereas that developed between rolling surfaces, such as a wheel rolling on a track or a ball rolling over the race of a ball bearing, is called *rolling friction*.

The resistance to motion of wheels and rollers over a smooth surface has frequently been attributed to the inaccuracies of the surfaces, and it has been supposed that if the inaccuracies were removed the resistance would entirely disappear, provided that the surfaces were made of elastic materials and the load on the roller were not great enough to cause a permanent deformation of either surface.

No material is perfectly inelastic, and when a cylinder rests on a surface the weight of the cylinder will cause it to indent the surface and the cylinder will flatten, as in Fig. 51. When rolling motion occurs, the distance rolled through in 1 revolution of the

cylinder will not be the true circumference of the cylinder. For example, suppose that a steel cylinder is rolled over a rubber surface which has lines drawn at intervals of 0.1 in. and that as the cylinder is rolled these lines stretch so that the intervals become 0.11 in. Then, the cylinder measures its circumferences on an extended surface, and the true distance rolled through will be one-tenth less than its circumference. If the distance through which the cylinder would roll if there were no extension or contraction is called the *geometrical distance*, then the cylinder in the foregoing case rolls through less than its geometrical distance. On the other hand, if a rubber cylinder is rolled over a

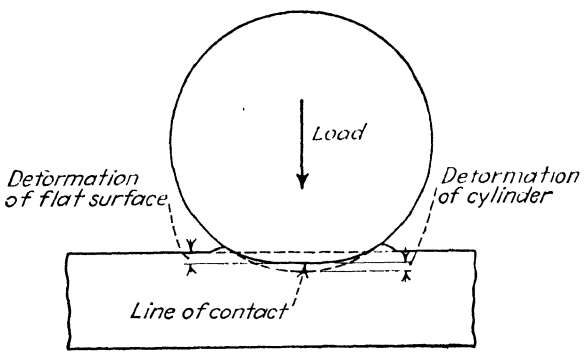


FIG. 51.—Elastic deformation of a cylinder and flat surface.

steel surface and the surface of the roller extends 10 per cent in passing over the steel surface, it is evident that in 1 revolution the cylinder would pass over a distance 10 per cent greater than its geometrical distance.

It must not be assumed that if the cylinder and plane surfaces were made of the same material these effects would balance. In the case of the flat surface the effect of the material surrounding the depression is to stretch the material in the depression further, whereas for the cylinder having a small flat on it the material surrounding the flat will compress the material adjacent to the flat and decrease its lateral expansion. The magnitude of the latter effect depends on the diameter of the cylinder. There are, thus, two independent causes that affect the rolling of a cylinder on a plane, *viz.*, the relative elasticity of the materials and the diameter of the cylinder. These two causes will act together or in opposition according to whether the cylinder is

harder or softer than the plane. Thus, a steel cylinder rolling on a rubber plane will roll through less than its geometrical distance, whereas a rubber cylinder on a steel surface will roll through a distance greater than, less than, or equal to its geometrical distance, according to the relation between its diameter and elasticity.

The character of the deformation caused by a steel cylinder rolling over a rubber surface is shown in Fig. 52, which represents a section through a cylinder and a plane flat surface. The lines on the rubber are assumed to be lines that were initially vertical and equally spaced. The motion of the cylinder is toward

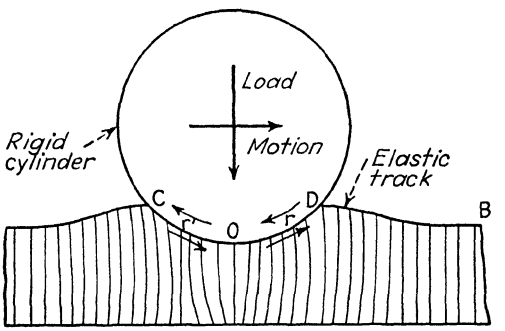


FIG. 52.—Slip between a rigid cylinder and an elastic track.

B, and *or* and *or'* are the limits of the surfaces on which there is no slipping. *C* and *D* are the limits of the surface in contact. Beyond these points the rubber is compressed because of the lateral extension of the material under the cylinder. The lines in this region are, therefore, less than their unstrained distance apart. From *D* to *r* the material is compressed, slipping takes place, and the lines are convexed outward. From *r* to *r'* there is no slipping; but from *r'* to *C*, expansion with slipping takes place and the lines are concaved outward. It is clear that the distance the lines from *r* to *r'* are apart will depend on the amount of the lateral compression from *D* outward, and it is quite possible that this is such that the distance the cylinder rolls through is equal to its geometrical distance, regardless of the actual slipping between *Dr* and *Cr'*. The actual slipping is obviously equal to the difference between the distances *rr'* and *DC*, and will always be greater than the loss of geometrical distance rolled through.

From the preceding explanation the importance of the distinction between real and apparent slip is brought out, the *apparent slip* being defined as the difference between the circumference of the cylinder and the distance moved through by its center in 1 revolution.

In many cases the lubrication of antifriction bearings does not decrease their frictional resistance; hence, their efficiency is actually decreased rather than increased. From Fig. 52, it is clear that if the coefficient of friction is very great r and r' will coincide with D and C and there will be no slipping and, hence, no frictional work done. On the other hand, if the coefficient of friction were zero, r and r' would coincide with O and there would be no friction and, hence, no work done in overcoming it. Therefore, the work spent in friction is zero for two values of the coefficient of friction, and, since work is required to overcome friction for all intermediate values of the coefficient of friction, it must pass through two maximum values. Hence, for some value of r and r', *i.e.*, for some value of the coefficient of friction, the frictional work is a maximum.

The usual formula for rolling friction differs from that of sliding friction to the extent that the resistance varies inversely as the radius of the cylinder. It is expressed as follows:

$$F = f_r \frac{W}{R}$$

where F = frictional resistance in pounds.
f = coefficient of friction in inches.
W = load on the cylinder in pounds.
R = radius of the cylinder in inches.

7. Frictional Power Loss.—The power absorbed by frictional resistance is always transformed into heat energy. For flat surfaces the frictional power loss in foot-pounds per minute is

$$E = fNV$$

where f = coefficient of friction.
N = normal pressure in pounds.
V = velocity of sliding in feet per minute.

For circular surfaces the frictional power loss is

$$E_c = f_c W \frac{\pi Dn}{12} = 0.262 f_c WDn$$

where f_c = coefficient of friction.
W = total load on the journal in pounds.
D = diameter of the journal in inches.
n = r.p.m. of journal.

For rolling surfaces, Fig. 51, the frictional power loss

$$E_r = FV = \frac{f_r W V}{R}$$

where f_r, W, and R = as defined above,
V = linear velocity of the center of the cylinder in feet per minute.

8. Types of Friction.—A consideration of the laws of friction, as applied to machinery, naturally divides itself into two main divisions, as follows:

a. Boundary friction, including: (1) dry or solid friction, which occurs between perfectly clean, dry, solid surfaces; and (2) thin-film friction, which occurs between solid surfaces partially or completely separated by a film of fluid so thin that the unknown intermolecular forces between the fluid and solid surfaces determine the character of the frictional resistance.

b. Fluid friction, which includes all cases of frictional resistance between solid surfaces completely separated by a film of fluid of sufficient thickness to conform to the laws of fluid flow.

9. Dry or Solid Friction.—The laws of dry friction are mainly empirical and, hence, are only rough approximations. They are chiefly based on the experimental results of Amontons (1699), Coulomb (1779), Vince (1784), Rennie (1828), Morin (1830–1834), and others. In many so-called *dry-friction experiments,* sufficient care was not taken to ensure that the contacting surfaces were perfectly clean and dry, with the result that such surfaces were often partially or entirely covered with extremely thin films of fluids. Hence, the so-called *laws* of dry friction are based on conditions more closely approximating those of thin-film friction than those of dry friction.

From the results of experiments conducted in 1699, Amontons concluded that the frictional resistance to relative motion of solid surfaces in contact was *independent of the area of contact and proportional to the normal load.* This is considered the first law of friction and is justly called Amontons' law. Amontons, however, concluded further that the frictional resistance was due to the

interlocking of the projections and depressions (asperities) of the surfaces in contact. Coulomb in 1779, after a very extensive series of experiments, reached the same conclusions.

This explanation of the cause of friction is doubtless true for relatively rough surfaces, but it is not valid for highly polished and true surfaces, such as those of many of the present-day bearings, even though they do contain microscopic projections and depressions. If it were true for all surfaces, however smooth, the higher the degree of polish, the less would be the friction, which has been conclusively proved not true.

When highly polished and true surfaces are pressed together, they adhere more or less firmly. For example, if two pieces of clean and true plate glass are pressed together with a sliding motion, they adhere so strongly that one may be lifted and even held in a vertical position without separating. Likewise, marble, copper, steel, and many other metals, and even alloys of dissimilar metals will adhere in this manner.

Phenomena of this character have led to the conclusion that for highly polished, dry, and true surfaces the friction developed between the surfaces is mainly caused by the strong mutual attraction of the surface molecules. In brief, dry friction is chiefly caused by adhesion; consequently, the forces are chemical rather than physical. These intermolecular forces seem to extend in all directions beyond the solid surfaces. Their range of action, however, is quite small, usually much less than the diameter of a molecule and in some cases even less than that of an atom.

In actual lubrication practices, it is very doubtful if conditions of true dry friction are ever encountered. When a pair of lubricated surfaces are forced together by a heavy load, the pressure tends to expel the lubricant from between the surfaces. But experiments show that it is very difficult, even with limited areas and excessive loads, to expel the lubricant completely. Perhaps, if heavily loaded machinery is permitted to stand for a relatively long period of time, so much of the lubricant will be expelled as to permit some metal-to-metal contact. Such conditions would, of course, only approximate true dry-friction conditions and would probably be more nearly like the conditions of thin-film friction.

10. Thin-film Friction.—At present, engineers are deeply concerned with problems of thin-film friction. Either it must be

overcome, or else present trends of higher speeds, temperatures, and loads will come to an early halt.

Based on the research works of many scientists, the present-day conception of the mechanism of a lubricating film is as shown in Fig. 53. In thin-film-friction conditions, the full fluid film does not exist; consequently, the boundary layers are of great importance.

The boundary film formed by a lubricant on a solid surface has a frictional value that depends on the chemical nature of both the metal and the lubricant. Much research work has been done to determine the structure and properties of adsorbed films, which adhere to solid surfaces and often increase the slipperiness of their surfaces. The slipperiness of the surface is commonly referred to as its *unctuousness* and the lubricating value of adsorbed films

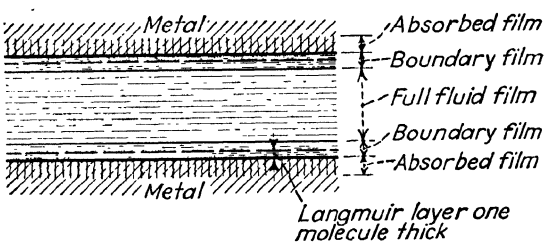


FIG. 53.—Mechanism of an oil film.

as *oiliness;* thus, the actual friction of a bearing operating under thin-film conditions is partly due to unctuousness and partly to oiliness.

It has been known for many years that animal and vegetable oils (fixed oils) possess some desirable lubricating properties not possessed by mineral oils. For example, these oils adhere more tenaciously to metal surfaces than mineral oils. In other words, they are said to possess greater oiliness. Faults, such as the lack of chemical stability, make them, however, undesirable as lubricants for most purposes.

The molecules of fixed oils and certain molecules (unsaturated ones) of mineral oils are of the long-chain type. One end, called the *polar end,* of this chain molecule contains two active oxygen atoms, which give the polar end of the molecule a stronger power of attraction for the metal than that of the nonpolar end. When a drop of lubricant containing these long-chain molecules is spread on metal, the molecules become oriented and stand upright, with

their polar ends in contact with the metal surface. These molecules appear to form a series of layers, as in Fig. 53. The layer immediately attached to the metal is of one-molecule thickness, whereas the remaining long-chain molecules form double layers, having their polar ends adjacent. The nonpolar ends of the molecules forms planes of cleavage, which probably allow the paired layers to slide over each other when relative motion occurs between the solid surfaces. The attraction between the long-chain molecules themselves appears to be less than that between the initial layer and the metal surface. This doubtless accounts for the fact that, generally, thin-film friction is less than fluid friction.

To circumvent dry friction, it is necessary to separate the solid surfaces a distance sufficient to remove their intermolecular attraction. In brief, the remedy is to substitute thin-film friction, or preferably fluid friction, for dry friction.

This remedy is not, however, always practicable. Although a drop of oil will spread over a clean metal surface and adhere to it in spite of vigorous rubbing and excessive loads, nevertheless it is frequently reduced to a thickness at some points that permits intermolecular forces to act. When such conditions exist, dry- or thin-film friction, or both, prevail. It may occur in machinery when starting and stopping, in crosshead and guides, pistons, slides, etc., and when a very sudden or impact load is applied to a bearing.

11. Film Breakdown.—When breakdown or seizure occurs, these intermolecular forces are so strong that one surface or both may be destroyed. The exact mechanics of breakdown are not known. It is known, however, that incipient breakdown starts at one or more tiny points, called *hot spots*, where the temperature rises suddenly above the melting point of the metal and actual welding occurs. The cause of the hot spots, however, is not known. One theory is that the shearing or breaking off the tiny asperities generates sufficient heat to cause the surfaces to weld. Another theory is that the hot spots are simply points where the intermolecular forces become so strong that the molecules are torn out of the surfaces with a release of sufficient heat to cause the surface to weld. The only certainty is that if the surfaces are sufficiently close together they are soon destroyed, even under light loads. It is, therefore, a function of a lubricant to maintain

the surfaces at a distance sufficient to eliminate the effect of these intermolecular forces.

12. Fluid Friction.—At the present time our knowledge of the laws of fluid friction is much more complete and advanced than our knowledge of those of dry- and thin-film friction.

It was discovered in 1883 by Beauchamp Tower that in the case of a lubricated journal bearing the surfaces of the journal and bearing were completely separated by a film of oil under pressure and that the component of the total oil pressure in the direction of the load was numerically equal to the load.

Under conditions of fluid friction, the lubricant is forced between the relatively moving surfaces because of its viscosity or internal friction. It is this physical property of a lubricant that renders it highly resistant to forces tending to separate its molecules, and this resistance is the cause of fluid friction.

At a speed depending on (*a*) the load, (*b*) the nature of the lubricant, and (*c*) the inclination of the rubbing surfaces, the surfaces tend to separate, and the comparatively thick pressure film formed between them carries the load. The extent to which this film increases in thickness varies with (*a*) the load, (*b*) the viscosity of the lubricant, (*c*) the area of the bearing, (*d*) the speed, (*e*) the shape of the surfaces, and (*f*) the relative position they assume.

In discussing the conditions of thin-film friction, it was stated that the thin lubrication film between solid surfaces appears to be greatly affected by the intermolecular forces of the opposing solid surfaces. In fluid friction, the lubricating film is so thick that the molecules of the lubricant are beyond the range of action of the intermolecular forces of the solid surfaces. When such a lubricating film exists, it possesses the same fluidity as the lubricant does in bulk, which is probably not true for very thin films that are acted on by intermolecular forces of solid surfaces.

When conditions of thick-film friction occur, therefore, the frictional resistance is no longer affected by the chemical constitution of the lubricant or the nature of the solid surfaces, as in thin-film friction, but is influenced only by the internal friction of the lubricant itself, which friction is proportional to the viscosity of the lubricant. Therefore, since viscosity is the only property of a lubricant on which fluid friction depends, it will be discussed next, before proceeding further with the subject of fluid friction.

13. Viscosity.—Viscosity is one of the most important properties of a lubricant, especially when thick-film conditions prevail; for it is the property that determines the bearing friction, temperature rise, rate of oil flow through the bearing, and, to a certain extent, the load-carrying capacity of the bearing.

All fluids, whether gaseous or liquid, possess viscosity in varying degree. It is generally known that molasses is more viscous (has a higher viscosity) than water, as is evidenced by the fact that it pours more slowly, is more difficult to stir, etc. Likewise, oil is more viscous than water, and water more viscous than gasoline, etc.

Some have assumed that a relationship exists between viscosity and cohesion. No relationship, however, has been proved to exist. To illustrate with very little effort, a soft iron ball may be rolled slowly around the pole of a strong magnet, but a considerable effort is required to pull the ball and magnet apart. Similarly, the molecules of water move about each other with very little effort, and, in consequence, water has a very low viscosity. Yet, according to calculations of Young and Dupré, the force required to tear the molecules of water apart is more than 360,000 lb. per sq. in.

The definition of viscosity is based on Newton's law for fluid flow, which states that *at any point in a fluid the shearing stress is directly proportional to the rate of shear.* Algebraically expressed, it is as follows:

$$S = \text{constant} \times R \tag{1}$$

where S = shearing stress.

R = rate of shear.

In Fig. 54 are shown two parallel plane surfaces AF and BE, which are separated by a thick lubricating film of h thickness. Plane AF is assumed fixed, and BE is assumed to be moving at a constant velocity V. When a lubricant separates two solid surfaces, one of which moves tangent to the other at rest, the layer of lubricant in contact with the moving surface is assumed to move at the same velocity as the surface; *i.e.*, there is no slip between the solid surface and the adjacent layer of lubricant. Similarly, the layer of lubricant adjacent to the fixed solid surface is assumed stationary. Between the two surfaces the lubricant may be considered as consisting of a series of very thin layers or

laminations, each moving at a velocity proportional to its distance from the fixed, solid surface.

Let the full lines *ABCDEF* indicate the original shape of a small volume of lubricant and the broken lines *AGHIJF* indicate the deformed shape of this same volume after a short interval of time. Let F represent the tangential force acting on the moving surface of area A. When surface *BE* is moving at constant velocity, F is balanced by the internal shearing forces of the lubricating film, which forces are not shown. By definition, the rate of shear, $R = V/h$. From Newton's law, $F/A = S =$ constant $\times V/h$. The constant of Newton's law is the coefficient

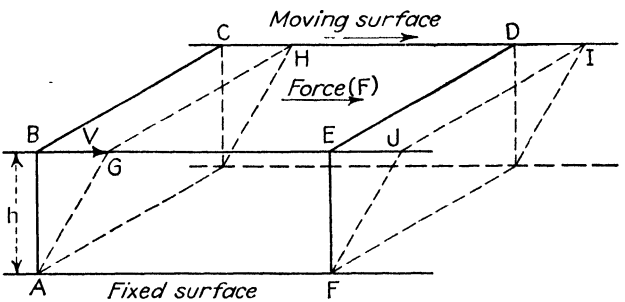


FIG. 54.—Mechanism of shearing action of an oil film.

of viscosity, or, as it is generally called, *viscosity*. If we denote viscosity by Z, Newton's law is

$$S = ZR \tag{2}$$

Or it may be written $F/A = ZV/h$. Solving for the frictional resistance F, we have

$$F = Z\frac{AV}{h} \tag{3}$$

From this equation, the frictional resistance for thick films is directly proportional to the viscosity of the lubricant, the area of the film in shear, and the relative velocity of the surfaces and is inversely proportional to the thickness of the film.

Solving Eq. (3) for viscosity Z, we have

$$Z = \frac{F}{A} \times \frac{h}{V} \tag{4}$$

In words, therefore,

$$\text{Viscosity} = \frac{\text{shearing stress}}{\text{rate of shear}}$$

Referring to Fig. 55, whenever the curve of the rate of shear, R, vs. shearing stress S passes through the origin, the material is classed as a *liquid*, even though the curve is not a straight line. When the curve intercepts the stress axis, the material is classed as a *plastic solid* and flow begins only after the yield stress S_0 has been reached. If the curve is a straight line and passes through the origin, the material is called a *Newtonian liquid;* but if it passes through the origin and is not a straight line it is classed as a *non-Newtonian liquid.* If it intercepts the stress axis and is a straight line or is approximately so, it is called a *Bingham plastic solid.*

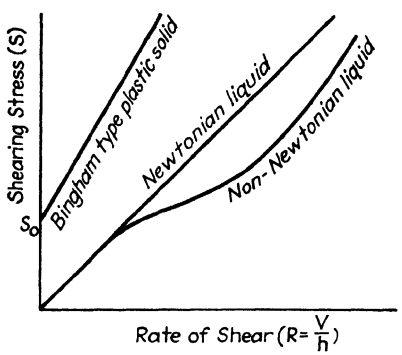


FIG. 55.—Rate of shear and shearing stress for liquids and plastics.

Viscosity is a physical property of an oil just as are density, color, pour point, and fire and flash points. It does not indicate in any manner the ability of an oil to retain its original properties or the rate at which it will deteriorate in service. Various other physical and chemical characteristics govern these properties, which are discussed, as well as the units of viscosity and methods of determining it, in Chap. VII.

14. The Significance of f vs. Zn/p Graph.—Both theory and practice indicate that the dimensionless expression, absolute viscosity × the velocity of the journal in r.p.m. divided by the bearing pressure in pounds per square inch of projected area, is of especial significance. Algebraically, this may be expressed as Zn/p.

If a certain bearing is tested under various conditions of load, speed, and temperature, a plot of the observed coefficients of friction against corresponding values of Zn/p gives a curve similar to that shown in Fig. 56. As shown, certain well-defined regions of the various types of friction and lubrication are exhibited. For very small values of Zn/p from A to B, the oil film is very

thin and the bearing operates in the region of boundary friction, where the intermolecular forces and perhaps some interlocking of the asperities cause most of the frictional resistance. In this region the friction is dependent on the unctuousness and smoothness of the bearing surfaces and the oiliness of the oil and perhaps to a limited extent on the viscosity of the oil. In the region from B to C, the film is somewhat thicker than in the region from A to B, the intermolecular forces, oiliness, and unctuousness are of less importance, and viscosity plays a more important part. This is the transition region from thin- to thick-film friction and lubrication. The curve from C to D is essentially a straight line, and

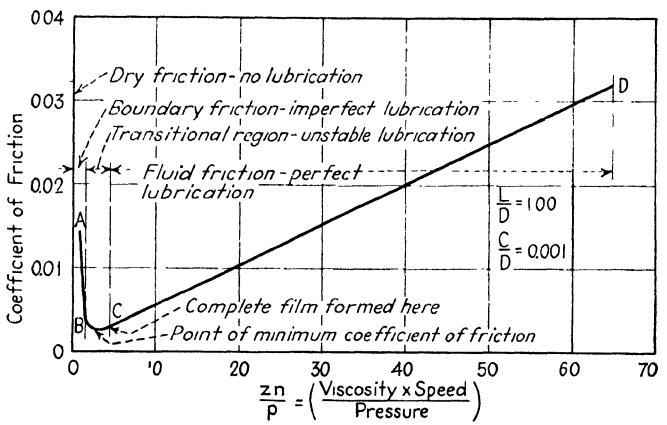


FIG. 56.—Typical plot of journal-friction observations. Bearings of different dimensions give similar curves with the position of the minimum value of f changed and the slope of the various parts of the curve changed.

the friction is virtually independent of the oiliness of the oil and the smoothness and unctuousness of the bearing surfaces and is almost if not wholly dependent on the viscosity of the oil. In this region the friction resistance conforms very closely to the law as expressed by the equation $F = Z(AV/h)$.

Referring to Fig. 49, we find that the friction force

$$F = f \times W = f \times p \times A,$$

where A is the projected area of the bearing. Therefore, $Z(AV/h) = f \times p \times A$, or $f = ZV/ph$. But $V = \pi Dn$. Therefore, $f = (\pi Dn/ph)Z = C(Zn/p)$, where $C = \pi D/h$, a constant for any given bearing.

Obviously, although the shape of the curve f vs. Zn/p will always be similar to that shown in Fig. 56, yet each bearing of different physical dimensions will have a characteristic curve of its own. The coefficient of friction depends not only on the viscosity of the oil, the speed of the journal, and the load of the bearing, but also on the diameter of the journal and the oil-film thickness. The thickness of the oil film in turn depends on several factors, the chief ones being the clearance, load, and speed, the length-diameter ratio of the bearing, and the viscosity of the oil.

The effect of clearance, which to a certain extent determines the end leakage, is shown in Fig. 57.

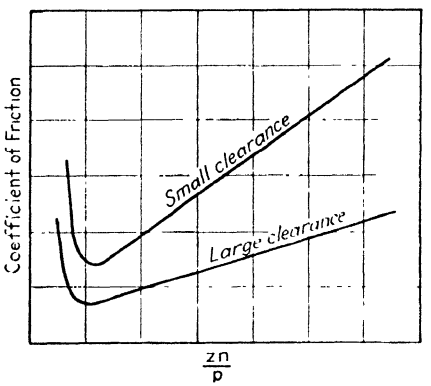


FIG. 57.—Effect of clearance on friction.

The minimum coefficient of friction, hence, minimum friction power loss, would be realized by operating a bearing in the region BC, shown in Fig. 56, but it would not be advisable to do so because of the unstableness of the oil film in this region. A bearing should be so designed that the operating value of Zn/p is not less than five times the minimum value of Zn/p.

The ratio of the operating value of Zn/p to the minimum value is sometimes referred to as the *factor of safety* of the bearing.

15. Oil-film Pressures.—In the case of fluid friction, when the rubbing surfaces are completely separated by an oil film of sufficient thickness to obey Newton's law of fluid flow, there is built up in the oil film a pressure that supports the bearing load.

In order to obtain a clear understanding of the mechanism of thick-film lubrication and the building up of the film pressure

the case of parallel plane surfaces will be discussed first. These surfaces are not a very common form of bearing or one that will carry a very heavy load, although they are used in many thrust bearings, such as step bearings, marine propeller-shaft thrust bearings (horseshoe type), and others.

Shown in Fig. 58 are two parallel plane surfaces of unlimited length and breadth, which are assumed to be separated by a film of oil of h thickness. The plane CD is fixed, whereas AB moves parallel to CD with a constant velocity V in the direction of the arrow. The velocity varies uniformly from V at AB to zero at CD; *i.e.*, the rate of shearing throughout the oil film is constant, as indicated by the uniform slope of the line FH.

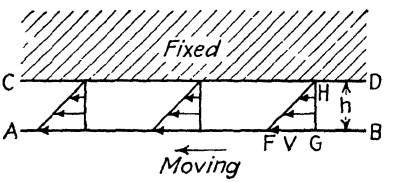


FIG. 58.—Shearing of an oil film between unlimited surfaces.

When AB is first set in motion, the inertia of the oil prevents it from assuming a steady condition of flow. After a comparatively short period of time, however, the velocity of the oil at any plane becomes proportional to the distance from CD. Under these conditions there is no pressure built up in the oil film and, hence, no tendency of the oil to push the surfaces apart. If, however, a load were applied in such a manner as to reduce the thickness of the oil film, a pressure would be produced in the oil film because of the viscosity of the oil.

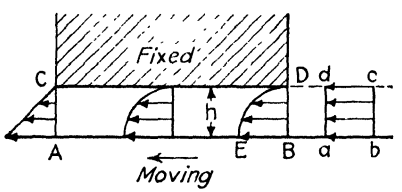


FIG. 59.—Shearing of an oil film between limited surfaces.

The surfaces in Fig. 59 are of finite dimensions. AB is assumed to be flooded with oil and moving parallel to CD at a constant velocity V. Prior to reaching point D, the whole oil film covering AB is moving with the same velocity as surface AB, as shown by the velocity rectangle *abcd*. On reaching D, however, the oil film is distorted. The layer of oil coming in contact with CD comes to rest, and the remainder is caused by its inertia to enter the space and flow in such a manner that the rate of shear becomes much greater near CD than near AB. Because of the viscosity of the oil film, its rate of shear is constant at all distances from CD at the exit end AC. Under these conditions, therefore,

the line *ED* is curved and the volume of oil entering between the surfaces is greater than that leaving at *AC*. The excess oil flows out in a direction perpendicular to the plane of the paper. This flow is commonly called *end leakage*.

A pressure is built up in the oil film because of the inertia effect, which tends to pack more oil into the space than viscous drag discharges. This pressure is a function of the density and viscosity of the oil and the velocity of *AB*. It is quite small and will not support a very heavy load.

Shown in Fig. 60 are two parallel surfaces *AB* and *CD*, which are assumed to be of unlimited length in a plane perpendicular to the paper. Surface *CD* is fixed, whereas *AB* is assumed to be moving, as indicated by the arrow, perpendicular to *CD*. The oil is squeezed from the surfaces; and in consequence of its viscosity a pressure is created in the oil film, which pressure is a maximum midway between *AC* and *BD*. Furthermore, the velocity of the oil will be a maximum midway between *AB* and *CD* because there is no tangential motion between the two surfaces.

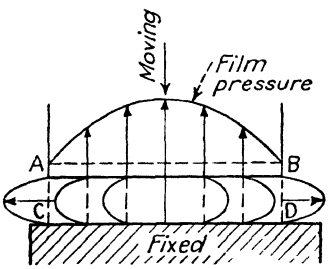


FIG. 60.—Oil-film pressure between approaching surfaces.

If at a certain position of the motion, such as is indicated by the dotted line *AB*, the oil in the space between *AB* and *CD* is divided into equal parts, as shown by the vertical dotted lines, and these lines are assumed to move with the oil, the lines will after a short period of time assume the positions indicated by the curved lines. The areas included between each pair of curved lines are the same as those between the dotted lines. Obviously, the slope of the curved lines represents the rate of shear of the oil film at different points; and because force is required to maintain the rate of shear at each point constant, a vertical load *W* is required to force the oil out between *AB* and *CD*, and the oil-film pressure tends to push the surfaces apart.

As shown in Fig. 61, *AB* is a plane surface, of unlimited length and breadth, moving in the direction of the arrow below the inclined surface *CD*, which is of limited dimensions. Inertia effect being neglected, the volume of oil carried into the space by viscous drag is proportional to area *BDE*, whereas that dis-

charged is proportional to area ACF. The excess volume carried into the space is squeezed out between the surfaces in a direction at right angles to the motion of AB. Because of its viscosity, the oil resists this squeezing action; in consequence a pressure is built up within the oil film, which pressure tends to push the surfaces apart.

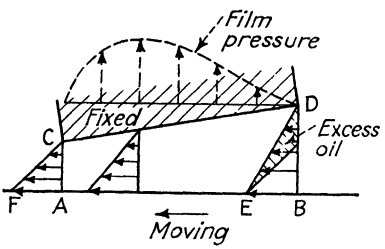


FIG. 61.—Oil-film pressure between inclined surfaces.

This film pressure tends to cause the oil to flow in all directions from the point of maximum pressure. The flow in the direction of motion of AB caused by the oil-film pressure acting alone is shown in Fig. 62. The flow actually occurring, the inertia effect of the oil being neglected, is that produced by the combined action of viscous drag and oil-

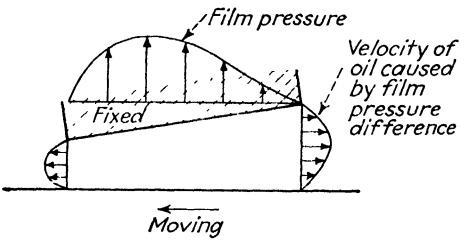


FIG. 62.—Flow of oil caused by oil-film pressure acting alone.

film pressure, as in Fig. 63. As the oil escapes much more freely at end BD and the sides near it than at end AC, the maximum

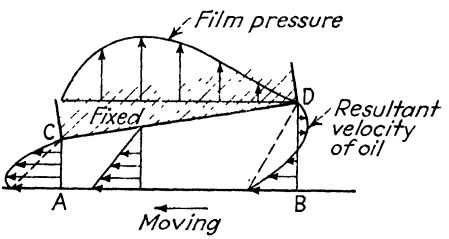


FIG. 63.—Resultant flow of oil caused by film-pressure and viscous drag.

film pressure is nearer AC than BD, and the general character of the film pressure curve is as shown above the figure.

When such surfaces are free to assume any position, the oil-film pressure, inclination of the surfaces, and position of the

resulting force adjust themselves to balance the load. For a given velocity and the nearer the surfaces approach each other, the greater are the friction and the oil-film pressure.

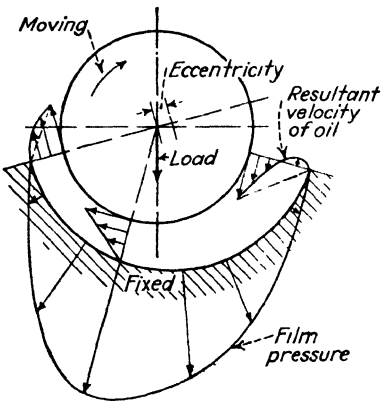


FIG. 64.—Oil-film pressure and oil flow in partial bearing.

The surfaces *AB* and *CD*, in Fig. 61, may be imagined to be flexible and curved in the form of a partial cylinder bearing as in Fig. 64. Practically the same conditions prevail in this case as those for flat surfaces. It will be noted that the center of the journal does not coincide with that of the bearing. The distance between the centers is called the *eccentricity*, which depends on the viscosity, the velocity of the journal, and the load. A line drawn through the centers passes through the point of minimum oil-film thickness or the point of nearest approach of the two surfaces in this case, at the exit edge of the bearing.

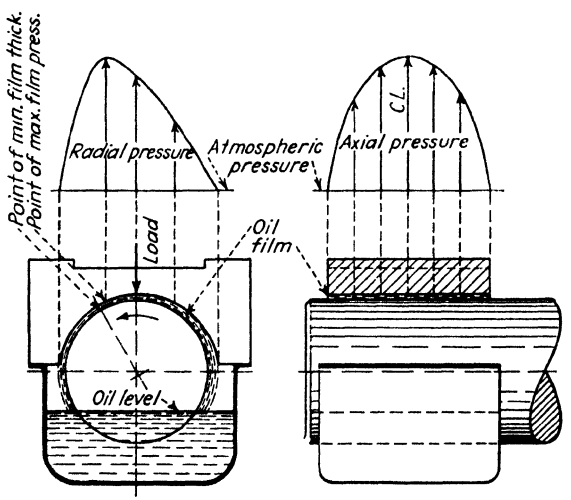


FIG. 65.—Pressure distribution in an oil film of a partial bearing.

The oil-film pressure varies in an axial direction as well as in a circular direction, as in Fig. 65.

When the bearing is of the complete cylinder type, the surfaces diverge beyond the point of minimum oil-film thickness, as in Figs. 66 and 67. In Fig. 66, the load is carried on the lower

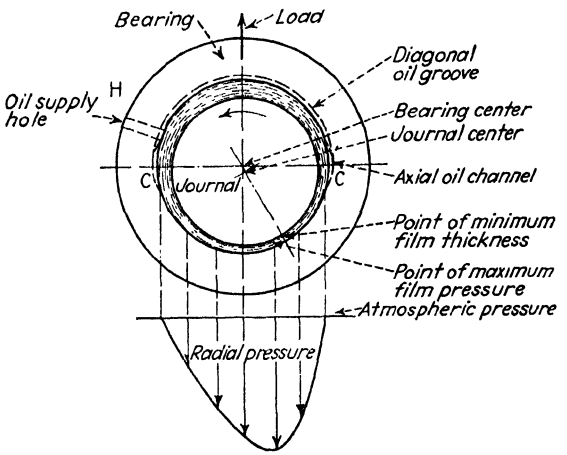


FIG. 66.—Oil-film pressure in a bearing having an oil groove and a channel cut in the unloaded side.

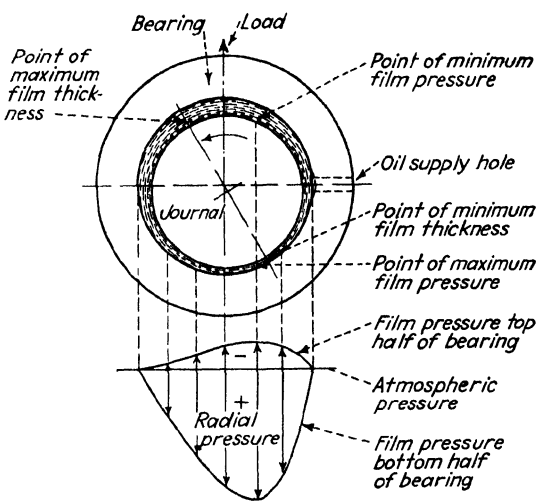


FIG. 67.—Oil-film pressure in a bearing having no oil grooving.

half of the bearing and the oil is supplied at *H*, from which large diagonal grooves are cut in the bearing surface to the axial channel *C*. Since the top half of the bearing is open, an oil-film pressure greater than atmospheric pressure cannot be built up in the

top half of the bearing. Consequently, the general shape of the oil-film pressure curve is as shown.

In Fig. 67 is shown a similar bearing, except that no oil grooves or channels are cut in the top half of the bearing. Because of the divergency of the clearance space beyond the point of minimum oil-film thickness and the fact that the top half of the bearing is not open to atmospheric pressure, the oil-film pressure decreases. It has been determined experimentally and deduced mathematically that the pressure on this part of the bearing may be negative, allowing oil to be drawn into the space without pressure behind it.

The side where the pressure of the oil film is greater is known as the *on side* and that where the pressure is less is called the *off side* of the bearing.

16. Oil-film Formation.—From the preceding discussion of oil-film pressures, it is evident that many factors affect the formation

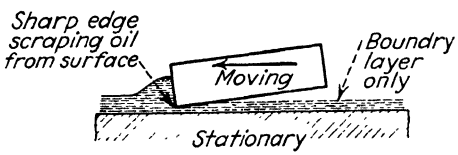


FIG. 68.—Flat sliding surface without bevel edge.

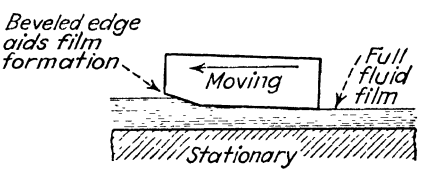


FIG. 69.—Flat sliding surface having lead-in edge beveled.

and thickness of oil films. The chief factors are: (*a*) the design of the bearing, including the shape of the surfaces, the grooving and chamfering, and the clearance; (*b*) the relative velocity and character of the motion; (*c*) the method and point of application of the oil; (*d*) the character of the load; (*e*) the characteristics of the oil, especially its viscosity and oiliness.

In Fig. 68 is shown a short block sliding on a flat surface, as, for example, a piston ring and cylinder wall. The block tends to tilt, and the sharp, leading edge tends to scrape the oil film from the surfaces. Figure 69 shows a similar block, with the leading edge chamfered or beveled. The beveled edge obviously tends

to aid the formation of an oil film. Shown in Fig. 70 is a ball or roller bearing in which the bevel is probably too abrupt to aid the formation of oil films between the ball or roller and the races. An oil film is shown between gear teeth in Fig. 71. In

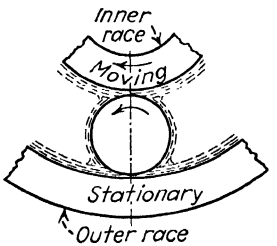


FIG. 70.—Film formation in a ball or roller bearing.

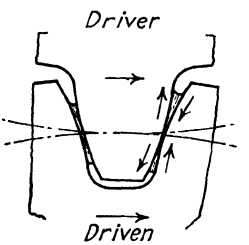


FIG. 71.—Film formation between gear teeth.

this case the bevel is not so abrupt, but the pressure between gear teeth is usually very high, often being as much as 1000 lb. per in. of tooth contact. Moreover, the relative velocity of sliding between the teeth is a maximum when the teeth first make contact and decreases to zero when the contact reaches the pitch point where the direction of slipping reverses, which is not favorable to oil-film formation.

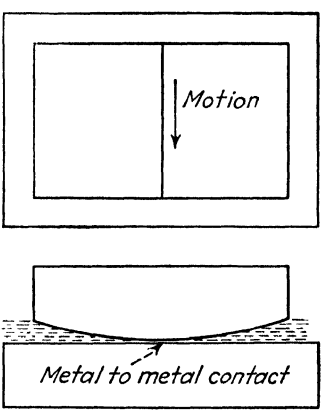


FIG. 72. –Effect of motion on oil-film formation.

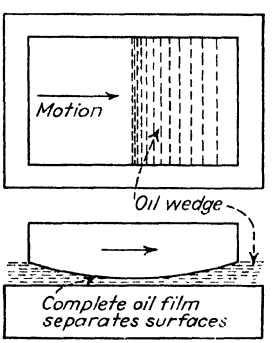


FIG. 73.—Effect of motion on oil-film formation.

The importance of the direction of motion between bearing surfaces is shown in Figs. 72 and 73. A film would readily form between the surfaces of Fig. 73 but would not do so between the surfaces of Fig. 72.

The extent of the surfaces in contact is also of prime importance. For example, the areas over which the load is distributed in ball and roller bearings and gear teeth are quite small; consequently, a relatively small load will squeeze the oil from the surfaces. In other words the end leakage becomes excessive for small-contact areas.

Another important consideration is the time available for the oil film to form. In the case of gear teeth, the time from the instant contact is made between a given pair of teeth until the pitch point is reached is usually very short, and it is doubtful if a complete oil film can form, especially if the gears run at a high speed. Likewise, the time required for a single stroke of a piston or crosshead of an engine or similar machine is usually

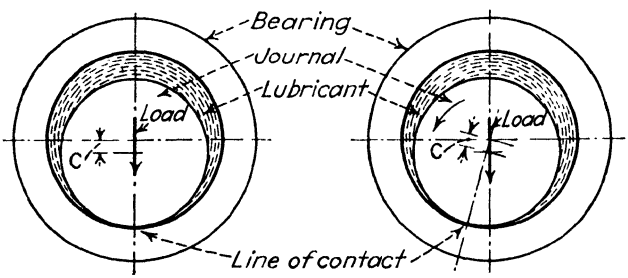


FIG. 74. FIG. 75.

FIG. 74.—Journal at rest, imperfect lubrication.
FIG. 75.—Journal rotating slowly, imperfect lubrication.

short. In such cases, also, the velocity is variable, being zero at the ends of the stroke and a maximum near the center. The velocity near the ends of the stroke is probably not sufficient to form an oil film. Low velocity coupled with a short time period is obviously not conducive to the formation of an oil film. On the other hand, high velocity and continuous motion in one direction are favorable to formation of thick oil films.

When a journal is at rest, the oil film between it and the bearing is virtually squeezed from the surfaces, as in Fig. 74, and the load is sustained mainly by the metallic surfaces of the bearing instead of by the oil film. As the journal starts to rotate, it rolls up on the bearing surfaces in a direction opposite to that of rotation, as in Fig. 75. As the speed increases, oil is drawn, because of its viscosity, around underneath it, and, as previously explained, an oil-film pressure is created that lifts the journal and tends to

center it in the bearing, as in Fig. 76. If the speed is further increased, the pressure in the oil film becomes greater and the resultant film pressure acting upward and to the right, as in Fig. 77, forces the journal to the right until all forces are in equilibrium.

Viscosity is the chief property of an oil to be considered in the formation of oil films. It is viscosity that determines the viscous drag which is responsible for the "pumping" of the oil between the surfaces. Other things being equal, the slower the motion, the higher must be the viscosity in order to create a complete film. Without motion, oil films cannot be formed or maintained, even though the edges are correctly beveled or chamfered.

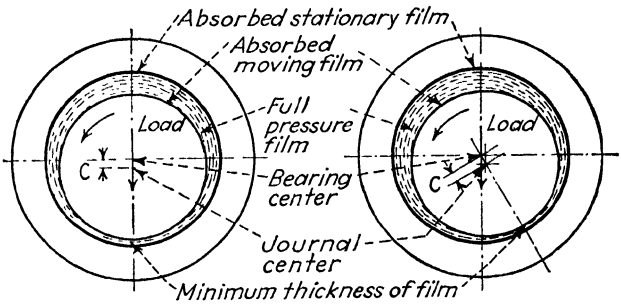


FIG. 76. FIG. 77.

FIG. 76.—Journal rotating at moderate speed, perfect lubrication.
FIG. 77.—Journal rotating at high speed, perfect lubrication.

In all cases, it is necessary to supply a sufficient quantity of oil to compensate for that lost through end leakage, if a complete film is to be established and maintained. Moreover, it is necessary that it should be supplied at a point where the film pressure is low, *i.e.*, on the unloaded side of the bearing. It is necessary, also, that adequate distributing grooves should be provided to assist in spreading the oil over the bearing surfaces, especially in an axial direction.

Regardless of the velocity of rubbing, method of application, grooving and chamfering of the edges, and viscosity of the oil, the load may be so high that the formation of an oil film is impossible. Other things being equal, the greater the load, the higher must be the viscosity of the oil to resist the squeezing-out effect. The manner in which the load is applied is also of importance. Shock loads tend to rupture oil films to a greater extent than steady ones, and intermittent loads are favorable to oil-film formation if they are applied gradually. For example, the eccentric bearing

of a punch press is usually designed for a load of 5000 to 6000 lb. per sq. in. of projected area. This load is applied only for a part of a revolution and, hence, for a very short period of time, and during the remainder of the revolution an opportunity is afforded for the film to re-form if broken.

17. Oil Grooves.—The sole object of oil grooves is to aid in the ready formation and maintenance of oil films over bearing surfaces. It follows that an oil groove that performs these simple duties is correct. On the other hand, any oil groove that tends to conduct oil away from the high-pressure area or that destroys the continuity of the oil film is incorrect. These fundamental principles offer a positive guide to correct oil-groove designing.

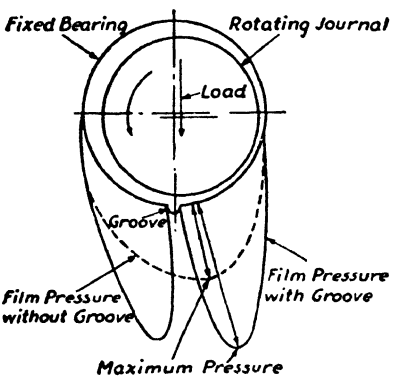


FIG. 78. Effect of oil groove in high-pressure area of a perfectly lubricated bearing.

The grooving of bearings has always been a greatly abused practice, as to both their design and location. The location is often such that the groove defeats the very purpose for which it was intended by draining the oil from the high-pressure area. As has been pointed out, the maximum oil-film pressure is many times greater than the average bearing pressure. Film pressures as high as 30,000 lb. per sq. in. have been attained when the bearing pressure was only 275 lb. per sq. in. Such a disparity in pressures, though unusual, emphasizes the folly of cutting a groove in the high-pressure area.

If the bearing load is assumed to be constant, the extent to which the film pressure may be increased by cutting an oil groove in the high-pressure area of a perfectly lubricated bearing is shown in Fig. 78. The film under the grooved condition is reduced in thickness, and the pressure may be sufficient to cause film breakdown. Thus, cutting grooves in bearings indiscriminately not only may drain the oil from the point where it is most needed but also may result in bearing failure.

The essential factors to be considered in designing oil grooves are bearing size, periphery of journal, bearing load, and method

of lubrication. Upon these factors depends whether or not perfect or imperfect lubrication prevails.

The length of a bearing is of greater importance than its diameter, for it is difficult to secure complete axial distribution of the

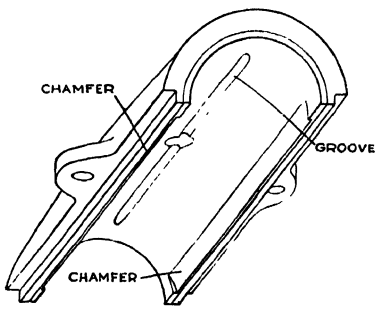


FIG. 79.—Proper method of chamfering and grooving a two-part bearing. (*Courtesy Socony-Vacuum Oil Co.*)

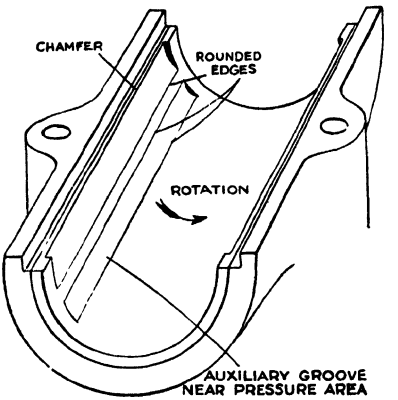


FIG. 80.—Correct grooving for slow speeds and heavy loads. (*Courtesy Socony-Vacuum Oil Co.*)

oil in long bearings. One-part bearings 8 in. and more in length should have more than one oil-inlet hole. Such holes should be connected, if perfect lubrication prevails, by a straight axial groove extending to within a short distance of the ends. Under no circumstances should such a groove be cut to the ends of the bearings.

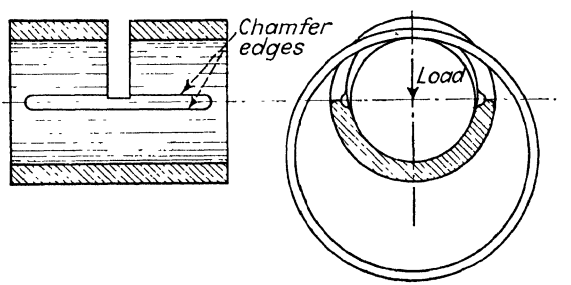


FIG. 81.—Correct grooving for a ring-oiled bearing.

Grooving is little influenced by bearing diameter, except as diameter affects speed, which should be considered as periphery velocity and not r.p.m., as it is the former and not the latter that draws oil into the clearance space.

Where surface speed is low and pressure is high, the oil wedge cannot readily form. If, however, the surface speed is above 25 ft. per min. and the bearing is grooved and the edges chamfered, as in Fig. 79, a film will generally form. For slow-speed heavily loaded bearings, grooving, as in Fig. 80, is recommended. Care should be taken to locate the groove about 30 deg. ahead of the high-pressure area.

The lubrication of any bearing is influenced by the method of application. Bath, ring, splash, and circulation oiling provide a copious supply of oil. For these methods, a straight axial groove cut through the oil-inlet hole, located in the low-pressure

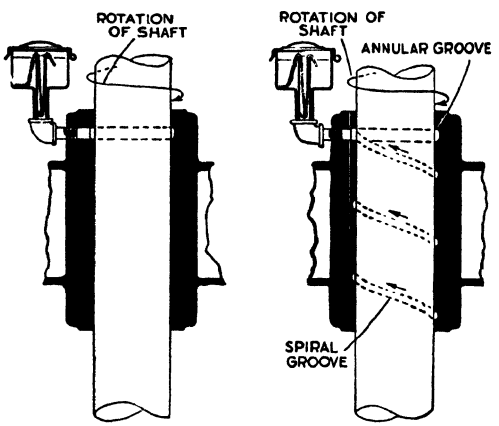


FIG. 82.—Suggested grooving for vertical bearings. Most vertical bearings do not require grooving. Sometimes an annular groove (left) is desirable; in a few cases a spiral groove (right) cut in the proper direction may be desirable to minimize leakage. (*Courtesy Socony-Vacuum Oil Co.*)

area of the bearing, generally fulfills all requirements. Correct grooving for ring-oiled bearings is shown in Fig. 81.

Where drop-feed, wick-feed, and hand oiling are employed, provision should be made for storing in the bearing sufficient oil to supply the bearing between applications. Chamfering the edges at the parting line is usually sufficient for this purpose and at the same time favors the introduction of the oil into the high-pressure area.

Chamfering is the beveling or cutting away of the inner edge of each bearing half at the parting line, the sharp corners being thus removed and wedge-shaped reservoirs provided. Chamfers

should not, as a general rule, extend the full length of the bearing but should stop short, as in Fig. 79.

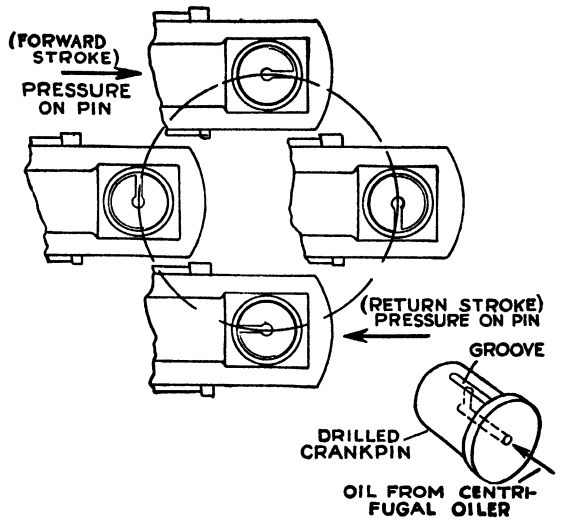


FIG. 83.—Correct grooving for a crankpin bearing. (*Courtesy Socony-Vacuum Oil Co.*)

For satisfactory operation, it is necessary that the cross section of the oil groove should be correct, as indicated in Fig. 86. Deep,

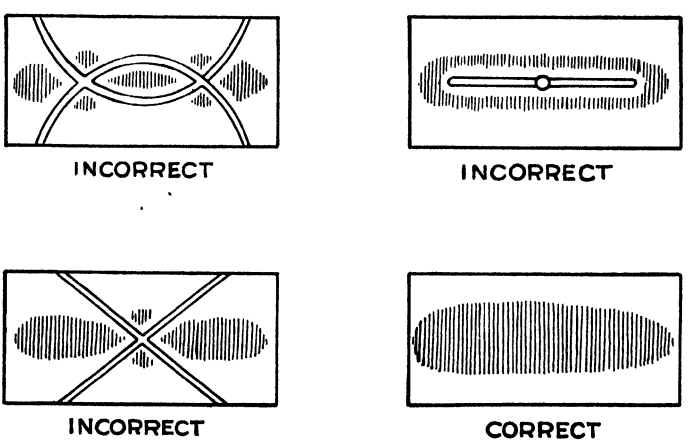


FIG. 84.—Grooving in the pressure area of a bearing increases the oil-film pressure. (*Courtesy Socony-Vacuum Oil Co.*)

vertical-sided grooves will act as oil scrapers, removing the oil and breaking the film. Comparatively shallow grooves, with

well-rounded or beveled edges, are most effective in distributing the oil. V grooving is objectionable because it may start a crack in the bearing lining; moreover, its capacity is less than that of a

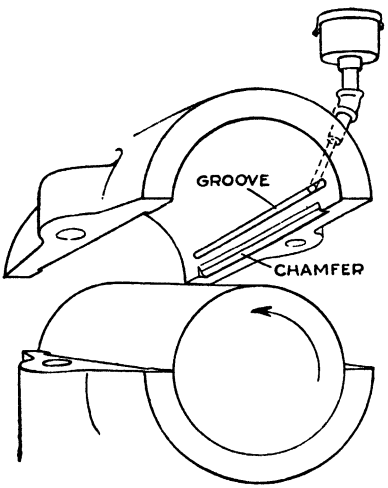


FIG. 85.—Correct grooving for bearing supporting load on the top half. (*Courtesy Socony-Vacuum Oil Co.*)

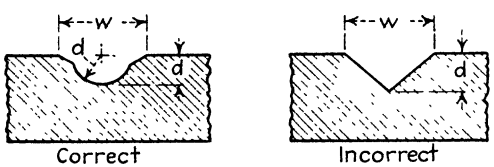


FIG. 86.—Correct and incorrect types of oil grooves.

round-bottom groove of the same width. Given in Table XXI are dimensions for the correct type of groove, shown in Fig. 86.

TABLE XXI.—DIMENSIONS OF OIL GROOVES
(Inches)

Bearing diameter	Width w	Depth d
½–1	9/64	3/64
1 –1½	3/16	1/16
1½–2½	9/32	3/32
2½–4	3/8	1/8
4 –5½	9/16	3/16

CHAPTER IX

LUBRICATING APPLIANCES AND SYSTEMS

Considerable care is generally exercised in selecting suitable lubricants for most machinery; but, often, too little attention is given to the design, selection, installation, and maintenance of the lubricating appliances and systems. Yet correct lubrication depends as much on the lubricating appliances and system as it does on the lubricant. Regardless of the quality and suitability of a lubricant for a particular service, efficient and trouble-free lubrication is unattainable unless the lubricant is unfailingly supplied at all times to the right points in proportion to the demand.

1. Essentials.—Some lubricating appliances are simple, having only a few moving parts; others have a multiplicity of parts with automatic alarms that show a light or ring a bell should lubrication fail or the bearing temperature become excessive. Regardless of the design and purpose, the following essentials should be considered in selection:

Reliability.—Should the lubricant supply stop, even momentarily, serious damage may result. Moreover, production will be reduced, and the cost of the reduction will generally far exceed that of repairing the machine. Bearing failure on a single machine will often disrupt production of an entire department and, sometimes, of the whole plant. Therefore, reliability is a first consideration when selecting a lubricating system.

Automaticity.—The appliance or system should start and stop supplying lubricant automatically when the machine is started and stopped. This feature is highly desirable and eliminates the uncertain human element. Neglecting to start feeding lubricant when the machine is started usually results in burned-out bearings, damaged gears, etc., entailing a shutdown, costly repairs, and time out of service. Forgetting to stop the lubricant feed when a machine is stopped causes a waste of lubricant, creates an unsightly mess and a fire hazard, and requires added labor cost for cleaning the machine and refilling the appliance.

Accessibility.—In spite of precautions to prevent ingress of dust and dirt, all lubricating appliances and systems require cleaning at times. Too frequently, lubricating containers, such as drums, cans, and tanks, are left open or partly uncovered; consequently, dust, dirt, water, and other impurities get into the lubricant and lubricating system. Few if any lubricating systems are completely enclosed. A considerable quantity of atmospheric dust and dirt may get into them through vents, breather pipes, etc., especially if the machine is in dirty surroundings. All lubricants, regardless of initial purity, oxidize to some extent in service, causing a deposit, commonly called *sludge*. Sludge may have a liverlike appearance, or it may be a dry-punk deposit. It may clog oilholes, passages, grooves, feed-control valves, and other parts and must occasionally be removed to avoid trouble. Accessibility for both cleaning and repairing is therefore highly desirable in any lubricating device.

Close Feed Regulation.—This characteristic is desirable in order to obtain proper rate of feed. Overlubrication may be as serious as underlubrication. It has been stated that, with antifriction bearings, overlubrication causes more failures than any other single item. Air compressors are likewise sensitive to overlubrication. In other instances, the excess lubricant is thrown onto belts and electrical equipment, thus damaging them. In food-preparation establishments and textile mills, overlubrication often causes damage to the product.

Feed Proportion to Demand.—In general, if the speed of a machine increases, so should the rate of supplying lubricant. High speed produces an increase in the lubricating-film pressure, which increases end leakage. Not only is a change in the rate of feed desirable from a lubrication standpoint, but also the lubricant may act as a coolant; in such cases, an increased feed is required for cooling purposes when speed increases. In many lubricating appliances, the rate of feed increases too rapidly with temperature, because of reduction in lubricant viscosity with temperature rise. In some designs, an attempt is made to compensate for temperature variations, but usually the rate of feed from such appliances depends on temperature fluctuation and not on temperature head.

Many variable-speed machines drive their own lubricating appliance. When machine speed increases or decreases, the lubricator automatically supplies more or less lubricant.

Easily Refilled.—In many lubricating devices, the filling hole is too small, causing oil to be spilled when the lubricator is being filled. Filling holes should be large and easily accessible.

Reasonably Priced.—It is seldom profitable to purchase lubricating appliances and systems solely on a first-cost basis. Maintenance costs of both the device and the machine and the effect of a forced shutdown should be given first consideration. If operation of a department depends on a particular machine, then a few dollars saved on the purchase of a lubricating device may result in an expenditure far in excess of the original saving.

Probably not any one appliance or system possesses all of the seven features outlined. Obviously, some may be of little consequence for certain applications and others of prime importance. A careful analysis of the lubricating requirements of the machine should be made; then the system that fulfills the needs to the greatest degree should be used.

In some cases, it is necessary to install different systems on the same machine when operated under different conditions. In many instances, machines are equipped, not with one system only, but with a combination of two or more systems. For example, internal parts of a machine may be provided with a splash, bath, or circulating system, and external parts lubricated with drop- or wick-feed oilers. Also, it is not unusual for certain parts of a machine to be lubricated with grease while, at the same time, other parts are oil-lubricated.

2. Classification.—Lubricating appliances and systems may be broadly divided into: (*a*) oiling appliances and systems and (*b*) greasing appliances and systems.

OILING APPLIANCES AND SYSTEMS

Oiling appliances and systems are of many and varied designs; for discussion, they are classified in Tables XXII and XXIII. In Table XXII the term *automatic* means that the lubrication system starts and stops feeding oil to the bearing as the machine starts and stops. *Nonautomatic* means that it is necessary to start and stop the appliance or system independent of the machine. Only appliances and systems in which oil is used over and over are considered efficient.

Systems and appliances in which oil-level and temperature variations cause an appreciable change in the rate of feed are not considered regular-feed devices. Hand and drop-feed oiling

are not considered reliable because of the human element involved in the former and the tendency of the drop-feed needle valve to become clogged.

Positive systems feed are those that feed by other means than gravity and capillary action of a wick. In general, systems in

TABLE XXII.—TYPES OF OILING SYSTEMS

System	Type of service	Characteristics
Hand oiling	Low-speed bearings, open gears, chains, wire rope, hoists, farm machinery, and other relatively cheap and rough machinery	Nonautomatic, unreliable, inefficient, and irregular. Cost low but maintenance cost usually high
Drop-feed oiling	Plain and antifriction bearings, chains, gears, etc. Commonly used on steam engines, air and refrigerating compressors, internal-combustion engines, machine tools, etc.	Usually, nonautomatic, unreliable, irregular, inefficient, adjustable to a certain degree, relatively cheap
Wick-feed oiling	Paper mills, rubber mills, cement mills, woodworking plants, ceramic machinery, railway-truck axles, small electric motors, general bearings, etc.	Nonautomatic, except the bottom-feed type, irregular, reliable, adjustable, moderately efficient, and relatively cheap
Bottle oiling	Plain horizontal bearings of small- and medium-size machine tools, shaft bearings of cotton, silk, rayon, and woolen mills; conveyor-shaft bearings, blowers, electric motors, etc.	Automatic, adjustable, reliable, and moderately efficient. Relatively cheap, limited application
Ring, chain, and collar oiling.	Electric motors, fans, blowers, centrifugal and rotary pumps, steam engines, compressors, line-shaft bearings, etc.	Automatic, reliable, efficient, not suitable for very low- and high-speed bearings. Only applicable to horizontal bearings
Bath oiling	Enclosed gears, chains, wire ropes, plain and antifriction bearings, thrust bearings, etc.	Automatic, reliable, efficient, regular, limited application, requires oiltight housing, first cost high
Splash oiling	Bearings grouped in oiltight housing, enclosed gears of all types, internal-combustion engines, compressors, steam engines, etc.	Automatic, efficient, reliable, regular, if oil is kept at correct level, requires high-grade oil, first cost high
Centralized oiling	Machine tools; steel, paper, and rubber mills; woodworking machinery, etc.	Generally, automatic and positive. May be built integral with machine. First cost relatively high
Circulating oiling	High-speed, heavily loaded bearings, high-grade gearing of all types, machine tools; steel, rubber, and textile mills; paper-mill machinery. Steam turbines, engines, compressors, fans, blowers, etc.	Usually, automatic, reliable, adjustable, efficient, wide range of application. Usually complex and first cost high

TABLE XXIII.—LUBRICATING APPLIANCES

1. Hand-operated squirt oilers
   - Push bottom
   - Enclosed pump
2. Drop-feed oilers
   - Single feed
   - Multiple feed
   - Variable level
   - Constant level
   - Hand operated
   - Automatically operated
3. Wick-feed oilers
   - Single feed
   - Multiple feed
   - Variable level
   - Constant level
4. Manually or hand-operated oilers
5. Hydrostatic lubricators
   - Single connection
   - Double connection
6. Bottle oilers
   - Globe body
   - Flat-side body
7. Ring, chain, and collar oilers
8. Mechanical force-feed oilers
   - Ratchet driven
   - Rotary driven
   - Motor driven
   - Single feed
   - Multiple feed
9. Centralized appliances
   - Single-line systems
   - Multiple-line systems
   - Oil systems
   - Grease systems
10. Oil pumps
    - Gear
    - Rotary
    - Centrifugal
    - Plunger
11. Special appliances for:
    - Air-operated tools
    - Silent and roller chains
    - Railroad equipment
    - Wire ropes

which an appreciable pressure is produced by some mechanical device, such as a pump, will force out dirt and any other obstruction that may become lodged in line, regulating valves, etc.

3. Hand Oiling.—Undoubtedly, the oldest method of oiling bearings is by a hand oiler, two designs of which are shown in Figs. 87 and 88. In the push-bottom type, Fig. 87, oil flow from the oiler is accelerated by depressing the springlike bottom. This oiler, which has to be held with the spout vertically downward, or nearly so, is not positive. If dirt obstructs flow through the spout or if oil is very viscous, little if any oil will flow out. Figure 88, an improved design with enclosed pump in which 500 lb. per sq. in. pressure can be developed by the thumb and 1000 lb. per sq. in. by the hand to force oil out of the spout, is more positive and quick acting.

A hand cup oiler, shown in Fig. 89, is specially designed for air-operated tools. This oiler, attached by means of a T fitting to the air line close to the tool, affords a means of measuring amount of oil introduced into the tool.

Hand oiling of a horizontal wire rope is shown in Fig. 90. In general, it is advisable to run the rope through a swab after oil has been applied, thus working oil into the interior of the rope, where it is most needed.

Silent or roller chains can be oiled by a brush, Fig. 91. Both sides of the chain should be oiled. This method is not recommended for high speeds or chains transmitting large horsepower or if the drive is in dirty, dusty surroundings.

There are many covering and closing devices, such as those in Figs. 92 to 94, that prevent dirt and dust from entering bearing

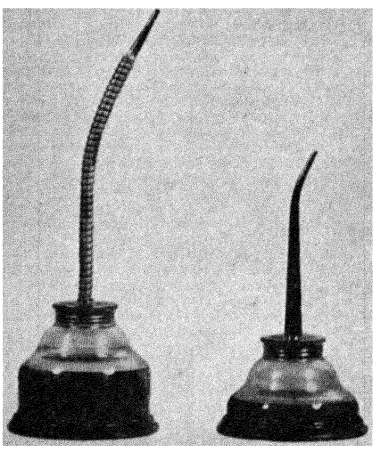


Fig. 87.—Transparent plastic push-bottom oilers.

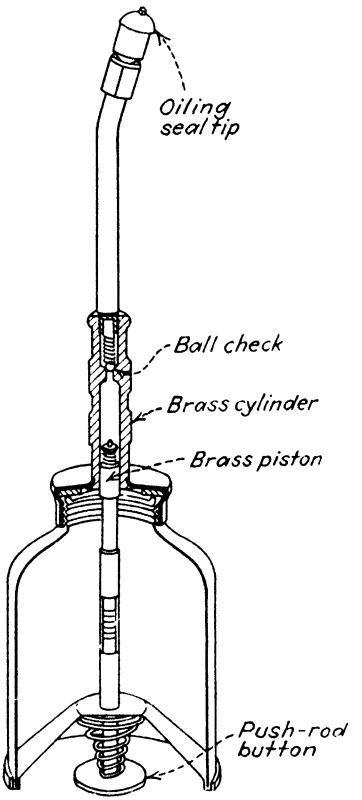


Fig. 88.—Oiler with enclosed pump.

oilholes. These covers are made in a wide variety of designs and shapes and of various materials, steel being most commonly used and brass next. Some have a large reservoir, into which cotton or wool waste is packed; this is then saturated with oil, thereby providing a small reserve supply of oil, which feeds more or less regularly to the bearing over a limited period of time.

Hand-oiled bearings and other machine parts are nearly always over- or underlubricated. The first condition causes waste of oil

and an untidy appearance as well as a fire hazard; underlubrication is a source of excessive wear, friction, and overheating. Con-

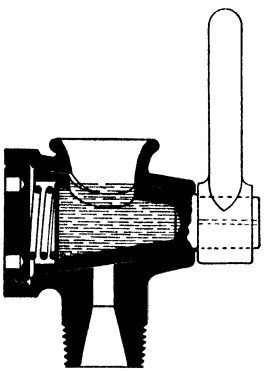


FIG. 89.—Cup oiler for air-operated tools.

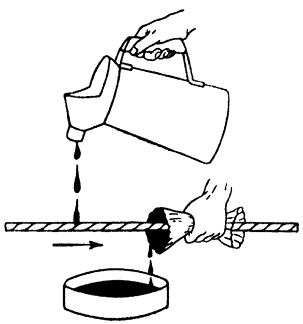


FIG. 90.—Hand oiling a horizontal wire rope.

tinuous and perfect lubrication is practically impossible with hand oiling and is unsatisfactory unless regular and close attention is given by the oiler.

4. Drop-feed Oiling.—Drop-feed oilers have been developed in a wide variety of designs, for use on plain and antifriction bearings, chain drives, and gears. They are commonly found on older steam engines, air and refrigerating compressors, internal-combustion engines, machine tools, etc.

Drop-feed oiling, a decided improvement over hand oiling, is satisfactory under certain operating conditions. Figure 95 shows a common drop-feed oiler, comprising a small

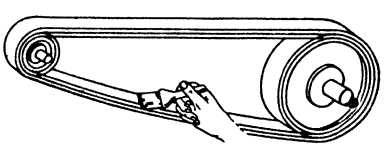


FIG. 91.—Hand oiling a silent or roller chain with grease or oil.

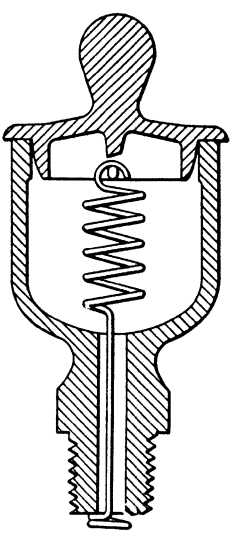


FIG. 92.—Oil cup with cover held in place by coil spring.

cup or reservoir, which supplies oil through an adjustable needle valve to the bearing. A snap lever provides for starting and stopping feed without disturbing rate of feed adjustment. A

so-called *sight feed* permits observing rate of flow. Figure 96 is similar to Fig. 95, except that its body is made of aluminum it being thus suitable for severe service where the usual glass cup

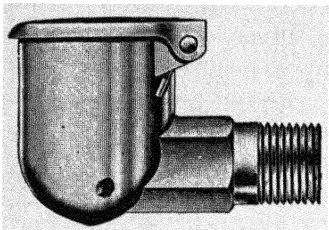


FIG. 93.—Right-angle oil cup with spring cover.

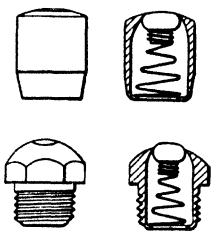


FIG. 94.—Ball-valve covers for oil holes.

might break. It has the disadvantage that oil in the cup is not visible at all times.

A drop-feed oiler designed for air and refrigerating-compressor cylinders is shown in Fig. 97, suitable for pressure up to 1000 lb.

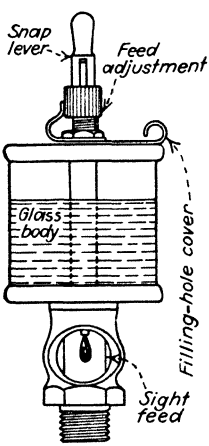


FIG. 95.—Conventional sight drop-feed oiler with glass body.

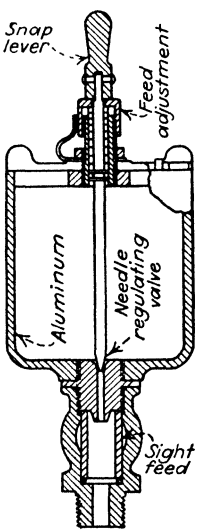


FIG. 96.—Drop-feed oiler with aluminum body for severe service.

per sq. in. By closing valve *B*, the reservoir can be filled without changing feed-regulating valve *C* or without stopping the compressor. Pressure in the oiler is equalized by tube *D*, which

admits full cylinder pressure above the oil. Flow, therefore, is solely due to gravity. These oilers are, however, sometimes referred to as *pressure oilers*. Special baffle diaphragm *E* and the ball check *F* in the shank divert back pressure from the sight-feed chamber and ensure proper formation of oil drops and their regular and clearly visible discharge. These oilers are generally made of bronze for use on air compressors and of iron and steel for refrigerating compressors and pumps handling ammonia or other liquids or gases to which ferrous metals offer high corrosive resistance.

Figure 98 shows one design of oiler for engine crankpins and other bearings having rotary motion. When the bearing is in motion, the oil is thrown against the feed tube and flows through channels *C* and *V* to the bearing. The feed automatically starts and stops when the bearing is started and stopped. The rate of feed is regulated by the adjustable needle valve.

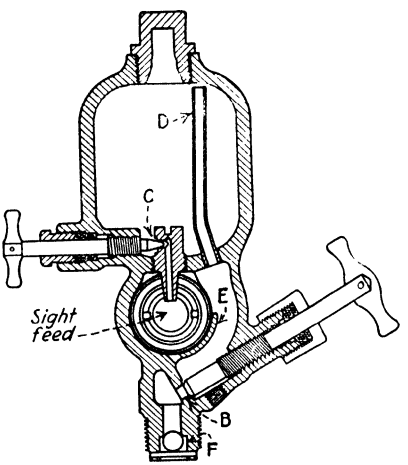


FIG. 97.—Drop-feed oiler for cylinder pressures up to 1000 lb.

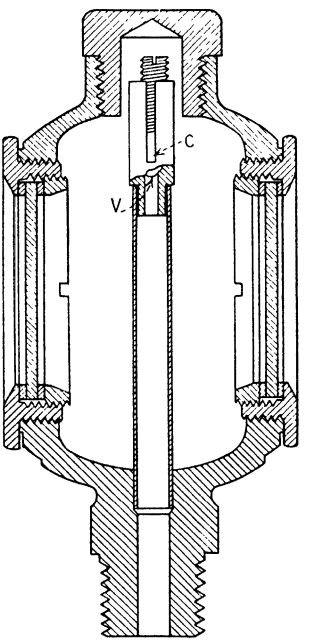


FIG. 98.—Oiler for crankpins and other rotary-motion bearings.

The oiler in Fig. 99 is specially designed for small steam-engine and pump cylinders where pressures do not exceed 200 lb. per sq. in. This type is known as a *down-drop oiler* and is installed directly on the steam chest. By closing steam valve *A*, the

reservoir can be drained and refilled while the engine is operating, without disturbing the feed-regulating valve *B*. The drain valve is not shown. In operation, steam passes through steam valve *A* and flows up through steam tube *C* and down into the water seal, where it is condensed. Condensate then overflows the seal into the reservoir. The oil, being lighter than water, floats to the top and flows through the drilled passages to the feed-regulating valve and thence down through the sight feed into the cylinder.

Figure 100 shows a drop-feed oiler for rotary compressors, vacuum pumps, and ammonia gas boosters. It has a needle valve *V* at the bottom of the oil reservoir, with a stem

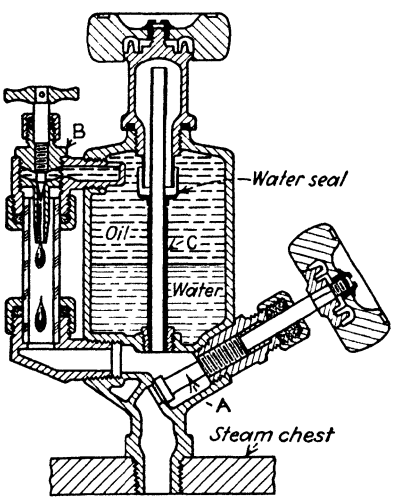


FIG. 99.—Drop-feed oiler for small steam-engine and pump cylinders.

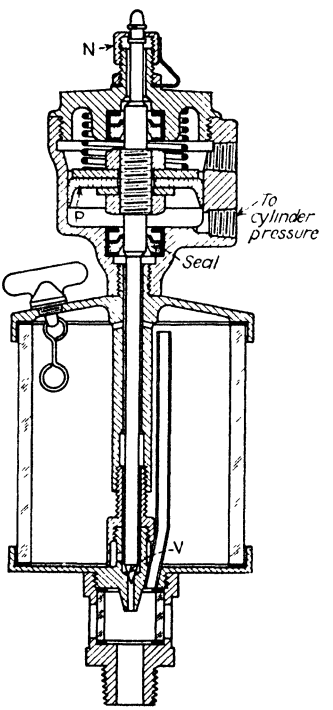


FIG. 100.—Automatic air-operated drop-feed oiler.

extended through the operating cylinder on top of the reservoir, and is opened and closed by pressure from the compressor discharge, exerted under a spring-loaded cup leather piston *P* in the cylinder. The rate of feed is controlled by the knurled feed nut *N* at the top of the stem, which limits the opening of the needle valve. Nut *N* can be used, also, to open the needle valve by hand in case the compressor is operated without pressure on the discharge side. A minimum of 5 lb. pressure is required to

operate the oiler satisfactorily. The seal around the needle-valve stem prevents leakage of air from the cylinder into the oil reservoir. This oiler is automatic since it will operate only when the compressor is running.

An electrically operated, automatic drop-feed oiler is available and is recommended for engines, pumps, and other machinery. The solenoid-operated valve mounted on the steel plunger controls flow of oil automatically. The solenoid valve comprises a coil of wire, enclosed in a cast-iron housing, and, when energized, lifts the steel plunger off its seat, thus permitting oil to flow out of the reservoir, in much the same way as in Fig. 100. When the current is cut off, the plunger falls by gravity to its seat, thus cutting off the flow of oil. Designs are obtainable having 1 to 12 feeds and four reservoir capacities, *viz.*: 1 pt. and 1, 2, and 4 qt.

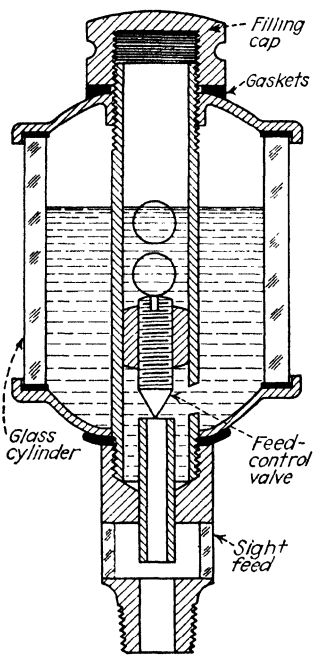


FIG. 101.—Temperature-regulated drop-feed oiler.

The drop-feed oiler shown in Fig. 101 is actuated by variations in temperature that occur in the oil film surrounding the bearing. These temperature variations are transmitted to the air above the oil in the reservoir. Owing to the change in temperature the air expands and contracts, thus forcing oil down through the feed-regulating valve to the bearing. In order to allow for contraction and expansion of air, this oiler should be filled not more than three-fourths full.

One design of drop-feed oiler, which maintains a constant level of oil in the reservoir and is used in conjunction with other methods of oiling, such as ring and bath, is shown in Fig. 102. This oiler operates in the same manner as a simple barometer. Oil feeds only when the level in the bearing reservoir is low enough to break the liquid seal and permit air to enter the oiler.

Shown graphically in Fig. 103 are the results of tests on four conventional drop-feed oilers of the design shown in Fig. 95.

These results show that for oiler 2, the rate of feed varied more than 140 per cent from full level to empty and more than 700 per

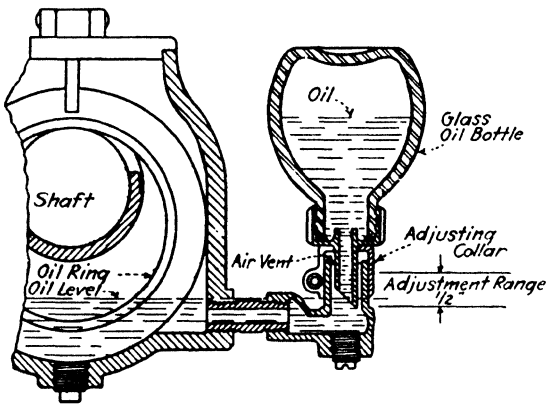


FIG. 102.—Constant-level oiler mounted on ring-oiled bearing.

cent for a temperature change of approximately 50°F. Hence, it may be concluded that temperature changes have a more pronounced effect than oil level or head on the rate of feed. The

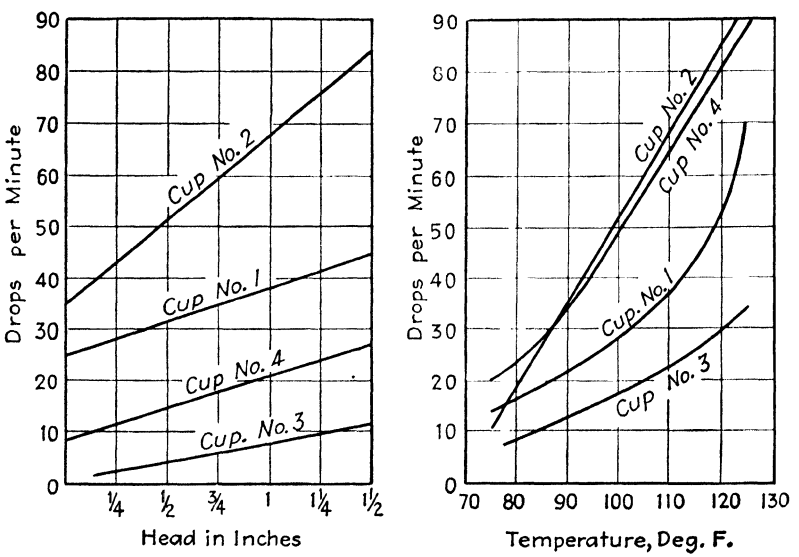


FIG. 103.—Performance curves of drop-feed oilers.

variation in the rate of feed was not the same for all four oilers because of the different flow characteristics of the regulating

valves. Obviously, the feed would have to be adjusted to deliver sufficient oil at the minimum head and temperature encountered in service. This means that the rate of feed for this type of oiler is excessive virtually all of the time.

5. Wick-feed Oiling.—Wick-feed oiling is one of the oldest methods of applying oil to bearings, guides, slides, etc., and is still quite commonly used. Some wick-feed oilers are inefficient and crude; but others, more scientifically designed, give excellent results if correctly applied and maintained.

Wick-feed oilers may be grouped as follows: (*a*) siphon oilers; (*b*) absorbent oilers, or pad oilers; and (*c*) bottom oilers. All of these are similar in that they employ mainly the principle of capillary action, *i.e.*, the absorbent characteristics of a porous material.

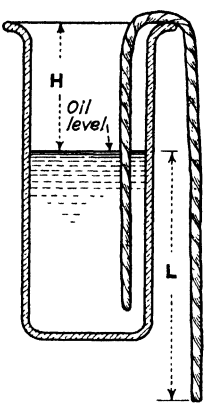


FIG. 104.—Wick-feed testing apparatus.

If one end of a small-bore glass tube is dipped into an oil bath, the oil rises rapidly in the bore above the level of the oil in the bath. The same is true if a drop of oil is placed on a joint between two metal surfaces; the oil is quickly drawn into the joint. Similarly, when a porous material, such as cotton or wool or felt, is dipped into oil, the oil rises and is held in the pores of the material. The wick of a common kerosene lamp and a moistened sponge are familiar examples of capillary action. Capillary action is dependent on the surface tension of the oil and the characteristics and form of the porous material.

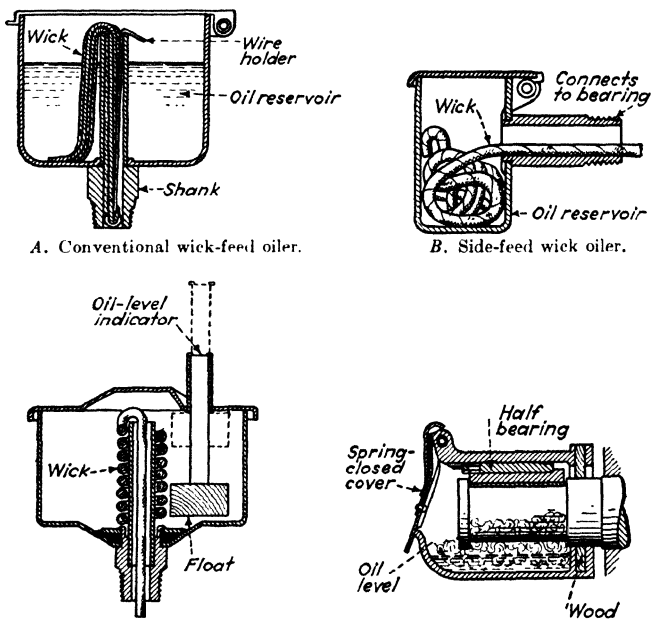
If not properly designed, the siphon oiler is deficient in many of the essential features of a good oiling appliance. This is evident from Table XXIV, which shows results obtained from the simple apparatus, essentially a siphon oiler, shown in Fig. 104.

These data show that when L is less than $\frac{1}{4}$ in. no oil flowed from the lower end of the wick, but that when L is $\frac{1}{4}$ in. the pressure is sufficient to break a drop loose every 40 sec. Increasing L increases the rate of feed until the difference between the oil level and the end of the wick becomes approximately 2 in. Further increasing L has but little effect on the rate of feed. These results clearly show that in order to have a uniform rate of feed the discharge end of the wick should be about 2 in. below the lowest

level of the oil in the reservoir. They also show that the rate of feed decreases very rapidly as H is increased above 2 in.

The results indicate that wick-feed oilers should be wide and shallow and that the end of the wick should be not less than 2 in. below the minimum oil level in the reservoir.

A single-feed siphon oiler is shown at A, Fig. 105. Siphon oilers are the most widely used of all wick-feed oilers and are made in a variety of forms. In general, they consist of an oil



A. Conventional wick-feed oiler. *B*. Side-feed wick oiler.

C. Indicating wick-feed oiler. *D*. Master Car Builders' railway-car bearing.

FIG. 105.—Typical wick-feed oilers.

reservoir having a central tube extending well below the base of the reservoir in the form of a shank, which is screwed either into an oilhole in the bearing or else into a delivery tube leading to the bearing. A wool or cotton stranded wick leads from the reservoir over the edge of the tube and down inside it toward the bearing. The oil is raised to the highest point of the wick by capillary action and then flows downward on the discharge side by a combination of gravity and capillary action.

Some of the older bearings are built with a wick-feed receptacle cast integral with the top half. In general, these receptacles are

TABLE XXIV.—RESULTS OF WICK-FEED OIL TESTS

Height L,* in.	Time between drops, sec.	Height H in.	Time between drops, sec.
4	4.0	⅛	10.0
3	4.0	¼	11.5
2	4.1	½	15.0
1½	4.5	¾	19.0
1	7.3	1	24.0
¾	10.0	1½	36.0
½	17.5	2	65.0
¼	40.0		
Under ¼	No flow		

* See Fig. 104.

too low to permit the discharge end of the wick to be placed as much as 2 in. below the level of the oil in the reservoir.

The effect of oil level on the rate of feed can be eliminated by so designing the oiler that the level remains constant at all times, as in Fig. 106.

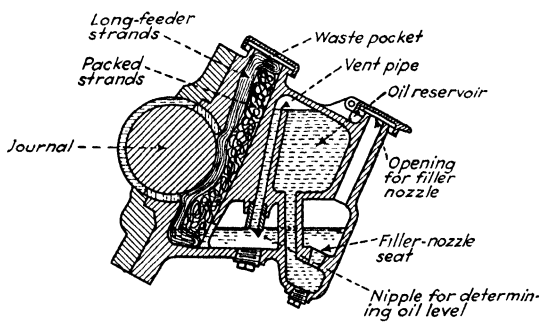


FIG. 106.—Constant-oil-level bearing for railway motor.

A cast-iron wick-feed oiler of the siphon type is shown in Fig. 107. This type of oiler is widely used in marine practice and is frequently called a *marine oiler*. It may have virtually any number of delivery tubes; and, by dividing the reservoir into compartments, different grades and kinds of oil may be supplied. A more modern cast-aluminum multiple wick-feed siphon oiler is shown in Fig. 108. It is equipped with shutoff valves, individual sight feeds, and individual feed-screw adjustments. When the shutoff lever is in the horizontal position, all valves are closed

and no oil feeds. This position of the lever closes the ball checks but permits the wicks to continue to feed oil into the secondary wells. Raising the lever to a 45-deg. position opens all valves more than the normal amount, and the oil in the individual secondary wells runs through and flushes the bearings. The lever may be held in this position until all the secondary wells are empty, or it may be raised quickly, allowing only a small amount of the flushing oil to flow to the bearings. When the shutoff lever is placed in the vertical position, the individual wicks feed

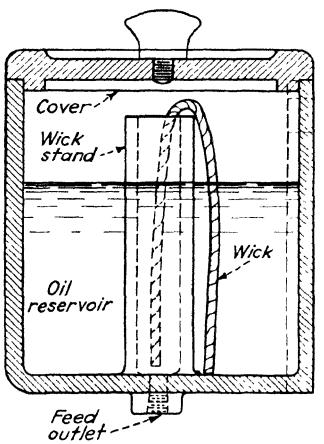


FIG. 107.—Cast-iron wick-feed oiler having six feed outlets.

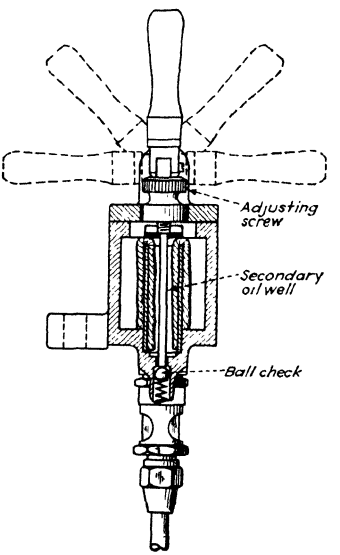


FIG. 108.—Cast aluminum wick-feed oiler.

oil according to the individual screw adjustments. This oiler is obtainable with 3 to 12 feed outlets.

The siphon oiler is not automatic, as it must be started and stopped by hand. Various devices, such as wire holders, shown in Fig. 105*A*, shutoff cocks, etc., are employed for this purpose. The rate of feed may be controlled by changing the number of strands of wicking, by using larger or smaller wicks, by selecting a tightly or loosely twisted wicking, or by means of a screw or some other adjustable device that can be clamped against the wick, thus choking off the oil flow. The last method permits a closer feed regulation than do the other methods; the rate

of feed can be reduced, if desired, to less than that of a single strand of wicking.

The most elementary type of wick-feed oiler is the pad or absorbent oiler, which operates on a combination of capillary and gravity feed action. This is an improvement over hand oiling, but the pad must be renewed frequently or its position changed in order to maintain a reasonably regular supply of oil to the bearing. The rate of feed is a maximum immediately after saturation when the pad is new and rapidly decreases until the pad has drained dry. This oiler has proved to be a very satisfactory means

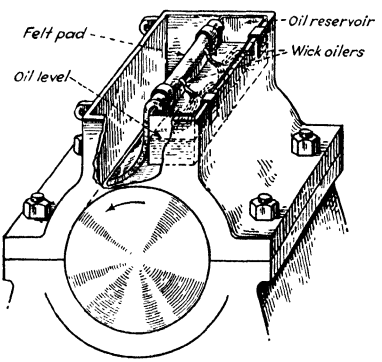


FIG. 109.—Pad or absorbent oiler.

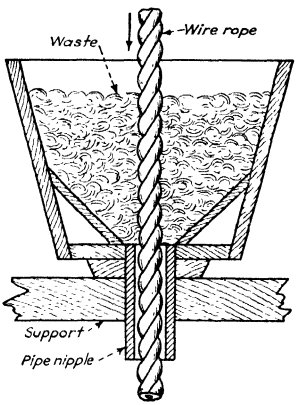


FIG. 110.—Wick-feed oiler for wire rope.

of oiling long, open-type bearings. The rate of feed is regulated by changing the number of wicks, and the felt pad tends to distribute the oil uniformly along the journal. This arrangement has been frequently substituted for grease-lubricated bearings having grease wells in the top half.

A cheap and easily constructed wick-feed oiler suitable for lubricating vertical wire ropes is shown in Fig. 110.

A wick-feed oiler specially designed for air-operated tools is shown in Fig. 111. This oiler is placed, for best results, in the air line about 12 ft. behind the tool. It will operate in any position and with the flow of air from either left or right. The rate of feed is controlled by using bushings having different-size orifices.

Another wick-feed oiler, which may be considered a pad oiler, employs a felt roller that rests directly on the journal and is sup-

plied with oil either by hand application or by drop-feed or siphon oilers. The roller serves to distribute the oil uniformly over the journal.

Bottom wick-feed oilers are quite different from those employing the absorbent pad placed above the journal and from the siphon oilers. In a bottom wick-feed oiler the oil reservoir is located below the journal, and the oil feeds upward to the journal solely by capillary action through wool or cotton waste or wicking pressed against the lower side of the journal. In some cases, specially treated wood plugs are used as wicks.

The bottom wick-feed oiler is automatic. It is one of the most efficient methods of lubrication, as the excess oil drains to the

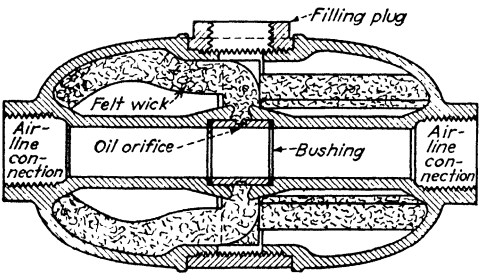


FIG. 111.– Wick-feed oiler for air-operated tools.

reservoir and is re-used. It is very convenient, requiring no attention when starting and stopping the machine and only an occasional replenishing of the oil supply.

In designing bottom wick-feed oilers, it should be remembered that capillary action will lift oil not more than 2 or 3 in.; therefore, the reservoir should be so designed that the oil level is not too low.

This oiler is especially well suited for bearings loaded on the top half. It can be used, however, for bearings carrying a light load on the bottom. In such instances, it is good practice to extend the wick up along the side of the journal, the area of greatest pressure being thus avoided.

Railway-car axle and motor bearings are generally lubricated by means of this type of oiler. The Master Car Builders' bearing is shown in Fig. 105*D*. The oil reservoir in this bearing is packed with absorbent, elastic waste, which is held in contact with the journal by its own elasticity.

Shown in Fig. 112 is a bottom wick-feed oiler applied to a fractional-horsepower motor. The felt wick is held in contact with the journal by the helical spring.

Although waste is sufficiently elastic to hold itself in contact with a journal when properly packed into the bearing, a wick must be held in position by means of a spring. In order to provide lubrication by means of a bottom wick-feed oiler, the absorbent material must at all times make contact with the journal. Wicking materials must possess a high degree of absorbent properties and retain these characteristics over a long period of time. Undoubtedly, the best material for wicks and packing is wool waste, yarn, and felt. Cotton materials are superior in lifting and feeding abilities, but they glaze or harden readily and have no inherent elasticity; consequently, contact with the journal is easily destroyed by vibration or jarring. Waste for packing should be clean and long-fiber wool yarn. In general, the strands should be not less than 18 in. or more than 30 in. long. For siphon oilers, Germantown or Berlin wool yarn is very satisfactory in most cases. Spanish wool yarn is very satisfactory for conditions that require a small feed and close regulation; one strand of it will feed about one-fourth as much as a strand of the Germantown or Berlin yarn. Wick strands should not be twisted together unless it is desired to reduce the rate of feed. Wool yarn lightly twisted may feed only one-third or one-fourth as fast as when loose.

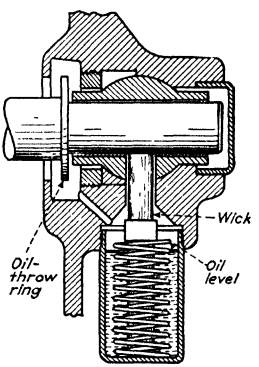


FIG. 112.—Bottom wick-feed oiler.

Wire-cored wicking is available and retains its form for a longer period of time than other wicking.

Stiff wool-felt wicking is generally used for bottom wick-feed oilers; it should be of the correct size and length.

All wicking and packing materials should be replaced or cleaned periodically; the time before cleaning or replacing is necessary will depend on surrounding atmospheric conditions and the protection offered by the housing and cover of the oiler against ingress of dust and dirt. Waste packing should, as the occasion warrants, be loosened so as to bring fresh waste in

contact with the journal, the hardening and glazing conditions that are gradually brought about by contact with a rotating journal being thus avoided. Gasoline and kerosene are suitable for washing and reconditioning wicks, pads, waste, etc.

Generally, a single point of feed is sufficient for bearings not over 8 in. long, and one additional feed for each additional 8 in. or fraction thereof. Bearings subject to severe vibration present some difficulty in mounting wick-feed oilers. In such cases the oiler should be mounted on a bracket independent of the bearing and connecting it to the bearing by means of flexible tubing or piping.

Though any sort of absorbent material acts as a filter and will ensure that the oil passed to the bearing is relatively clean, yet it is important to keep the oil clean in handling and avoid the presence of moisture, dust, dirt, etc., in the oil reservoir, thus guarding against wicking clogged by water and other impurities. Consequently, all wick-feed oilers should be provided with tight dustproof covers, and other precautions should be taken to exclude all impurities from the oiler.

The first cost of waste and yarn should not be given first consideration. The use of good-quality absorbent materials permits reclamation and more economical lubrication. The use of inferior waste and yarn that cannot be used repeatedly and the failure to recover oil from old packing are a common source of loss where the selection of the material has not been given proper consideration.

6. Bottle Oiling.—Bottle oilers, as shown in Figs. 113 to 115, comprise an inverted oil-reservoir bottle with threaded neck, a base with integral shank, and a steel or brass feed spindle. In Fig. 113, the bottle oiler is supported on the bearing cap so that the lower end of the spindle rests on the journal. As the journal revolves, the bearing becomes warm and heat is transmitted through the spindle to the air above the oil in the bottle. This heat causes the air to expand, which, with an almost imperceptible pumping action of the feed spindle, forces oil to creep slowly down the spindle to the bearing.

A special design of bottle oiler for loose pulleys is shown in Fig. 114. As the pulley revolves, oil is thrown outward by centrifugal force. Feeding depends on periodic expansion and contraction of air within the bottle. A rise in temperature causes

the air to expand, thus forcing out a small quantity of oil. A subsequent drop in temperature causes the air to contract, permitting additional air to come into the bottle through the tube and replace the oil previously forced out by expansion of air. To provide air space, this oiler should be filled not more than three-quarters full of oil.

When bottle oilers are attached to bearings by pipe threads, the design of Fig. 115 is commonly used. This type is used on grinders and other machine tools where dust, chips, and other impurities are likely to get into the bearing through the connection.

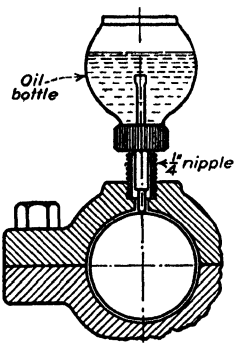


FIG. 113.—Typical bottle oiler.

The glass bottle permits the amount of oil in the bottle to be readily observed; when the bottle becomes empty, it may be removed and replaced with a full one. Where a large number of these oilers are used, spare bottles may be filled in the oil room and carried in a basket or tray to the bearings, the waste incident to

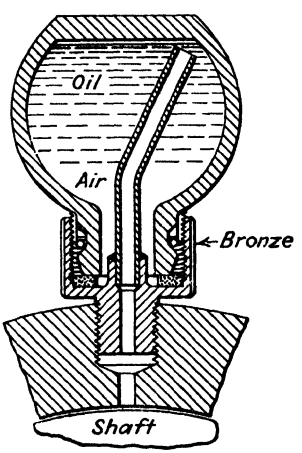


FIG. 114.—Special bottle oiler for loose pulleys.

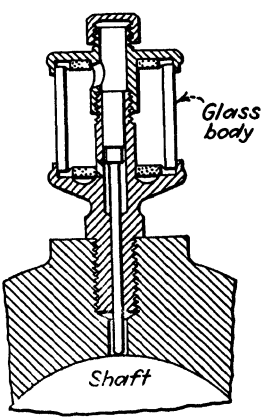


FIG. 115.—Screwed-shank bottle oiler.

filling and the possibility of impurities entering the oil during refilling being thus eliminated.

Table XXV may be used for determining the number of bottle oilers required for bearings of various dimensions; but it should

be used only as a guide as it is necessary to consider load, speed, operating temperature, and sometimes other factors, when the number of oilers required for a bearing is being decided upon.

The application of bottle oilers is limited to horizontal or nearly horizontal bearings and to locations where glass reservoirs are not exposed to danger of breakage. Nor are they satisfactory for bearings subject to wide temperature variations or for rapidly moving parts, such as crankpins and crossheads. Although they are automatic, yet they are not entirely foolproof. The clearance between the feed spindle and the bore of the shank must be adjusted to suit the viscosity of the oil used. Also, the spindle and bore of the shank should be occasionally cleaned to ensure the correct feed.

TABLE XXV.—BOTTLE OILERS FOR DIFFERENT-SIZE BEARINGS

Bearing dimensions, in.		Oilers required
Length	Diameter	
Less than 6	Less than 3	1
Less than 6	3–6	2
6–10	Less than 6	2
6–10	More than 6	3 or 4

Bottle oilers are widely used in paper, rubber, cement, and flour mills and on equipment such as blowers, grinders, line shafting, and shoe and textile machinery.

7. Ring, Chain, and Collar Oiling.—Ring, chain, and collar oiling are extensively used on horizontal bearings, such as line shafts, electric motors and generators, small steam turbines, centrifugal pumps, main bearings of internal-combustion and steam engines, air compressors, and refrigerating machines.

Figure 116 shows a typical oil-ring bearing commonly used on electric motors. It comprises a housing, the bottom of which forms an oil reservoir, a ring which rides on and turns with the journal, and the bearing. A slot in the top of the bearing permits the ring to ride on the journal. The ring rotating with the journal carries oil up to the top of the bearing, where it is distributed, by oil grooves and channels, over the bearing length. Any oil that drops or is thrown off the ring or is squeezed from the ends of the bearing returns to the reservoir and is re-used. Oil

seals and slingers prevent leakage, and the guard prevents the ring from becoming displaced. An oil-ring bearing is, in effect, a self-contained, compact, automatic, circulating oiling system

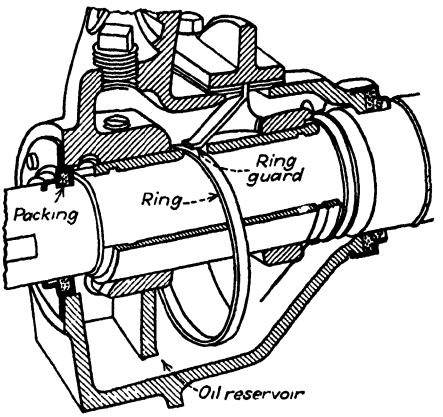


FIG. 116.—Oil ring applied to an electric motor bearing.

that requires very little attention. Where high-temperature conditions are encountered, the oil reservoir sometimes has a water-cooling system, as in Fig. 117.

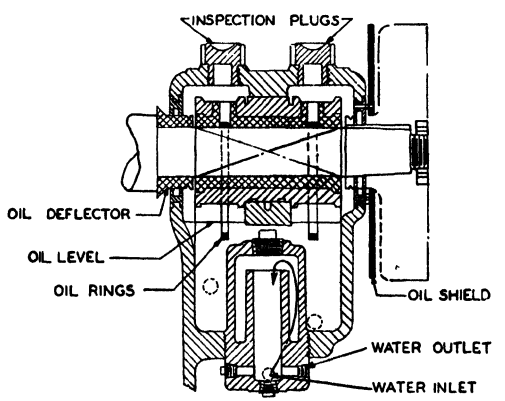


FIG. 117.—Water-cooled ring-oiled bearing of a steam turbine.

Oil-ring bearings are frequently employed in conjunction with circulating systems, the oil being continuously fed to the reservoir by an oil pump. An overflow on the reservoir ensures correct oil level at all times.

Figure 118 shows an oil ring lubricating a silent-chain drive. The ring dips into oil contained in the enclosing case and delivers it to a cup, from which it drains through a pipe onto the chain.

Oil rings of many cross-sectional forms are used, some of which are shown in Fig. 119. The types shown at *F* and *G* have greater oil-carrying capacity than the others. The type *F* ring has a

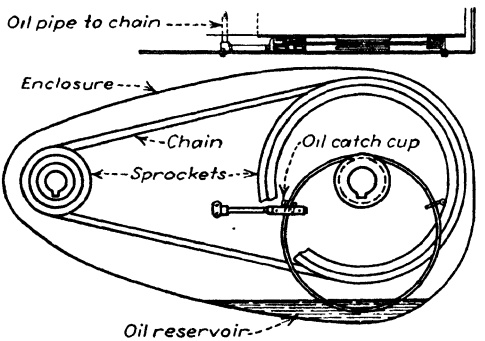


FIG. 118.—Ring oiler applied to silent-chain drive.

cross section like a hat with the brim riding on the shaft. Because of its wider contact with the shaft and the slots on its inner periphery, the ring has low slippage on the shaft and high oil-carrying capacity. The laminated ring *G* has been used successfully on large bearings where large oil-carrying capacity is required. In operation, the laminations tend to separate and

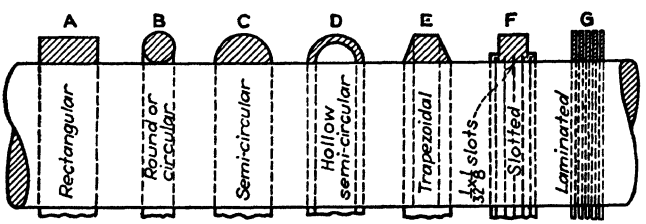


FIG. 119.—Oil rings of various cross sections.

fill in between with oil to be carried up to the top of the bearing, which gives the ring a much larger oil-carrying capacity than have those of conventional cross section.

Experience has shown that rings can be depended on generally to supply adequate oil for 4 in. either side of the ring. Thus, bearings more than 8 in. long should have two or more rings. Usual practice is to make the diameter of the ring approximately

twice the diameter of the shaft or a little less. One-piece rings are preferable to multipiece designs, which are more likely to foul because of the joints. In any case, the ring should be as smooth and round as possible, for rough and distorted rings are likely to stick.

Oil-ring bearings are not satisfactory for low and extremely high speeds. At low speeds the ring does not rotate sufficiently fast to deliver the required amount of oil; at very high speeds, the ring slippage may be excessive, or else the oil is thrown off the ring by centrifugal force. In either case the ring will not supply the requisite amount of oil. Shafts from 1 to 2 in. in diameter have been satisfactorily lubricated by means of rings when

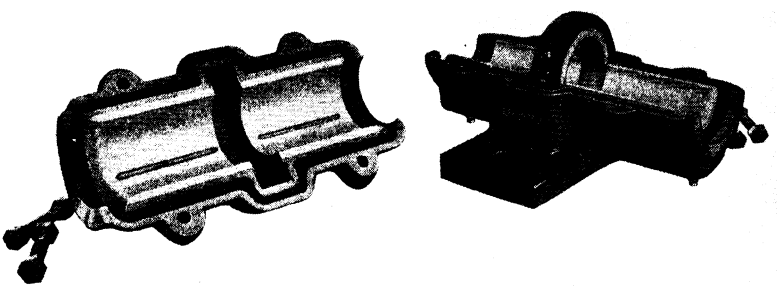


FIG. 120.— Collar-oiled lineshaft bearing. (*Courtesy Link-Belt Co.*)

rotating as high as 3600 r.p.m. A 4-in. shaft, however, could not be lubricated by this method at such high speed.

For large slow-speed bearings an endless chain has proved very satisfactory, as a flexible chain with many joints has a greater oil-carrying capacity than solid rings. Chains are not suitable, however, for high speeds, for centrifugal force tends to cause the chain to form a circle, thus reducing the arc of contact between the chain and shaft. At high speeds, also, the chain is likely to be thrown against the housing and be broken. Chains are more susceptible to breakage than rings and not so reliable. Moreover, chains at high speeds tend to churn the oil and thus cause foaming and leakage.

On oil-collar-lubricated bearings, the collar is rigidly fixed to the shaft and divides the bearing into two parts, as in Fig. 120. Such bearings are especially suitable for low speeds and heavy-

bodied oils. Sometimes the collar is forged integral with the shaft, but more frequently it is split and clamped to the shaft for easy removal. Oil-collar bearings are generally provided with scrapers at the top that remove the oil from the collar and divert

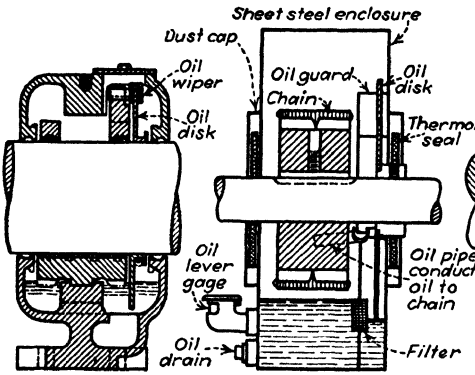


FIG. 121.

FIG. 122.

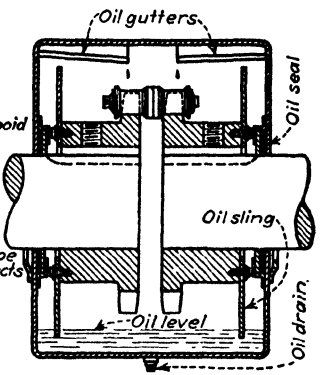


FIG. 123.

FIG. 121.—Disk oiler applied to propeller shaft.

FIG. 122.—Disk oiler provided with automatic-level device applied to silent-chain drive.

FIG. 123.—Disk oiler applied to roller-chain type of coupling.

it into grooves. The collar will, to a certain extent, maintain axial alignment of the shaft but cannot be expected to carry any appreciable amount of the end thrust.

Although the oiler, shown in Fig. 121, is commonly spoken of as a *disk oiler*, it is in effect a collar oiler. Figure 122 shows a similarly designed oiler for a silent-chain drive. In this type, provision is made to maintain constant oil level at all times. Two specially designed oilers are shown in Figs. 123 and 124. The former is applied to a roller-chain flexible coupling and the latter to a silent-chain drive. In both cases, oil is thrown from the oiler by centrifugal force and directed to drop onto the chain.

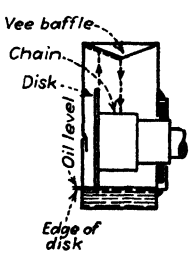


FIG. 124.—Collar oiler applied to silent chain.

In all cases, it is important to maintain correct oil level in the reservoirs of ring-, chain- and collar-oiled bearings. The reservoir should be ample enough to allow the oil sufficient time to cool before re-use and of sufficient depth to permit impurities to settle out. A common mistake is to equip bearings with reservoirs of

too small capacity. The housing should always be provided with an inspection plug or port and a drain plug at the lowest point in the reservoir. Drain the reservoir, and refill with fresh oil periodically if the surroundings are extremely dusty. If the bearing housing is not dustproof, draining may be required every 3 months or oftener.

Ring, chain, and collar oilers cannot be used except in horizontal bearings, which support the load on the bottom half. Nor can they be used on bearings of mobile equipment or equipment subject to severe vibration.

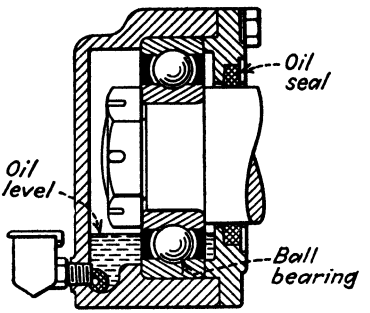


FIG. 125.—Bath-oiled ball bearing.

8. Bath Oiling.—Machine tools, textile machines, and many other machines operate with their feed-transmission gears partly immersed in an oil bath contained in an oiltight housing. Bath oiling is also employed for various bearings, such as step, suspension, spindle, and thrust.

Bath oiling is limited to design conditions that easily and economically permit the construction of oiltight reservoirs. From the standpoint of operation and maintenance, it is quite

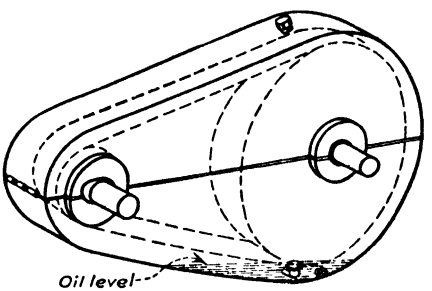


FIG. 126.—Bath-oiled silent-chain drive.

essential that a correct oil level should be maintained at all times. Too much oil causes excessive churning and agitation, resulting in excessive heat and power losses, oil leakage, and deterioration. The installation of a constant-oil-level device is highly desirable in all cases.

Figure 125 shows a typical bath-oiled ball bearing. This method is applicable to slow- and moderate-speed antifriction

bearings. Oil level should be just sufficient to cover the balls in their lowest position. The wick-feed cup protects this bearing from overfilling.

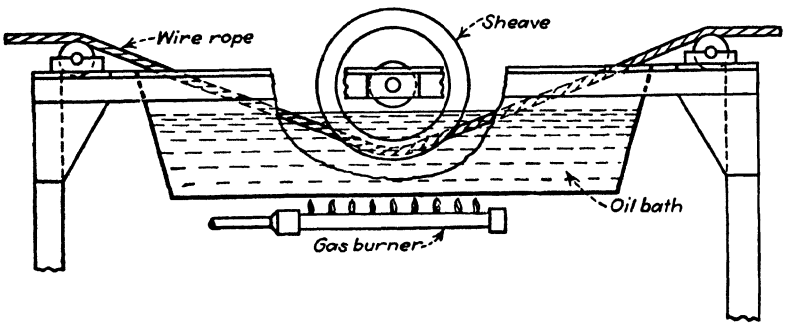


FIG. 127.—Bath oiler for horizontal wire rope.

Silent- and roller-chain drives of slow and moderate speeds and of small and medium horsepower are commonly bath-oiled, as in Fig. 126.

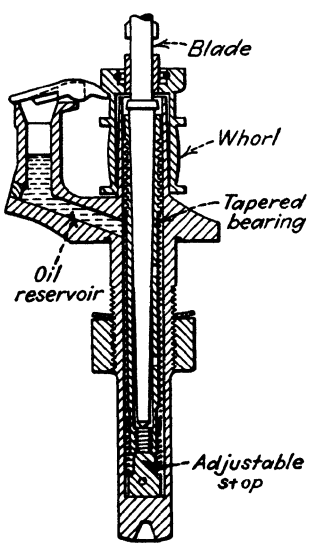


FIG. 128.—Bath-oiled ring spindle.

Illustrated in Fig. 127 is a bath-oiling device applied to a horizontal wire rope. A wiper on the outgoing end of the rope returns excess oil to the bath. It is also advisable to provide a cover for the bath where it is used continuously.

A typical textile spindle bearing is shown in Fig. 128. The spindles rotate at a speed as high as 12,000 r.p.m. in a tapered bearing called a *bolster*. An adjustable stop is arranged at the bottom to carry the weight of the spindle and to provide a means of adjusting the clearance. As shown, the base is constructed with an oil spout for filling, provided with a hinged cover called a *doffer guard*. Drilled holes through the walls of the bolster permit the oil to circulate between the spindle and bolster and the bolster and housing.

Enclosed in a common housing, as in Fig. 129, is a thrust-and-radial bearing at the lower end of a vertical shaft. It is designed

for heavy, slow-speed machinery. Both bearings are bath-oiled, and a dust shield is bolted to the shaft above the housing. A sight oil gage is provided so that correct oil level can be maintained.

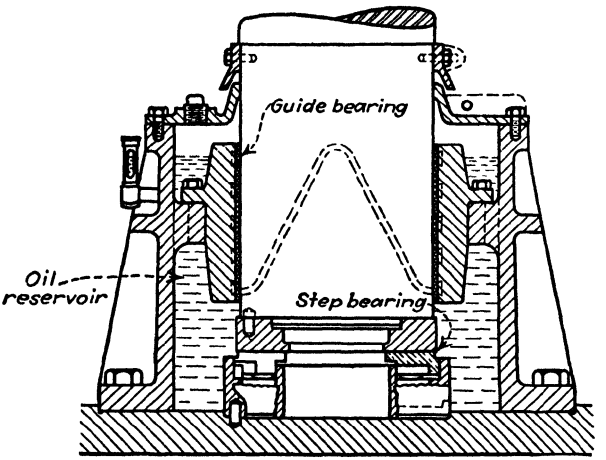


FIG. 129.—Bath-oiled radial-and-thrust bearing for heavy, slow-speed machinery.

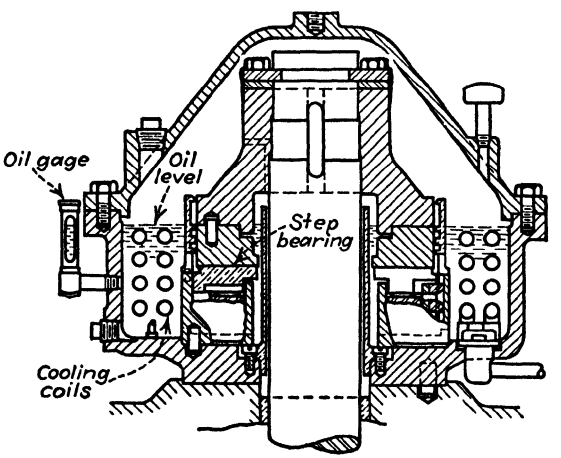


FIG. 130.—Bath-oiled Kingsbury-suspension bearing.

A Kingsbury-suspension bath-oiled thrust bearing, Fig. 130, designed for high speeds, is provided with a cooling coil. This unit is self-contained; it is separate from the frame of the machine and not a part of it.

A bath-oiled worm-gear speed reducer is shown in Fig. 131. The oil reservoir is provided with a cooling coil, which is essential where operating temperatures exceed 200°F. The worm, gear, and worm bearings are provided with oil direct, whereas the gear bearings are supplied by oil that clings to the gear and is scraped off and diverted into channels, which lead to the gear bearings.

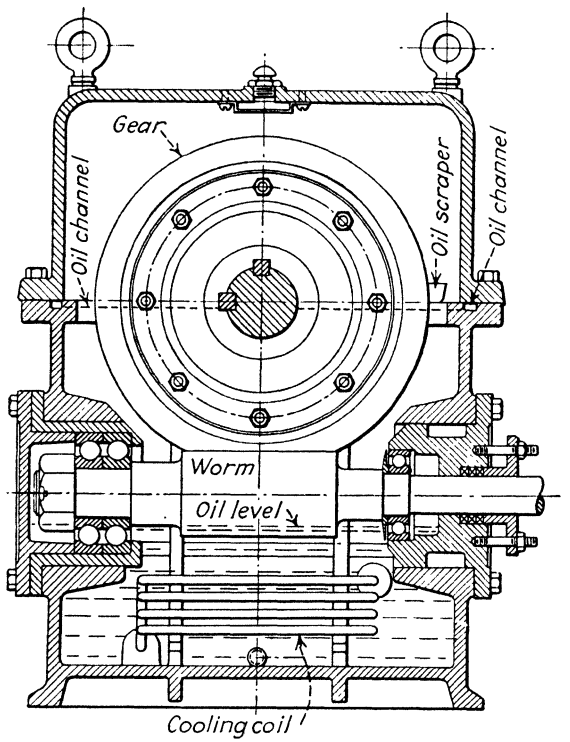


FIG. 131.—Bath-oiled worm-gear speed reducer.

Bath oiling is economical and requires very little attention, except a periodical draining of the reservoir and refilling with fresh, clean oil. The maintenance of the correct oil level is very important; hence, a frequent inspection of the oil level should be made.

9. Splash Oiling.—This method of oiling is very commonly used for machinery having cranks, bearings, and gears enclosed in oiltight housings, which are utilized as oil reservoirs. Moving parts dip into and splash the oil in a sheet or spray into the bear-

ings, or into channels from which it flows by gravity to the various parts. Connecting rods are frequently provided, with a scoop that directs and increases the spray.

Adequate lubrication is assured with this system as long as the oil level is correctly maintained and the parts are properly fitted. Because of the constant and severe agitation of the oil, emulsification, if water is present, and oxidation of the oil are promoted.

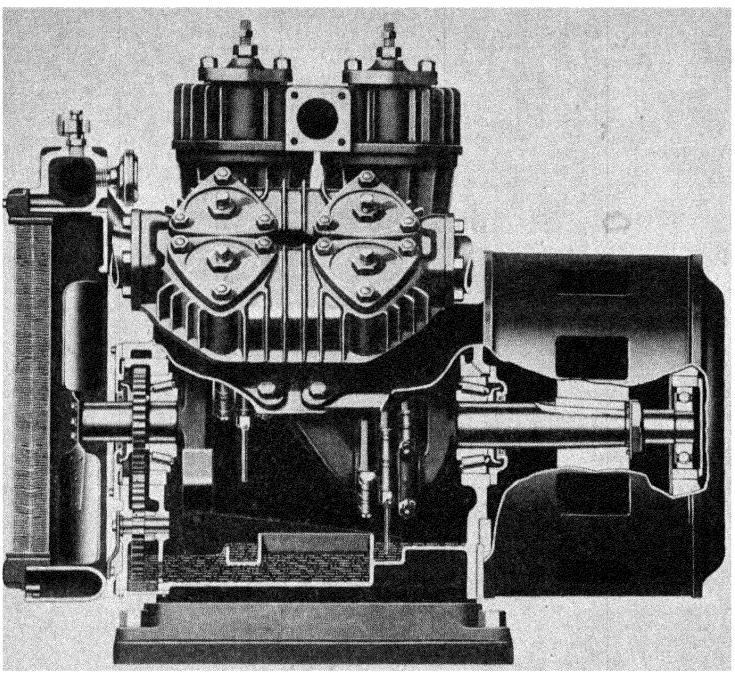


FIG. 132.—Two-stage air compressor with all bearings splash oiled. (*Courtesy Ingersoll-Rand Co.*)

If water is present in a splash-oiling system, it must be regularly and frequently removed, preferably by means of an automatic device. Otherwise, it will raise the oil level, thus causing excessive churning, which affects the splash.

In the operation of any splash-oiling system, it is important to maintain the correct oil level. Carrying the oil level too low results in insufficient lubrication, whereas excessive churning and heating of the oil are caused if the level is too high. Care in

maintaining the correct oil level tends to promote better lubrication and longer oil life.

If impurities are present in the oil, they are kept in suspension and splashed into the bearings, gears, etc. Consequently, elevated troughs and channels are sometimes provided into which the oil is splashed and from which it drains through a filter or screen by gravity to the parts. This is commonly called a *splash-circulation system.*

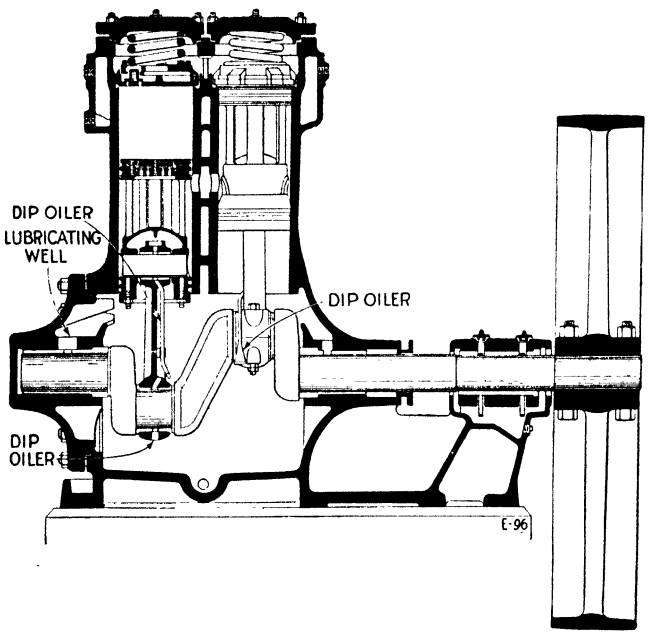


FIG. 133.—Splash-oiled ammonia compressor with dip oilers for crankpin and wristpin bearings. (*Courtesy Socony-Vacuum Oil Co.*)

In Fig. 132, a two-stage air-cooled motor compressor has all parts of it splash lubricated except the pilot ball bearing. An ingenious arrangement of troughs in the crankcase, which serves as an oil reservoir, keeps the oil level in the troughs constant, regardless of the quantity of oil in the crankcase. The lower large gear at the left dips into and lifts the oil from the crankcase and splashes it into a longitudinal trough from which it flows to the transverse troughs.

A splash-oiled vertical ammonia compressor is shown in Fig. 133. Splash oiling is provided for the cylinders, stuffing box, and

bearings, and the wristpins are lubricated by means of a so-called *dip oiler*, as shown in Fig. 134, which is provided with a check valve at the lower end and pumps oil up through the tube to the wristpin bearing.

10. Centralized Oiling.—Centralized-oiling systems are suitable for machine tools, printing presses, textile, glassmaking, rubber-mill machinery, and other medium- and heavy-duty machinery. They are also used on light-duty machinery, such as accounting, tabulating, and sewing machines, food-preparation machinery, motion-picture projectors, and other machines where excess oiling is detrimental or objectionable.

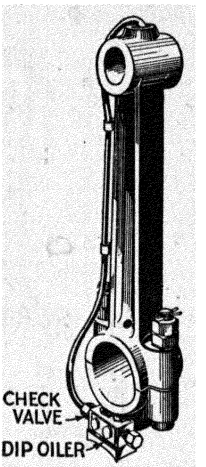


FIG. 134.—Connecting rod, showing dip oiler by means of which oil is pumped to the crankpin and wristpin bearings of the compressor shown in Fig. 133. (*Courtesy Socony-Vacuum Oil Co.*)

Multiple wick-feed and drop-feed oilers that are used to supply oil to scattered bearings are simple centralized systems. They probably constitute the most common type of the system. They have, however, been previously discussed, and so consideration will not be given them here.

Centralized systems may be divided into two chief divisions: (*a*) hand-operating systems, and (*b*) automatic systems.

A single-line hand-operated system, consisting of an oil reservoir, a hand-operated pump, and oil-measuring valves or controls, is shown in Fig. 135. For a single discharge, the pump handle is operated once only with a continuous downward push until it stops solidly against the oil in the tube, after which it is returned to its top position. If additional oil is required, the operation is repeated after a few seconds.

Normal operation of the pump delivers oil through the tube distributing system under an average pressure of approximately 500 lb. per sq. in. When the line pressure at the control reaches 75 lb. per sq. in., the outlet check valve in the control opens and the control piston is forced downward by the pressure, oil being thus delivered to the bearing. The lower end of the piston seating on the shoulder in the control body acts as a cutoff valve and prevents any additional quantity of oil from being delivered to the bearing. After all the controls connected in a system have delivered oil to the bearings, the releasing of the pump handle

relieves the line pressure and permits the spring under the piston to return it to its top positions, the oil meanwhile passing from above to below the piston through the clearance between the piston and cylinder, thus priming the control for the next operation. The construction of the control valves and the pump is shown in Fig. 136.

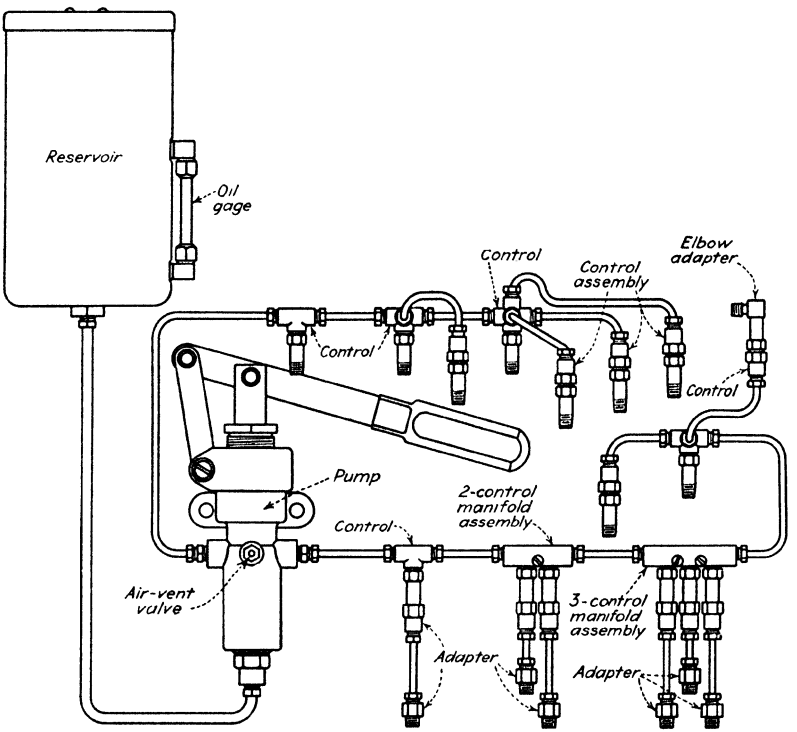
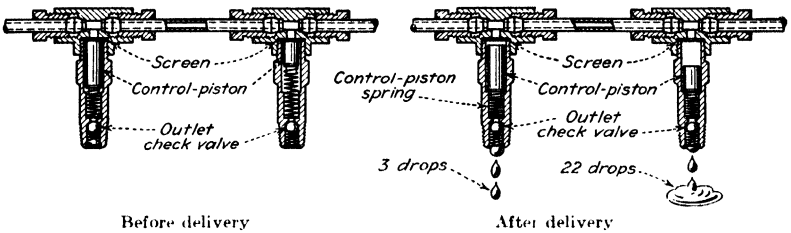


FIG. 135.—Single-line, hand-operated centralized oiling system. (*Courtesy Bowen Products Corp.*)

A number stamped on the body of each control indicates its stroke and diameter, from which the volume of oil delivered is known. Controls generally have been standardized so that three delivery volumes are all that are usually required. These three sizes are known as *small*, *medium*, and *large* and deliver, respectively, 3, 11, and 22 drops per operation.

Another design of a hand-operated centralized system, consisting of a central pump-reservoir unit, a single-line distributing system, and an automatic control valve at each bearing, is shown

in Fig. 137. The pump-reservoir unit is operated by pumping the hand lever until a pressure of 1000 lb. or more is indicated



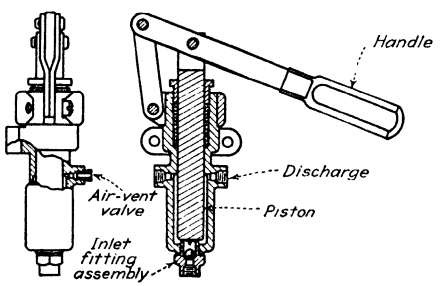


FIG. 136.—Measuring valve and pump for system, Fig. 135.

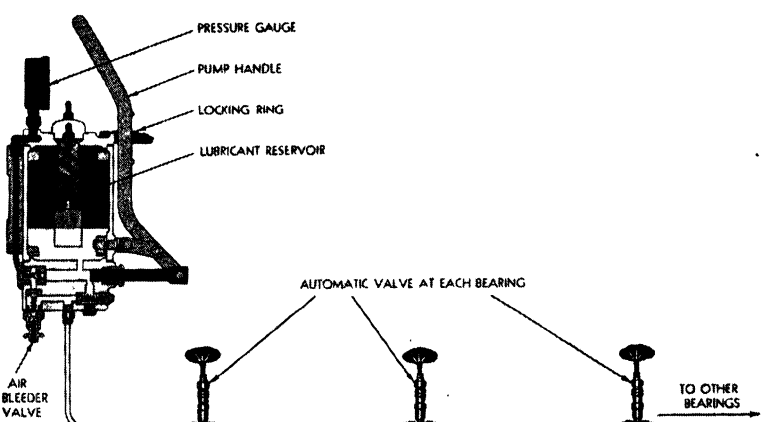
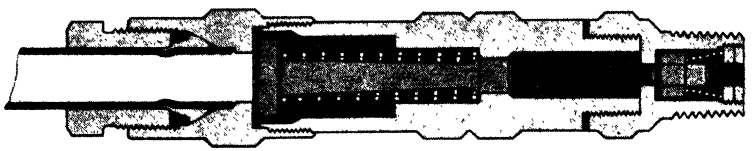


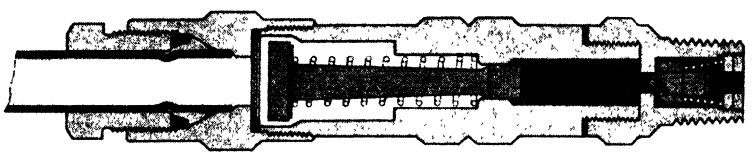
FIG. 137.—Manually operated centralized system for oils and soft greases. (*Courtesy The Farval Corp.*)

on the gage. This operation develops pressure throughout the entire system to discharge all control valves at the bearings.

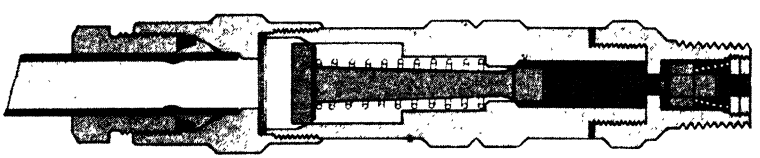
When the hand lever is placed in the locked position shown, the pressure is relieved throughout the system. The operation of control valves is shown and described in Fig. 138.



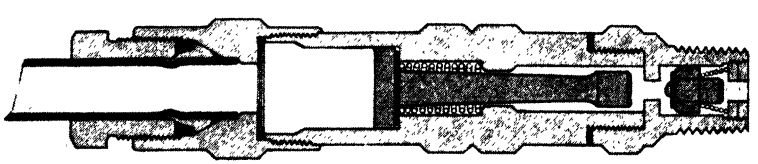
A. Valve in normal position with no pressure on the line. In this position the piston is seated against the fiber gasket, closing the supply line which is always full of oil.



B. Piston moved forward sufficiently by the pressure on the supply line to permit the oil to pass around the piston, completely filling the valve chamber.



C. Piston moved forward, closing the intake and the valve chamber is completely filled with oil. Inlet and outlet are both closed in this position and the valve is loaded with a measured charge of oil ready to be forced into the bearing.



D. Piston closed against the valve seat, having discharged the measured quantity of oil into the bearing.

FIG. 138.—Construction and operation of control valve of system, Fig. 137.

This system is primarily designed for the distribution of oils; it will handle, however, some grades of soft grease. When grease is used, care must be taken to select a product in which the soap

base and mineral-oil content will not separate under conditions of service.

Figures 139 and 140 show, respectively, sectional views of the central pump unit and control valve of a hand-operated system specially designed for handling light-bodied pure mineral lubricating oils. It is principally intended for textile machinery, although it is suitable for any light-duty machinery that requires a light-

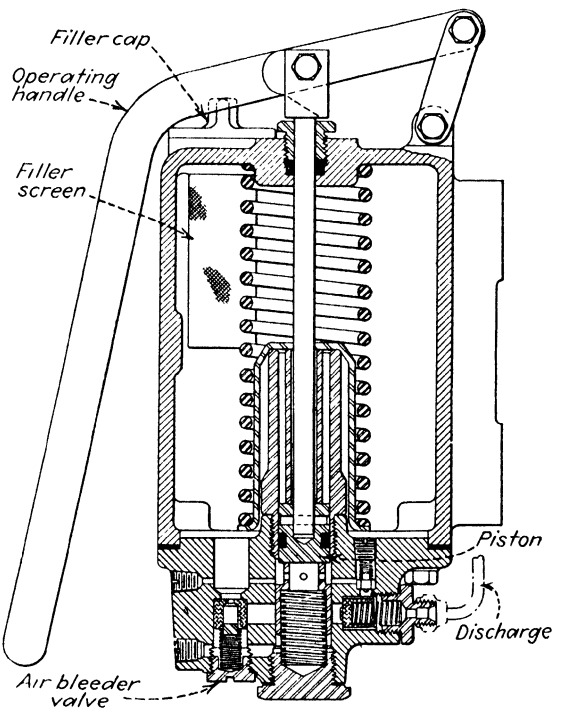


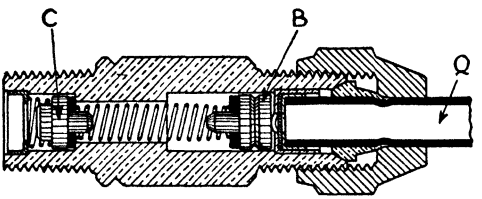
FIG. 139.—Hand-operated central pump unit especially designed for small machines and others requiring light oils.

bodied oil. It operates in the same way as the system shown in Figs. 137 and 138.

The simplest and most widely used automatic system employs a mechanical force-feed lubricator of the types shown in Figs. 141 and 142. Where such lubricators are employed, they are usually mounted directly on and driven by the machine that they serve. They may be mounted, however, off the machine at some convenient and near-by place and driven by an electric

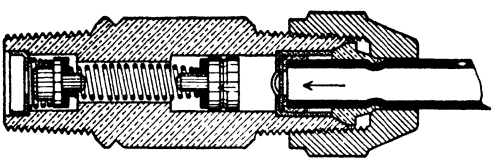
motor or some other device. Individual feed lines are connected, preferably through sight feeds, to the various bearings.

The mechanical force-feed lubricator is obtainable with the following specifications: either right- or left-hand drive; ratchet,



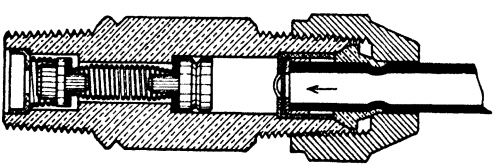
(a)

Valve in normal position and valve chamber fully charged, but no pressure on supply line *Q*, which is full of oil.



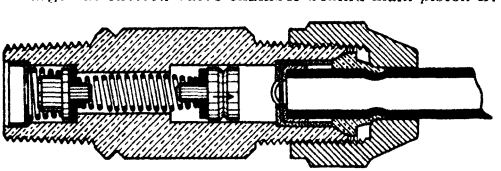
(b)

Main piston *B* moving forward by oil pressure in supply line *Q*. Oil ahead of piston *B* is being discharged past check valve *C* into the bearing.



(c)

Valve in discharge position after delivering full charge of oil into bearing. Fresh measured charge has entered valve chamber behind main piston *B*.



(d)

Return movement of piston *B* when pressure is relieved on supply line *Q*. Oil is now flowing from inlet chamber at right of piston *B* to spring chamber at left. All oil has been transferred when piston *B* reaches position shown at (*a*).

FIG. 140.—Control valve for use with pump, Fig. 139.

gear, or motor drive; vertical or horizontal patterns; one or more individual oil compartments for handling different oils; 1 to as many as 30 adjustable individual feed outlets; and a reservoir having a capacity of 1 pt. to 4 gal. Various finishes are available

—nickel-plated, painted, black enamel, polished brass, etc. Lubricators are also available with a heating chamber for outdoor service where temperature conditions warrant their use. In general, this type of lubricator is capable of producing a pressure as high as 500 lb. per sq. in.; however, some designs are constructed for working pressures as high as 2000 lb. per sq. in. Most designs are capable of being regulated to feed from a fraction of a drop to several drops per minute, the rate of feed not being affected by temperature variations.

Although because of the high positive pressure that they produce they are generally employed for supplying cylinder lubrication, these lubricators are suitable for many other machines.

Shown in Fig. 143 is a design of a fully automatic centralized system, comprising: a pump-reservoir unit, driven from a rotating shaft of the machine served or by an electric motor; control valves at each bearing; and a single-loop distribution line connecting the pump and control valves. The control valves are individually adjustable at the bearings to feed as little as one drop in 10 pulsations or as much as five drops per pulsation, their rates of feed being visible at all times through sight-feed glasses. As many as 100 control valves may be operated from a single pump. The control valves may be arranged in gangs with drip lines to groups of bearings or individual valves may be located at each bearing served with the loop line leading through them, or on dead ends, or on branch lines, flexible, if needed, to connect moving parts of the machine.

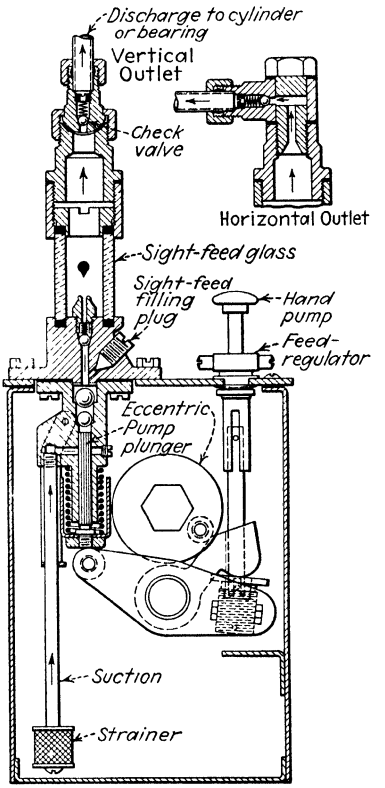


FIG. 141.—A typical mechanical force-feed lubricator especially designed for Diesel-engine service, but also suitable for other machines.

An indicating lever is provided at the pump; the lever rises and falls at each pulsation, which may be two per minute or less for

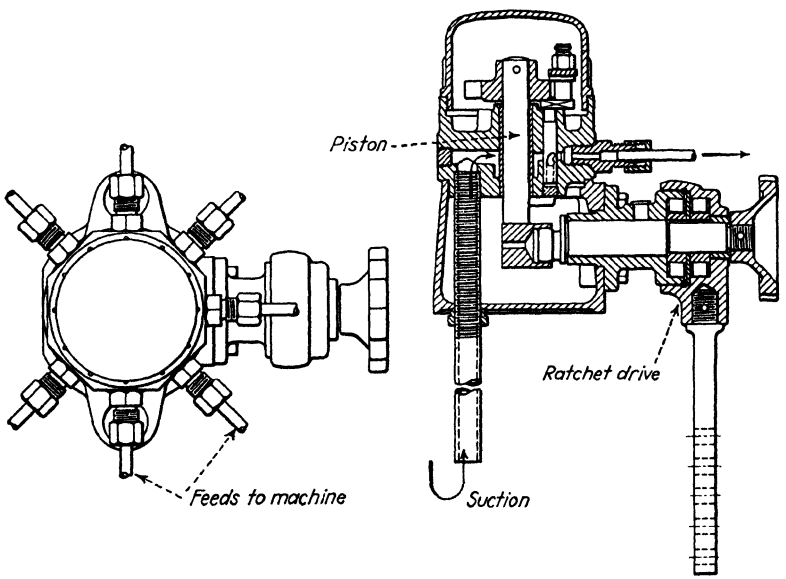


FIG. 142.—Another mechanical force-feed lubricator in which the piston is actuated by a ratchet drive that simultaneously reciprocates and oscillates the piston, opening and closing the suction and discharge ports.

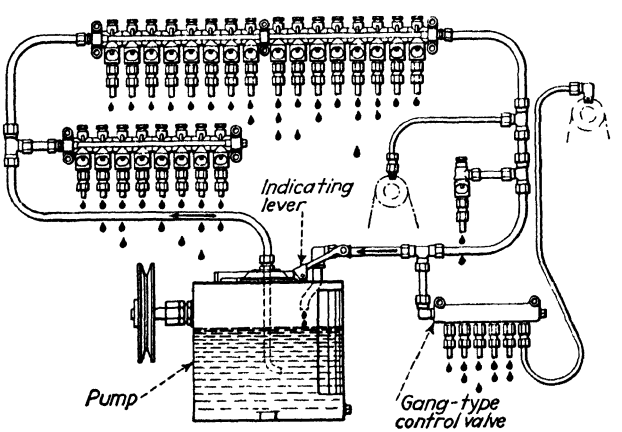
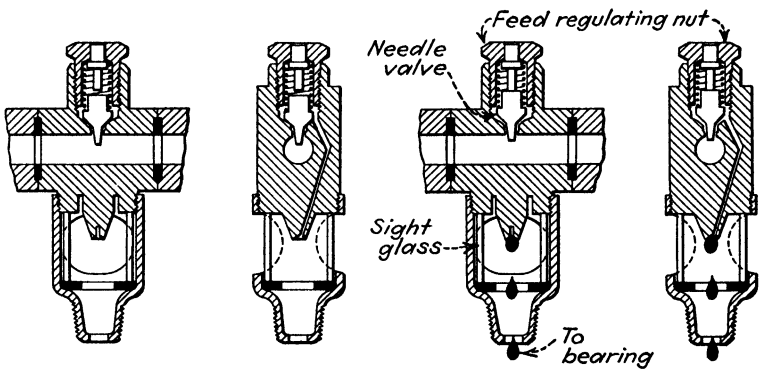


FIG. 143.—Automatic centralized oiling system, showing discharge to bearings. (*Courtesy Rivett Lathe and Grinder, Inc.*)

systems requiring a very slow rate of feed. Holding the indicating lever down causes all control valves to discharge oil rapidly

to the bearings, as when a cold machine is started. The number of pulsations per minute is governed by the style and model of the pump and its speed. Six styles and nine different models of pumps are manufactured, having a reservoir capacity of 1, 3, 4, and 16 qt. Individual feeds as low as 1 drop per hr. or as high as 10 drops per min. can be secured.

Figures 145 and 146 are illustrations of a compactly designed control valve and central pump suitable for a wide variety of machines. Although it is widely used on machine tools, printing presses, etc., it is especially suitable, because of its compactness,



(*a*) Position of control valve during circulation pressure, which is not sufficient to lift the spring-loaded needle valve from its seat, consequently the oil flows directly through the valve.

(*b*) Position of control valve during pulsation pressure. By blocking the return flow of oil to the pump automatically at predetermined intervals the oil pressure is built up in the line sufficiently great enough to lift the spring-loaded needle valve from its seat. In consequence, the oil flows through the drilled passage and sight-feed glass to the bearing.

FIG. 144.—Control valves of system, Fig. 143.

for small machines such as accounting, sewing, and food-preparation machines, motion-picture projectors, and many other small machines that require close oil-feed regulation.

Essentially, this system consists of a central oil-pump unit, which is available in various forms and capacities to suit a wide variety of machines, a flow control valve at each bearing, and a single-line distribution pipe system. As shown in Fig. 145, the control valve contains a felt filter, flow metering pin, and a check valve, which prevents the pipe line from draining and oil from the bearing from feeding back through the pipe line. The felt filter gives protection against the possibility of dirt, chips,

lint, etc., reaching the bearing. The total amount of oil to be fed is determined by the operation and adjustment of the central pump unit. The control valves, however, are selected to feed a proportionate amount of this oil to each bearing. The feed rate of the valve depends on the clearance of the metering pin, each valve being stamped with a feed-rate number; the higher the number, the greater the flow rate. Any number of bearings from 1 to 100 or more can be served by one pump unit, and the bearings may be at a higher or a lower level than that of the pump unit.

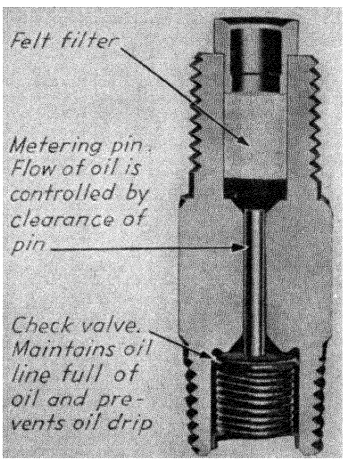


FIG. 145.—A compact control valve used in conjunction with the central pump units, Fig. 146. (*Courtesy Bijur Lubricating Corp.*)

Three main types of pump unit are available:

a. Cyclic or high-pressure type, which is driven from a rotating shaft of the machine that it serves by means of a gear or chain. The lubricating cycle, which may be adjusted from 5 min. to 5 hr., is controlled by a positively driven cam, the contour of which determines the duration of, and interval between, the feeding periods. This type is particularly suitable for machines requiring close-feed control.

b. Continuous type, which is driven from a rotating shaft or a reciprocating member of the machine. This type feeds oil to the bearings at a slow, continuous rate, which rate depends on the piston diameter, stroke, and speed. Various standard sizes are available to meet a wide range of requirements as regards drive speed, feed rate, and reservoir capacity. Figure 146 illustrates a 2-pt. and 6-pt. reservoir size of this type of unit.

c. One-shot type, which is hand-operated, but which is so designed that an extra supply of oil may be given the bearings whenever necessary. This type is particularly adapted to machines that require infrequent oiling, such as from twice a day to once a month, and small office machines. It is capable of being regulated to feed 1 to 900 drops per operation and produces

a normal line pressure of about 50 lb. per sq. in. Figure 147 is a schematic diagram showing location of junctions and other parts of this system. Distributing lines are usually $\frac{5}{32}$-in. O.D. copper tubing. Where space is limited, however, branch lines of $\frac{3}{32}$-in. O.D. are permissible.

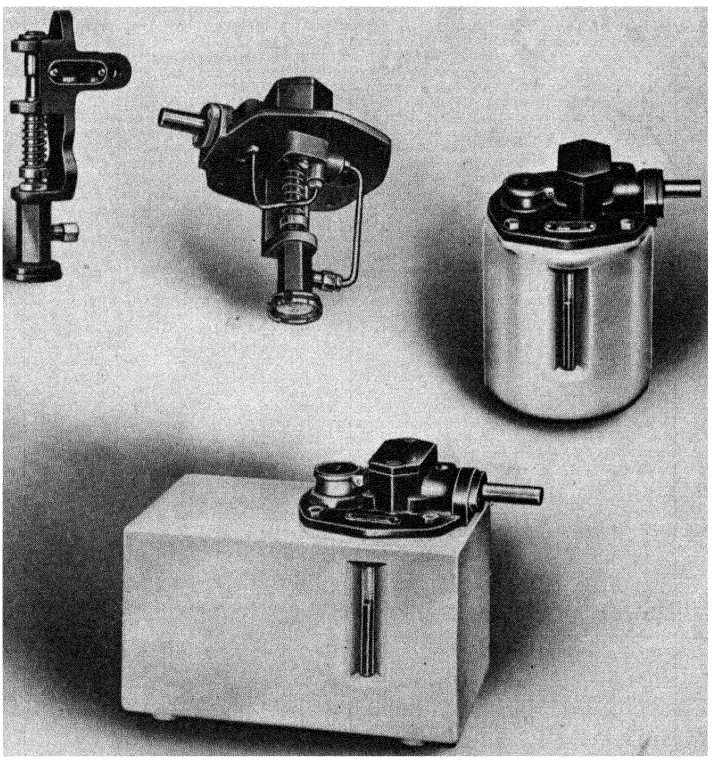


FIG. 146.—A 2- and 6-pint lubricating pump unit of a continuous centralized system suitable for light machines. (*Courtesy Bijur Lubricating Corp.*)

Usually, a complete centralized system is provided for each machine. In some instances, however, it is entirely practical to group two or more small machines and serve them from one central pumping unit.

Whether a hand-operated or an automatic system should be used depends chiefly on whether the machine in question can be properly lubricated by the application at infrequent intervals

of predetermined amounts of oil. If the machine can be properly lubricated at intervals of 4 to 8 hr. or more, a hand-operated system is usually advisable. If, on the other hand, the machine in question requires a continuous or frequent feed of less than 4 hr., an automatic system will usually prove to be better.

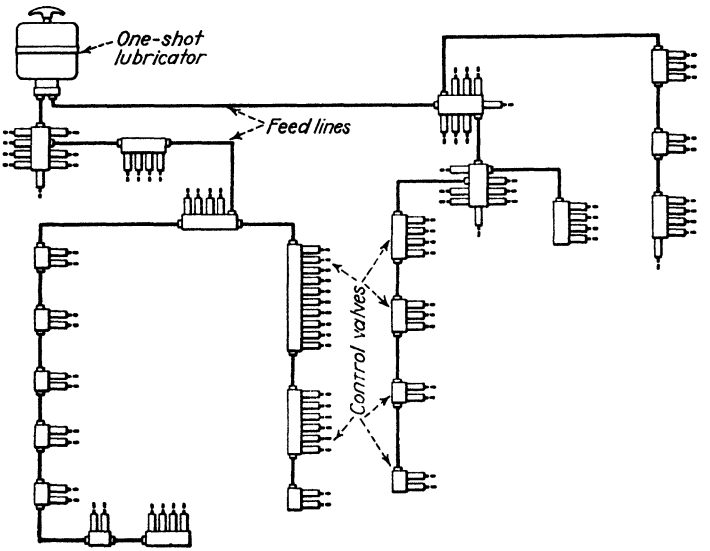


FIG. 147.—Schematic diagram, showing location of junctions and other parts of a one-shot system for an accounting machine.

11. Circulating Oiling.—Circulating-oiling systems are broadly divided into (*a*) gravity circulating-oiling systems, and (*b*) pressure or force-feed systems.

Essentially, a gravity system comprises an upper or elevated reservoir, a sump or lower reservoir, a circulating pump, and the necessary supply and return piping and fittings. The upper reservoir is located above the highest bearing, and the oil flows by gravity to the bearings, from which it drains to the lower reservoir, which is frequently an integral part of the frame of the machine. The sole duty of the pump is to draw the oil from the lower and deliver it to the upper reservoir. The oil pressure at the bearings, therefore, depends entirely on the elevation of the upper reservoir. This pressure is seldom more than 5 lb.

Since the oil pressure is usually low, it is good practice to provide, at easily accessible points in the supply lines, strainers

for the removal of foreign materials that might restrict and even stop the oil flow. The supply lines should also be provided with sight feeds so that the rate of feed can be quickly observed and properly regulated. Although this system is suitable for steam engines, air compressors, and many other machines, yet it has been largely displaced by the force-feed system, which is more reliable and capable of supplying larger volumes of oil required for cooling the modern high-speed machine.

A less costly variation of this system is one in which the upper reservoir is omitted and the oil is pumped at low pressure directly to sight-feed cups at the bearings. This variation does not

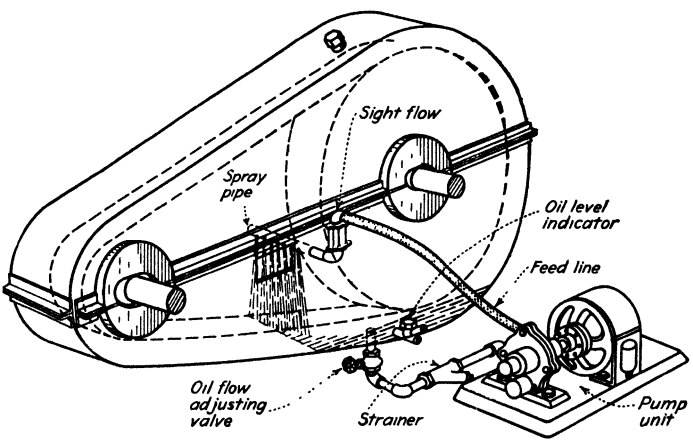


FIG. 148.—Circulating oiling applied to a high-speed large horsepower silent-chain drive.

provide a reserve supply of oil in case of pump failure and is, therefore, less dependable than the more complete system.

The force-feed system delivers the oil directly to each bearing under considerable pressure. Oil is drawn by the pump from a central reservoir, located below the lowest bearing, and is pumped to each bearing, from which it drains back by gravity to the reservoir.

The oil pressure is usually controlled by (*a*) varying the speed of the pump, (*b*) a pressure-relief valve, or (*c*) the use of different-sized orifices at the bearings. The two latter methods are more generally used than the former, for the pump is usually driven by the machine at a constant speed.

The general application of the circulating system is indicated by Fig. 148, which shows it applied to a high-speed large-horsepower silent-chain drive. The constant spray of oil onto the chain provides a copious supply for both lubrication and cooling purposes. It also flushes the chain of dirt, which causes excessive wear in the joints.

A vertical four-cylinder, Diesel engine provided with a force-feed system is shown in Fig. 149. The oil is taken from the

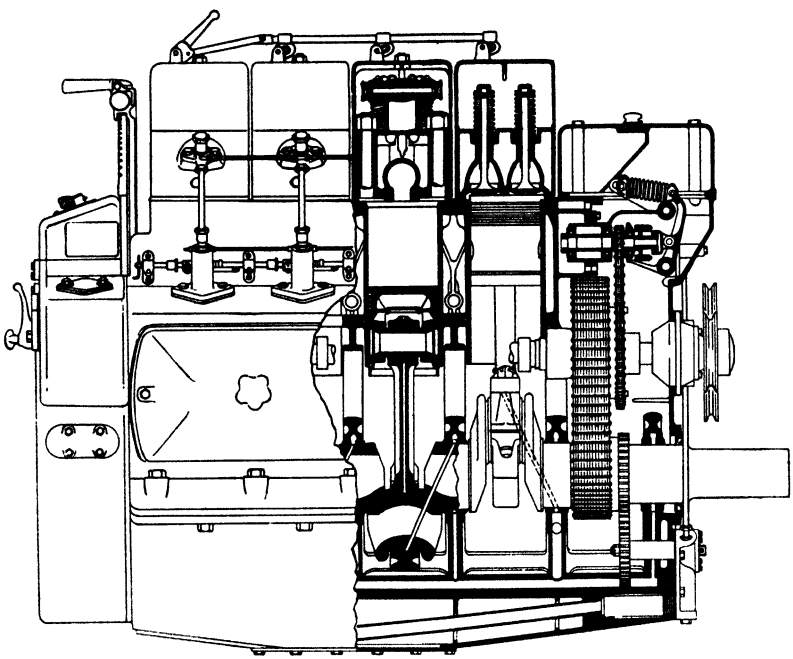


FIG. 149.—Force-feed oiling applied to high-speed Diesel engine. (*Courtesy Socony-Vacuum Oil Co.*)

crankcase, which serves as an oil reservoir, by the circulating pump (not shown) and delivered to headers, from which it is forced to the main, crankpin, and wristpin bearings, the camshaft and fuel-pump bearings, and the valve gear. Sufficient oil is thrown from the crankpin and wristpin bearings to lubricate the cylinder walls. Pressure-relief valves in the oil headers control the oil pressure.

A small vertical steam engine equipped with a complete circulating system for the external parts is shown in Fig. 150.

This engine is completely enclosed and oiltight. The base contains an automatic water drain (not shown), which constantly separates and discharges any condensation that accumulates.

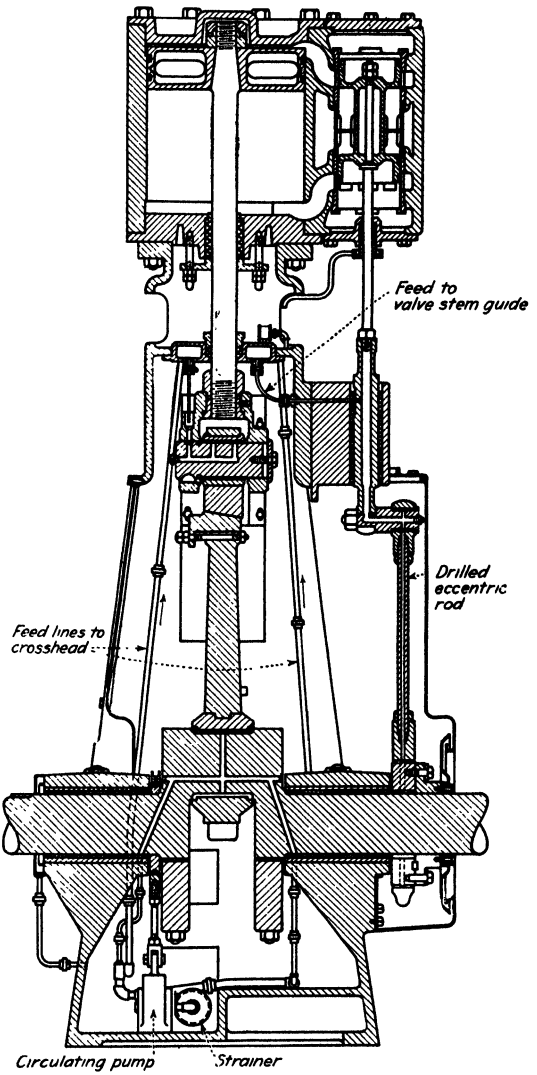


FIG. 150.—Completely enclosed, circulation-oiled, vertical steam engine.

Perhaps the circulating system has reached its highest degree of perfection in its application to the steam turbine. In Fig. 151

is shown a circulating system for a modern steam turbine. The oil in this case is not only required to lubricate and cool the bearings but also to act as the hydraulic medium for operating the governor gear.

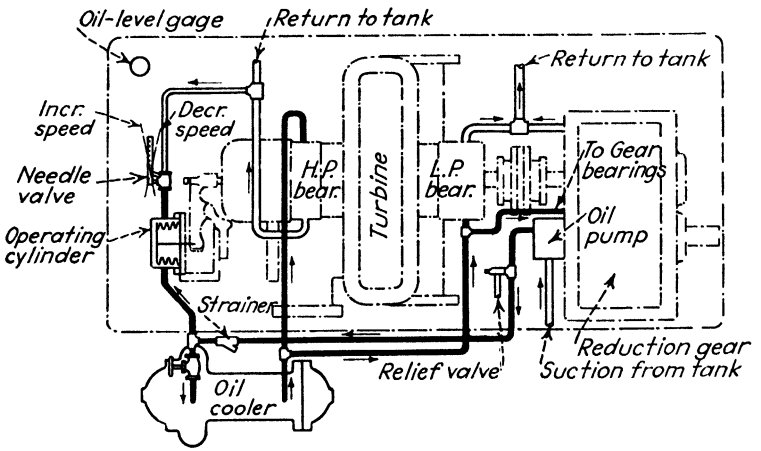


FIG. 151.—Schematic diagram of a circulation-oiling system for a steam turbine and reduction gears. (*Courtesy General Electric Co.*)

The advantages of circulating oiling may be summarized briefly as follows:

1. It affords a copious supply of oil for both lubricating and cooling purposes.
2. It tends to flush bearings, gears, etc., of dirt and other foreign substances, which are often abrasive and cause excessive wear.
3. Oil consumption is minimized, for the oil is used over and over and purifiers may be easily installed, in which case the oil can generally be used virtually indefinitely.
4. It is automatic, positive, and, hence, very reliable.

Its chief disadvantage is its initial high cost.

GREASING APPLIANCES AND SYSTEMS

12. Classification.—For the purpose of discussion, greasing systems may be broadly divided into five methods of application: (1) hand, (2) grease cup, (3) grease-packed, (4) grease well, and (5) pressure.

13. Hand Applications.—A paddle, swab, or brush is generally used where grease is applied by hand, as is frequently done for open gears, chains, wire rope, and some bearings. In general,

this method is wasteful and unreliable, involving, as it does, the human element. Much more grease is usually applied than is required, the excess being thrown off and wasted. Because of an operator's negligence, equipment may operate for some time without adequate lubrication.

14. Grease-cup Applications.—This method, an improvement over hand application, does not eliminate the uncertain human element. The compression grease cup, Fig. 152, the cheapest and perhaps the most widely used, screws directly into the bear-

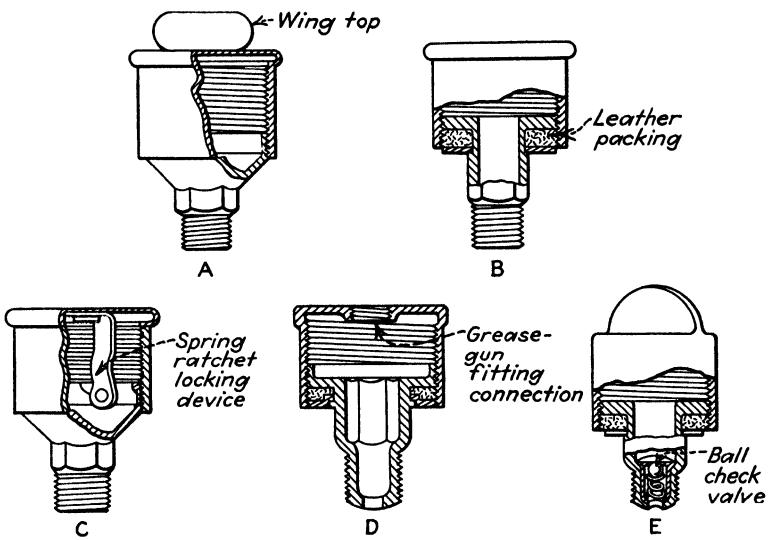


FIG. 152.—Typical compression grease cups.

ing that it serves. Grease is forced into the bearing by screwing down the threaded top, which is filled with grease. Figure 152*A* is an inexpensive design having a wing top, and Fig. 152*B*, for high-temperature conditions, has a leather packing to prevent grease leakage.

Where vibration is severe, an internal or external friction spring, or a spring-ratchet device is provided, as in Fig. 152*C*, to keep the cap from backing off. To facilitate refilling, this type of cup is also obtainable with a grease-gun fitting in its top, as in Fig. 152*D*. For circulating pumps and other services where water is likely to back up into the cup, grease cups are provided with a ball check valve, Fig. 152*E*.

All these cups are made with either male or female threads and in capacities of ¼ to 22 oz. They are threaded for standard ⅛- to ¾-in. pipe, depending on capacity.

Compression cups feed little grease except when the top is being screwed down; thus, application of lubricant is periodic.

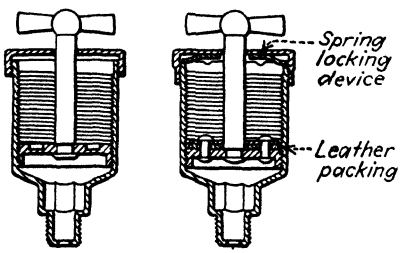


FIG. 153.—Screw-piston grease cups suitable for forcing grease through long pipes.

The designs of Fig. 153 are widely used on marine and gas engines and are adapted to other machines where screw feed is satisfactory. When the T handle attached to the piston stem is turned, grease is forced out of the cup into the bearing. As considerable pressure can be applied to the grease by means of

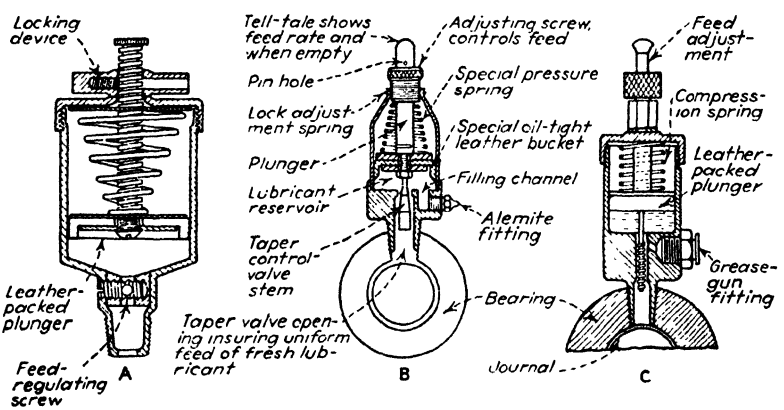


FIG. 154.—Three designs of automatic grease cups.

the threaded piston, this type is adapted for forcing grease through pipes of considerable length. The design on the right of Fig. 153 has a simple, spring-locking device that prevents the cap from being unscrewed by vibration. The leather packing on the plunger tends to hold the piston in position and eliminate danger of grease being drawn from the bearing.

In the automatic spring-feed cups, shown in Figs. 154*A* to *C*, a spring acting against a leather-packed plunger forces grease slowly into the bearing. Rate of feed may be regulated, and the handle may be set at any position on the stem to stop the flow of grease, when desired. A spring-locking device prevents the handle from being jarred from any set position on the stem. Designs *B* and *C* are similar to *A*, except that they are provided with grease-gun fittings, which eliminate the necessity of removing the top for refilling.

The designs of Fig. 154 require little attention except refilling and an occasional cleaning. They are especially suitable for inconveniently located bearings and provide a fairly uniform rate of feed. They are obtainable in brass, bronze, or pressed steel.

15. Grease-packed Application.—Frequently, bearings are enclosed so that they can be grease-packed. Usually, some type

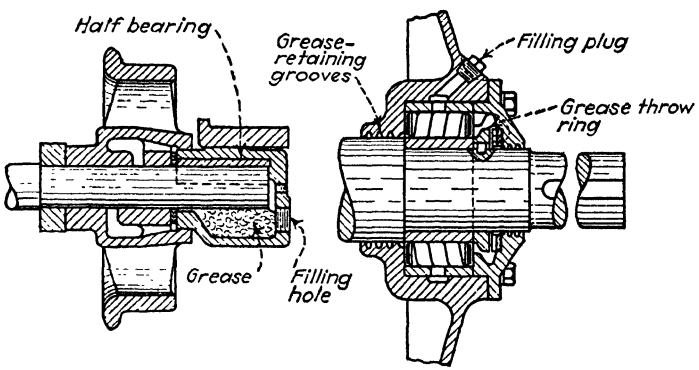


FIG. 155. FIG. 156.

FIG. 155.—Grease-packed mine-car-wheel bearing.
FIG. 156.—Grease-packed roller bearing of a synchronous motor.

of grease-retaining ring or seal is provided where the shaft extends through the housing. This system, if seals are maintained in good condition, ensures comparative freedom from impurities that may be in the surrounding atmosphere, requires little attention, and is reliable. It is frequently used for ball and for roller bearings. These bearings should not be filled more than one-third full of grease; otherwise, they are likely to overheat. Figure 155 is a grease-packed mine-car-wheel bearing, and Fig. 156, a grease-packed synchronous-motor roller bearing.

16. Grease-well Applications.—Some bearings are designed with open tops, sides, or bottoms and are lubricated by placing

grease in the adjacent well, where it presses against the revolving journal. Friction heat from the bearing melts the grease slowly to provide lubrication. Comparatively hard block greases are widely used for this type of bearing, the blocks frequently being made to fit the well. A typical block-grease-lubricated bearing is shown in Fig. 157.

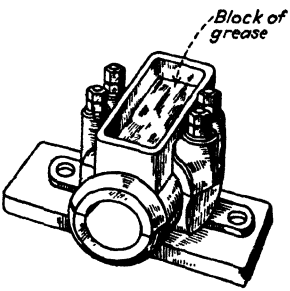


FIG. 157.—Bearing provided with top well for block grease.

In some cases a perforated plate, with $\frac{1}{8}$-in. holes on $\frac{7}{16}$-in. centers, is fitted to the journal and the grease is fed through the plate. A spring-loaded follower plate is sometimes used to press the grease firmly against the journal. Where such a device is used, spring pressure should not be sufficient to destroy the grease-block form. Pressure required depends on grease hardness. There should be ample clearance between the grease block and well on all sides, otherwise the block may hang in the well and not make contact with the journal.

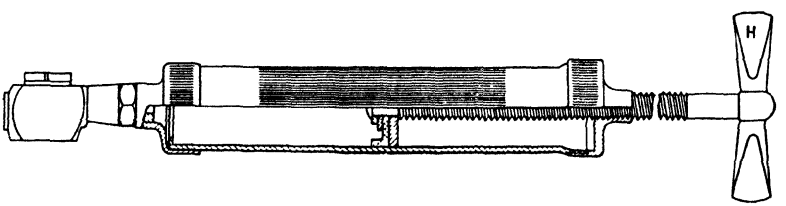


FIG. 158.—Screw-plunger gun equipped with double-duty button-head coupling.

17. Pressure Applications.—Pressure application of grease may be simple, employing a hand-operated grease gun, or it may be relatively complex, involving the use of compressed air or an electric- , steam- , or air-driven pump to force the grease into the bearings.

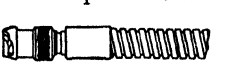


FIG. 159.—Bayonet-type coupling for screw-plunger gun, Fig. 158.

Figures 158 to 163 show typical hand-operated grease guns. The simplest is the screw-plunger type, shown in Fig. 158, operating on the same principles as the compression grease cup. By turning handle *H*, the leather-packed plunger is moved toward the discharge end, forcing grease out of the gun. T handle *H* may be replaced by a wheel or crank. At the discharge

end a ball check prevents flow of grease out of the gun after it is disconnected from the fitting. This type is made in 2-, 4-, 6-, 8-, 12-, and 14-oz. sizes and is capable of producing a pressure up to 2000 lb. per sq. in.

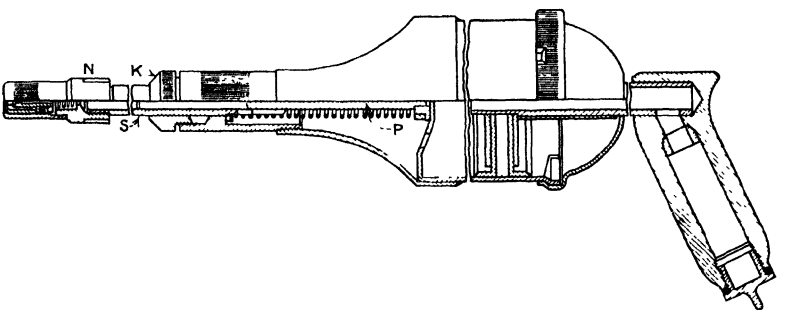


FIG. 160.—Automatic hydraulic-type gun with filler-type handle.

When the hydraulic-type gun, shown in Fig. 160, is pressed against the fitting, sleeve *S* slides back on plunger *P* and forces a measured charge of grease into the bearing. When pressure is released, the spring returns the sleeve to its forward position. The discharge port is automatically closed by the ball check, and a fresh charge of grease is taken into the sleeve. Application of pressure to the pistol-grip handle forces grease in the cylinder toward the sleeve and nozzle at each application. This type of gun is capable of developing pressure up to 10,000 lb. per sq. in., and is available in 5-, 9-, 16-, and 28-oz. sizes. The quantity of grease delivered per stroke can be varied in this gun by placing

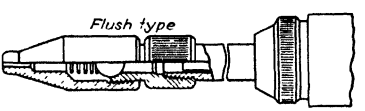


FIG. 161.—Grease-gun coupling for flush-type fittings.

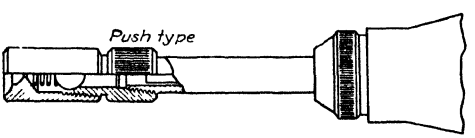


FIG. 162.—Grease-gun coupling for push-type fittings.

collars of different lengths between nozzle *N* and shank *K*, the length of stroke thus being varied.

To apply grease under very high pressure as, for example, with heavy-bodied grades or when tight or clogged bearings are encountered, a so-called *gat gun*, Fig. 163, is used. When the

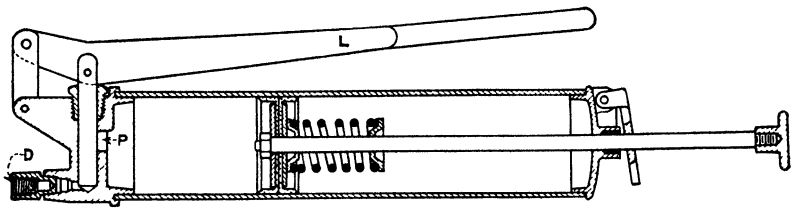


FIG. 163.—Gat-type gun for high-pressure application.

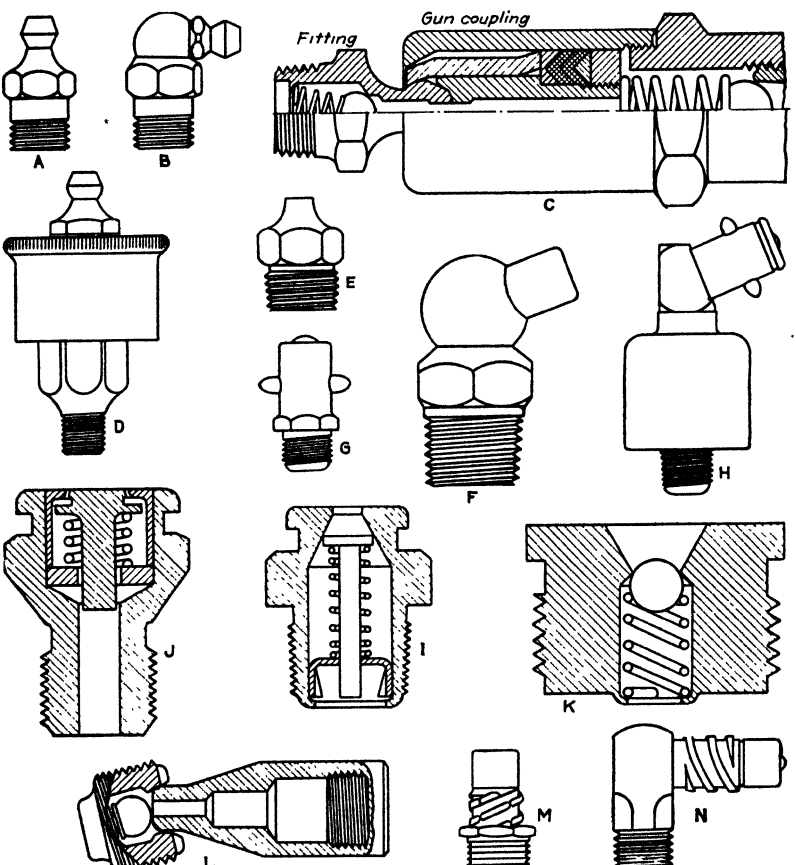


FIG. 164.—Typical grease-gun fittings. *A* and *B*, straight and 90-deg. hydraulic fittings; *C*, cutaway view of hydraulic fittings and gun coupling, showing how coupling grips the fitting; *D*, straight grease-cup fitting for filling cup from gun; *E* and *F*, fittings for application of push-type grease gun; *G* and *H*, fittings for screw-plunger gun with bayonet-type coupling; *I* and *J*, buttonhead grease-gun fittings; *K*, flush fitting, used where space is limited; *L*, grease-gun nozzle applied to flush fitting; *M* and *N*, standard dot-type grease-gun fittings for heavy machinery.

hand lever *L* is raised, grease from the main chamber is forced into the high-pressure chamber through port *P*. Pushing lever *L* down forces the grease through the discharge tube, connected at *D*, and into the bearing. A pressure as high as 10,000 lb. per sq. in. can be easily produced by this gun, which is made in 15- and 20-oz. sizes. Another gat gun, known as the *volume type*, has a capacity of 16 oz. and delivers ¼ oz. of grease per stroke. A third type has a pistol-grip handle and a capacity of 5½ oz.

Where grease guns are used, it is necessary to equip bearings with special fittings of various types, such as are shown in Fig. 164. *A* and *B* show one of the newer designs, and the cutaway view *C* indicates how the gun coupling grips the fittings. These are so designed that the greater the pressure, the tighter the seal. With this type of fitting and a hydraulic type gun, Fig. 160, pressures up to 10,000 lb. per sq. in. can be developed. *D* shows a hydraulic fitting applied to a grease cup for filling.

At *E* and *F* are two designs of push-type fittings. Though in appearance this fitting is similar to the hydraulic type, the seal between gun and fitting is quite different. Contact between the two is around the outer rim of the cone-shaped fitting. The seal has no tendency to become more secure with increased pressure, as is the case with the hydraulic-type fitting. With this fitting and a push-type gun, a maximum pressure of 6000 lb. per sq. in. can be produced.

Figures 164*G* and *H* are pin-type fittings with which is used a screw-plunger type of gun, fitted with either a rigid bayonet coupling or a conduit hose, Fig. 159. This fitting, designed with a crosspin, permits the bayonet coupling to be locked in place, and a maximum pressure of 2000 lb. per sq. in. can be produced. For dusty conditions, this fitting may be equipped with dust caps.

Figures 164*I* and *J* show buttonhead fittings, widely used on heavy-duty machinery because of their sturdiness. With this fitting, it is necessary to provide a screw-plunger gun with different coupling from that used for the pin-type fitting. Three styles of coupling are made: pull-on, push-on, and hook-on, any one of which can be used with any of the screw-plunger guns.

Flush-type fittings for revolving or moving parts where a protruding fitting might be dangerous are shown in Figs. 164*K* and *L*. They are also used on bearings where lack of space prohibits the use of protruding fittings. This design, as the name indicates,

consists of a recessed fitting, which, when installed, is set flush or nearly so with the bearing surface. As shown, a ball check is provided in the fitting, and the push-type gun makes contact around an internal, conical-shaped recess. A maximum pressure of 6000 lb. per sq. in. can be produced. Two different sizes are available: standard and giant, the latter being widely used on mine-car-wheel bearings.

Dot-type fittings commonly used on heavy machinery, such as contractor's equipment, cranes, concrete mixers, and bridge machinery, are shown in Figs. 164*M* and *N*. These fittings have a section of male Acme thread, and the gun coupling has a corresponding female thread. A positive seal is made by placing the screw-type gun coupling over the fitting and giving it a quarter turn to the right. This securely clamps the gun coupling to the

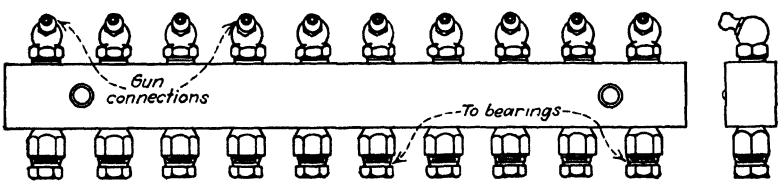


FIG. 165.—Ten-unit grease-gun manifold for centralizing greasing from a single location.

fitting and automatically opens the ball check. For regular service the fitting has a single-ball check. For use on air valves and water pumps, it has a double check. A maximum pressure of 3000 lb. per sq. in. can be developed. These fittings are made in regular and mogul sizes, and dust caps are available for both sizes where conditions warrant.

All these different fittings are made in a large number of angles, shapes, and sizes, only a few of which are shown. They are made with standard male and female pipe threads, as well as S.A.E., machine, and wood-screw threads. Rivet and drive types are also available, as well as drive bushings of various diameters for simplifying their installation in existing holes.

Fittings in Fig. 164 are extensively used on bearings relatively widely spaced. The lubrication of such bearings, however, can be centralized in a header, as shown in Fig. 165. The header is placed at any convenient place on or near the machine and is connected by means of tubing to the bearings, all bearings being thus made accessible. The machine may be lubricated in opera-

tion, danger to the oiler is minimized, and time required for lubricating is greatly reduced.

The pressure-greasing systems described flush the bearings of old grease and impurities on each application, reduce grease wastage, and prevent the ingress of dirt into the bearing through the oilhole, which is securely sealed at all times by the ball check in the fitting.

As a further precaution to exclude impurities from bearings, equipment has been developed by which it is possible to transfer grease from the original barrel to the bearings without a possi-

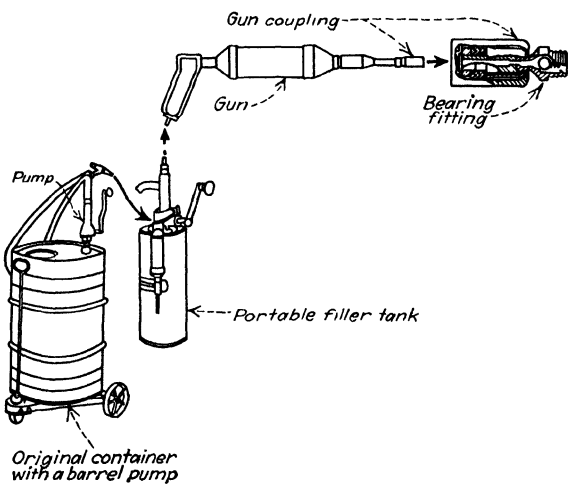


FIG. 166.—From barrel to bearing without exposing the grease to contamination. (*Courtesy Stewart-Warner Corp.*)

bility of contamination. This equipment comprises a special pump, which is inserted into the barrel through the bung, as in Fig. 166. A hose is attached to the barrel pump and provided with a fitting for easy connection to the portable filler tank, consisting of a 20-lb. reservoir and a hand-operated pump. The portable filler tank is filled at the barrel and is carried by the oiler about the plant. A hand-operated pressure gun that can be filled through the handle is used. It is filled whenever necessary by removing a plug from the handle, as in Fig. 160, and placing the opening over the nozzle of the portable filler-tank pump. This system gives the oiler a substantial supply of grease to apply to the bearings with a light gun.

Where a large supply of grease is needed at all times, specially designed high-pressure volume guns, either hand- or power-operated, are employed. Such guns are connected to the bearings by a special rubber hose with suitable end connections. The volume gun, Fig. 167, is air-operated and is specially designed for handling heavy greases. The special worm and helix arm inside the reservoir, operated by the air motor, forces the grease to the high-pressure piston. This gun develops a pressure thirty-three times the air pressure used, which varies from 125

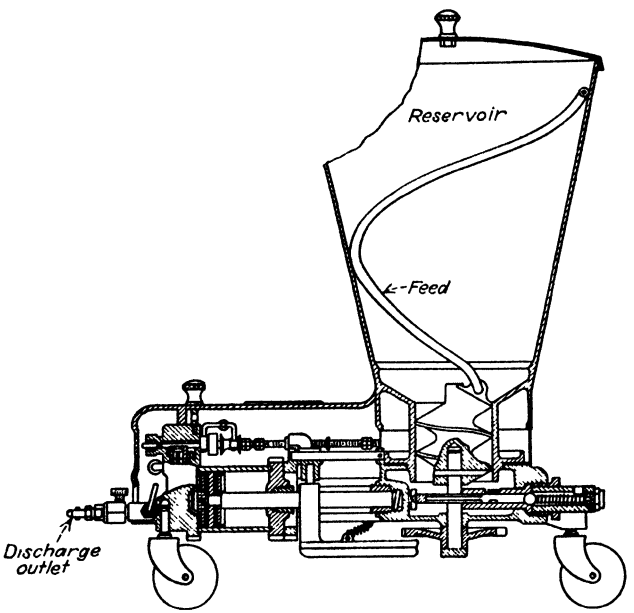


FIG. 167.—Air-operated large-capacity grease gun especially designed for handling heavy grease.

to 150 lb. per sq. in. Gun capacity is 40 lb. of grease. Other types of volume gun are electrically operated, are capable of producing pressures up to 5000 lb. per sq. in. at the control valve, and have a capacity of 25 lb. Air and electric volume guns, similar in design to those shown, are available with various capacities and rates of delivery. Also, steam-operated volume guns can be had where neither air nor electricity is available.

Hand-operated guns are available with capacities of 5 to 28 lb. of grease and for pressures up to 500 lb. per sq. in. They can deliver 0.3 to 1.2 oz. of grease per stroke and are widely used for

manufacturing plants, oil fields, tractor track rolls, mine-car wheels, covered springs and as loader pumps where air or electric power is not available.

To circumvent the time-consuming and unreliable point-by-point method of application, centralized greasing systems have been developed. These systems do not provide a continuous supply of grease, but frequency of application can be made virtually continuous. They are made either in manual or in automatic-mechanical types.

Even though a centralized system does not re-use grease, it may be more efficient than a circulating-oiling system, under some operating conditions, for grease generally will remain in bearings longer than oil. Ordinarily, it is not possible to lubricate all bearings with the point-to-point method when a machine is in operation. A centralized system not only permits lubricating the machine while in operation but also reduces the application hazard in lubricating hard-to-get-at bearings.

Centralized greasing systems are widely used for all sorts of metal-forming machine, such as presses, punches, and shears, and for machinery in the steel, rubber, paper, printing, and textile industries. These systems centralize the points of application by: a central combination pump-reservoir unit, which may be manually, air- or electrically operated; a measuring or feeder valve located at each point of application; and the necessary piping or tubing and fittings for conveying grease from the central unit to each individual bearing.

The heart of these systems is the measuring or feeder valve, one design of which, for a single-line system, is shown in Figs. 168 to 170. A central pump forces grease into the feeder from left to right, Fig. 168. Primary piston P and sliding valves V are moved to the right, Fig. 169. This action of the primary piston and sliding valves admits grease to the main cylinder and forces the main piston M to the right. From the previous operation or cycle, the cylinder to the right of the main piston is full of grease, which is forced through port P_1 to the bearing. In Fig. 170, the main piston has completed its stroke and forced a measured quantity of grease into the bearing. In this position, grease is free to flow through, the feeder acting as part of the circuit, to operate the next feeder and lubricate the next bearing. This process continues until each feeder in the system has oper-

ated to deliver a measured quantity of grease to its respective bearing. Then, no more grease can be forced into the bearings until the four-way valve at the pump is reversed, which may be done manually or automatically. The four-way valve reverses

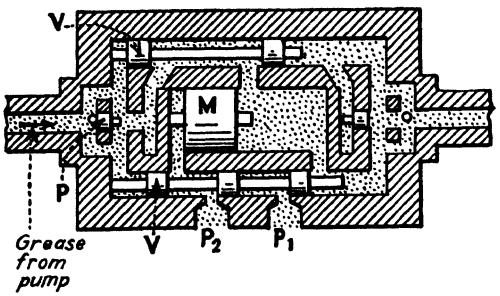


FIG. 168.

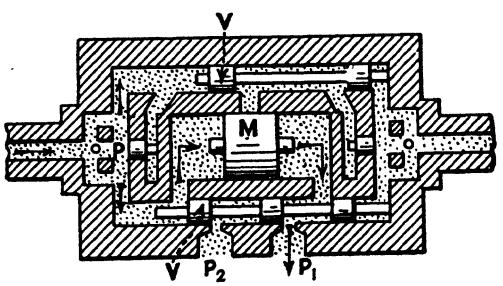


FIG. 169.

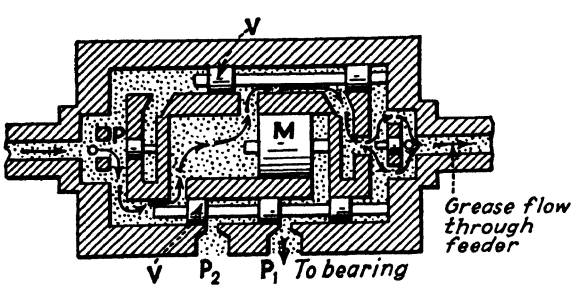


FIG. 170.

FIGS. 168–170.—Steps in the operation of an automatic feeder valve for a single-line series system. (*Courtesy Trabon Engineering Corp.*)

grease flow in the circuit, and the cycle is repeated, but from right to left.

The single-line system using feeders, as in Figs. 168 and 170, and with a manually operated pump, is illustrated in Fig. 171.

Grease forced by the pump into the four-way valve at *A* leaves at *B* and goes to feeders *E* and *F*, back into the four-way valve at *C*, and out at *D* to position indicator *E* and reservoir *G*. Turning the four-way valve 90 deg. clockwise will bring the passages through it to the position shown by the dotted lines. Then, grease flow will be reversed beyond the four-way valve. That is, it will enter at *A*, flow to *C*, through the line to *B*, out at *D*, and return through indicator *F* to the reservoir. The line from and to the four-way valve can be any length and can have almost any number of feeders connected in series, each serving a bearing.

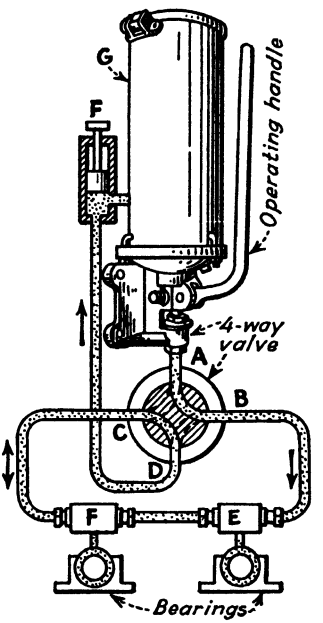


FIG. 171.—Manually operated pump, four-way reversible valve and two feeder valves for a single-line system. (*Courtesy Trabon Engineering Corp.*)

Figures 172 to 174 show a design of feeder for a so-called *dual-line system*. Position of its various parts when grease under pressure from the pump first enters the feeder at the line connection *L* is shown in Fig. 172. Top piston valve *V* is first moved downward, thus permitting the grease to flow through port P_1 to the chamber above the piston *P*, which is moved downward, Fig. 173. Downward movement of piston *P* forces grease from the lower chamber through port P_2 past the lower piston valve V_1 into the bearing through connection L_1, the lower chamber having been filled with grease from the previous operation. In Fig. 174, valves and piston have completed the operation. Next operation or application of grease to the bearing occurs in the reverse order, grease from the pump entering the feeder at line connection L_2.

Figure 175 shows a dual-line automatic system comprising a central pump-reservoir unit, two main distributing lines, and feeder valves, as in Figs. 172 to 174, located at each bearing. The central unit includes an electric motor, double-plunger pump, four-way hydraulic reversing valve, speed reducer, adjustable accumulator, and a suitable grease reservoir. The

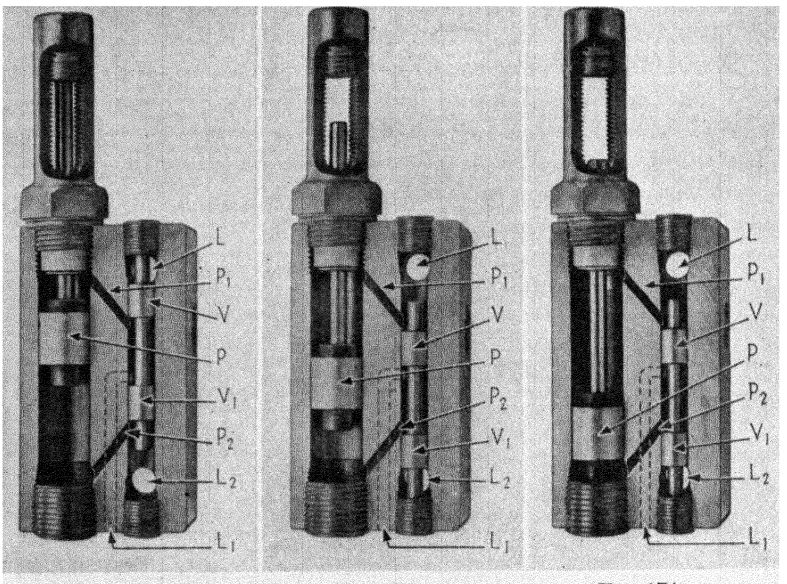


FIG. 172. FIG. 173. FIG. 174.

FIGS. 172–174.—Three positions of a feeder valve for a dual-line system. (*Courtesy The Farval Corp.*)

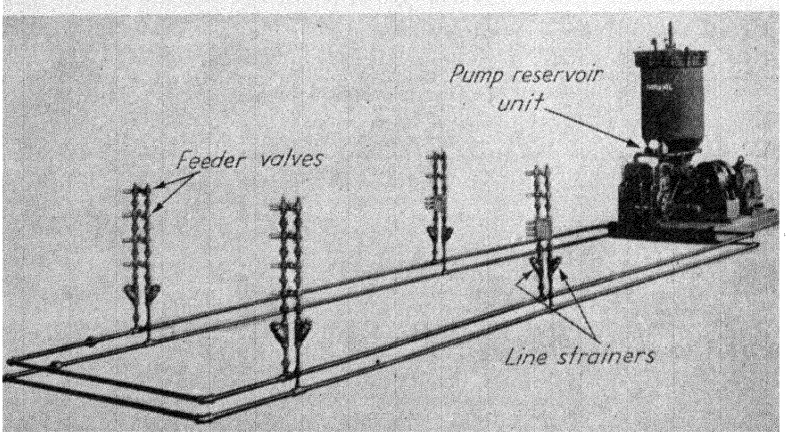


FIG. 175.—Central pump reservoir, piping, and feeder valves of a dual-line system. (*Courtesy The Farval Corp.*)

pump unit delivers grease alternately to both main distributing lines at high pressure throughout the circuit. Pressure applied to either of the lines causes feeders connected to them to discharge a measured amount of grease to each bearing and, at the same time, recharge feeders for the next operation. The four-way reversing valve at the pump delivers grease from the pump alternately to each of the main distributing lines. An adjustable pressure control valve can be set for virtually any pressure.

Frequency of operation is hydraulically controlled. The system can be electrically controlled, but the hydraulic method is

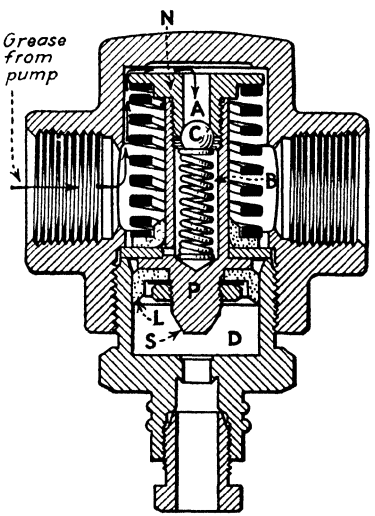


FIG. 176.

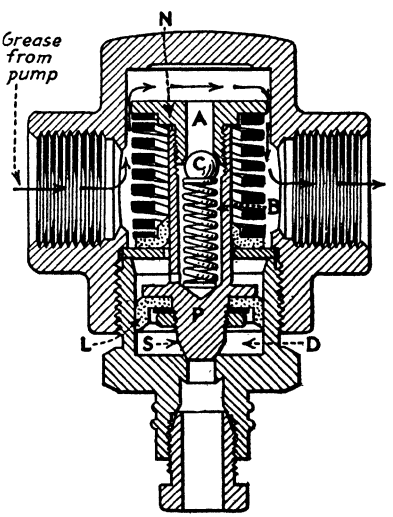


FIG. 177.

FIG. 176.—Spring-loaded feeder valve before operation.
FIG. 177.—Spring-loaded feeder valve after operation.

generally preferred because of its simplicity. The accumulator is adjustable and acts as a simple expansion chamber to receive a predetermined quantity of grease each cycle of operation, before pressure can be built in the line to discharge all feeders. With the pump delivering a fixed quantity of grease per unit of time and because the accumulator must be filled at each cycle of operation, capacity of the accumulator directly affects the length of time required for one complete operating cycle.

Figures 176 and 177 show a spring-loaded feeder valve in normal and discharged positions. When pressure is applied at the pump, grease is forced into the feeder up past the hexagonal

nut N into chamber A, past ball check valve C into chamber B. This action causes the leather-packed plunger assembly P to move downward into chamber D, thus forcing the grease charge into the bearing. When plunger P is stopped by stem S, no more grease can be forced into the bearing and the grease is free to flow through the feeder, Fig. 177, to the next feeder in the circuit.

When all feeders in the circuit have been discharged and pressure has been released at the pump, the large helical spring pushes

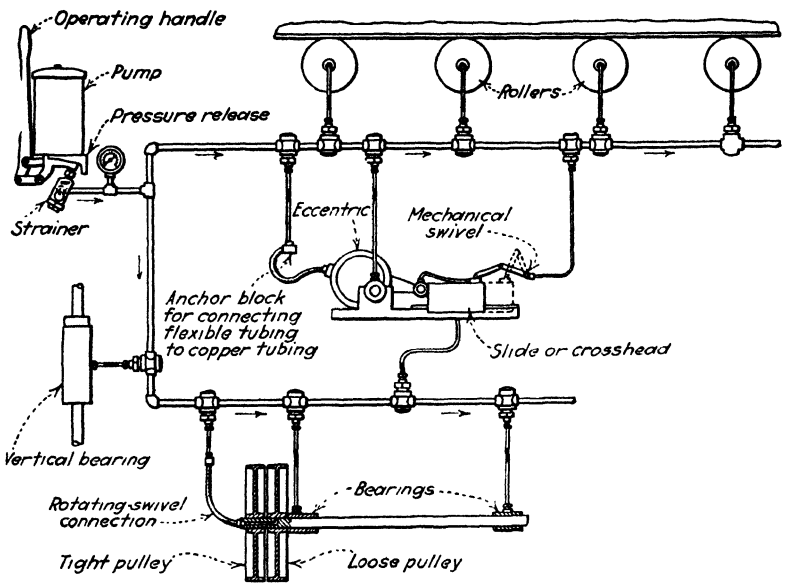


FIG. 178.—Schematic diagram, showing possible applications of a centralized greasing system. (*Courtesy Stewart-Warner Corp.*)

the plunger assembly upward, thereby subjecting grease in chamber B to pressure. Since the grease is prevented from escaping back into the line, by ball check valve C, it is forced by cup leather L into chamber D, thus charging the feeder for the next operation. This feeder is so designed that no more grease than the volume of chamber D can be forced into the bearing at one application.

Figure 178 is a schematic diagram of a manually operated system employing these feeders. This system comprises: a central pump-reservoir unit, which may be mounted at any

convenient place on or near the machine; feeder valves; and necessary piping, fittings, etc., for connecting the pump-reservoir unit to the bearings. The pump is actuated until a line pressure of 2000 lb. is built up. Then, pressure is released into the line by a valve at the pump, at which time a measured quantity of grease is forced into all bearings by the feeders.

CHAPTER X

OIL-PURIFICATION METHODS

Lubricating-oil cost is generally small in comparison with other operating expenses such as for labor and fuel and other supplies. Plant engineers, however, cannot afford to throw away large quantities of lubricating oils after short periods of use, nor can they afford to risk lubricating expensive machinery with dirty, contaminated oils.

1. Type of Impurity.—All lubricating oils, regardless of the type of crude from which they are made, methods used in refining, and provisions made to exclude foreign substances from the oiling system, undergo in service certain chemical and physical changes and become contaminated with foreign substances. Some oils undergo more extensive and faster chemical and physical changes than others, and some oiling systems are more effective in excluding dirt, dust, water, and other contaminants from the oil. Irrespective of the original purity of the oil and effectiveness of the system in keeping out impurities, oils become unfit for service unless cleaned.

Two kinds of impurities accumulate in oil systems: One class includes substances that are extraneous or foreign to the oil. The other comprises inherent impurities chemically formed by the oxidation of the oil while in service. The latter also includes substances present in the crude or introduced for refining purposes and not completely removed from the finished oil.

Foreign impurities may be either solid or liquid. Solid impurities usually consist of dust and dirt from the atmosphere, carbon particles resulting from burned fuel and lubricating oil. In circulating-oiling systems, grains of sand, loosened by hot oil flowing through oil ducts and passages, and iron oxide as a result of corrosion of oil pipes, reservoirs, sumps, etc., find their way into the oil. Liquid impurities may be either water from leaky glands or oil coolers or moisture condensed out of the atmosphere. They may also include diluents, in the case of internal-combustion

engines, and various chemicals and liquors where used in manufacturing processes.

The accumulation of foreign impurities is independent of the original purity or quality of the oil. The extent to which they are present in the oil depends on the surrounding atmospheric conditions, on the design and mechanical condition of the lubricating system, and on how effective bearing seals and reservoir gaskets are in excluding dirt and water.

Inherent impurities may be divided, according to their sources, into three general groups:

1. Crude impurities, such as sulfur compounds, which, owing to incomplete refining, have not been removed from the finished oil.

2. Refining impurities, such as water, various acids, alkalies, solvents, and other chemicals used in the refining processes and which have not been removed completely from the finished oil.

3. Formed impurities, which consist mainly of oxidized hydrocarbons, developed as a result of chemical reactions in the oil itself.

Obviously, the extent to which inherent impurities are present depends on the character of the crude, the refining processes, and the care exercised in refining the finished oil. These impurities combine both chemically and mechanically with foreign impurities to form what is commonly called *sludge*. The character of sludge varies widely, depending upon the nature of the original oil and the degree to which it has been exposed to foreign impurities. It has been proved that most foreign impurities act as catalyzers to promote oil oxidation and sludge formations. It behooves operators, therefore, to keep foreign impurities out of the oiling system as much as possible.

2. Effects of Impurities.—If impurities are permitted to collect, the oil becomes unfit for further use. This is not due to the oil wearing out or losing its lubricating properties, as many believe, but to the fact that it becomes contaminated with detrimental impurities, which are likely to clog oil ducts, holes, passages, and pipes. Moreover, many solid impurities are of an abrasive character and cause excessive wear. Sludge is usually of an acid nature and if permitted to collect for any appreciable period will cause corrosion, especially to highly polished surfaces.

Removal of impurities from oil is, therefore, most essential if lubricating difficulties are to be avoided. It has been proved that if impurities are removed constantly or at frequent intervals the reclaimed oil is as good as, and some think better than, new oil.

3. Steam Turbines.—Steam turbines are lubricated by means of a circulating system or ring oiling, or sometimes by a combination of these two systems. The oil is used over and over and continuously agitated in the presence of heat, air, and, usually, some water. These conditions are very favorable to oil oxidation and emulsification, especially if foreign impurities are present. Water is nearly always present and may come from leaking shaft-packing glands, leaking water pipes in the oil cooler, and moisture from air drawn in the system and cooled below its dew point.

Heat in the oil is generated by shearing the oil films in the bearings and is conducted from the steam through the spindle and housing. Air is present in the bearing pedestals, the reservoir, and many other points in the system. In the bearing pedestals, a constant mist of oil is sprayed from the bearing ends and intimately mixed with the air. If the return lines from bearings and governor gear discharge above the oil lever in the reservoir, air is beaten into the oil at this point. Unless the suction of the pump is kept submerged at all times, air will be drawn into the system and intimately mixed with the oil.

Solid impurities are always present in steam-turbine oiling systems. Some remain in the system after cleanings, and others enter with the air while the machine is operating. Core sand, rust, and other particles of foreign material loosen by the rapid flow of hot oil through the pipes, ducts, and passages and are circulated with the oil unless effective screens are provided.

Impurities, coupled with the effect of heat, rapid circulation, and aeration, cause the oil to oxidize, with resulting sludge and emulsion formations. Sludge usually coats oil-cooler tubes and restricts the flow through the piping, passages, and ducts. This reduces cooler effectiveness and causes an increase in oil operating temperature, which in turn increases the rate of oil oxidation and sludging.

4. Steam Engines.—Where compounded oils are used for lubricating the cylinders of steam engines, it is very difficult to reclaim the cylinder oil. Equipment required is expensive and the quantity of oil used is relatively small, so that it usually does

not pay to reclaim it. On the other hand, a considerable quantity of oil is used for the main, crosshead, and crankpin bearings, which can be reclaimed without much difficulty.

External parts of steam engines may be lubricated by any one of several methods or by a combination of two or more. Methods commonly used are drop feed, wick feed, splash; force-feed circulation; and combination splash and drop feed and combination splash and force feed.

Regardless of the oiling method, foreign matter, especially water and sludge, collect in the crankcase sump. Most of the water comes from steam leakage through the piston and valve-stem stuffing boxes and is subsequently condensed. A small amount may be condensed atmospheric moisture.

Solid impurities are always present and consist of rust, atmospheric dust and dirt, metal particles, and other substances. When boiler feed water is treated, chemicals used for this purpose may be carried over with the steam and then through leaky glands find their way into the crankcase oil. Where such conditions exist, the task of reclaiming the oil becomes more difficult and expensive.

5. Internal-combustion Engines.—All types of internal-combustion engine impose severe service on the lubricating oil. Temperatures and bearing pressures are high. In designs that employ oil-cooled pistons, the lubricating oil is not only required to act as lubrication but also cools the pistons. In such cases, the oil is subjected to the intense heat of the piston top, which causes cracking of the oil. In most cases, blow-by occurs, which contaminates the oil with exhaust products, such as sulfur compounds, water, carbon, carbon dioxide, and other gases. Where water-cooled pistons are used, water leaks are common and a considerable quantity of water may find its way into the lubricating oil.

These impurities, plus the heat and rapid circulation and splashing of the oil, promote oxidation and sludging. It is obviously desirable to remove the contaminations constantly or at frequent intervals.

6. Air Compressors.—Methods employed for lubricating air compressors are similar to those used for steam and Diesel engines. The service, however, is not so severe. Temperatures are generally lower, and the oil is not exposed to steam or products

of combustion. Consequently, the rate of oil deterioration is lower than for steam and Diesel engines. Purification is necessary, however, because of the gradual accumulation of atmospheric dust, dirt, rust, and other substances.

7. Refrigerating Compressors.—Refrigerating compressors are similar to air compressors, except for the added factor of the refrigerant. It is impossible to keep the lubricating oil entirely away from the refrigerant, which generally has a harmful effect on the oil. Anhydrous ammonia has no effect, but in the presence of moisture it forms ammonium hydroxide and causes sludging. Carbon dioxide has practically no effect on oil, but because of the low temperatures encountered an especially fluid oil is required. Both Freon and methyl chloride dilute the oil considerably, reducing its viscosity. Sulfur dioxide in the presence of water forms sulfurous acid, which may cause severe corrosion. Further, sulfur dioxide combines with the color-bearing material of oils and forms sludge.

8. Purification Methods.—No single method of purifying lubricating oil is best suited for all operating conditions and machines. Purification methods must be matched to the nature of the impurities involved and the operating conditions of the machine. Methods of purification may be divided roughly into three principal groups: (1) batch, (2) continuous, and (3) combination batch and continuous.

9. Batch Purification.—Batch purification provides for withdrawing the entire volume of oil, preferably while still hot, and running it into a settling tank. This oil should be permitted to remain quiet in the tank for at least 10 days. During this time, water and insoluble impurities gravitate to the tank bottom and much of the sludge, soluble in the oil at the normal operating temperature, becomes insoluble and settles out. Batch settling is the only method, generally accepted at present, for reducing the soluble content of lubricating oils.

For the purpose of increasing the rate of settling, batch-settling tanks are sometimes provided with steam-heating coils. Figure 179 shows a batch-settling tank without heating coils, and Fig. 180 one with these coils. Where time will permit, more thorough clarification is obtained without coils. Furthermore, practically no settling will occur while the oil is being heated, because of the convection currents created.

Clarified oil should be withdrawn with care to prevent remixing the settlings and oil. This can be done by providing a float suction, as in Figs. 179 and 180.

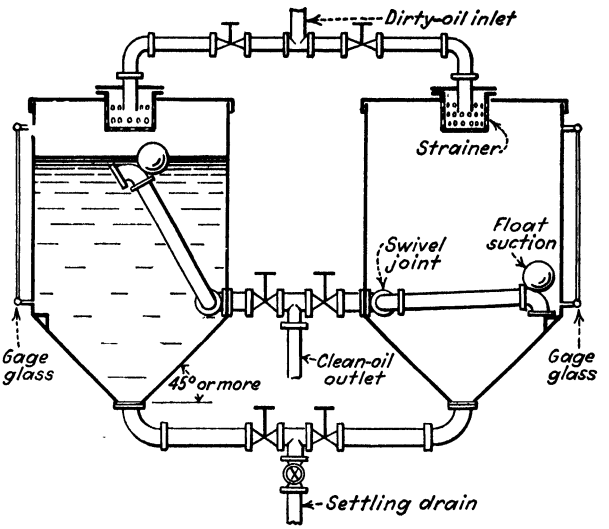


FIG. 179.—Self-cleaning batch-settling tanks.

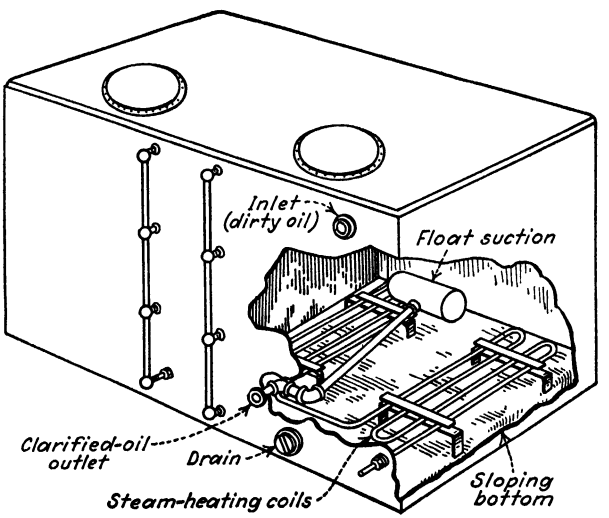


FIG. 180.—Another design of batch-settling tank that requires less headroom than Fig. 179.

Disadvantages of this method are as follows: (1) Two complete batches of oil are generally required. (2) It is generally neces-

sary to shut down the machine to change the oil. (3) Considerable space is required for settling tanks. (4) At least 10 days are required for thorough clarification. (5) Impurities are not removed as they collect but build up to some predetermined concentration, at which time the batch is withdrawn and purified. Obviously, for a considerable period the oil may be heavily loaded with impurities and is practically never clean. Under certain conditions, disadvantages 2, 3, and 4 are not of any consequence. For example, in many instances the schedule of oil purification can be arranged to coincide with regular shutdowns for cleaning and overhauling.

In general, equipment required for batch purification is relatively inexpensive and simple. The purifier itself is generally easily made and may be only an old discarded steel drum or wooden barrel. It is recommended, however, where any considerable quantity of oil is to be purified, that a special tank or tanks should be obtained, similar to those of Figs. 179 and 180. It will usually be found advisable to provide two tanks; furthermore, wherever headroom is available, conical bottoms are recommended. This type of bottom, if sloped 45 deg. or more, makes the tank practically self-cleaning.

Batch purification is adaptable to all mineral oils, such as those commonly used for lubricating steam turbines and engines, Diesel engines, air and refrigerating compressors, and other similar machines.

10. Continuous Purification.—Continuous purification provides for continuous cleaning of all or any part of the oil each cycle as it is circulated through the system. When only a part of the oil flows through the clarifier each cycle, it is commonly called a *by-pass purification system*, as shown in Figs. 181, 182 and 183. A continuous purifier may be simply a fine-mesh metal screen or strainer or a cloth strainer, or it may be any one of several designs of gravity and pressure-type filter, or of various types and designs of centrifuge.

Screening is the simplest and one of the most commonly used methods of continuous purification. It is frequently used in combination with other devices and methods to relieve other parts of the purifying system of wear and tear. Its use is limited to removing the coarse contaminants, such as metal chips and particles or grit and scale. Soluble sludge, acid constituents,

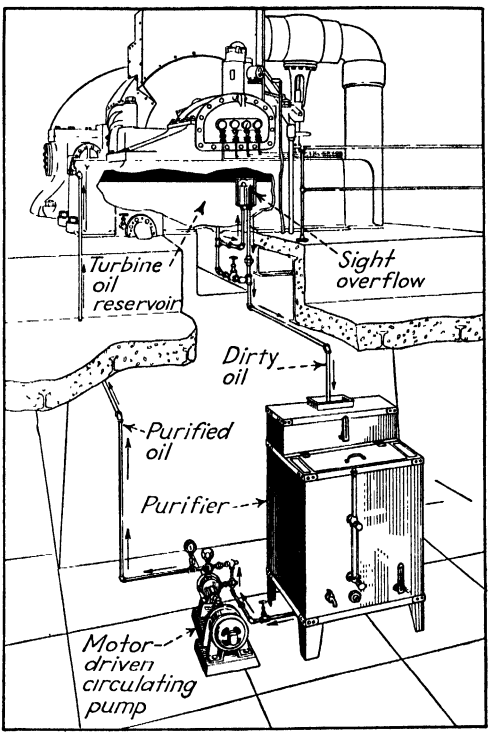


FIG. 181.—Continuous by-pass purification system applied to a steam turbine.

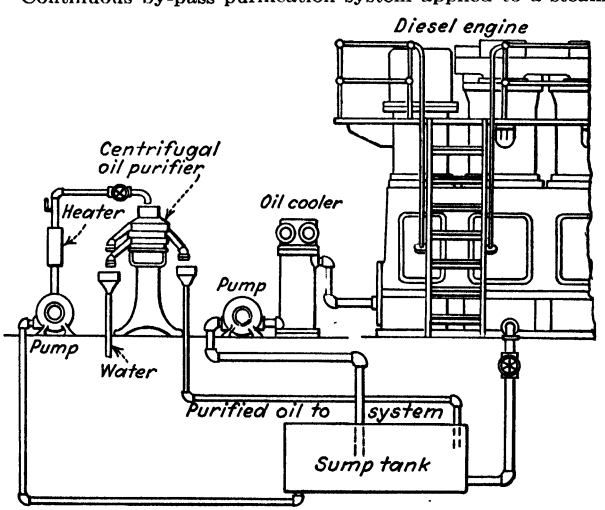


FIG. 182.—Continuous by-pass system using a centrifuge for purifying Diesel-engine oil.

water, the finer insoluble-sludge particles, and atmospheric dust cannot be removed by screening.

The continuous method of purification, where all oil flows through the clarifying device, has the disadvantages that the equipment required, in most instances, is large; its initial cost is out of proportion to the savings; and only a relatively small proportion of the soluble products of oxidation is effectively removed. Comparatively recently, however, small high-capacity-by-pass pressure filters have been designed that largely overcome the first two disadvantages.

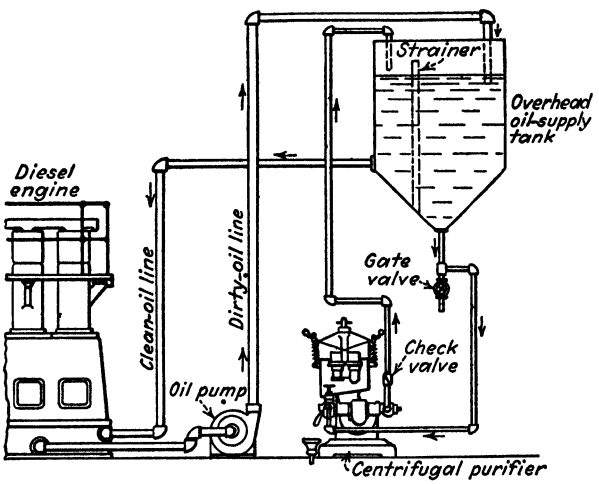


FIG. 183.—Continuous by-pass system using a centrifuge for purifying oil of a gravity-circulation-oiled Diesel engine.

In the by-pass system of continuous purification, oil is taken from the reservoir bottom, where water, sludge, and other impurities collect, and a portion of it is passed through the purifier, the remainder being circulated as usual. The purified oil is returned directly to the main reservoir.

In this method, usually about 10 per cent of the oil per cycle is circulated through the clarifier; hence, the equipment is smaller and costs less than when all oil is passed through. The degree of purification of the oil is much less than when all oil is passed through the clarifier each cycle. In either case, soluble products of oxidation, etc., are not removed, so that their concentration gradually increases. This concentration eventually becomes so

high that the oil must be changed or else batch-treated to remove them.

Combination batch and continuous purification in most instances is a combination of the batch and the by-pass methods. The by-pass part of the treatment partially removes water and other insoluble impurities while the oil is in service. This retards the rate of oxidation and guards against formation of severe emulsions. The batch treatment periodically removes all insolu-

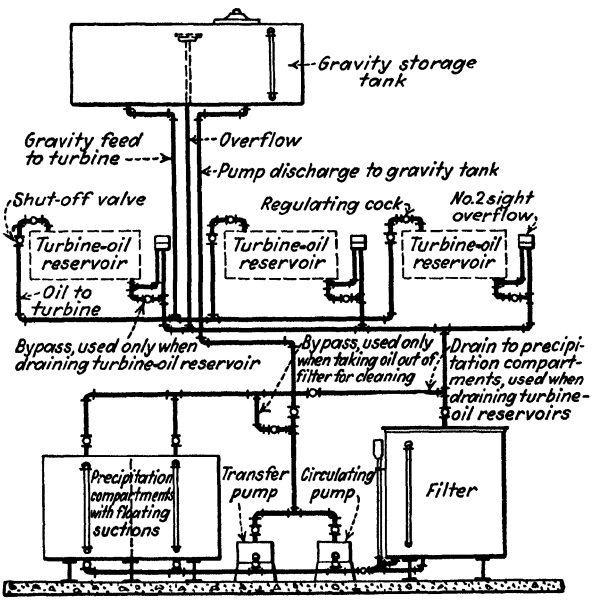


FIG. 184.—Combination batch and by-pass purifying system arranged so that one filter and one pair of settling tanks serve three turbines.

ble impurities and reduces soluble impurities to a point at which they are no longer a detriment. This method is very widely used for purifying steam-turbine oils.

11. Gravity Purifiers.—Gravity-type purifiers remove impurities from lubricating oil by screening, precipitation, filtration, and washing with water. In general, provisions for performing these processes are incorporated in a single unit.

Screening consists of passing contaminated oil through a fine-mesh metal cloth or perforated metal plate. Screening, invariably the first process, removes any coarse, solid impurities that

may have got into the oil, thus relieving the precipitation chamber and filtering elements of doing this job.

The precipitation or settling process employs gravity to separate impurities from the oil. Most impurities, including water, are heavier than clean oil and settle out readily. Others, however, have the same or practically the same specific gravity as oil and cannot be removed by precipitation. The more nearly equal the specific gravities of oil and its impurities are and the more viscous the oil, the greater the time required for separation.

Fortunately, heating reduces both the specific gravity and viscosity of oils, and so oil is generally heated by steam coils or electric heaters to decrease time required for precipitating impurities. However, more thorough clarification can be had by not heating, provided that sufficient time can be given to the process. This is because sludge that is insoluble and would precipitate at the lower temperatures becomes soluble at higher temperatures and will not settle out. Quicker settling is effected by causing the oil to flow through the precipitation chamber in shallow or thin layers. This is generally accomplished in the purifier by the use of baffles or trays, which divide the mass of flowing oil into relatively shallow layers.

All impurities cannot be removed by screening and precipitation, and so some other method must be incorporated within the purifier to complete the cleaning. Basically, this is generally screening, with fabric instead of metal screens. Some designs use cotton waste, wood wool, felt, excelsior, or some other loose material as the filtering medium. Others use a filter bag of special cloth supported by a metal frame.

It is generally desirable to have the filtering element arranged in several units, so that any unit can be removed for cleaning or be quickly replaced by a clean one without interfering with filtering. When oil contains very fine particles, a large filtering area and a slow rate of flow through the element are required if satisfactory clarification is to be secured. Even with a finely woven cloth-filtering element and a slow rate of oil flow, soluble sludge is not removed to any appreciable extent. It is therefore desirable to pass the oil through at as low a temperature as possible.

Figure 185 shows one design of a precipitation chamber. *A* is the primary screen through which contaminated oil flows into the filter and then over heating steam coils *B*, the specific gravity

and viscosity of the oil being thus reduced. Oil then flows down through tube *C* and out over baffle *D*. It next flows upward in a zigzag course, passing under and over precipitation trays *E*, *F*, *G*, and *H*. The flow is at a slow rate, and the oil is divided into relatively shallow layers by the trays.

The heavier impurities and most of the water are precipitated at baffle *D*. Any remaining water precipitates into the trays and

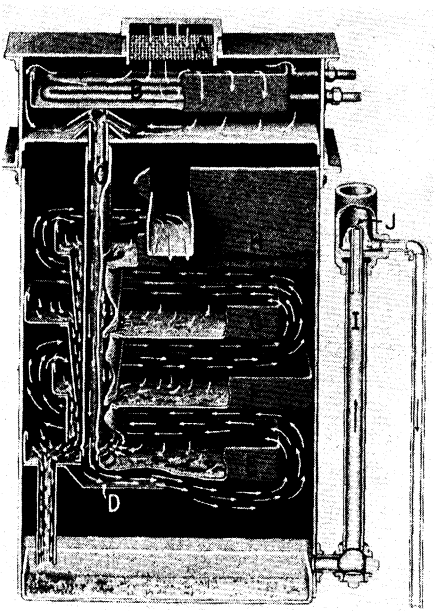


FIG. 185.—Gravity-type precipitation chamber. (*Courtesy S. F. Bowser and Co., Inc.*)

is returned to the bottom of the precipitation chamber by funnel-shaped cups surrounding tube *C*. As water accumulates in the bottom of the chamber, it is forced to rise through overflow *I*. Gradually, water in this column is overbalanced by oil and water-head in the precipitation chamber, and it then overflows at *J* until the two columns are again balanced. Overflow tube *J* can be adjusted for oils of different specific gravities.

Oil after passing the trays overflows through the trough into the filtering chamber, as in Fig. 186, completely submerges filter

units *B*, then flows through and out clean-oil outlets *C* into clean-oil chamber *D*. When one filtering element is removed, its passage *C* is automatically closed by a spring-actuated valve. This valve automatically opens when the unit is replaced. Pressure forcing the oil through filtering elements is the same at all levels, being equal to the differences in height between oil level in the filter chamber and the outlets *C*, normally about 3 in.

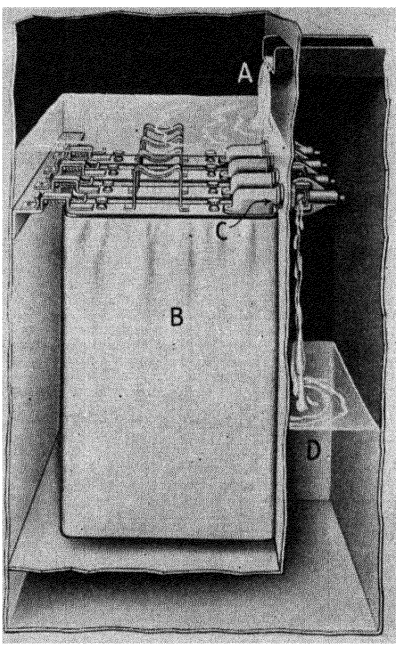


FIG. 186.—Gravity-type filtering chamber. (*Courtesy S. F. Bowser and Co., Inc.*)

This head adjusts itself to the rate at which the filter is being worked. When head is abnormally high, either the filter is being overworked or elements need cleaning and an investigation should be made to determine the cause.

The purifier, shown in Fig. 187, is similar to the one in Figs. 185 and 186. Contaminated oil enters through screen *A* and, after passing over heating coils *B* and through screens *C* and *D*, flows into vertical tube *E*. When it discharges from the lower end of this tube, the oil spreads out under the bottom saucer-shaped tray, takes a zigzag course upward, over and under the

other trays, and finally is discharged through pipe *A* into the cylinder filter *B*. It then flows outward through filter bag *C* into clean-oil chamber *D*. Water separated from the oil in the precipitation chamber is automatically removed through the overflow at the left.

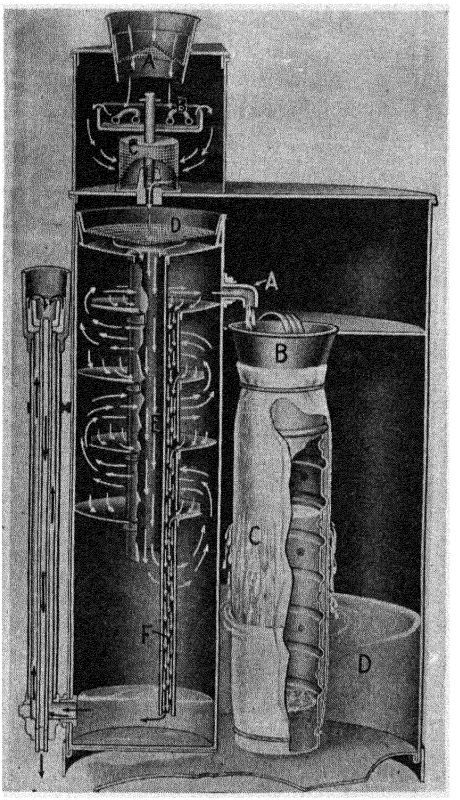


FIG. 187.—The heavier impurities are removed by the screens at the top, and the water and oil flow upward over the saucer-shaped trays; final purification takes place in filter *C*. (*Courtesy S. F. Bowser and Co., Inc.*)

This purifier, as well as the one in Figs. 185 and 186, operates on what is commonly termed the *dry method* of purification, since the oil does not flow through water for washing.

Figure 188 is a sectional view of an oil filter employing the wet method of purification. In this filter, contaminated oil enters pan *A*, heated by hot water, where the heavy impurities are precipitated into the sediment tray to relieve the filtering cylinder

of this burden. Packed in the filtering cylinder is a small quantity of animal bone black, through which the oil percolates to flow down tube *B*. From the lower end of the tube, it flows slowly over filter plate *D* in a very thin layer, the thickness gradually decreasing as flow progresses to the outer edge of the plate. From the edge of this first plate, oil rises to a second plate, by which it is gathered toward the center, where it passes through holes to a third plate, where it is again spread into a thin layer as it flows from the center to the outer edge. This atomizes the oil and exposes it to a washing action as it floats slowly up through the water contained in chamber *D*, which is maintained about one-third full. From chamber *D*, clean oil is drawn off through cock 1. Surplus water is drawn off through cock 2, or the purifier may be equipped with an automatic overflow. Any remaining impurities fall to the bottom and drain to the sewer.

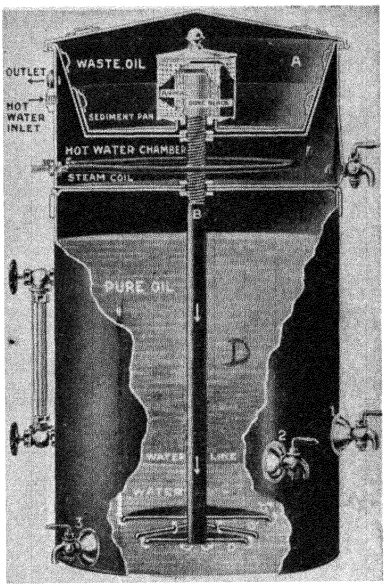


FIG. 188.—Preliminary filtering takes place in the top chamber and final purifying is done as the oil flows up through the water in the bottom of the tank. (*Courtesy Burt Mfg. Co.*)

In Fig. 190, contaminated oil passes through washable filtering materials *E*. It then flows down into the precipitation chamber. In this chamber, water and heavier impurities settle out, the oil rising to the top and overflowing through vertical tubes to filter bags *C* and *D*, through which it passes to the clean-oil chamber surrounding the bags. Purified oil is withdrawn through cock *B* at the bottom.

Figure 191 shows a small batch purifier specially designed for filtering not only the oil drained from the crankcases of steam and gas engines and air and refrigerating compressors but also the drippings from other machinery. Contaminated oil comes in through the basket-type screen into the dirty-oil compartment on the left, where it may be heated by steam coils. After the

heat is turned off, the oil is allowed to stand in this compartment until water and heavy impurities settle out. This usually requires several days, after which the oil is passed to the filtering compartment by opening the connecting valve. An adjustable float valve automatically controls flow into the filtering compartment and maintains a head of 1 to 6 in. over the filtering units. The oil passes through them into the clean-oil compartment,

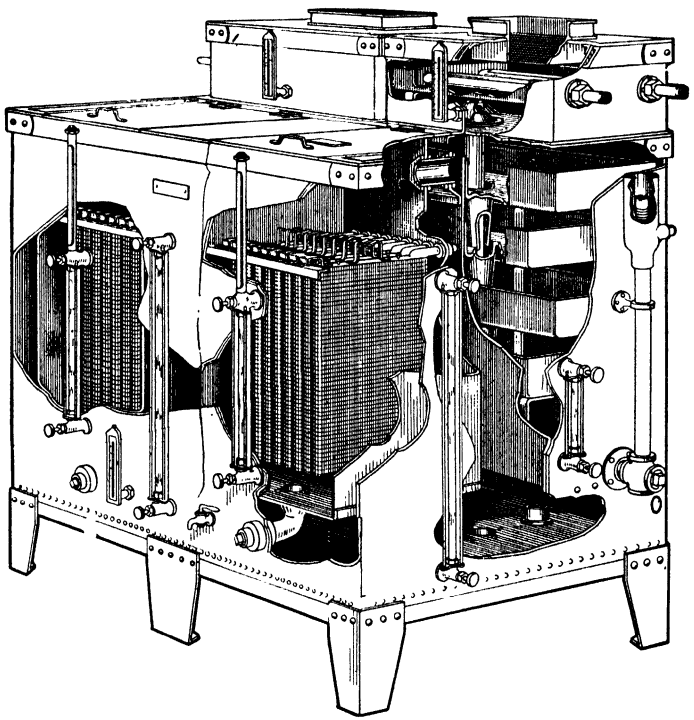


FIG. 189.—Duplex gravity-type filter operating on the same principle as Figs. 185, 186, and 187. (*Courtesy S. F. Bowser and Co., Inc.*)

equipped with a quart self-measuring piston-type pump for withdrawing the oil.

Gravity-type purifiers are suitable for filtering all types of lubricating oil. They are applicable wherever space is available and where they can be free of vibration and rolling and pitching motions and where the oil is supplied at atmospheric or a very low pressure. They are not suitable for the so-called *force-feed systems* of lubrication or for mobile machinery such as steamships

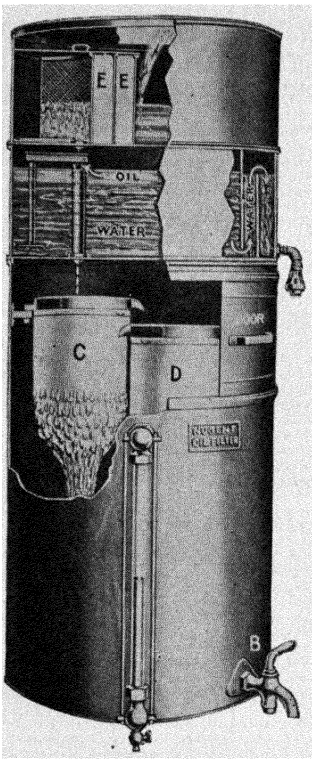


FIG. 190.—Small purifier using the wet process of purification. (*Courtesy Wm. W. Nugent and Co.*)

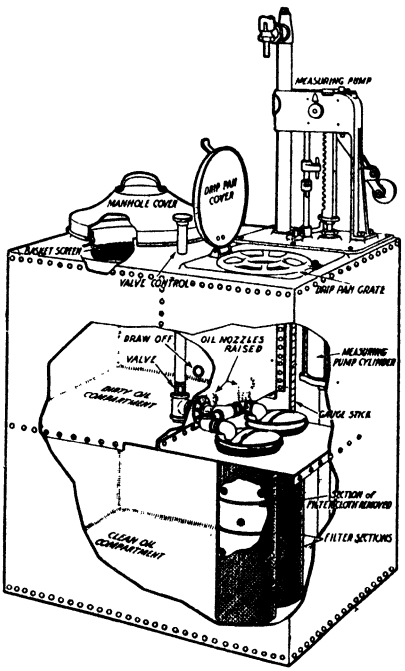


FIG. 191.—Small batch purifier specially designed for filtering engine and compressor crankcase oils.

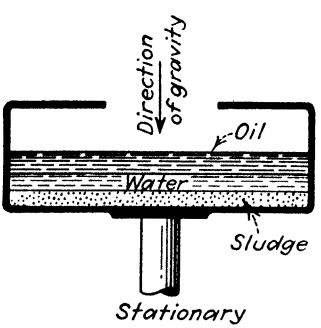


FIG. 192.

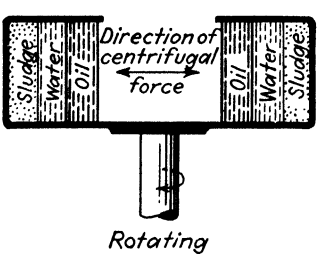


FIG. 193.

FIG. 192.—Principle on which a gravity oil filter operates.

FIG. 193.—A centrifugal purifier operates on the same principle as a gravity purifier, but the force acting to separate impurities from the oil is many times greater, and oil, water, and sludge are arranged in vertical layers.

and automotive units. They may be used in by-pass, batch-settling, continuous by-pass, and batch systems.

12. Centrifugal Purifiers.—Purification of lubricating oils centrifugally is fundamentally precipitation. It employs the same basic principle as the gravity-type purifier and batch purification. Centrifuging, however, is faster because the separating force is several thousand times that of gravity.

As in batch-treatment and gravity purifiers, the relative position of oil and various impurities depends on their densities. Figure 192 represents a stationary, shallow vessel containing a mixture of oil, water, and sludge. The only force acting on the mixture is gravity. Because of differences in specific gravities of these substances, if permitted to stand quietly they separate as shown. Figure 193 shows the same vessel rotated at high speed about its vertical axis. The mixture is now subjected to centrifugal force as well as to gravity, the former being as much as 64,000 times the latter in some modern centrifuges. In Fig. 193, oil, water and sludge are arranged as in Fig. 192, but in vertical planes instead of horizontal ones.

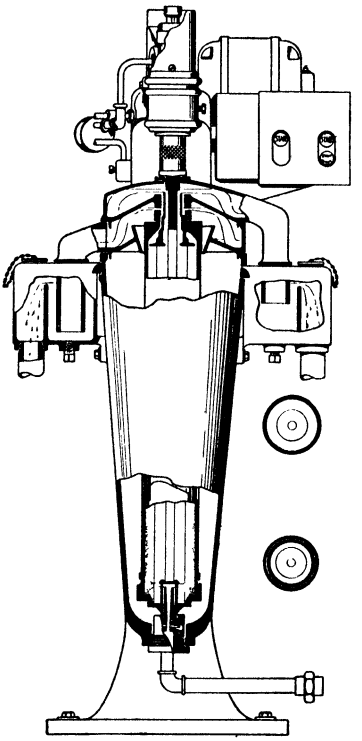


FIG. 194.—Centrifugal purifier with long small-diameter bowl in which oil is separated from its impurities. (*Courtesy Socony-Vacuum Oil Co.*)

If we neglect turbulence, the thinner the layer, the quicker separation will occur as the impurity travels at the same rate. This principle is embodied in actual centrifuges by two separate and distinct designs. In Fig. 194, liquid depth is reduced to a minimum by using a long, small-diameter bowl. The theoretical path taken by a solid impurity as the mixture flows upward through the bowl is in an inverted spiral. The practical path is nearly a straight line to the outside of the bowl, as commercial

bowls have a three-wing blade to prevent swirling and to shorten the effective distance the impurity must travel. The heavier the impurity, the quicker it is thrown out. Consequently, the heaviest impurities collect near the bottom, where dirty oil enters the bowl.

The center of the bowl is occupied by a solid cylinder of oil with an air space in its center; water surrounds the oil in the form

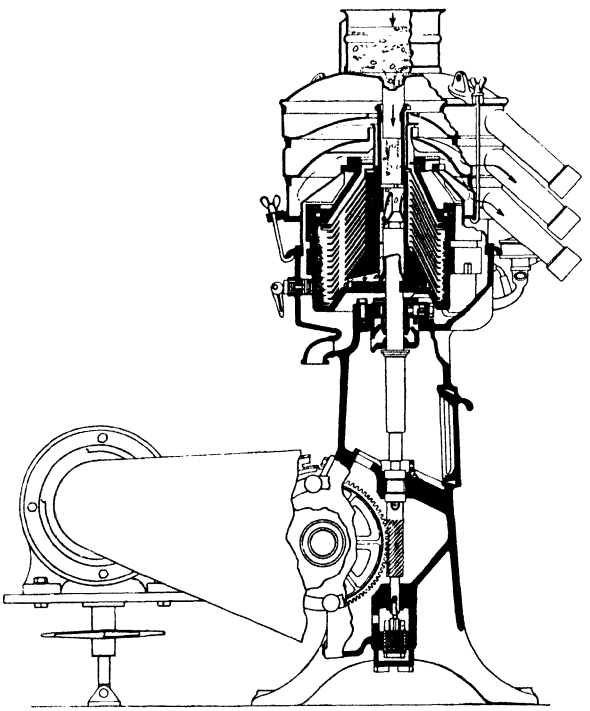


FIG. 195.—Oil in this centrifugal purifier is divided into thin layers by disks to increase rate of separation. (*Courtesy Socony-Vacuum Oil Co.*)

of an annular cylinder, and impurities are deposited against the inside surface of the bowl. At any point, static pressure upward equals that downward. Oil, being lighter than water, requires a higher head in order to balance that of the water. The amount of water or oil held in the bowl at any one time can be governed by varying the difference in the head between the oil and water. From the foregoing, it is obvious that this head governs the radical position of the line of demarcation between oil and water layers in the bowl.

Practical advantages of such a design are the high efficiency of the nonturbulent streamline flow of liquid (providing a short direct path for the impurities to travel directly away from oil flow) and the ease of cleaning and handling the bowl.

Figures 195 and 196 show a design very different from that in Fig. 194 but based on the same fundamentals. The object of both is to remove impurities in the shortest possible time and in minimum space.

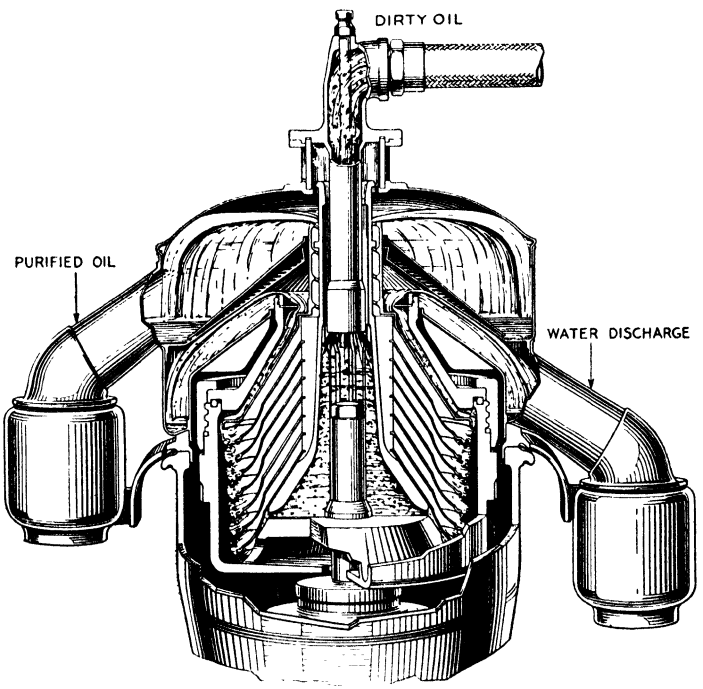


FIG. 196.—Cross section of bowl for centrifugal purifier, Fig. 195. (*Courtesy DeLaval Separator Co.*)

Figure 196 is a cross section of a bowl similar to that used in Fig. 195. In the bowl and rotating with it are frustums of cones or disks that divide the oil in thin layers and direct its flow. These cones speed up rate of separation, having the same effect as using a shallow gravity tank instead of a narrow deep one. Holes near the base of the cones permit flow up through them. Dirty oil flows in at the top and down a central pipe into the bowl. As it rotates with the bowl, centrifugal force causes oil to flow to the bottom.

As oil works its way up through holes in the cones, water and other impurities are thrown to the outside and cleaned oil flows up between cones to a passageway surrounding the central incoming pipe and out into the purified-oil discharge. Water thrown to the side of the bowl is forced up by the higher head of oil and overflows into the water discharge.

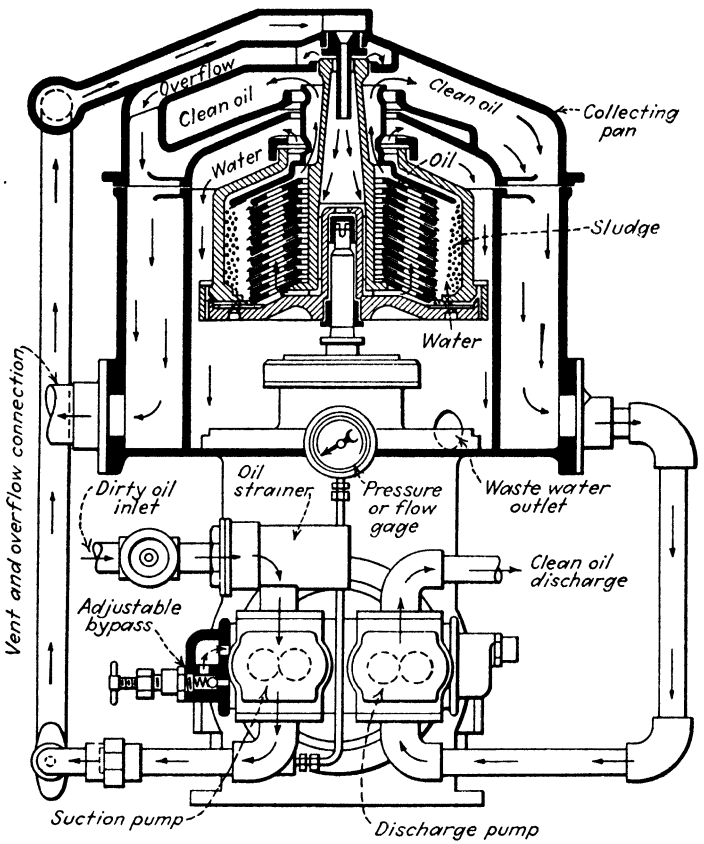


FIG. 197.—Dirty oil is delivered to this centrifugal purifier by one pump, and clean oil is discharged to the lubricating system or storage by another pump.

Figure 197 is another design of centrifuge. Dirty oil is pumped into the centrifuging bowl, and purified oil is delivered to the lubrication system or to storage by another pump. Flow of oil through the equipment is clearly indicated by the arrows.

The term *capacity*, as applied to centrifuges, is often used loosely. A centrifuge may be said to have two capacities:

1. Through-put capacity, which is the total quantity of oil that may be put through the machine regardless of the degree of purification effected and without overflowing.

2. Effective capacity, which is the quantity of oil that may be put through the machine with the desired degree of purification.

Effective capacity generally has no relation to through-put capacity. For example, a certain machine has a through-put capacity of 450 gal. per hr., whereas its effective capacity is between 200 and 300 gal. per hr. Obviously, through-put capacity is of little importance, but effective capacity is a major consideration to the user.

Effective capacity depends on many factors, the most important being: viscosity of the oil undergoing purification; temperature of the oil; amount, size, weight, and other characteristics of the impurities; degree of purification desired or required; and persistency of emulsion if water is present.

It is obviously impossible to evaluate all factors in advance of installation and, hence, to state that a certain machine has a definite capacity in so many gallons per hour. A capacity-temperature chart can be prepared to take care of viscosity and temperature, but not for the characteristics of impurities, degree of purification required, persistency of the emulsion, etc. In consequence, builders of these machines generally give effective capacities over a wide range, which frequently shows variations between the minimum and maximum capacities of as much as 100 per cent.

TABLE XXVI.—CAPACITIES FOR DIESEL-ENGINE SERVICE

Brake hp. of engine	Effective capacities, gal. per hr.		
	Viscosity, 200 S.U.S. or less		Viscosity, 300–400 S.U.S., continuous by-pass method
	Continuous by-pass method	Batch method	
300	...	...	30
600	60	40	50
900	...	...	75
1200	100	70	
1800	150	100	125
3600	300	200	

In general, the effective capacity of a centrifuge should be such as to render it possible to handle the entire batch of oil in the system every 2 to 6 hr., depending on the degree of purification desired and the operating conditions. Given in Table XXVI are effective capacities recommended by one builder for Diesel-engine service.

Centrifuge capacity may be increased by heating the oil before introducing it into the machine. Since all oils become less viscous upon heating, less resistance is offered to the passage of impurities

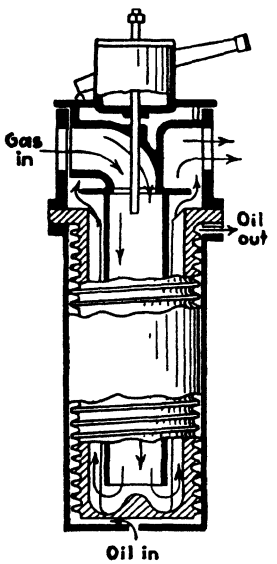


FIG. 198.

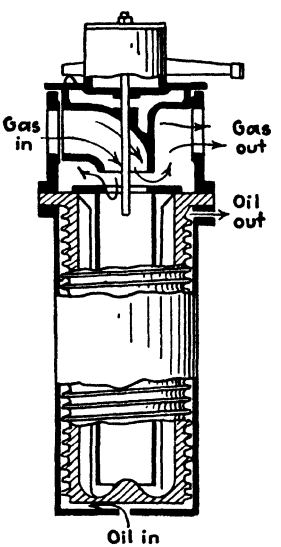


FIG. 199.

FIGS. 198 and 199.—Cross section of fuel- and lubricating-oil heater that uses exhaust gases as the heating medium. (*Courtesy Goulds Pumps, Inc.*)

through the oil; thus, separation is quicker at elevated temperatures. It is general practice to heat oil to a temperature between 160 and 180°F. before running it into the machine.

Where heating is practiced, it is usually done by means of exhaust gases in Diesel installations, electrical heaters, or steam coils. An increase of 30 to 40°F. will about double the rate of purification. If an oil contains solid impurities only, such as metallic, dust, and dirt particles, it may be purified faster than if water and minute carbon particles and soluble sludge are present.

Figures 198 and 199 show an oil heater for Diesel lubricating and fuel oil, using exhaust gas from the engine. Oil to be heated

flows into the bottom of the heater and upward along helical grooves in the outside of the heat exchanger, enclosed by a smooth casing. Exhaust gas flows down a central tube and then in a thin layer along the inside of the exchanger. To control flow of gas through the heater, the central tube is raised or lowered. In Fig. 199, all gas is by-passed around the heating element. Flow of gas through the heater is not cut off but is allowed to flow to prevent cooling and condensation in the piping connections. In actual operation, the position of the tube baffle is either thermostatically controlled and operated by an oil cylinder and piston or manually controlled to maintain proper oil temperature.

Centrifuges are said to operate as *clarifiers* when they are employed to remove impurities mainly and little if any water from the oil. In this case the discharge is a single effluent—purified oil. When they are used to remove both solid impurities and a considerable amount of water, they operate as *separators* and discharge two effluents—purified oil and water. In general, by making a simple adjustment, the same machine may be used as a clarifier or as a separator.

Dirt and sludge retained in the bowl should be removed at regular intervals—generally, once or twice a day is sufficient, depending on the quantity of impurities in the oil. Furthermore, all internal parts of the bowl should be cleaned periodically and rinsed in hot water.

Centrifuges, of course, will not separate liquids that are mutually miscible. For example, they will not remove diluent or kerosene from lubricating oils. For this reason, centrifugal purification has little if any effect on viscosity and flash and fire points. Unlike the filter, the centrifuge does not appreciably decrease in efficiency and capacity as purification proceeds.

The centrifuge lends itself to continuous, by-pass, and batch purification. It is adaptable to steam-turbine and -engine, air- and refrigerating-compressor, and many other services. It will effectively remove water, inorganic constituents (insoluble sludge), dust, dirt, coarse carbon particles, etc., but will not appreciably remove the so-called *colloidal* carbon particles or the organic acid constituents (soluble sludge). In general, purified oil is dark in color; if it is desired to restore the oil to its original color, or approximately so, it is necessary to batch-treat or filter

it through a chemical clay, such as fuller's earth or bauxite or a solution of sodium silicate in water (water glass).

13. Pressure Filters.—Pressure and vacuum type filters have become quite common with the introduction of force-feed circulating systems and are adapted to steam engines, air and refrigerating compressors, machine tools, internal-combustion engines,

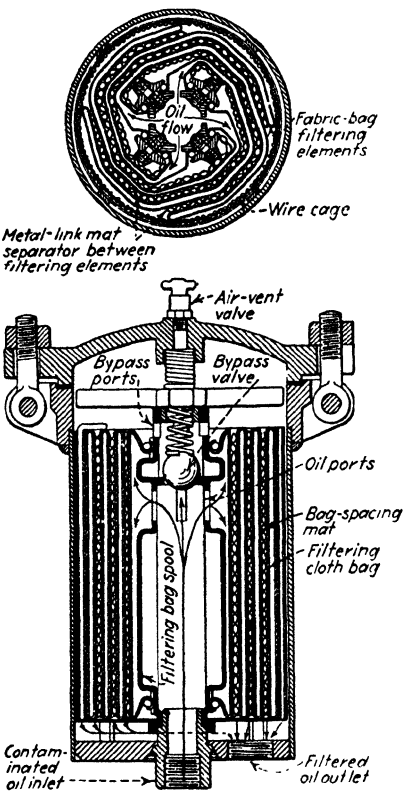


FIG. 200.—Large area is secured in this filter by using four bags having spacers between them and the whole rolled up to fit into the cylindrical housing.

gear drives, etc. Pressure and vacuum filters are identical in design, the difference being in the relative positions of filter and oil-circulating pump. If the filter is placed in the pump discharge line and, hence, is subject to a positive pressure, it is a pressure type. On the other hand, if the filter is in the pump suction line, it is termed a *vacuum filter*.

Figures 200 and 201 show two designs of pressure filter using cloth or fabric as the filtering medium. In Fig. 200, the filtering element comprises four fabric bags, with flexible-link metal matting separators between them, the whole being rolled up to fit into a cylindrical container. Oil enters the filter at the bottom under pump pressure and is forced along the path indicated by the arrows. As a precaution, a spring-loaded relief valve by-passes oil to the bearings to prevent the filtering element becoming

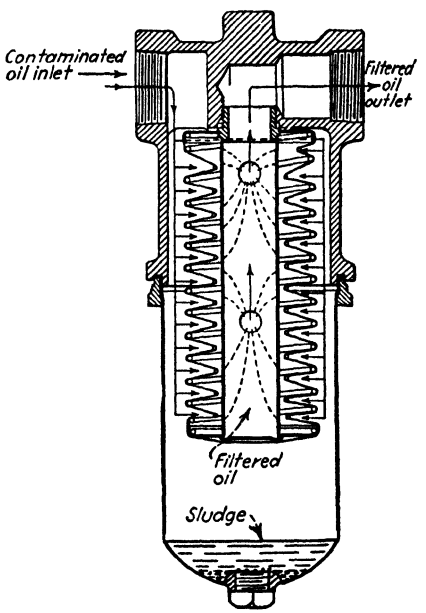


FIG. 201.—An extended area is obtained in this filter by winding the fabric filtering cloth over two helical springs of different diameters.

clogged with sludge. This filter is designed for a working pressure as high as 100 lb. per sq. in. and is available in capacities of 65 to 720 gal. per hr., based on an oil having a Saybolt viscosity of 182 sec. Filtering-element area varies from 2 to 21 sq. ft., depending on capacity. Filtering elements are wool, linen, or cotton. Wool is generally recommended for use when the oil has a high sulfur content, and linen or cotton is used where a high degree of filtration is required, such as on large gears lubricated with a highly viscous oil.

In the filter, Fig. 201, oil is forced through the filtering element in the direction of the arrows, leaving the deposit of sludge on

outside surfaces. The sludge deposit acts as an additional filter bed, increasing effectiveness as deposit thickness increases. However, resistance to flow through the filter also increases. It is, therefore, necessary to wash the element periodically depending on the amount of impurities in the oil. In this filter, large filtering area is obtained by winding the fabric over two helical springs of different diameters, giving the appearance of a deep-root thread.

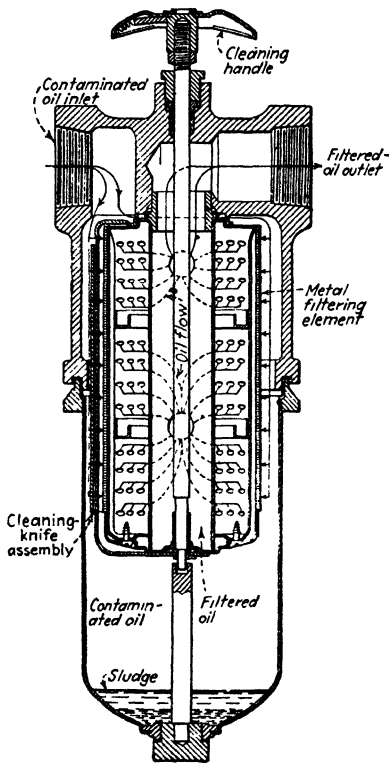


FIG. 202.—Cross section of a filter in which the filtering medium is a closely spaced metal ribbon wound on edge to form a cylinder.

Figures 202 and 204 show two metal-element pressure filters. In Fig. 202, the filtering element is constructed by winding a ribbon of bronze, monel metal, stainless steel, brass, or other metal edgewise to form a cylinder, which is placed over a corrugated frame. The ribbon has a flat front edge and tapers in cross section, as in Fig. 203, thus providing a wedge-shaped oil passage to prevent clogging behind the front edges. At regular intervals, projections of uniform height support the ribbon radially to the frame on which it is supported. Projection height, which varies from 0.015 to 0.0005 in., determines the degree of filtration. Oil flow is in the direction indicated by the arrows.

Two designs of knife cleaning mechanism are used on the filter, Fig. 202. In one, the knife is rotated by a handle while the filtering element remains stationary. In the other, the knife remains stationary while the filtering element is rotated.

The filter of Fig. 202 is obtainable in single-, double- and triple-element types, as well as in single-, double-, and triple-stage types. In multielement types, the filtering elements are arranged in

parallel and flow from each element into a common discharge header. In the multistage type, elements are in series and oil passes successively through each. This filter is obtainable in

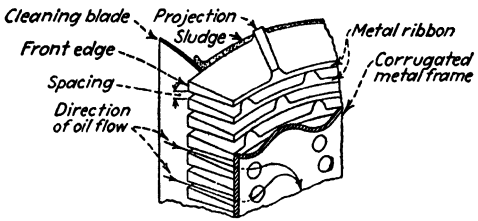


FIG. 203.—Enlarged section of the filtering element for the filter shown in Fig. 202.

capacities of 11.2 to 153 gal. per min., based on kerosene at 80°F. and 15 lb. per sq. in. pressure. Capacities, of course, vary with pressure, oil viscosity, and size of slots.

Essentially, the filter of Fig. 204 consists of a stack of round, thin, perforated disks, each separated from its neighbors by a thin metal spacer, the thickness of which determines the degree of filtration. Oil enters the filtering element from the outside, passes through the small spaces or slots between disks, flows up through the center, and passes out through the outlet pipe. Any solids larger than the thickness of the spaces between disks are prevented from passing through the filter and are held against the outside surfaces of the element.

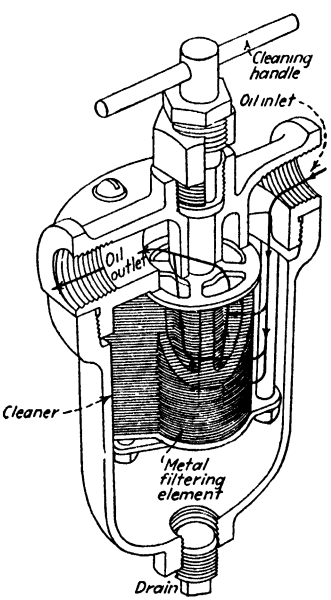


FIG. 204.—Filtering element in this type consists of a stack of closely spaced metal disks.

The layer of sludge accumulated on the outside surfaces of the filtering element acts as an additional filter bed and improves filter effectiveness. This accumulation, however, increases the resistance and makes necessary its removal, accomplished by a built-in cleaning device, as in Fig. 205. This consists of a fixed rod, to which is attached a series of cleaning blades, one of which extends

into the space between each pair of disks as far as the inner edge of the rim. When the central spindle carrying the disks is rotated, the cleaning blades scrape off the layer of sludge on the element and comb out any dirt that may have lodged between disks. One complete revolution of the element is required for a cleaning operation. Sludge thus removed sinks to the sump below the element, whence it is removed through the drain hole. Where continuous cleaning is desired, the filtering element is rotated continuously by means of an electric motor and the sump is provided with a shutoff valve so that it can be cleaned while the filter is operating.

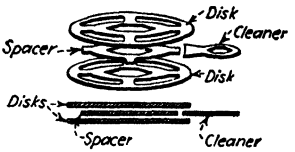


FIG. 205.—Showing how filtering disks and cleaning elements are arranged in the filter of Fig. 204.

This filter is obtainable in single-, double-, and four-element types varying in capacities from 5 to 900 gal. per min., based on oil having a Saybolt viscosity of 300 sec., spacing between disks of 0.006 in., and a pressure drop across the filter of 5 to 10 lb. per sq. in. Internal parts may be obtained, made of various materials in order to meet specific operating conditions. Materials frequently used are bronze, mild steel, and stainless steel; for extremely corrosive conditions, chrome-plated steel disks, cleanings, rods, etc., are used.

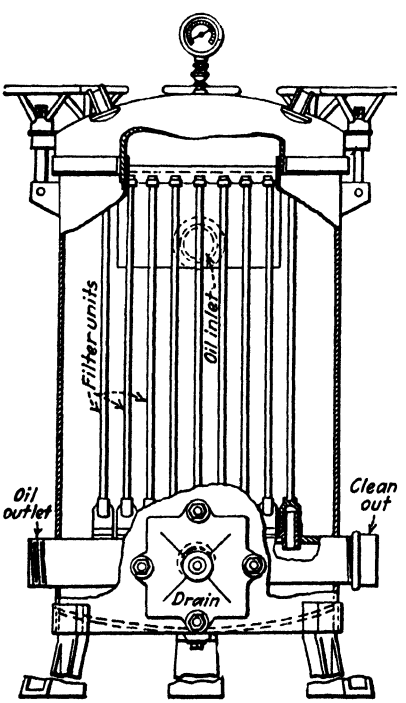


FIG. 206.—Multiple-bag type pressure filter.

Figure 206 is a section through a pressure type filter that may have six to nine filtering elements or plates, depending upon capacity required. These filtering plates may be cloth bags over a coarse-mesh galvanized-iron wire screen or they may be two pieces of fine monel-metal gauze with a

coarse-mesh screen inserted between them and the assembly bound around the edges with a sturdy frame, as in Fig. 207. The coarse-mesh screen is used to prevent filtering surfaces from touching under pressure, thus assuring an open channel through which the oil can flow. The choice of filtering material depends on service. For most bearing oils the cloth element meets the requirements, but monel metal is used for heavier, more viscous oils.

This filter is available in four sizes, varying in capacity from 5 to 200 gal. per min. and having filtering areas from 4.5 to 38 sq. ft. It is capable of withstanding a working pressure as high as 50 lb. per sq. in. Elements should be removed and cleaned when a differential of 12 lb. exists between the inlet and outlet pressures.

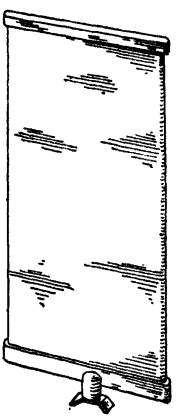


FIG. 207.—Filtering element for the filter shown in Fig. 206.

A pressure by-pass type filter designed for large stationary internal-combustion engines is shown in Fig. 208. It contains three molded cylindrical hard-baked blocks of adsorbent minerals. Each of the two elements on the left contains 5¾ lb. of bauxite and 3¾ lb. of wood-fiber cellulose. The element on the right contains 13 lb. of fuller's earth and ¾ lb. of cellulose. Various combinations of bauxite and fuller's-earth elements are used, depending on the characteristics of the dirty oil. Various numbers of elements are used, also, depending on the size of the engine.

The dirty oil from the engine enters the housing through the ½-in. pipe in front and at the bottom. It flows radially inward through the elements from which it is discharged into the 3-in. manifold in the rear at the bottom. From this manifold the oil flows back to the engine. The pressure-relief valve at the right end is connected directly from the inlet to the outlet and ensures that the filter is operating under the correct pressure.

This filter is efficient in removing not only solid impurities but also asphaltenes, carbonaceous materials, and other constituents having acid- and sludge-forming properties.

The pressure-type filter, in Fig. 209, is designed for internal-combustion engines in capacities of 2 to 200 gal. per hr. Its filtering elements are hundreds of paper disks or washers, about

1.5 in. in diameter, specially treated to resist deterioration, and stacked or assembled around a tube, with a helical spring that presses them together with a force of 80 lb. Oil under 30 lb. pressure enters the housing near the bottom, completely submerging the filtering elements, through which it flows in a radial direction to their centers and thence upward to a manifold at the top. From the manifold the oil returns through the three-way valve either to the machine oiling system or to a purified-oil

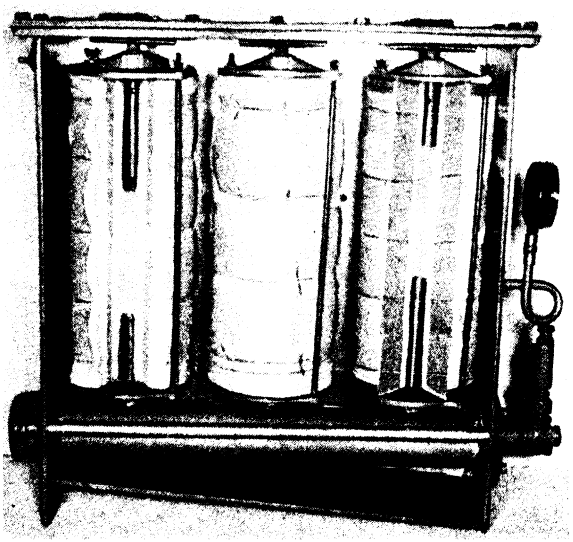


FIG. 208.—Pressure filter suitable for stationary and marine Diesel and natural-gas engines. (*Courtesy Briggs Clarifier Co.*)

tank, depending on whether the filter is used with a by-pass or batch system of purification.

This filter employs what is commonly termed *edge filtration.* It is claimed that the maximum width of the spaces between the disks is less than 0.00004 in., an exceedingly fine screen being thus provided. In some designs an electrically driven rotary pump or an air-pressure type receiving tank may be provided for delivering the oil to the filter at a pressure of not more than 30 lb.; in the design of Fig. 209 an inlet orifice controls oil pressure.

In all designs, filtering elements are cleaned by compressed air. After the filter is drained, a compressed-air hose is attached to the three-way valve at the outlet and air is blown through the

elements in the opposite direction to that of oil flow. Thus, any sludge that may have collected on the outer surfaces is dislodged and drops to the bottom, where it is removed through the drain.

The division plate has two by-pass valves, one for by-passing oil in cold-weather starting and when the oil is too viscous to be pumped through the filtering elements, and the other for relieving air pressure above 40 lb. when the elements are being cleaned.

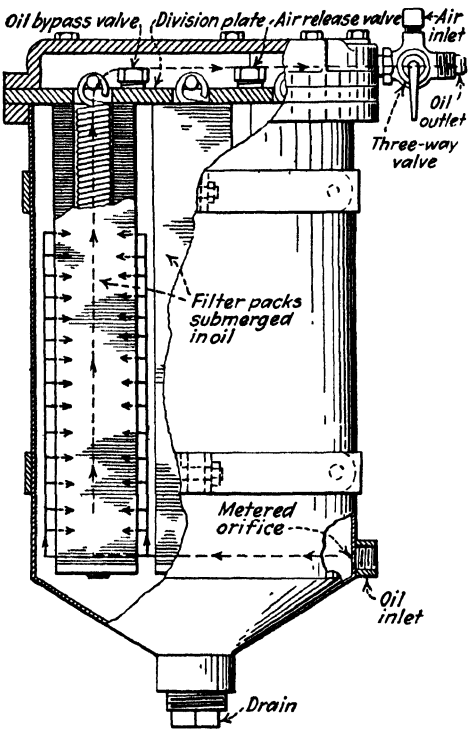


FIG. 209.—Filtering elements in this filter are comprised of stacks of special paper disks held together by helical springs.

This filter may be obtained either with thermostatically controlled heating elements or with a hot-water or steam-heated jacket for heating the oil to the recommended temperature of 160°F. In internal-combustion engines, the hot-water jacket may be connected into the cooling system of the engine. Also, for internal-combustion-engine service where dilution is excessive, an electrically heated rectifier may be used.

CHAPTER XI

LUBRICATION OF BALL AND ROLLER BEARINGS

In the operation of machinery equipped with antifriction (ball and roller) bearings, correct lubrication is of vital importance. It ranks with proper mounting and the selection of the right type and size of bearing for its particular duty. Because the operation of antifriction bearings is so simple and easy, inadequate attention is frequently given to their lubrication.

1. Functions of Lubricants.—It is little wonder, however, that lubrication is often not given the attention that it deserves, for an examination of recommendations on the subject reveals many conflicting opinions as to the proper lubricants and methods of application. The functions of a lubricant, however, are pretty generally agreed to by both the users and manufacturers of these bearings. These are:

1. To protect the accurately and highly polished surfaces from rust and wear.
2. To minimize friction between the stationary and moving parts.
3. To aid in the dissipation of heat generated by the deformation of the load-bearing parts and by friction.
4. To form a supplementary seal between stationary and rotating parts, which prevents the ingress of dirt, dust, and other abrasive materials and minimizes the leakage of lubricant from the bearing.

Antifriction bearings are accurately made; tolerances are frequently held to limits of 0.0001 in.; surfaces are ground and often lapped to an ultrafine finish. Such surfaces are naturally susceptible to rusting unless protected at all times by a correct lubricant.

It is shown in Chap. VIII that, fundamentally, rolling friction is caused by sliding action, as in plain bearings, guides, and crossheads. In addition to the rolling friction between the ball or roller and its races, sliding action also occurs between the ball and roller and the retainer. Points of such sliding are shown in Fig. 210.

2. Characteristics of Lubricants.—The required characteristics of lubricants for antifriction bearings are: (*a*) high chemical

stability, (*b*) minimum tendency to absorb moisture, and (*c*) maximum oiliness.

In all types of antifriction bearings, the load-bearing areas are so small as to produce very high unit-bearing pressure. Thus, unless the lubricant possesses sufficient viscosity to form a film capable of withstanding this high pressure, metal-to-metal con-

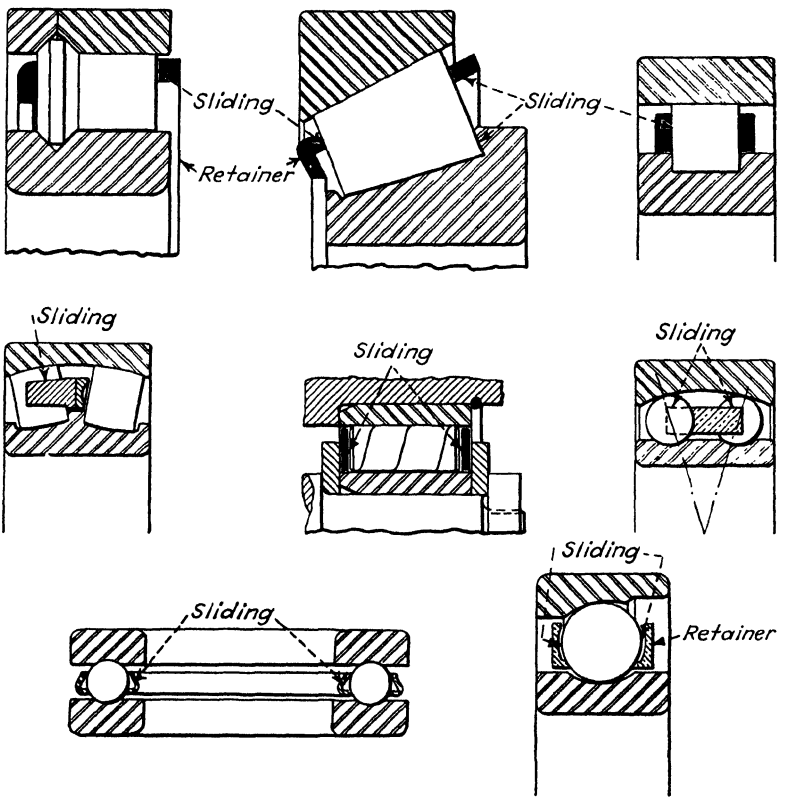


FIG. 210.—Points of sliding in antifriction bearings.

tact will occur, resulting in excessive wear and noisy operation. If the film does not rupture, it aids in distributing the load over a larger area, reducing the maximum pressure between the contacting surfaces, as in Fig. 211. It also cushions the balls or rollers as the load is alternately applied and removed during each revolution.

Under excessive load conditions that rupture the film, oiliness is of prime importance, for under such conditions the film is an

absorbed one and viscosity is virtually of no significance. A lubricant may possess a high viscosity but at the same time be deficient in oiliness; or, conversely, it may possess high oiliness and low viscosity.

Lubricants used for antifriction bearings should obviously be free from abrasive materials that act as lapping compounds. Rarely do lubricants contain such materials when they leave the refinery, but in too many instances they become contaminated through careless handling. Drums and other containers are left uncovered; gun fittings are seldom, if ever, cleaned; oil retainers and seals are neglected, the ingress of dirt and dust being thus permitted. In repair work, bearings are frequently washed with dirty gasoline containing rust, sand, and other abrasive materials.

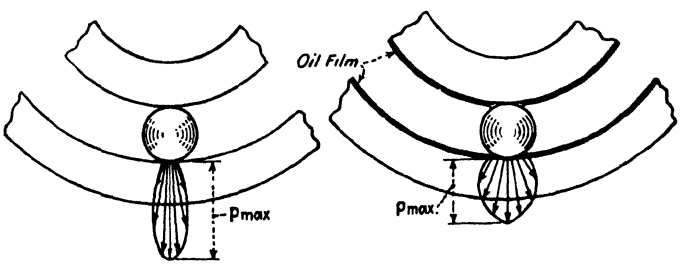


FIG. 211.—How an oil film aids in distributing the load over a greater area, thus decreasing the maximum intensity of pressure.

Solidifying matter not of an abrasive nature tends to clog oil passages and ducts and the bearing itself, causing unnecessary wear and friction by interfering with the free action of the balls or rollers. Gummy deposits formed by oxidation of the lubricant when subjected to high-temperature and -speed conditions act in a similar manner.

Moisture is very detrimental to antifriction bearings, and its presence even in very small quantities will cause severe corrosion. For this reason, lubricants intended for antifriction bearings should be strongly resistant to the absorption of moisture.

3. Lubricating Factors.—In selecting a lubricant for antifriction bearings, six factors should be given consideration; (*a*) design of housing, (*b*) operating temperature, (*c*) speed, (*d*) load, (*e*) size, and (*f*) method of application.

4. Housing Design.—Housing for antifriction bearings varies in construction, depending mainly on whether oil or grease is to be used for lubrication. Oil is a more efficient lubricant for these

bearings than grease because of its lower frictional resistance. It is, however, more difficult to prevent from leaking out of the housing, which leakage causes not only a loss of oil but also an unsightly appearance and in some instances damage to parts such as commutators and electric insulation. Oil, therefore, requires a more complicated and expensive housing. Moreover, oil is not so effective as a seal and requires more frequent attention.

5. Operating Temperature.—In choosing a lubricant for antifriction bearings, the question of operating temperature is of prime importance, for the viscosity of oil and the consistency of grease decrease rapidly as temperature increases. A lubricant that may be perfectly satisfactory at normal temperature would probably be unsuitable at a lower or higher temperature. Surrounding temperatures below 32°F. require an oil of low pour point (−10°F. or lower) and of relatively low viscosity to ensure ready distribution at starting. Operating temperatures above 150°F. require comparatively viscous oils.

Similar considerations must affect the selection of grease. Low temperatures (below 32°F.) require a soft- or medium-consistency grease for quick distribution, whereas at high temperatures (above 150°F.) a high-grade soda-base grease of hard consistency (no. 3) that will not "bleed" or separate is required. If an unstable grease is used and bleeding occurs, the free oil may be thrown out, leaving in the bearing only the soap base, which hardens and soon destroys the bearing. Moreover, hardening and drying of some greases are accompanied by an increase in acidity that is likely to cause corrosion. This, however, can be overcome by using high-grade greases that do not deteriorate with age in storage and service.

Water, which is used in the manufacturing of grease soaps, must be completely eliminated from the finished product, for its presence may cause hydrolysis, resulting in rapid decomposition and an increase in acidity.

The operating temperature of antifriction bearings depends on many factors, the most important ones being: (*a*) load, (*b*) speed, (*c*) construction of housing and support, (*d*) surrounding air temperature, (*e*) ventilating conditions, and (*g*) quantity of lubricant used.

The higher the load, speed, and surrounding air temperature, the greater will be the operating temperature. On the other

hand, the more massive the housing and support and the better the ventilation, the lower will be the operating temperature.

Not the least of these factors is the quantity of lubricant packed into or fed the bearing. In fact, after the bearing has been installed, this is the only controllable factor. A too meager supply or an oversupply will in either case cause overheating. Underlubrication means metal-to-metal contact, resulting in rapid wear, heating, and early replacement. Overlubrication, especially in the case of grease, will also cause an early replacement of the bearing, but not because of wear. If an oversupply is used, the bearing will overheat because of excessive fluid friction. Such overheating causes expansion and binding of the balls or rollers in the races. Such expansion tends to loosen the inner race from the shaft, permitting it to move relative to the shaft. Because the race is made of hard alloy steel and the shaft is generally soft steel, the shaft wears rapidly, permitting misalignment and pounding. Similarly, the outer race may become too loose in the housing and similar results follow.

6. Speed.—Speed and temperature are related, temperature being in part the result of speed. High speed requires that if oil is used it should be of low viscosity and used sparingly to prevent overheating. Likewise, for the same reason, if grease is employed, it must be of soft consistency. Experience has proved, however, that an extremely hard grease may be used successfully at extremely high speed, say above 10,000 r.p.m. In this case the grease channels, and a sufficient amount of oil for lubrication "sweats" from the grease. The grease used must be of such a consistency that it remains quite hard at the operating temperature.

In general, oil is preferable for high speeds and grease for low speeds. Whether the dividing line is 1000 or 2000 r.p.m. depends mainly on the method of application and type of closure.

In connection with speed, ball and separator speeds are more reliable indexes of lubrication requirements than shaft speed, for bearings of two or more different sizes may be mounted on the same shaft operating at the same speed. For example, a small bearing mounted on a shaft, operating at, say 2500 r.p.m., might be splash-lubricated, whereas a larger bearing mounted on the same shaft might, because of higher ball speed, create sufficient

friction to cause overheating, necessitating the use of a different lubricant or method of application.

7. Load.—In any radially loaded antifriction bearing, the load on any specific ball or roller is not constant but varies from zero to some maximum valve, depending on the position of the ball or roller with respect to the direction of the load on the bearing. The higher the speed, the shorter is the time during which any particular ball or roller is subjected to the maximum load, and the less likely is the oil film to be ruptured. However, owing to the spacing of the balls or rollers, the load is not transferred from one ball or roller to the adjacent one gradually but to a certain degree is applied suddenly, resulting in minute vibrations and impact- or shock-loading conditions. This action is greatly magnified at high speeds and is at least one reason for the decreased load-carrying capacity of these bearings at high speed. This more or less sudden transferring of the load from one ball or roller to the next also explains why these bearings are not suitable for certain precision-grinding spindles.

Thus, it is apparent that the load considered alone is not a true criterion for selecting lubricants for these bearings but that it is necessary rather to consider jointly speed and load, because of the former's effect on the latter.

8. Size.—As previously indicated, size enters into the problem of selecting a lubricant for antifriction bearings mainly because of its effect on ball or roller and separator speeds. If the speed of these elements is made the basis of selection rather than the shaft speed, it is not necessary to consider size in choosing a suitable lubricant.

9. Methods of Application.—Methods of application may be divided into two general divisions, as follows:

I. Methods of oil application:
   1. Drop feed
      a. Sight drop-feed cups, Fig. 212
      b. Wick-feed cups and boxes, Figs. 213 and 214
   2. Splash, Fig. 215
   3. Bath, Fig. 216
   4. Atomization or spraying, Fig. 217
   5. Circulation oiling, Fig. 218
   6. Ring or collar oiling

II. Methods of grease application:
   1. Grease-packed, Fig. 219

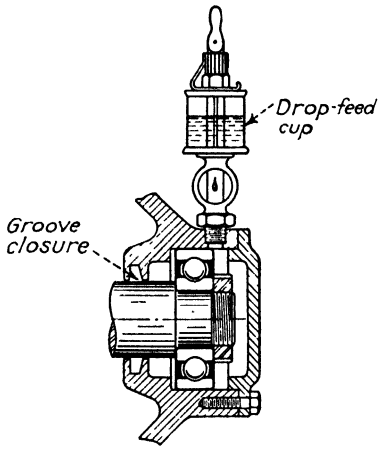


FIG. 212.—Sight drop-feed oilers applied to a ball bearing.

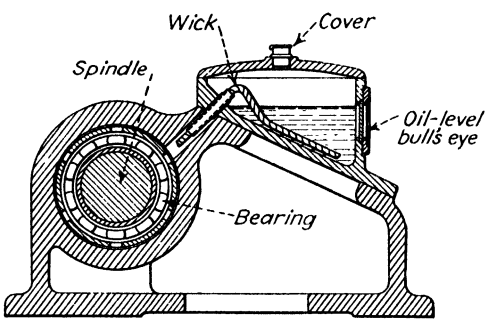


FIG. 213.—Wick-feed oiler applied to a high-speed, precision-grinder spindle.

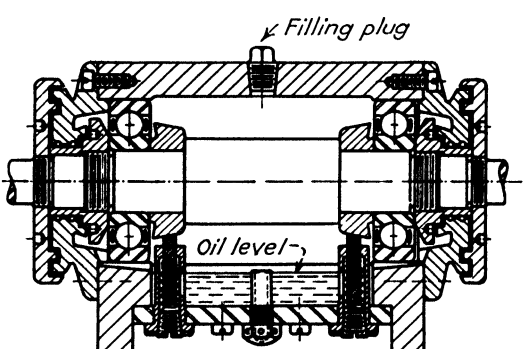


FIG. 214.—Bottom wick-feed oiler applied to a spindle.

2. Grease gun, Fig. 220
3. Grease cups

In the case of splash, circulation, and ring oiling, the oil is used over and over for a considerable period of time, depending on the frequency of draining. For these systems a high-grade oil should be used to minimize oxidation and sludging.

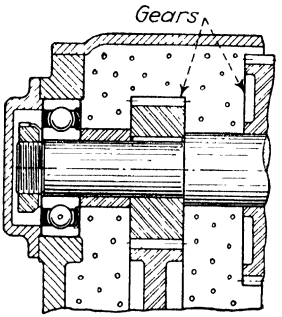


FIG. 215.—Splash oiling by means of adjacent gears.

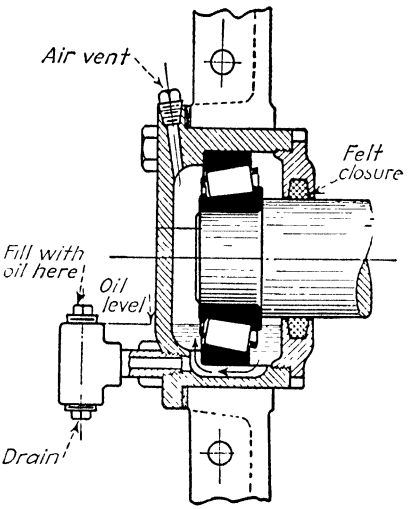


FIG. 216.—Bath oiling applied to a tapered roller bearing.

Where drop feed is used, the oil is used only once and then runs to waste; thus the oil is not required to render long-continued

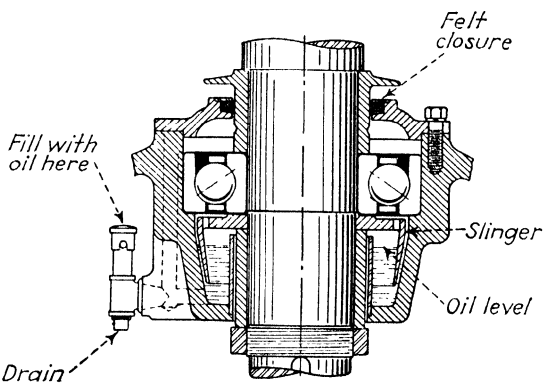


FIG. 217.—The tapered slinger, clamped to the shaft, sprays oil into the bearing above.

service. A relatively low grade of oil may be used in this case, provided that it is free of abrasive and other foreign matter and is noncorrosive.

The grease-packed method requires less attention than any of the other methods. Frequently, where operating conditions are not severe, antifriction bearings are grease-packed in assembly and no further attention is required.

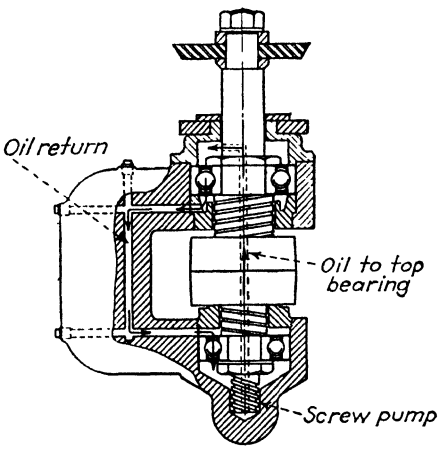


FIG. 218.—Self-contained circulation system applied to a high-speed vertical spindle.

Where it is necessary to refill antifriction bearings, this is usually accomplished by the installation of grease cups or gun fittings screwed directly into the housing or connected through

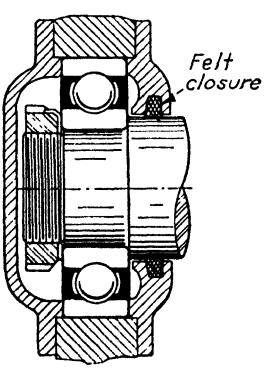


FIG. 219.—Grease-packed ball bearing.

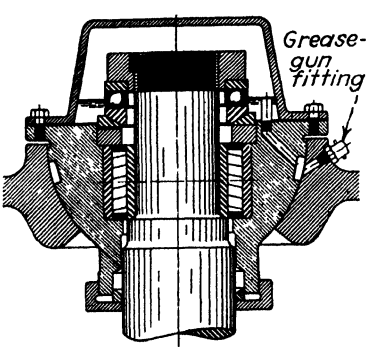


FIG. 220.—Grease lubricated suspension bearing equipped with grease-gun fitting for filling.

piping to a common header located at some convenient position. Where such fittings are used, it is advisable to tap a hole opposite the fitting and, when refilling, add only enough grease to cause

the old grease to ooze out at this point. Overfilling grease-packed bearings is a frequent mistake. They should never be filled more than half full, and generally one-third full is sufficient. Filling them too full causes overheating and leakage.

Splash, bath, and all methods of grease application are restricted in general to relatively low speeds; drop-feed, wick-feed, and circulation methods are satisfactory for medium speeds, whereas spraying, or atomization, wick-feed, and circulation methods are best adapted to high speed conditions.

TABLE XXVII.—GUIDE TO SELECTION OF ANTIFRICTION BEARING OILS

Type of bearing	Operating temperature, °F.	Speed, r.p.m.	Body of oil	Viscosity, S.U.S.		
				100°F.	130°F.	210°F.
Ball bearings	32–140 (Normal)	3,000–15,000	Extra light	64	48	36
		300– 3,000	Light	126	73	41
	.....	50– 300	Heavy medium	285	128	47
	.....	Under 50	Heavy	380	160	51
	140–180 (High)	Over 3,000	Heavy medium	285	128	47
	.....	300–3,000	Heavy	380	160	51
	.....	Under 300	Extra heavy	505	200	55
	Over 180 (Very high)	Any	Steam cylinder oil	1950	775	140
	Under 32	Any	Light*	139	79	42
Roller bearings	32–140 (Normal)	300–3,000	Light	126	73	41
		50– 300	Heavy medium	285	128	47
	.....	Under 50	Heavy	380	160	51
	140–180 (High)	Over 3,000	Heavy medium	285	128	47
	.....	300–3,000	Heavy	380	160	51
	.....	Under 300	Extra heavy	505	200	55
	Over 180 (Very high)	Any	Steam cylinder oil	1950	775	140
	Under 32	Any	Light*	139	79	42

* This oil should have not less than −15°F. pour point.

Tables XXVII and XXVIII give the properties of suitable lubricants for various normal operating conditions. Excessive- and shock-load conditions require special consideration.

TABLE XXVIII.—GUIDE TO SELECTION OF ANTIFRICTION-BEARING GREASES

Type of bearing	Temperature, °F.	Speed, r.p.m.	Viscosity of mineral oil, S.U.S. at 100°F.	Type of grease	Consistency	Remarks
Ball and roller bearings	32–150 (Normal)	Up to 2,000	400–500	Calcium or soda	No. 3 (medium)	12 to 15 per cent soap, remainder mineral oil. Use calcium base in presence of moisture, as soda-base grease emulsifies with water. These greases should be free from free acids, alkalies and fillers. Moisture and ash content should be less than 2 per cent. Greases are not suitable for speeds above 5000 r.p.m. when moisture is present
		3,000– 5,000	300–400	Calcium or soda	No. 2 (soft)	
		5,000–10,000	200–300	Soda	No. 1 (very soft)	
		Above 10,000	100–150	Soda	No. 0 (semifluid)	
	150–200 (High)	Up to 2,000	500–600	Soda	No. 4 (hard)	18 to 20 per cent soap, remainder mineral oil. Greases should not be used in the presence of moisture at these temperatures. These greases should be devoid of free moisture and contain no fillers such as talc, rosin, graphite, mica, etc. They should be of a smooth texture—not of a fibrous or spongy nature
		2,000– 5,000	400–500	Soda	No. 3 (medium)	
		5,000–10,000	300–400	Soda	No. 2 (soft)	
		Above 10,000	200–300	Soda	No. 4 (hard)	

CHAPTER XII

LUBRICATION OF STEAM TURBINES

In 1896, the steam turbine as a practical machine was virtually unheard of although its principles were known at least two centuries before the Christian era. Its actual commercial development started in 1900 when, at Hartford, Conn., a 1500-kw. unit was installed, which was more than twice the size of any previ-

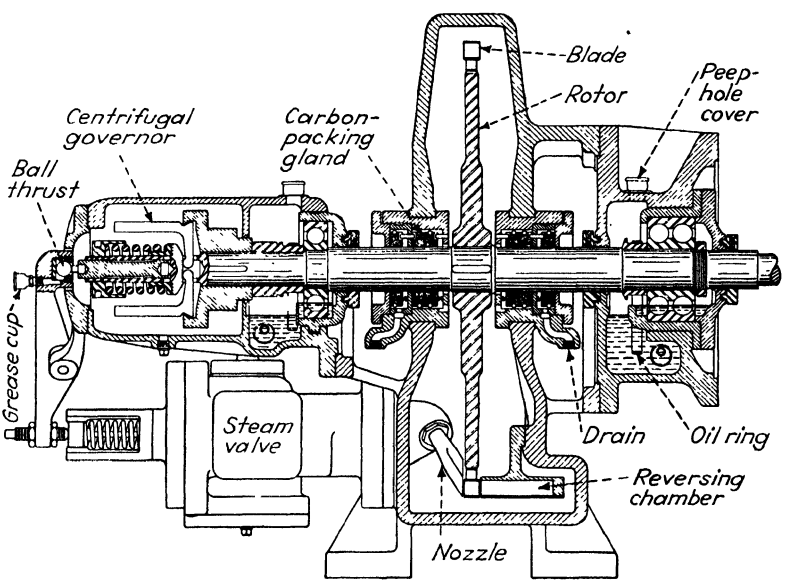


FIG. 221.—Horizontal mechanical-drive turbine with ring-oiled ball bearings.

ously built. Despite the fact that the operation of this unit was unreliable as compared with present-day standards, it caused the tremendous potential possibilities of the turbine to be recognized. Many builders were encouraged and entered the field, with the result that the installed capacity of steam turbines is now over 50 million horsepower in this country alone, an outstanding record of growth in a little more than a third of a century.

1. Classification.—A general classification of steam turbines is unsatisfactory because of the overlapping of the various groups. There are several possible bases for classification, such as: (*a*) *principle of operation*—impulse, reaction, and combined impulse and reaction; (*b*) *method of utilizing energy of steam*—simple, velocity compounded, pressure compounded, and pressure-

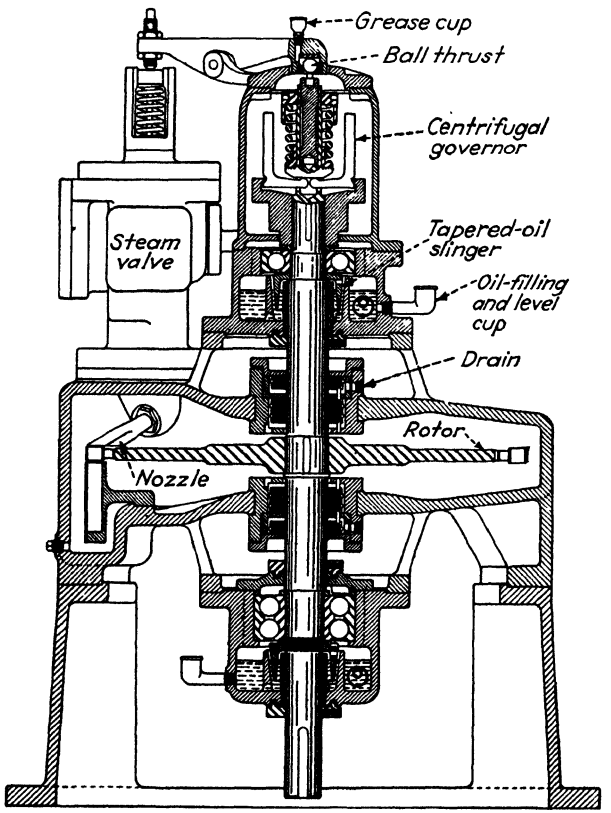


FIG. 222.—Vertical mechanical-drive turbine with ball bearings.

velocity compounded; (*c*) *steam pressure*—high pressure, low pressure, mixed pressure (mixed flow), noncondensing, condensing, and bleeder (extraction); (*d*) *number and position of cylinders*—single-cylinder, multicylinder, tandem compound, vertical compound, and cross compound; (*e*) *direction of steam flow*—single flow, double flow, axial flow, radial flow, and tangential

flow; (*f*) *field of service*—mechanical-drive turbines, industrial turbines, and central-station turbines.

From the standpoint of lubrication, however, it is necessary to consider only the following classifications: (*a*) *method of drive*—direct-connected turbines, geared turbines; (*b*) *method of lubrication*—ring oiling, Figs. 221, 223, and 224, circulation oiling, Figs. 151, 225, and 226.

A direct-connected turbine is connected by either a rigid or a flexible coupling to the driven machine. When so connected,

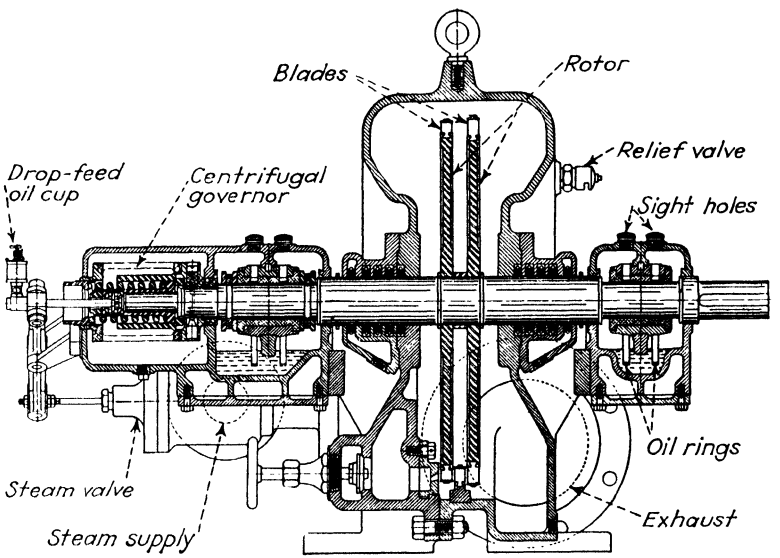


FIG. 223.—Mechanical-drive turbine with ring-oiled bearings.

the turbine and the drive machine operate at the same speed. For best economy, a turbine must operate at a relatively high speed, whereas it is essential for many other machines to be operated at low speed. Consequently, a turbine connected to the driven machine through a reduction gear set is called a *geared turbine*. In both cases, the method of lubrication may be either ring or circulation oiling. In a few designs a combination of ring and circulation oiling is used; the rings supply the oil whenever the oil pump is not operating at sufficient speed to furnish adequate oil to the bearings, as when starting and stopping.

CONSTRUCTION

2. Lubricated Parts.—The parts of a steam turbine that require lubrication comprise: the main radial and thrust bearings, the miscellaneous parts of the governor gear and steam-admission valves, and the flexible coupling and gear set in some cases.

3. Radial Bearings.—The rotor assembly is supported at either end by a radial bearing. The shells of these bearings are

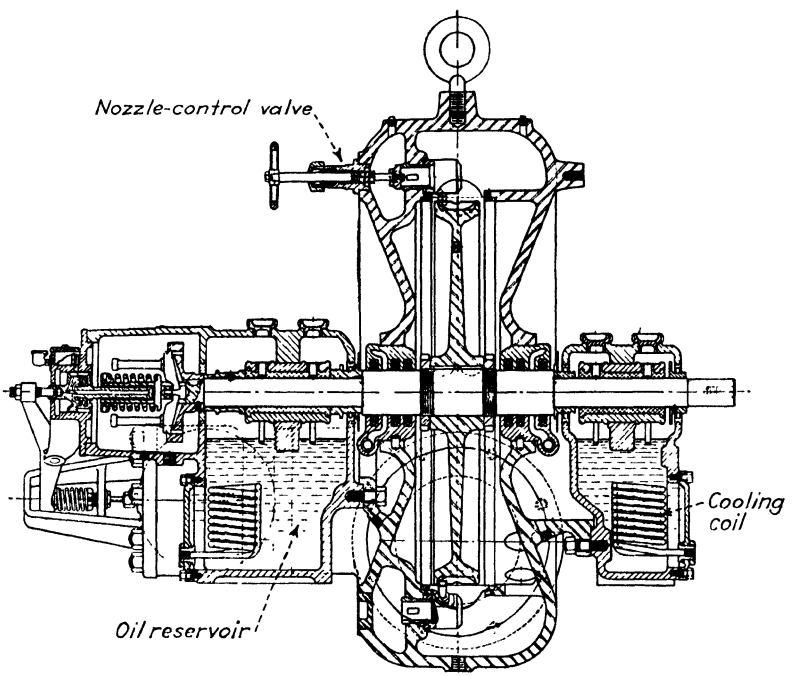


FIG. 224.—Mechanical-drive turbine for high-pressure superheated steam and equipped with water-cooled ring-oiled bearings.

split horizontally, are usually made of cast iron but sometimes of semisteel, are usually lined with babbitt although bronze is occasionally used, and often have spherical seats. Ball bearings are also used to a limited extent on some of the smaller mechanical-drive units, as in Figs. 221 and 222.

The ring-oiled bearing, Fig. 223, the operation of which is explained in Chap. IX, is used on mechanical-drive units of less than 500 hp. The operating temperature of this type of bearing varies widely because of the differences in the construction of

various makes, in the size of the oil reservoirs, and in the surrounding air temperatures and owing to a general lack of provisions for controlling oil temperature; but the normal operating temperature is between 140 and 180°F. If, however, high-temperature steam is used and/or if the unit is installed in a hot location, the operating temperature may be as high as 275°F. or more. On the other hand, these units are sometimes located out of doors and the operating temperature may be as low as 100°F. Such a low

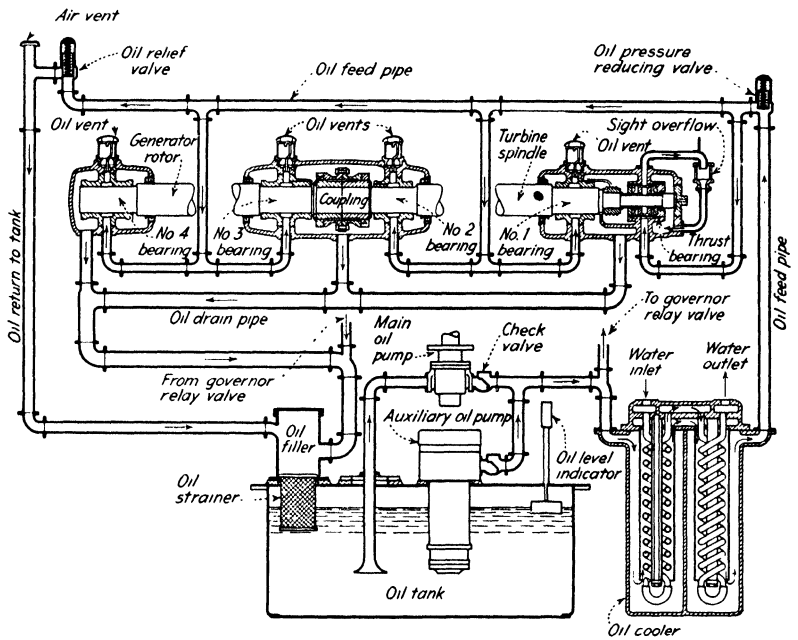


FIG. 225.—Diagrammatic sketch of a circulating-oiling system of a large turbine.

temperature, however, is rare. Some ring-oiled bearings are water-cooled either by circulating water through coils immersed in the oil reservoirs, as in Fig. 224, or through jackets cast integral with the bearing pedestals around the oil reservoirs, Fig. 117.

Ring-oiled bearings may be equipped with one or two oil rings, depending on the size of the unit. An oil ring provides a copious supply of oil for lubrication purposes, but it does not flood, flush, and cool the bearing so effectively as circulation oiling.

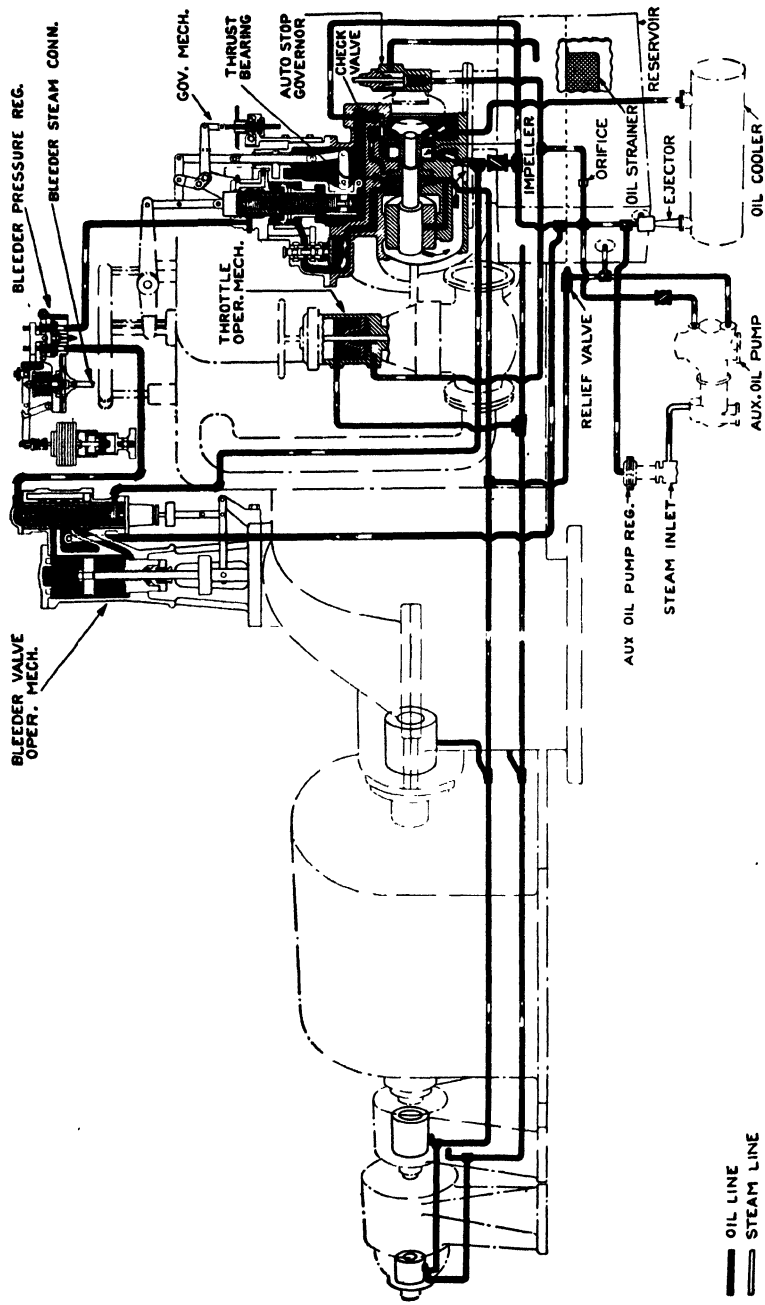


FIG. 226.—Circulation oiling applied to an industrial-type turbine.

In circulation-oiled bearings, shown in Figs. 227, 228, and 229, a copious amount of oil is delivered at a pressure of 5 to 35 lb., depending on the make and size of the turbine. In Fig. 227, the oil enters the shell at the horizontal joint and is distributed along the journal by an axial groove and across the top of the bearing by the wide, shallow, diagonal groove. Most of the oil flows out

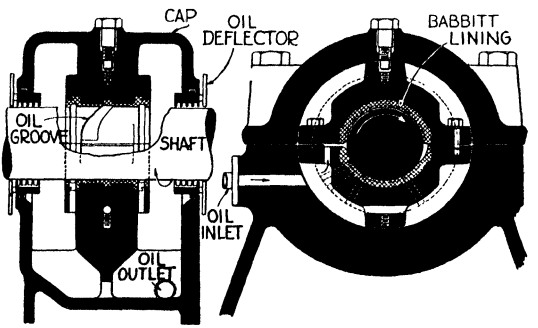


FIG. 227.—Main bearing, used on a large circulation-oiled turbine. (*Courtesy Socony-Vacuum Oil Co.*)

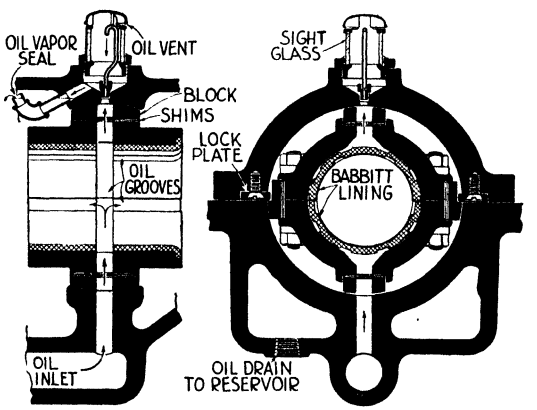


FIG. 228.—Another design of a main bearing for a large turbine. (*Courtesy Socony-Vacuum Oil Co.*)

of the bearing through orifices diametrically opposite the point of entry. A sufficient quantity of oil is carried down, however, between the journal and lower-half lining for lubrication purposes. This oil forms a film that completely separates the journal and bearing.

The bearing shown in Fig. 228 is provided with a combination sight glass and oil vent. The flow of oil through this bearing is indicated by arrows.

The oil is introduced at the bottom of the bearing shown in Fig. 229, flows through a Y tube, embedded just under the babbitt lining, and enters the bearing at either side. Axial grooves conduct the oil along the bearing, and the journal, aided by long, tapered chamfers, distributes the oil around the bearing.

Because circulation-oiled bearings are always supplied with an excess of oil and an oil cooler is invariably used, they generally operate within the temperature range of 110 to 160°F., with 130°F. considered normal for most units. They are usually provided with ball seats, and thus are self-aligning, and are very

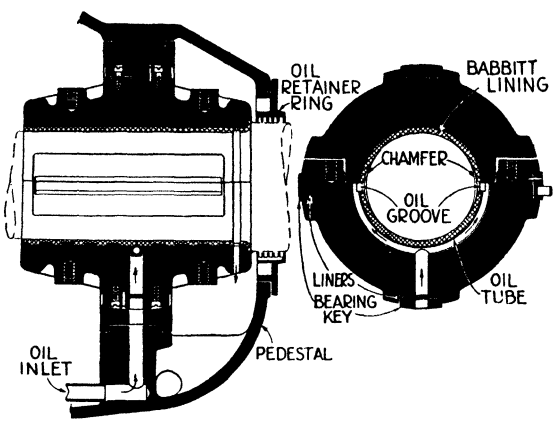


FIG. 229.—Main bearing of a large turbine that employs circulation oiling. (*Courtesy Socony-Vacuum Oil Co.*)

accurately fitted, the clearance varying from one to three thousandths of an inch per in. of diameter. Bearing pressures are low, usually less than 100 lb. per sq. in. and never more than 200 lb. per sq. in., despite the fact that the weight of some rotor assemblies is more than 300,000 lb. The high journal speeds, which are often as high as 10,000 ft. per min. and in some cases more, are very favorable to perfect lubrication.

4. Thrust Bearings.—Regardless of the type of turbine, a thrust bearing is always provided for holding the rotor assembly in the correct axial position with respect to the casing. Often, the thrust bearing is built adjacent to the high-pressure-end main bearing, as in Fig. 230. A portion of the oil entering this bearing flows radially inward through drilled holes to the main shaft and then radially outward between the babbitted tapered thrust

surfaces, thus lubricating them. Shims are provided so that adjustment can be readily made for wear.

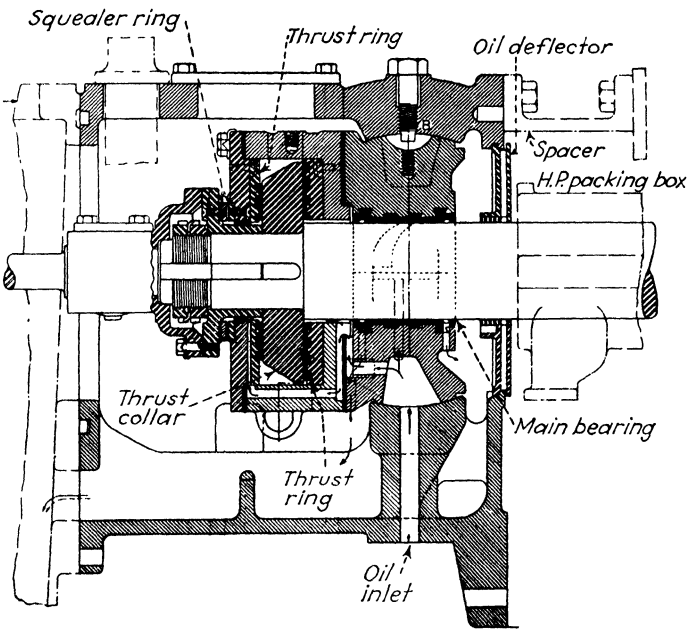


FIG. 230.—Single-collar, tapered land, thrust bearing.

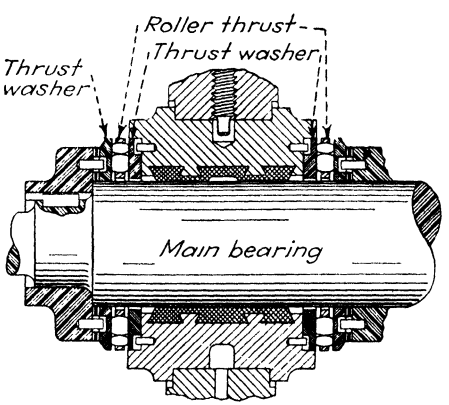


FIG. 231.—Roller-type thrust bearing.

The roller-thrust bearing, in Fig. 231, is used on some of the mechanical-drive units. It is lubricated by oil, which is squeezed from the ends of the main bearing. Shims are provided for axial

adjustment; in making the adjustment, a total of 0.005 to 0.008 in. is allowed for oil-film clearance.

The Kingsbury thrust bearing, shown in Fig. 232, is used on many of the industrial and central-station turbines. The thrust shoes of this bearing are babbitt faced, are pivoted at the back, and automatically adjust themselves so that wedged-shaped oil films are formed between the surfaces of the shoes and the thrust collar. The bearing pressure between the thrust surfaces is

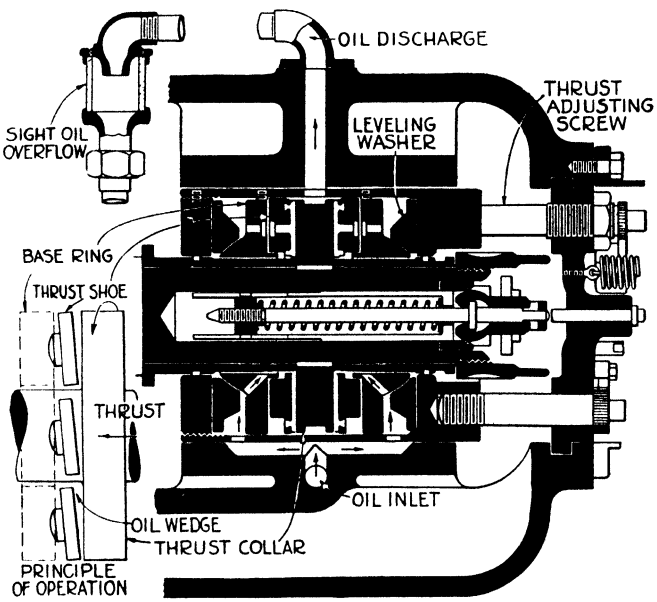


FIG. 232.—Kingsbury thrust bearing applied to a turbine. (*Courtesy Socony-Vacuum Oil Co.*)

usually about 200 lb. per sq. in. of shoe area but sometimes may be as much as 300 lb. per sq. in.

Ball-thrust bearings are commonly used on mechanical-drive units. They are generally located adjacent to the radial bearing at the high-pressure end and are commonly lubricated by oil that is squeezed from the ends of the radial bearing. In some units, as in Fig. 221, the radial bearings are of the ball type, one of which is nearly always of the radial-thrust type.

A small, vertical, mechanical-drive turbine equipped with ball bearings is shown in Fig. 222. Special impellers, which rotate with the main shaft and are immersed in the oil reservoirs, located

immediately under the bearings, lift the oil upward into the bearings, from which it returns to the reservoirs by gravity.

5. Miscellaneous Parts.—Provisions are generally made for lubricating the enclosed parts of the governor-gear and steam-admission valves from the main circulating-oiling system. The miscellaneous exposed parts, which consist mainly of pin bearings and of sliding members and their guides, are occasionally hand-lubricated; but more frequently they are equipped with drop-feed or wick-feed oil cups, grease cups, or grease-gun fittings. These parts, in general, have a to-and-fro motion or a reciprocating

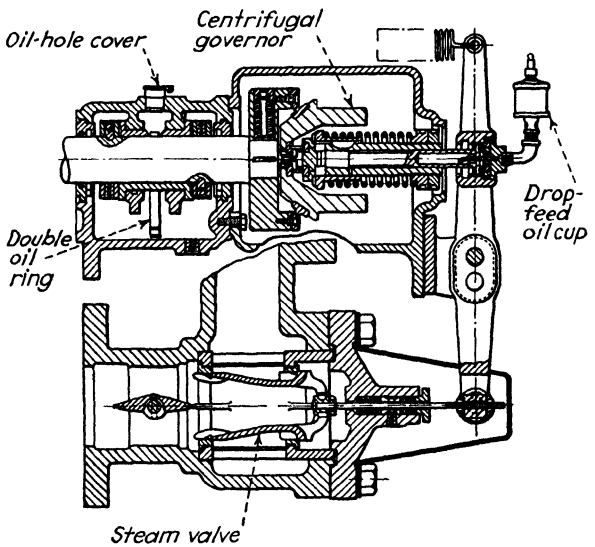


FIG. 233.—Centrifugal mechanically operated governor gear.

motion. Bearing pressures, as a rule, are not high, but it is essential that these parts should move easily, quickly, and smoothly to ensure quick action when load variations occur.

6. Flexible Couplings.—Flexible couplings, which provide for a limited axial movement of the driven shaft, reduce starting shocks and, to a minor degree, provide for bearing wear, shaft deflection, temperature distortion, and foundation settling; they are used to connect many mechanical-drive and some industrial turbines to the driven machines.

In general, the motion between the bearing surfaces of flexible couplings is small and oscillatory whereas pressures are high.

Two methods of lubrication are generally employed: (*a*) Oil squeezed from the ends of the adjacent main bearings drops into an annular channel on the end of the coupling, from which it flows through drilled holes to the bearing surfaces of the coupling, as in Fig. 235. (*b*) Oil is introduced through a fitting or plugged hole into the coupling, as in Fig. 236.

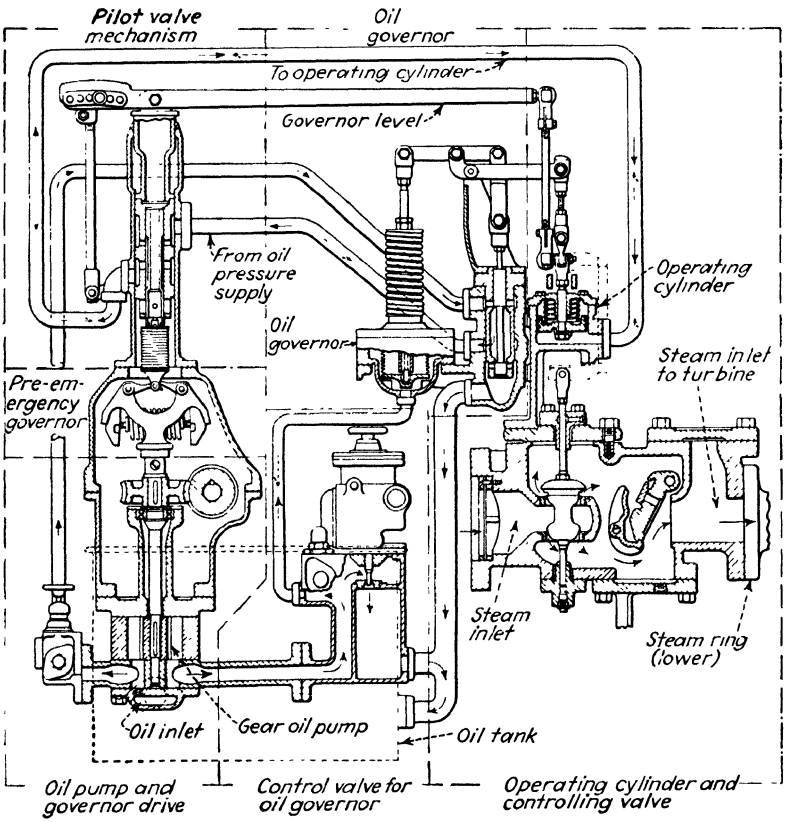


FIG. 234.—Oil relay for controlling steam-admission valves and governor gear.

One end of the pins of the pin type coupling is mounted in bronze bushings, and clearance is provided so that the shafts can move axially. In another pin type coupling, the ends of the pins in the driven half of the coupling are mounted in rubber bushings and do not require lubrication. In fact, oil must be kept away from the rubber bushings, which it deteriorates.

The gear-type coupling, shown in Fig. 236, is lubricated by oil introduced through a hole in the casing. When the coupling rotates, centrifugal force causes the oil to form an annular ring

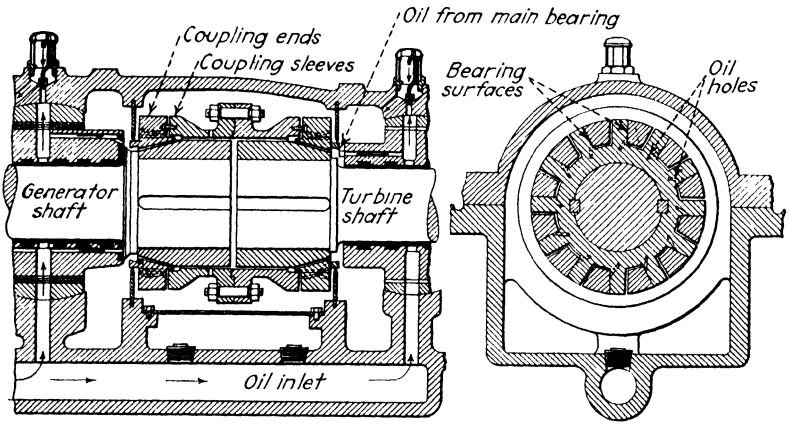


FIG. 235.—Double-sleeve type of flexible coupling.

around the inside of the housing, thus submerging the teeth in oil. This coupling is also designed to be lubricated by oil drip.

7. Gear Sets.—For driving direct-current and 25-cycle alternating-current generators, paper-mill machines, centrifugal pumps, and many other machines, reduction gear sets are used, permitting both the turbine and driven machine to operate at their most efficient speeds.

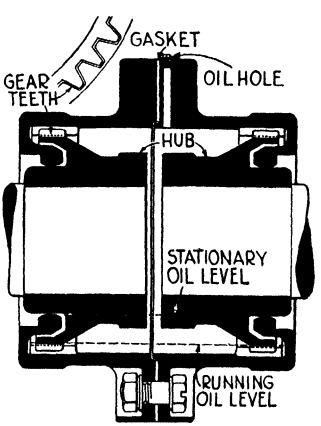


FIG. 236.—Bath-oiled, gear-type flexible coupling. (*Courtesy Socony-Vacuum Oil Co.*)

Virtually all gears are of the double helical or herringbone type and may be single, double, or triple reduction. They are enclosed in oil-tight housings and are connected to the turbine and driven machine by flexible couplings. Bearing pressures are generally within the range of 100 to 200 lb. per sq. in., and the contact pressure between the teeth varies from 500 to 1000 lb. per in. of tooth face or from 40,000 to 60,000 lb. per sq. in. Pitch-line velocities are often as high as 15,000 ft. per min. and in some

cases as high as 20,000 ft. per min. The pinion is usually made of heat-treated nickel steel or chrome nickel steel and made integral with the shaft. In the larger sets, the gear is usually a steel forged ring shrunk and keyed onto a cast-iron spider. In the smaller sets, the gear is usually a solid forging shrunk onto the gear shaft. The gear is always much softer than the pinion.

From a lubrication standpoint, gear sets used in conjunction with steam turbines may be classified as follows:

a. Self-contained, circulation-oiled sets, in which a pump, built integral, supplies oil from 3 to 10 lb. pressure to all bearings and,

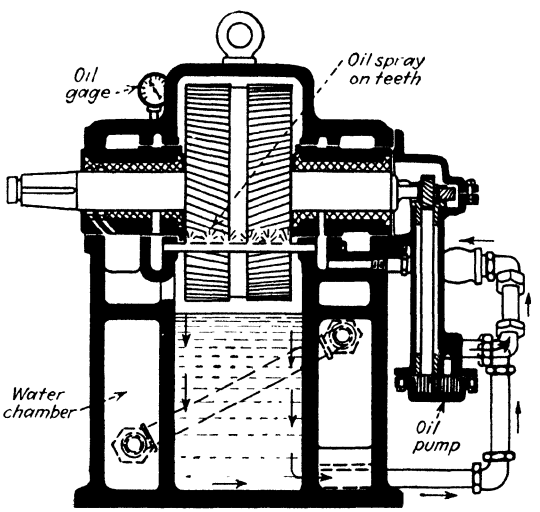


FIG. 237.—Self-contained reduction gear set. (*Courtesy Socony-Vacuum Oil Co.*)

through spray nozzles, to the mesh of the teeth. The lower part of the housing serves as an oil reservoir, as in Fig. 237. On the larger sets, provisions for water cooling are usually made. This, depending on the size, consists either of a cast-in water-cooling chamber or water-cooling coils submerged in the oil.

b. Splashed-oiled sets, in which the gear dips into the oil, as in Fig. 238. Oil adhering to the teeth lubricates them at mesh. The bearings are lubricated by the surplus oil that is thrown from the gear against the sides and top of the housing, from which it drains through channels and ducts to the bearings.

In some high-speed sets, because the splash is insufficient to supply the bearings, combination splash and circulating oiling is

used, the bearing being supplied by circulation and the teeth by splash.

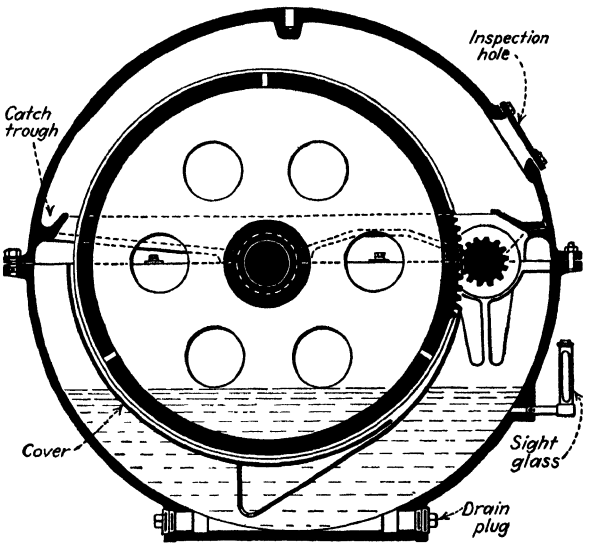


FIG. 238.—Splash-oiled reduction gear set. (*Courtesy Socony-Vacuum Oil Co.*)

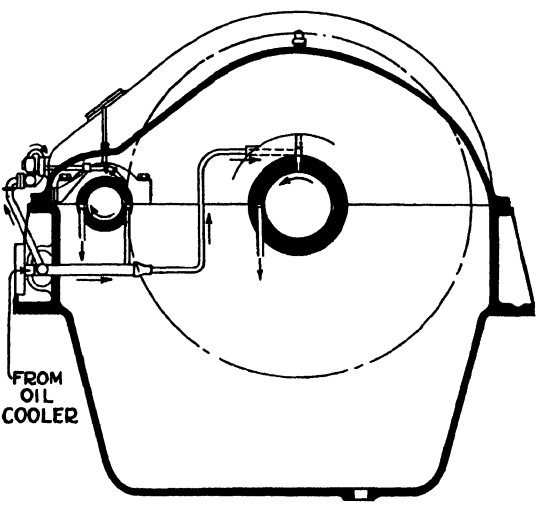


FIG. 239.—Large gear set lubricated with oil from turbine circulation-oiling system. (*Courtesy Socony-Vacuum Oil Co.*)

c. Circulation-oiled sets (Fig. 239), which are supplied with oil from the main circulation-oiling system of the turbine, are very commonly used. A branch from the main system supplies oil

through spray nozzles to the mesh of the teeth and to all bearings. The oil drains to the bottom of the housing, from which it returns by gravity to the main oil reservoir. In this case, the same oil is used, of course, for the turbine and gear set.

8. Shaft Glands.—At the high-pressure end of a turbine and, also, at the low pressure end, if the unit is of the noncondensing type, steam tends to leak outward around the shaft where it comes through the casing. If the unit is of the condensing type, air tends to leak inward around the shaft at the exhaust or low-pressure end. To prevent either the outward leakage of

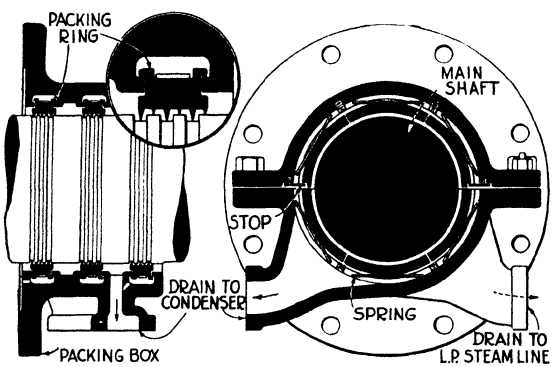


FIG. 240.—Low-pressure labyrinth packing gland. (*Courtesy Socony-Vacuum Oil Co.*)

steam or the inward leakage of air, packing glands are used, of which there are three distinctive designs: (*a*) carbon rings, (*b*) labyrinth, and (*c*) water seal.

In the carbon-ring type, in Fig. 221, a number of carbon rings are supported in a packing case securely bolted to the casing. Each ring is made up of three, four, or five carbon segments held together by either garter or coach springs, made of monel metal or some other corrosive resisting material. In some cases, the rings make contact with the shaft, but in others a small clearance is provided between the rings and shaft by "arch-binding" the segments. In some designs a section of the packing case is water-cooled to ensure sufficient condensate for lubricating the carbon rings. The use of this type of gland is restricted to the smaller units. With a shaft that is slightly out of balance or that vibrates, this type may score the shaft, thus permitting leakage. In a few designs, metallic packing rings are used instead of carbon.

The labyrinth gland, shown in Fig. 240, prevents leakage by offering high resistance to the flow of steam or air. It is comprised, in general, of a series of sharp-edged rings, alternately attached to the shaft and the packing case, the clearance between which is extremely small. Some are so designed that the flow of steam is reversed successively as it passes through each pair of rings. Any small amount of steam that may find its way through the serpentine path of the gland is led back into the turbine through a suitable connection.

Water-seal glands, as in Fig. 241, are generally used in conjunction with labyrinth glands and consist of an impeller or rotor attached to the shaft and running in an annular groove in the packing case. A small amount of water is constantly supplied and is forced by the impeller against the periphery of the annular groove, sealing the clearance space. The water may be supplied from a low-pressure line or an overhead tank at sufficient elevation to produce at the gland a pressure of 15 to 20 lb. In any case, the sealing water should be soft and free from acid, gases, and other scale-forming impurities. Scale formed in the gland impairs the seal and may be the cause of water leaking into the adjacent bearing, thus contaminating the oil. Condensate is recommended for this purpose.

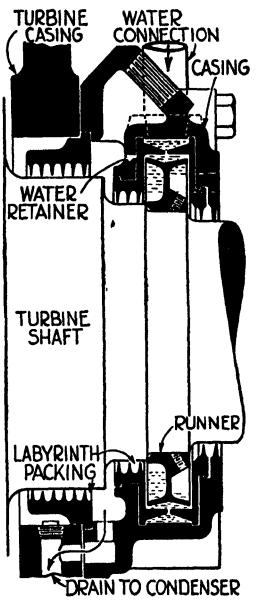


FIG. 241.—Hydraulic gland with labyrinth packing. (*Courtesy Socony-Vacuum Oil Co.*)

A steam seal is generally provided on both the carbon ring and the labyrinth glands of condensing turbines. Steam slightly above atmospheric pressure is supplied to the low-pressure gland, whereas high-pressure steam is used for the high-pressure gland. Often, the steam that leaks past the first two or three carbon rings or labyrinth rings of the high-pressure gland is used for the low-pressure gland. In other cases, low-pressure steam is supplied from some other readily available and suitable source. Various automatic controls are used to regulate the supply of steam to the glands where the load changes frequently.

Noncondensing turbines do not require steam seals, but the glands are provided with vapor pipes and drains for the removal of escaping steam and condensate.

Shaft glands do not require lubrication of any sort, but they should be maintained in good condition at all times, as they are the most common source of water in the lubricating oil. The bearings are in close proximity to the glands, and, if the glands leak, water and steam readily flow along the shaft and frequently into the bearings. In ring-oiled bearings, such leakage increases the oil level and may cause an overflow at the ends of the bearings and excessive bearing temperatures. Water should not be admitted to water-seal glands until the turbine is up to half speed and should be cut off, upon stopping the turbine, when the turbine throttle is closed, for an effective seal is not formed at less than half speed. When steam seals are used in conjunction with water-seal glands, the gland steam should be shut off before water is admitted to the gland, as the steam tends to blow the water along the shaft and into the bearing. Gland drains should be kept fully open at all times so that water will not accumulate in the pockets or wells of the gland and leak into the bearings.

LUBRICATING FACTORS

In the early days, the lubrication of the steam turbine gave much trouble, for many reasons. Much has been learned, however, in a quarter of a century of turbine operation. So, today, it is generally known what is good and what is bad practice. There is still a widespread attitude of apprehension about lubricating steam turbines. This apprehension certainly is not justified in the light of the experience gained during the last 10 years. The fact is that, although the steam turbine is exacting in its lubrication requirements, it is the most easily and perfectly lubricated of all prime movers, if not, indeed, of all industrial machinery, provided that a few simple and inexpensive precautions are taken.

9. Duties of the Oil.—Turbine oils are expected to give exceedingly long periods of service. Industrial units are often operated for a week or more, and those in central stations are frequently run for several months and even as long as a year without a shutdown. Reliability and continuity of service are two very important considerations in steam-turbine operation.

The oil in circulating systems performs three different duties. It cools as well as lubricates the main bearings and the enclosed parts of the governor gear and serves as the medium for actuating the governor gear. In geared turbines, the same oil often lubricates and cools the gear set.

The problem of lubricating the bearings and governor gear is not difficult. Unit pressures are low, and speeds, during actual operation, are high enough to produce perfect lubrication. Temperatures are controlled within reasonable limits, and a copious quantity of oil is supplied at all times.

The principal concern of the operator is to select a correct oil and, more particularly, to take the proper care of it while in service and during periods of shutdown. There are six factors, apart from the oil itself, that tend to cause the oil to deteriorate in service: (*a*) water, (*b*) heat, (*c*) impurities, (*d*) air, (*e*) constant agitation, and (*f*) electric action. These factors, individually and collectively, bring about emulsification, oxidation, sludge formations, and foaming.

10. Emulsification.—An *emulsion* is a mechanical mixture of oil and water. Consisting of pure oil and water an emulsion is temporary and will readily separate on standing. The presence of small amounts of dust, dirt, metallic particles, and oxidized hydrocarbons decreases the rate of separation and makes the emulsion more persistent.

Conditions in turbines are generally favorable to the formation of emulsions. Some water is nearly always present in the oil. Its source may be leaky shaft glands, leaky water pipes in the oil cooler, broken or leaky gaskets on water-cooled bearings, faulty water seals, and condensed atmospheric moisture.

A pure emulsion alone is probably not seriously harmful, but emulsions tend to collect and hold impurities, which accelerate oxidation and sludge formations. Combinations of emulsions and sludge and oxidized hydrocarbons are particularly harmful and should be prevented by excluding water from the system as much as possible. It is good practice to withdraw samples of oil from the system at regular intervals and let them stand in bottles to determine the quantity of water present. These samples should be withdrawn from a point in the system where the oil is representative of that being used. If water is present in unusual amounts, it may be detected by the collection of drops on the

sight-flow glasses; by the appearance of the water in the gage glasses of tanks; and by the amount of water removed by the purifier.

When water finds its way into the oil reservoir, some of it is usually vaporized and subsequently condensed on the cooler surfaces above the oil level. Rusting of these surfaces follows, and, eventually, particles of rust drop into the oil. These act to make the emulsion more persistent and to accelerate oxidation. They may also clog lines and small orifices in the system. In extreme cases, water may even reach the enclosed parts of the governor gear and cause rusting, interfering with the proper functioning of the controls.

11. Oxidation.—The conditions in steam-turbine oiling systems tend to promote oil oxidation, the principles of which are explained in Chap. VII, page 116. In both ring and circulation oiling, the oil is constantly agitated at an elevated temperature in the presence of air and various solid impurities, many of which act as catalyzers to accelerate oxidation. An increase of 20°F. in temperature roughly doubles the rate of oxidation.

A variety of complex products form when oil oxidizes—alcohols, ketones, aldehydes, esters, organic acids, metallic soaps, etc. For practical purposes, however, these products may be divided into two classes: (1) those soluble in the oil at the operating temperature, and (2) those insoluble in the oil at the operating temperature.

Soluble products of oxidation are not deposited in the parts of the system that are at the normal operating temperature, but some become insoluble when they come into contact with the cooling coils and other parts of the system that are below the normal operating temperature.

A small percentage of the insoluble products of oxidation are carried in suspension by the oil, but most of them precipitate in the cooler, strainers, bearing housings, oil pipes, and reservoir.

Oil oxidation is indicated by an increase in color, acidity, saponification number, and viscosity. Oil that oxidizes rapidly will generally show a corresponding rapid increase in these test values. These changes are probably not dangerous in themselves, but they indicate that sooner or later sludge deposits will form.

12. Sludge.—Chemically, sludge is precipitated oxidized hydrocarbons. All deposits formed in turbine-oiling systems,

however, are commonly called *sludge*. This so-called sludge is an intimate mixture of emulsified material, precipitated asphaltic and resinous substances, solid impurities, metallic soaps, and some good oil. In some cases, it is a shiny black or reddish brown, liverlike mass; in others, it is a dry, cokelike, gritty material.

Sludge may be oil soluble or oil insoluble. The oil-soluble type remains liquid in the oil at the operating temperature but precipitates when cooled. It is therefore carried in suspension by the oil until it comes into contact with cooler parts of the system, where it precipitates. This occurs particularly in the oil cooler, where owing to precipitated sludge the oil flow is restricted and the heat transfer from the oil to the cooling water is decreased. Naturally, a reduction in heat transfer in the cooler causes an increase in the operating temperature of the oil. It follows, also, that an increase in oil temperature increases the rate of oxidation and, thus, an increase in sludge formation and deposit. Thus, a vicious cycle results, always tending to produce more and more sludge at an increased rate.

A part of the insoluble sludge is also carried in suspension by the oil, but it tends to settle out in the oil pipes, passages, reservoirs, and many other points in the system, particularly at points where the flow of oil is slow.

In the case of turbines driving electric generators, sludge formation is sometimes accelerated by stray electric currents. These currents are conducted from the generator through the shaft, arc across the oil films in the bearings, and flow through a bearing pedestal or oil-pipe connection to the bedplate and to the ground or back to the generator through another bearing pedestal. These currents, arcing through the oil films, break off tiny bits of metal, which become entrained in the oil stream. The oil darkens quickly, increases in acidity, and deposits a chocolate-colored, brittle sludge in many parts of the system, especially in the oil cooler. The remedy is to insulate completely one of the bearing pedestals from the bedplate, including the oil-pipe connections to the bearing.

Sludge, as a rule, forms slowly; but sometimes, because of a rapid temperature rise, a sudden and unexpected accumulation of water, or a breakdown of the oil, it forms quickly.

Sludge tends to clog oil pipes and passages partially or completely, increase operating temperature, and cause sluggish

operation of the governor gear. It also acts as a catalyst to accelerate sludge formation. *Because of this action, it is very important that all traces of sludge should be removed upon cleaning the system preparatory to the introduction of a fresh batch of oil.* The bearings and oil piping should be dismantled and cleaned as well as the oil cooler and reservoir.

13. Foaming.—Foaming results when air is rapidly absorbed by oil. It is usually the result of some mechanical fault or of poor operating practice coupled with rapid circulation of the oil. Foaming occurring in the bearing pedestals and oil reservoir may overflow, causing an unsightly appearance and an oil loss and creating a fire hazard. Foam, escaping from the bearing pedestals, is sometimes drawn into the winding or onto the commutator, brushes, or collector rings, causing sparking and breakdown of the insulation. Foam entrained in the oil stream reduces the oil pressure, causing poor governor action and a decrease in the flow of oil to the bearings.

Mechanical faults tending to cause foaming are: air leakage into the pump suction line; level of oil in reservoir too low, uncovering the pump suction; vents on reservoir and bearings not adequate; drop of oil from return lines to reservoir too high; too small return lines from bearings; and high discharge velocity from pressure-regulating valve.

A new batch of oil will sometimes foam, which can usually be remedied by not turning on the water of the cooler until the normal operating temperature is reached. Adding too much new oil to the system at any one time occasionally causes foaming. For this reason, it is good practice to add new oil at a given time only in amounts not in excess of 10 per cent of the capacity of the system. Foaming can sometimes be stopped by operating the oil at a slightly higher temperature; this rise can be effected by reducing the flow of water through the cooler. This practice tends, however, to increase oil oxidation and is not always advantageous.

14. Atomization and Leakage.—If the oil pressure is carried too high, the bearings are likely to be oversupplied and oil may be sprayed from the ends in thin sheets against the housings and atomized. If the bearing seals are worn or ineffective, a considerable loss of oil will result. Water-seal glands are not effective at slow speed; and if oil pressures are not carefully controlled

upon starting and stopping, oil is likely to leak past the seals into the drains of the glands. Adequate return piping prevents the bearings from becoming vapor-bound, and atomized oil will drain readily to the reservoir.

Oil leakage and atomization create an unsightly appearance and cause slippery floors, added fire hazard, and an increase in oil consumption. These difficulties can be largely eliminated by carefully regulating the oil pressure, by maintaining bearing seals in good condition, and by providing adequate returns from the bearing pedestals.

OIL CHARACTERISTICS

The first problem of steam-turbine lubrication is to select an oil that will render long and trouble-free service with minimum consumption and frictional power loss.

15. Viscosity.—Although considerable time was required to establish the correct viscosity values of oils for steam turbines, these are now virtually standardized and proved by many years of successful operation. There are a few exceptions because of unconventional construction, unusual operating conditions, etc., but the values given in Table XXIX are satisfactory for normal conditions.

In general, a turbine oil in any case must possess sufficient viscosity to support the bearing loads without the film rupturing. At the same time it should not be so viscous as to cause high

TABLE XXIX.—GUIDE TO SELECTION OF STEAM-TURBINE OILS

Type of system	Type of turbine	Bearing temperature, °F.	Pour point, °F.	Flash point, °F.	Viscosity, S.U.S.		
					100°F.	130°F.	210°F.
Circulation ...	Direct-connected	Any	5	385	150	85	42
	Geared	Any	10	395	320	143	50
Ring-oiled.....	Direct-connected or geared	140–180 (normal)	25	425	660	270	66
		Below 140	5	385	150	85	42
		Above 180 where excessive leakage occurs	40	500	1550	605	118

Note.—For all direct-connected, most single-reduction, and some double-reduction marine turbines, the same oil as is recommended for geared land turbines is suitable. For some single- and double-reduction marine turbines, however, an oil having a viscosity between 400 and 500 S.U.S. is required.

temperatures, excessive power loss, and poor separation from impurities and water. Ring-oiled bearing units generally require oils of higher viscosity than circulation-oiled ones because of higher normal bearing temperatures. A compromise is necessary in the case of geared turbines using the same oil for the turbine and gear set. The oil used must not be too viscous for the bearings, but at the same time it must possess sufficient viscosity to minimize the wear of the teeth and to cushion and quiet them.

Bearing and gear-tooth pressures in marine practice are, as a rule, somewhat higher than in land practice. Consequently, oils of higher viscosity are recommended for comparable units.

Excessively viscous oils should be avoided because of the inevitable increase in temperature, rendering the oil more susceptible to oxidation, subsequent sludge formation, and rapid deterioration. Moreover, frictional power losses are increased, the time required for separation from impurities and water increases with viscosity; emulsions formed are more persistent; and viscous oils are more difficult to purify than are light oils.

16. Chemical Stability.—For turbine oils, chemical stability ranks on a par with correct viscosity. Many laboratory tests have been devised for determining the chemical stability of oils, but none of them has proved sufficiently satisfactory to be standardized. Consequently, the only reliable method of measuring chemical stability is a service test of the oil in a turbine in actual operation.

The neutralization number, viscosity, steam-emulsion number, gravity, and saponification and precipitation numbers serve individually and collectively when run on samples of oil withdrawn at regular intervals to measure the rate of oil deterioration. They do not indicate, however, when a turbine oil is unsafe for further service. As long as these test values increase gradually, there is no cause for alarm, as this is natural; but a sudden increase in one or more is an indication that some change has occurred in operating conditions that should be investigated.

The neutralization number is more commonly used than any other test as an index of oil deterioration. As usually determined, it measures both the water-soluble and water-insoluble acids, and it has been shown that only the water-soluble acids cause sludge. But the neutralization number alone does not identify the type of acid present, which is important, as many of the constituents of oil have acid characteristics but are not harm-

ful. So, in determining the serviceability of an oil, the neutralization number should be considered in conjunction with other tests. Experience indicates, however, that an oil having a neutralization number of less than 0.80 tends little to sludge. For values higher than 0.80, it is necessary to consider the type of acid present before predicting sludging probabilities. Some oils having a neutralization number of 2 and higher render perfectly satisfactory service. The neutralization number of most new turbine oils is within the range from 0.01 to 0.02.

The safe limiting value for demulsibility of turbine oils is not known with any degree of certainty. It is generally believed, however, that emulsion difficulties are not likely to occur until the oil has a steam emulsion value (A.S.T.M. method D 157-36) of more than 600. There is no definite relationship between the A.S.T.M. method D 157-36 and the federal government method no. 320.32, but it is believed that an oil having a steam emulsion number from 600 to 700 will show a demulsibility at 130°F. from 50 to 60 ml. per hr. In general, new turbine oils have steam emulsion numbers of less than 200; many are less than 100.

17. General Characteristics.—Turbine oils should be refined mineral oils free from all impurities, such as dirt, acids, and water, and without the admixture of any fatty oils, resins, soaps, or other nonhydrocarbon materials. They should offer maximum resistance to emulsification, oxidation, and foaming and be of the correct viscosity for the service at hand.

These characteristics are best obtained in a comparatively low-viscosity; highly refined, neutral, pale oil. Most turbine oils are now refined by the solvent method, which produces oils of far greater chemical stability than was possible by any previous refining method.

18. Oil Purification.—If properly taken care of, the modern steam-turbine oil has an indefinite service life. Many cases are known where turbine oils have been in use as long as 15 years. If products of oxidation, emulsification, and sludge are effectively removed, purified turbine oil is equal to new. The cost of a new batch of oil is not large as compared with total plant cost, but unless the oil is changed at frequent intervals (in which case the oil cost is high) there is a greater likelihood of a serious breakdown occurring without than with a purification system. Considering cost and the important position that a turbine usually occupies, the increased factor of reliability of operation provided by puri-

fication justifies the small additional operating expense incident to it.

The most commonly used methods for purifying turbine oils are: (*a*) continuous by-pass, (*b*) batch treatment, and (*c*) combination by-pass and batch treatment. The necessary equipment and methods of operation of these systems are explained in Chap. X. Rarely, these methods are supplemented by a water-wash treatment, which does not seem to be practical or necessary in most cases. Occasionally, also, "sweetening," which provides for withdrawing about 10 per cent of the oil from the reservoir at regular intervals and replacing it with fresh oil, is practiced. This method is not generally satisfactory, as it results in contaminating the fresh oil rather than improving the condition of the oil in the system. Sweetening should not be confused with the term *make-up*, which refers to the oil that must be added to replace losses.

As a general rule, it is not good practice to mix different brands of oil or oils from different turbines.

19. Cleanliness.—It is no longer difficult to obtain good turbine oils. The requirements are well known, and the knowledge and facilities for refining them are possessed by nearly all of the oil companies. Trouble-free turbine lubrication rests largely with the operator, since experience shows that it is chiefly a matter of cleanliness. Success depends on keeping dirt out of the oil and sludge out of the cooler, reservoir, piping, screens, purifier, settling tanks, turbine room, and basement.

Before starting a new turbine or one that has been shut down for a long period of time, it is very important that the system should be scrupulously cleaned before filling with oil.

It is good practice in the case of a new turbine completely to drain the oil after 300 hr. of operation and then thoroughly to clean the oiling system before refilling.

At least annually, the oiling system should be carefully inspected and thoroughly cleaned. The oil cooler, piping, bearings, and other parts should be disassembled and cleaned. Reservoirs and settling tanks should be hosed out with hot water or steam and wiped clean and dry. Linen rags are recommended, as cotton waste and other rags leave fluff and lint. If the cooler cannot be cleaned thoroughly with hot water or steam, it should be immersed in a cleaning solution consisting of 4 oz. each of trisodium phosphate and soda ash, dissolved in 1 gal. of water.

CHAPTER XIII

LUBRICATION OF STEAM ENGINES

In the modern sense the steam engine did not exist prior to 1711 when Thomas Newcomen, an ironworker, and John Cawley, a plumber and glazier, patented and built the first engine using the principle of a steam-actuated piston in a cylinder. Since the steam was condensed in the cylinder of the Newcomen-Cawley engine and others that soon followed, the steam engine was not a commercial success until James Watt, in 1769, added a separate condenser. This cleared the way for improvements that have made the steam engine still the most widely distributed and commonly used source of power.

The modern steam engine bears little if any resemblance to the original engines of Watt and Newcomen, and yet the principle of operation is the same. Many improvements have, of course, been made that have greatly increased the efficiency of the steam engine and extended its usage. The modern steam engine is highly perfected. Its reliability and adaptability have enabled it successfully to maintain its position as king of prime movers.

1. Classification.—To meet a wide range of conditions in many different services, steam engines are built in many types and designs. But from the standpoint of lubrication, it is necessary to consider only the following constructional features:

1. Type of valve:
   - *a.* Single valve.
     - Slide valve.
     - Piston valve.
   - *b.* Corliss valve.
   - *c.* Poppet valve.
2. Position of cylinder:
   - *a.* Horizontal.
   - *b.* Vertical.
3. Flow of steam:
   - *a.* Uniflow.
   - *b.* Counterflow.

2. Single-valve Engines.—In the single-valve engine, the steam enters the cylinder at high pressure through the same valve and port from which it later exhausts at a much lower pressure. The valve and ports are thus subjected alternately to high- and low-pressure steam and are continually changing temperature. As the cutoff and compression points are also controlled by this one valve, there is no opportunity to adjust one event independently of the other. For these reasons the single-valve engine has the highest steam consumption but, because of its simplicity, the lowest first cost. It is rarely used on engines of more than 125 hp.

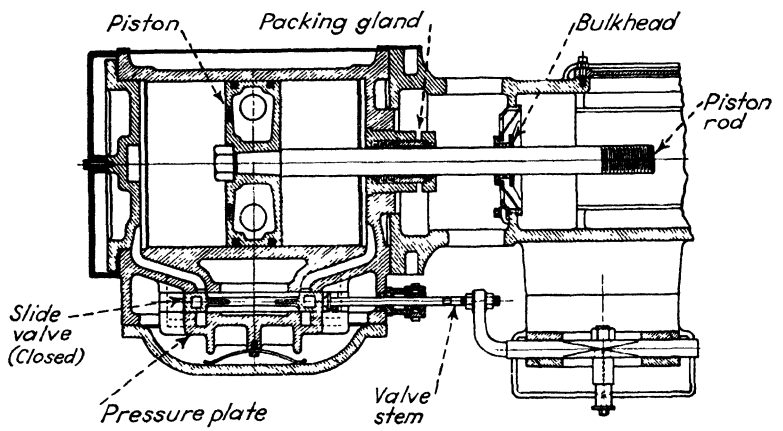


FIG. 242.—Section of a single-valve cylinder, showing valve and steam chest.

Single valves are of two designs: slide valves, shown in Fig. 242, and piston valves, shown in Fig. 243. Slide valves in turn are of two types: the D-slide valve and the balanced-slide valve. All single valves have a reciprocating motion like pistons, which makes the formation and maintenance of oil films difficult.

The D-slide valve is unbalanced because the steam pressure acts only on the back of the valve, forcing it against its seat. With large valves and high steam pressure, the power required to actuate the valve may be large, especially if the valve and its seat are not well lubricated. Because it is unsymmetrical and may warp, this valve is not suitable for high-temperature steam. It is best adapted to low-pressure wet steam because it lifts easily from its seat to permit slugs of water to pass through.

This valve is sometimes designed to operate between the seat and a *pressure plate*, which prevents the steam pressure from acting on the back. This construction minimizes the friction between the valve and seat and is called a *balanced valve*.

The piston valve is, in effect, a balanced cylindrical slide valve, as the steam pressure is exerted equally on all sides. It is applicable to engines of all sizes and is especially suitable for those using high-pressure superheated steam, because it is symmetrical and does not tend to warp. But it is not suitable for very wet steam, as it is likely to be broken by slugs of water because it cannot lift from its seat.

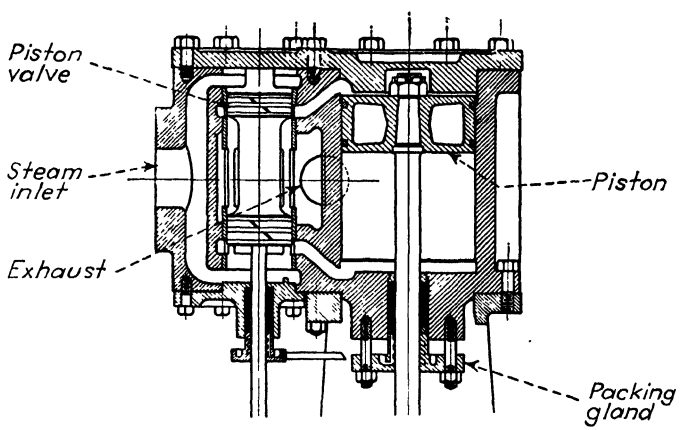


FIG. 243.—Section through a vertical engine cylinder, showing piston valve.

Single valves are simple in design, easy to adjust, retain their adjustment for long periods of time, and are low in first cost but wear rapidly unless well lubricated.

3. Corliss-valve Engines.—These are also frequently called *four-valve engines* because they have an intake and exhaust valve at each end of the cylinder. Two of these control admission and cutoff of the steam, and the other two control release and compression. The events can thus be adjusted for more economical steam consumption than is possible with the single valve.

The Corliss valve is skeleton cylindrical, located at right angles to the axis of the cylinder, and placed either in the cylinder heads or above and below the cylinder at the ends, as in Fig. 244. It is oscillated through a small angle by a wrist plate mounted on the side of the cylinder or the frame. The wrist plate in turn is

operated through a rocker arm by an eccentric mounted on the crankshaft. Two types of gears are used to operate this valve: the releasing type and the nonreleasing type. In the releasing type the steam valve is positively opened by the valve gear but is closed by means of a tripping mechanism and a dashpot. The exhaust valve is both positively opened and positively closed by the gear.

The releasing type of gear, because it does not operate satisfactorily at speeds above 150 r.p.m., has been largely displaced by the nonreleasing type of gear, by which all valves are positively opened and closed.

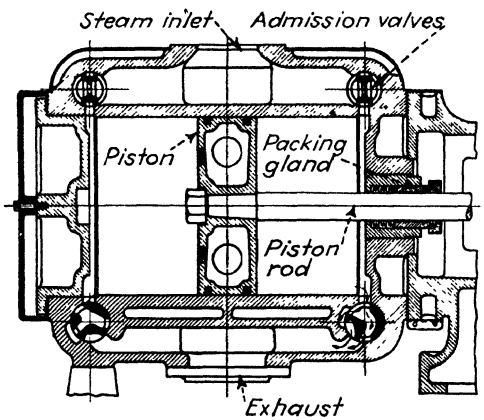


FIG. 244.—Section through a counterflow cylinder, showing Corliss-type valve.

Although more efficient than the single valve, the Corliss valve is yet not suitable for high steam pressure and temperature or for very high rotative speeds. It is limited to approximately 50°F. superheat and 175 lb. steam pressure. Because of its rocking motion, which is similar to the reciprocating motion of the single valve, it is subject to the same lubricating difficulties as the single valve. In fact, it is often more difficult to lubricate than the single valve. It is heavy and essentially unbalanced, and it oscillates instead of rotating; rubbing speeds are high, and steam passes through rather than across the rubbing surfaces, so that the oil, if carried by the steam, is not effectively distributed over the long, narrow surfaces. In some cases, it is particularly difficult to distribute the oil to the ends of the valves. These factors are common to all four valves; but, in addition,

the exhaust valves are subjected at times to severe washing action of water, as they are usually located at the bottom of the cylinder.

4. Poppet-valve Engines.—Poppet valves were developed to overcome the difficulties of warping and high friction that are inherent characteristics of other types of valves when high-pressure superheated steam is used. It is an adaptation of the poppet valve that is used so successfully for internal-combustion engines, although it is quite different in construction. There is no motion of the valve on its seat as it lifts to open. In some designs, the valve is positively opened by a link mechanism con-

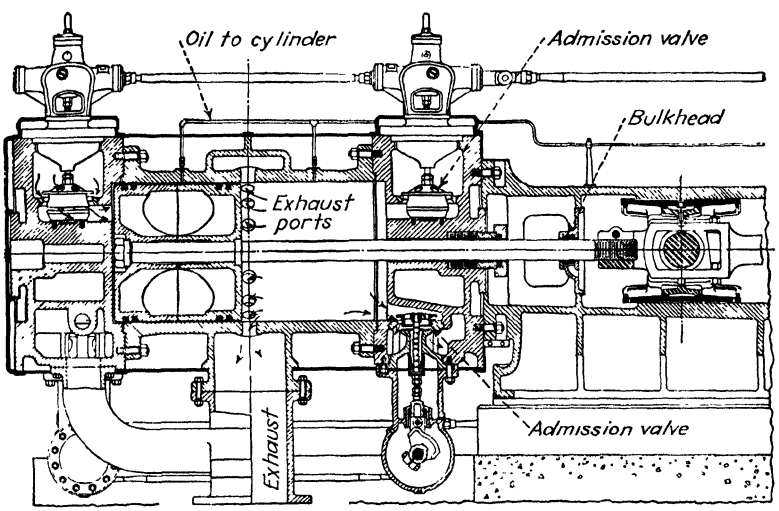


FIG. 245.—Section through a uniflow cylinder equipped with poppet valves.

nected to an eccentric on a lay-shaft, which is parallel to the cylinder and driven by the crankshaft through miter gears. In others, the valve is opened through links by an eccentric on the crankshaft. In all cases, poppet valves are closed by spring pressure.

For condensing engines, two admission and two exhaust valves are generally used. Noncondensing engines employ only two valves, one at each end of the cylinder. They may be located in the heads of the cylinder, as in Fig. 245, or near the ends of the cylinder, as in Fig. 246. It is possible to adjust each of the four valves separately.

Aside from the external parts of the valve gear, the stem is the only part of the valve that requires lubrication. The stem is

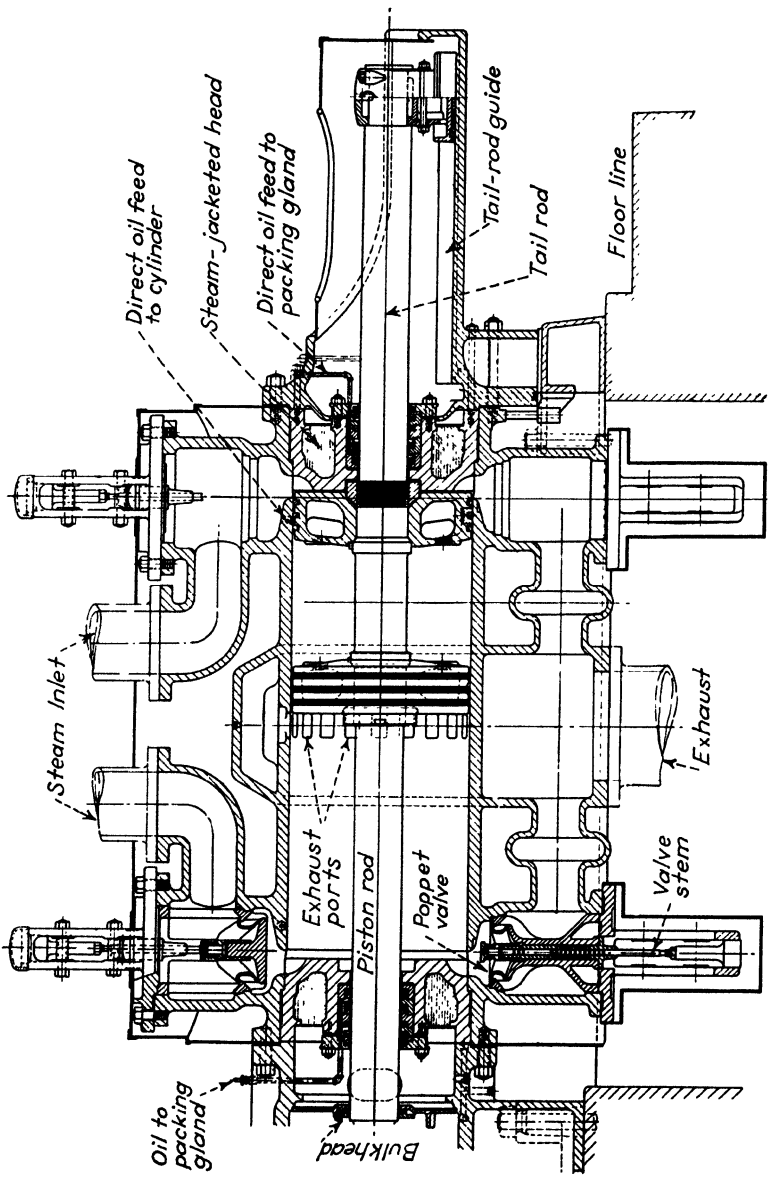


FIG. 246.—Section through the cylinder of another design of a poppet-valve uniflow engine.

long and has a very short reciprocating motion with respect to its guide. Some stems have a packing gland but more commonly shallow annular grooves are cut into the stem, which fill with condensate. Such stems require virtually no lubrication as the water acts as a lubricant. In any case, the stem should be sparingly lubricated because excess oil is sure to carbonize and cause valve sticking.

5. Horizontal and Vertical Engines.—The cylinder or cylinders of a steam engine may be either horizontal or vertical. At present horizontal engines predominate, but the trend is toward the high-speed, enclosed, multicylinder unit because it lends itself better to high-speed design and is more compact, requiring little floor space.

Large horizontal engines, having heavy pistons, are usually built with a tail rod, as in Fig. 246. In this construction, the weight of the entire piston assembly is supported by the crosshead and tail-rod guides; the pressure on the cylinder wall is mainly the tension of the piston rings, which is usually less than 10 lb. per sq. in. Similar conditions prevail in vertical engines, as the weight of the piston is carried by the crosshead-pin bearing. Consequently, in engines equipped with tail rods, and especially in vertical engines the oil-feed requirement is small compared to that of other engines, as a very thin oil film is sufficient to effect the piston seal. Vertical engines do not, in general, require as much oil as horizontal engines. In some vertical engines, using very wet steam, it is practical to dispense entirely with oil, as the water in the steam serves adequately as a cylinder lubricant. This is an advantageous procedure where the condensed steam is used as make-up boiler feed, and where adequate oil separation cannot be secure otherwise. The rate of wear may be higher, but this is less objectionable than oil in the boiler feed.

6. Counterflow and Uniflow Engines.—When the design is such that the steam flows in opposite directions into and out of the cylinder, as in Fig. 247, the engine is called a *counterflow*. In such engines, the steam is admitted to and exhausted from the same end of the cylinder. Thus the cylinder is alternately subjected to the high-temperature admission steam and to relatively low-temperature exhaust steam. The temperature of the hot admission steam is therefore reduced as the steam sweeps over the cooled surfaces of the cylinder and is partially condensed.

This initial condensation is probably the largest single source of lost energy in the counterflow engine.

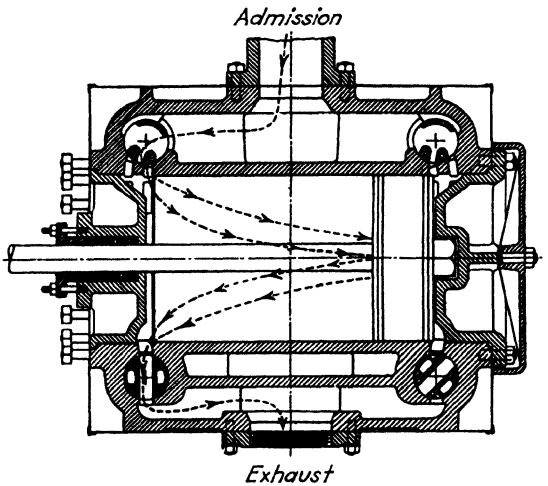


FIG. 247.—Section through a Corliss-valve engine, showing counterflow principle.

This loss is greatly reduced in the uniflow type of engine, shown in Fig. 248, in which the steam enters the cylinder in the usual way but is exhausted through ports arranged around the

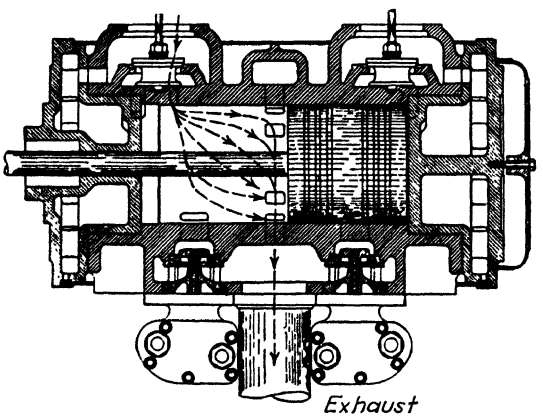


FIG. 248.—Section through a uniflow cylinder, showing uniflow principle.

periphery of the cylinder midway between the ends. The piston uncovers these ports near the end of its stroke. The steam flows through the cylinder in one direction only; the cylinder is not

subjected to the low-temperature exhaust steam, and thus initial condensation is greatly reduced.

Uniflow engines may be operated condensing or noncondensing, as at either end of the cylinder are provided auxiliary exhaust valves or clearance pockets for controlling the compression pressure. All large- and most medium-size uniflow engines are provided with tail rods, as in Fig. 246, for the pistons are long and relatively heavy.

There is a marked difference among conditions that prevail in the cylinders of uniflow and counterflow engines. When dry saturated steam is admitted into an engine cylinder, it expands and pushes the piston forward, heat being extracted from the steam and converted into mechanical work. The steam is cooled and partially condensed, and its temperature drops steadily from admission to exhaust. It is well known that the temperature of the cylinder wall at any point corresponds to that of the steam at that point. In the counterflow engine, the temperature of the cylinder walls at the end of the exhaust stroke is therefore virtually the same as that of the exhaust steam; the hot admission steam comes into contact with the cylinder walls when they are coldest.

In the uniflow engine, steam is also admitted at the end of the cylinder; but when the piston reaches the end of its stroke, the exhaust ports are uncovered and the cold, wet steam is exhausted. As the piston covers the ports again, compression begins; from this point on, work is done on the steam entrapped in the cylinder and raises the steam pressure and temperature to that of the incoming steam. Whether or not the piston is moving forward or backward, therefore, the temperature of the steam at any point along the cylinder is virtually the same as that of the cylinder wall at that point. Thus, in the uniflow engine there is a high-temperature zone at each end of the cylinder and a low-temperature zone surrounding the central exhaust belt. Temperatures of these zones change but little during a cycle and differ from the conditions that prevail in counterflow engines where the cylinder walls are alternately heated and cooled.

The cylinders of uniflow engines are generally more difficult to lubricate properly than those of counterflow engines because:

1. Oil tends to carbonize and form deposits in the high-temperature end zones of the cylinder.

2. The unidirectional flow of the steam is not so effective in spreading the oil over the cylinder-wall surfaces as the back-and-forth flow of steam in the counterflow engine.

Using the steam, therefore, as a distributing agent for the oil cannot be solely depended on in the uniflow engine. Moreover, most uniflow engines have steam-jacketed heads, which separate most of the oil from the steam before it enters the cylinder. This difference in the nature of the steam flow in the cylinders makes a vast difference in the distribution of the oil and the maintenance of the oil film.

7. Parts Requiring Lubrication.—Irrespective of type, design, and operating conditions, the question of lubrication of steam engines should be considered from the point of view of: (*a*) the cylinder or internal parts, and (*b*) the bearings or external parts.

The internal parts that require lubrication are the piston, cylinder walls, valve, piston rod, and valve stem. The external parts include the main crankshaft bearings, crankpin bearing, crosshead and guides, tail rod and guide, where provided, governor gear, and sometimes other miscellaneous parts, such as the reversing gear.

CYLINDER LUBRICATION

The lubrication of the external parts of steam engines presents simple and comparatively few problems. The most difficult problems are encountered in the lubrication of the internal parts. It is here, also, that the greatest frictional losses and wear occur. The proper lubrication of the cylinder and valve has for many years been considered, and not without some justification, a difficult task. But, recently, knowledge gained by research and experience, coupled with improvements in design, construction, lubrication methods, and lubricants has largely eliminated internal lubricating troubles.

8. Function of Cylinder Oil.—As in all reciprocating machines, the steam cylinder oil should minimize frictional losses and wear and seal the piston and rings against steam blow-by.

Poor internal lubrication is indicated by excessive cylinder, valve, and ring wear, high friction losses, lost power, groaning, vibration of slide-valve stems, or sluggish closing of Corliss and

poppet valves. Absence of these signs indicates that the internal parts are being lubricated, but it does not follow that the lubrication is correct, as the consumption may be excessive.

9. Factors Affecting Cylinder Lubrication.—In selecting the correct steam cylinder oil, four influencing factors are always of prime importance: (*a*) steam temperature, (*b*) steam pressure, (*c*) steam quality, and (*d*) engine load.

In some instances, it is also necessary to consider additional factors, such as use of exhaust steam, feed-water treatment, size, speed, and mechanical condition of the engine, etc.

10. Steam Temperature.—The trend is toward the use of higher steam temperatures and pressures. The average high-pressure engine today operates at about 200 lb. pressure and 100 or more degrees superheat. It is the practice of at least one builder to design all uniflow engines for pressures of 200 lb. and 200 degrees superheat irrespective of the conditions prevailing when the installation is made.

Since the viscosity of oil is reduced by increased temperature, high-temperature steam requires the use of higher viscosity oil. If the viscosity is too low, not only is the oil easily scraped from the cylinder walls by the rings, but it is also readily removed by the scouring action of the steam, resulting in excessive friction, wear, and blow-by.

Conversely, low-temperature steam points toward the use of lower viscosity oil. If a too viscous oil is used, an excessive feed is generally required to secure quick and uniform oil-film coverage over the cylinder walls and valve seat. Moreover, excessive feed tends to promote the formation of deposits.

11. Steam Pressure.—Steam pressure and temperature are closely related in that, with the exception of steam in the superheated state, it is impossible to alter one without causing a corresponding change in the other. High pressure generally means high temperature.

Pressure of itself, however, affects internal lubrication. The greater the pressure, the more firmly are the rings pressed against the cylinder walls and the valve against its seat. Greater pressures increase the tendency to scrape the oil films from the contact surfaces of the rings and valve. Since the more viscous an oil is, the more tenaciously it adheres to a surface, high pressure indicates the use of higher viscosity oil.

12. Steam Quality.—When steam is formed in a boiler, the water generally boils violently, and some water in the form of a fine mist is entrained in the steam. Steam containing entrained moisture is called *wet saturated steam.* If all moisture is removed, it is termed *dry saturated steam.* If all moisture is removed and it is heated above its saturation temperature (boiling temperature), it is described as *superheated steam.* Thus, steam is commonly spoken of as being *wet, dry,* or *superheated.* Quality is the ratio of the weight of dry saturated steam to the total weight of dry saturated steam plus entrained moisture. Thus, *quality* refers to the *dryness* of steam.

Moisture in steam is probably the most important single factor to consider in selecting a steam cylinder oil. Wet steam containing even a very small amount of moisture will readily wash films of pure mineral oil from the cylinder walls and valve surfaces. To counteract this washing action, compounded oils should always be used in the presence of moisture. Some heat is always lost by radiation of the steam line from the boiler to the engine, and, unless the steam is superheated at the boiler, it is wet at the engine. Excessive radiation losses are caused by poorly insulated lines, and sometimes by lines that are too large, in which the velocity of steam flow is so low that time is permitted for excessive condensation to occur. Lines should, therefore, be efficiently insulated, of the proper size, and as short as is practicable. It is advisable to equip long lines with traps at suitable points to remove the water and prevent it reaching the cylinder.

Priming and foaming, where they occur, may cause considerable entrained moisture in the steam. These are generally caused by high concentrations of dissolved or suspended solids or both in the boiler feed water. Other contributing factors are carrying the water level too high, forcing the boiler beyond its rated capacity, and too small steam-outlet connection. Foaming depends mainly on the viscosity of the surface film, whereas priming is chiefly a matter of increased surface tension. From the standpoint of lubrication, priming is generally more deleterious than foaming, for in priming slugs of water are released and pass into the steam line. Instances have occurred in which these slugs of water have broken the valve of the engine. If the critical point at which foaming and priming occur is determined and if

concentration is kept below this point, little trouble will be experienced. The concentration can be controlled by reducing the use of boiler compounds and by frequent blowing down of the boiler. Surface blowing, where applicable, is an effective remedy for foaming.

Foaming and priming not only greatly increase the moisture content of the steam but also cause boiler-water impurities to be carried over by the steam to the engine. These impurities are chiefly dissolved and suspended solids of chlorides, phosphates, sulfates of calcium, magnesium, and sodium and chemicals, such as soda ash, lime, salt, trisodium phosphate, that are used for treating feed water. Rust and scale from the inner surfaces of pipes and superheater tubes constitute another class of impurities. Most of the solid impurities are abrasive and, if permitted to enter the engine, cause rapid wear, necessitating eventual reboring of the cylinder and replacement of valves and piston rings. Most of the chemical impurities readily react with compounded cylinder oils and destroy their lubricating properties. All impurities contribute to the formation of troublesome deposits.

A condition that often prevails and is frequently overlooked is that when superheated steam is used, the degrees of superheat are generally not sufficient to give superheated or even dry saturated exhaust steam. Though the steam is superheated at the throttle, the expansion in the cylinder reduces the superheat and generally the steam is quite wet at the beginning of the exhaust stroke. Thus, on the exhaust stroke, the cylinder contains wet steam. Under these conditions, it is a common practice of some operators to use high-viscosity pure mineral oil. The use of pure mineral oil is satisfactory, however, only when it is definitely known that the steam remains superheated or dry saturated throughout the cycle. Under wet conditions, pure mineral oil is readily washed from the cylinder walls and valve surfaces. Where a pure mineral oil is used under wet conditions, the necessary feed is generally excessive. This not only is wasteful of oil but also leads to the formation of carbon deposits, as the excess oil collects in the counterbore and valve pockets and, because of high temperature, carbonizes. Experience indicates that best results are secured under these conditions by the use of a medium-viscosity moderately compounded (3 to 5 per cent) cylinder oil. The compounding has no bad effect in the presence of superheated

steam and usually permits the oil feed to be considerably reduced below that required by a pure mineral oil.

Since water is the major single factor adversely affecting the lubrication of steam cylinders under wet-steam conditions, all practical precautions should be taken to minimize the moisture content of the steam. The installation of an efficient steam separator just ahead of the throttle will appreciably remove entrained water and impurities carried over from the boiler. The mistake is often made of installing a separator that is too small. The efficiency of separators decreases as the velocity of steam flow increases. At low velocities, most separators are better than 98 per cent efficient, whereas at a velocity of 5000 ft. per min. many have very little effect. The separator should be drained through a trap, inspected, and cleaned whenever necessary to ensure proper operation. The installation of a suitable dry pipe or purifier is also generally helpful.

13. Engine Loads.—Paradoxical as it may seem, engines operating under light loads are more difficult to lubricate than those running under full- or overloads. This is because a lesser weight of steam is used at light loads than at full- or overloads. This leads to the following effects:

1. A reduced velocity of flow through the steam line, resulting in greater condensation, and poorer atomization of the oil introduced through the atomizer.

2. Increased initial condensation, because reduced weight of steam produces lower cylinder temperatures. This causes increased water in the cylinder, and hence, more severe washing effect.

3. A reduced flow and, hence, less steam activity, resulting in poorer oil distribution over the cylinder walls and valve surfaces.

Because of lower average temperatures prevailing in the cylinder and less active steam, light-loaded engines require lower viscosity oils than those operating at full- or overloads. And, similarly, because of increased condensation, they require oils containing relatively high percentages of compounding.

14. Methods of Application.—Two methods are commonly used to apply oil to steam-engine cylinders: (*a*) atomization or indirect application to the steam; and (*b*) direct application to cylinder walls, valves, etc.

Either a mechanical force-feed or a hydrostatic lubricator is virtually always used to feed the oil. The former is generally more efficient, reliable, economical and, hence, preferable. These lubricators are illustrated and discussed in Chap. IX.

15. Atomization Method.—In this method, the steam is used to carry the oil to the internal parts that require lubrication. A small tube or pipe, called an *atomizer*, is inserted through the wall of the steam line preferably 4 or 5 ft. back of the throttle but *between* the separator and engine and connected to the lubricator, as in Fig. 249. Oil is delivered to this atomizer against which

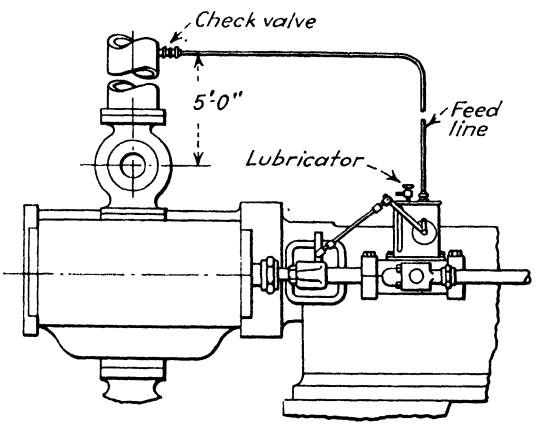


FIG. 249.—Proper method of installing an atomizer and lubricator on a single-valve engine.

the steam impinges at high velocity, breaking the oil into a fine spray and thoroughly mixing it with the steam. The oil-bearing steam comes into contact with all internal parts that require lubrication with the exception of the stems of poppet valves and the end bearings, and sometimes other surfaces, of Corliss valves. The oil is thus distributed to the spindle of the throttle valve, inlet and exhaust valves, cylinder walls, piston, rings, and piston rod. If the correct oil is selected, it will adhere to these surfaces and form a complete uniform lubricating film.

In compound engines, having no receiver, the exhaust steam from the high-pressure cylinder usually carries a sufficient amount of the atomized oil for lubricating the low-pressure cylinder. In compound engines, having a receiver, however, the receiver acts as an oil separator, requiring oil to be fed direct to the valves and

cylinder or preferably through an atomizer inserted into the pipe from the receiver to the cylinder. If the force of the low-pressure steam is insufficient thoroughly to atomize the oil, an atomizer constructed as shown in Fig. 250 should be used.

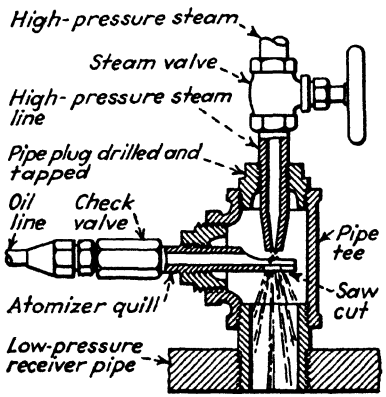


FIG. 250.—Special atomizer for low-pressure cylinder lubrication.

16. Factors Affecting Atomization.—The degree of atomization is influenced by (*a*) mechanical means of atomization, which include design of the atomizer, installation of atomizer, feed regulation; (*b*) condition of steam, *viz.*, velocity of steam at atomizer, temperature, and quality; and (*c*) physical properties of the oil, *viz.*, viscosity, percentage and nature of compounding, and filtered or nonfiltered.

17. Design of Atomizers.—More or less complicated atomizers are often used, but it is doubtful if they are any better than the simpler designs shown in Fig. 251. If a two-piece design is used, the quill should be securely pinned to the bushing so that it will not come loose and drop into the valve.

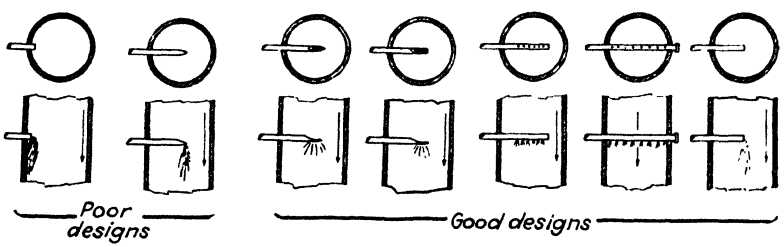


FIG. 251.—Correct and incorrect designs of atomizers.

18. Installation of Atomizers.—For best results the following points should be observed when installing an atomizer:

1. Locate the atomizer 4 or 5 ft. ahead of the throttle unless limited to a shorter distance by the position of the separator. It should never be located ahead of the separator, which would remove the oil from the steam before it gets into the engine.

2. Always install in the feed line adjacent to the atomizer a check valve; this ensures that oil is available immediately the engine starts and that steam will not back into the lubricator.

3. Before installing quill, make certain that it is free of dirt, filing, and scale. Never use materials that are likely to scale or corrode badly. Make sure that the open side of the quill faces steam flow. A punch mark on the cutaway side will aid in properly locating the face of the quill.

19. Condition of Steam.—The higher the steam velocity, the greater is the impact on the oil and the more complete is atomization. Under full- and overloads, the steam velocity is generally sufficient thoroughly to atomize the oil, if it is of the correct viscosity. But under light loads, because of the low steam velocity, atomization is often incomplete, and it is usually necessary to add a supplementary feed directly to the cylinder.

High temperature, because of its thinning and surface-tension effects on the oil, is conducive to good atomization. Thus, at high temperatures, high-viscosity oil may be used with assurance that complete atomization will result.

Steam cylinder oil is more easily atomized by wet than by superheated steam because its surface tension is lowered by moisture. Though high-temperature superheated steam thins oil, aiding atomization, yet this apparently has a lesser effect than has moisture in reducing the surface tension.

20. Properties of Oil.—Other things being equal, low-viscosity oil atomizes more quickly and completely than oil of high viscosity. The lowest viscosity oil that will properly lubricate the internal parts should therefore be used.

Because filtering removes some of the more cohesive constituents, filtered oils atomize slightly more easily than nonfiltered oils. Filtered oils, however, do not adhere to wet surfaces as tenaciously as do nonfiltered oils.

Compounded oils have lower surface tensions than pure mineral oils and, to a certain degree, the higher the percentage of compounding, the lower the surface tension and the more easily an oil atomizes. Among the fixed oils used for compounding steam cylinder oils are rapeseed, lard, tallow, and *degras*. It is generally believed that oils compounded with lard or tallow atomize slightly more easily than do those compounded with rapeseed and *degras*.

The oils obtained from the seeds of several cultivated varieties of *Brassica campestris* are variously known as *rape*, *colza*, and

rubsen, but all are sold as commercial rapeseed oil. It is a clear pale-yellow oil but becomes dark and very viscous when blown with air. When blown, it is frequently used to increase the viscosity of certain cylinder oils and at the same time to provide the desirable emulsifying properties.

Lard oil is obtained by expression of hog's fat at low temperature. First-quality or prime lard oil is nearly colorless or pale yellow, whereas second-quality or tinged lard oil is yellow or brownish red and contains from 8 to 15 per cent free fatty acid. The prime grade is superior to the tinged grade as a compound for cylinder oils, as it is less likely to become rancid and gummy.

Tallow oil is obtained by expression from beef and mutton fats. Beef tallow oil is superior as a compound to mutton tallow oil, because it is less inclined to become rancid and gummy.

Degras is obtained as a by-product in the manufacture of chamois skins, which during the process are treated with whale or cod-liver oil, washed in lye, and acidified with sulfuric acid. In the last operation, a fatty material separates and is skimmed off, which is the *degras* so widely used for compounding cylinder oils. It varies widely in quality, and only the better grades should be used for compounding.

The greater the moisture content of steam (the lower its quality), the higher should be the percentage of compounding in the oil. The percentage of compounding, however, should be no larger than is necessary to form a ready and persistent emulsion. Compounded oils are less stable and have a greater tendency to form carbon deposits than noncompounded oils. In general, steam cylinder oils contain 4 to 13 per cent compounding, 8 to 10 per cent being about the maximum used, except under especially wet steam conditions.

21. Limitations of Atomization.—The atomization method is applicable to virtually all types of engines and operating conditions, with the following three exceptions:

1. Where superheated steam is used, the oil is not thoroughly atomized and dispersed in the steam, and it is good practice to introduce some of the feed directly to the cylinder wall. Under this condition, the atomizer should be located just behind the throttle.

2. In steam-jacketed engines, the steam passes through the jackets before entering the cylinder. The jackets act as oil separators to remove most of the oil from the steam before it enters the cylinder. This applies particularly to uniflow engines, nearly all of which have jacketed cylinders.

3. Because of the reduced activity of the steam in underloaded engines, it is also generally necessary to feed a large portion of the oil direct to the cylinder and over the valves.

22. Direct Application.—In addition to these three specific operating conditions in which it is generally advisable to apply oil direct to the cylinder walls, direct feeds are sometimes applied to the stems of poppet valves, to piston rods, and to the ends and seats of Corliss valves.

Since poppet valves are generally used under superheated steam conditions and the stems require a very small amount of oil, care should be taken not to overlubricate them. Poppet valves are closed by spring pressure (not positive); if these valves are overlubricated, carbon and gummy deposits are likely to form, causing them to act sluggishly and even stick. In general, direct feeds to poppet valves are inadvisable and unnecessary.

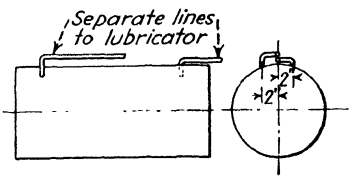


FIG. 252.—Direct oil feeds to cylinders of engines of less than 300 hp.

Oil is sometimes fed directly to the piston rod by swabbing, drop-feed cup, or a mechanical force-feed lubricator. When applied by swabbing or drop-feed cup, the oil is applied externally and the greater portion is scraped off by the gland and runs to waste. Particularly under high-temperature conditions and when metallic packing is used, it is good practice to feed some oil directly into the packing gland.

In general, Corliss valves are best lubricated by the atomization method; but in some instances they are particularly difficult to lubricate and drastic measures have to be taken. They are sensitive, heavy, and unbalanced and oscillate instead of rotating; to a great extent the steam passes through the valves rather than across the seats, so that very little of the oil dispersed in the steam comes into contact with the rubbing surfaces. This is especially true of the ends that sometimes require direct feeds. In extreme instances, it may even be necessary to feed oil directly to the valve seats. It is important that the edges of the valve seats should not be so sharp as to scrape off the oil film. Oil-film formation and maintenance may often be greatly aided by slightly beveling these edges.

Shown in Figs. 252, 253, and 254 are correct positions for direct feeds to cylinder walls of uniflow engines having jacketed cylinder heads. The hole in the cylinder walls should be $\frac{1}{8}$ in., or smaller, to prevent an accumulation of carbon at this point. Preferably, the oil should be introduced at the instant the piston covers the opening; the piston then spreads the oil more effectively over the cylinder walls.

The direct method has several inherent disadvantages and should be resorted to only when it is evident that the atomization method cannot be successfully used. In general, it is necessary to feed oil in relatively large quantities to secure distribution. Excess feeding leads to oil in the exhaust steam, promotes carbon formations, and increases cost of lubrication.

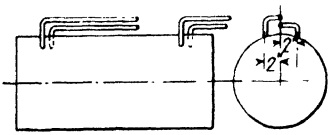


FIG. 253.—Direct oil feeds to cylinders of most engines of more than 300 hp.

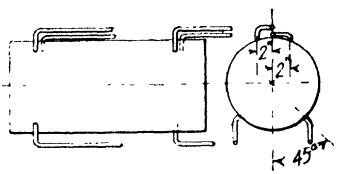


FIG. 254. Direct oil feeds to cylinder of engines of more than 300 hp. where uniform distribution cannot be secured by feeds shown in Fig. 253.

23. Rate of Oil Feed.—Whether or not the interior parts of an engine are being correctly lubricated can be determined accurately only by removing the cylinder-head and valve-chest cover and examining the cylinder walls and valve seat. Well-lubricated cylinder walls, valves, and pistons have a dull, slightly oily appearance immediately after disassembling. The oil films on these surfaces should be sufficient to penetrate one or two thicknesses of cigarette paper and stain slightly the third when pressed against the surface for about 5 sec. If the surfaces appear highly polished and vary from bright iron white to steel blue in color, it may be safely assumed that they are being properly lubricated.

If the feed is excessive, it should be reduced gradually and frequent inspection of the interior of the engine should be made to determine the results secured. Time is required for a lubricating film to form. The suitability of an oil and the proper feed, therefore, should not be decided upon too hastily. Any test

should cover a period of several weeks. Approximate oil feeds may be obtained from Table XXX, which should not be relied upon, however, for final adjustments.

TABLE XXX.—APPROXIMATE OIL FEED FOR STEAM CYLINDERS

Drops per min.	Cylinder size, in.	Oil feed, pints per 10-hr. day
4	8 by 8	0.40
8	12 by 12	0.75
16	18 by 18	1.50
24	24 by 24	2.25
32	30 by 30	3.00
40	36 by 36	3 75
48	42 by 42	4 50

24. Oil in Exhaust.—If no use is made of exhaust steam, the use of compounded oils presents no problem. But if the exhaust steam is used as boiler feed, for heating or processing purposes, for making ice, as in a distilled-water ice plant, or for air conditioning, etc., their use often poses serious problems. The bad effects of oil in boiler feed and processing steam used in food-preparation plants, chemical industries, laundries, textile and paper mills, etc., are well-known and need not be discussed here.

Although there are many methods used for removing oil from exhaust steam and condensate, yet prevention is always better than cure. Hence, it is desirable to adopt a lubrication practice that will require the minimum feed of oil to the cylinder, consistent with safe and efficient lubrication. This means, of course, that the proper method of application and the correct oil for the engine and operating conditions at hand must be employed.

Oil in exhaust steam or condensate exists as *oil in suspension*, or as *oil in emulsion*, or as both. Oil in suspension consists of comparatively large globules of oil, probably the mineral-oil content of the cylinder oil, whereas oil in emulsion consists of very minute particles of water coated with oil, which is probably the compounding portion of the original cylinder oil. In general, there will be virtually no free oil unless overlubrication has been carried to excess.

Various methods and devices, which depend on heat, pressure, centrifugal force, absorption, baffle impingement, and filtration,

are employed for separating the oil from the steam and condensate. If the oil exists in suspension only, it can usually be satisfactorily removed by an oil separator or grease extractor. *Oil separator* is the term used to describe devices designed for separating oil from steam, and *grease extractor* is used to describe devices designed for separating oil from condensate. Virtually all oil separators operate on the principle either of centrifugal

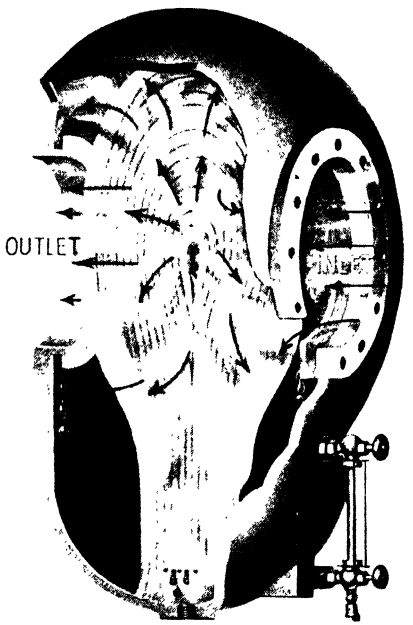


FIG. 255.—Horizontal, baffle-impingement type of oil separator. (*Courtesy Wright-Austin Co.*)

force or of baffle impingement or on a combination of these principles. Grease extractors generally employ in combination the principles of filtration and absorption.

A baffle-impingement separator is shown in Fig. 255, and two designs of centrifugal separators are shown in Figs. 256 and 257. A common error is to install separators that are too small. The velocity of flow through exhaust lines is generally high, and the separator must be of sufficient size to reduce the velocity to a maximum of 2000 or 3000 ft. per min.; otherwise, separation will not be efficient.

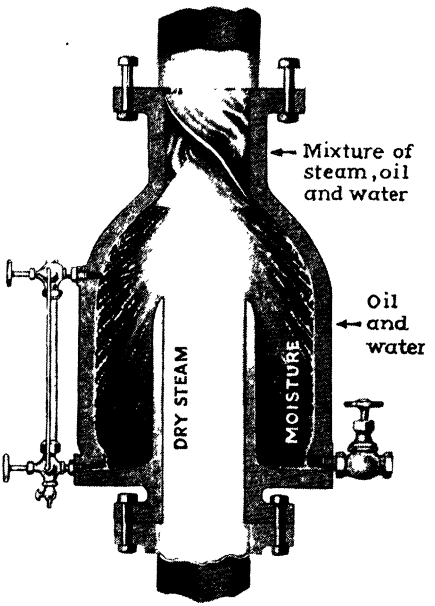


FIG. 256.—Sectional view of a centrifugal-type separator. (*Courtesy The Swartwout Co.*)

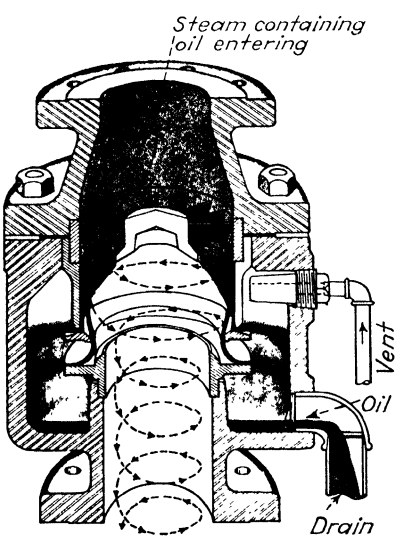


FIG. 257.—Another design of a centrifugal-type oil separator.

Usually, open feed-water heaters are equipped with an oil separator as well as a filter bed of asbestos, coke, charcoal, luffer sponges, or other filtering materials that trap the globules of oil. A final safeguard may be provided in the form of a feed-water filter, as shown in Fig. 258. A grease extractor designed for closed heating systems is shown in Fig. 259.

Sometimes, it is necessary to resort to chemical treatment to remove oil in emulsion. This is accomplished by producing a

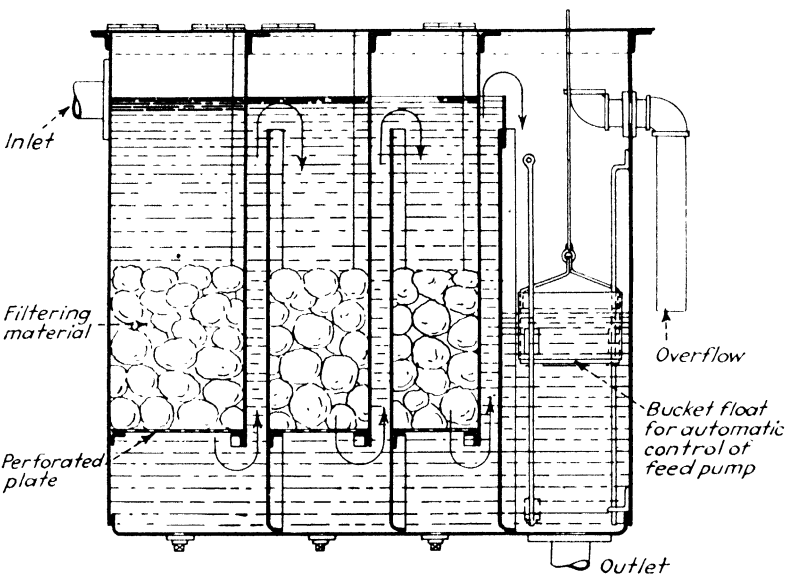


FIG. 258.—Sectional view of a feed and filter tank.

flocculent precipitate by the addition of alumina-soda or other chemicals. The larger precipitated particles absorb the emulsified oil particles so that subsequent filtration easily removes the flocculent precipitate and with it the oil.

The removal of oil from exhaust steam is sometimes a difficult problem, but analyses show that it can be reduced to one-half part of oil per million parts of water. It should be borne in mind that filtered oils are easier to remove than nonfiltered oils. Also, it is common practice to use pure mineral cylinder oils when exceptionally oil-free exhaust is necessary; for they do not readily emulsify, and thus they easily separate from steam and condensate. However, to lubricate a steam cylinder properly, a

greater amount of pure mineral oil than of compounded oil is required. This not only increases the cost of oil but may also lead to serious carbonization of excess oil in the engine.

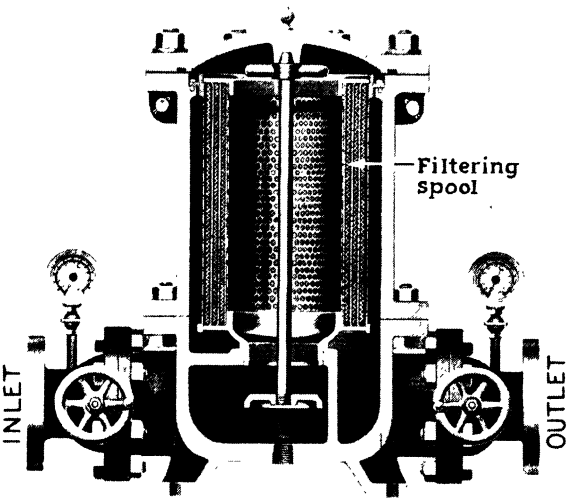


FIG. 259.—One design of a grease extractor. (*Courtesy Elliot Co.*)

25. Recommendations.—Table XXXI may be used as a general guide in selecting cylinder oils for steam engines operating under normal conditions. In addition to possessing the physical characteristics listed in the table, they should possess maximum chemical stability, especially when used under superheated steam conditions.

TABLE XXXI.—GUIDE TO SELECTION OF STEAM CYLINDER OILS

Steam properties			Engine load	Oil characteristics			
Pressure, lb. gage	Temperature, °F.	Quality		% compounding	Flash point, °F.	Fire point, °F.	Viscosity, S.U.S. at 210°F
Over 100 lb...	650 and above	Superheated	Any	None	610	680	225–240
Over 100 lb...	500 to 650	Superheated	Over 50%	4– 5	610	680	192–215
Over 100 lb..	Under 500	Wet or dry	Over 50%	5– 6	540	600	135–145
Under 100 lb.	Under 500	Wet or dry	Any	8–12	485	545	90–100
Any..... ..	650 and less	Any	Under 50%	8–12	485	545	90–100

Under wet-steam conditions, aside from correct viscosity, the most important property of a steam cylinder oil is its ability to replace moisture and resist the washing action of wet steam. This depends chiefly on the amount and nature of the compounding and, to a lesser extent, on whether the oil is filtered or nonfiltered. Nonfiltered oil possesses greater adhesive properties than filtered oils and for this reason is usually recommended for very wet steam conditions.

In addition to correct viscosity, high chemical stability is very important under superheated-steam conditions, for high temperature promotes carbon and gum deposits. Filtered oils, being more stable than nonfiltered, are considered best for superheated-steam conditions

EXTERNAL LUBRICATION

The selection of oils for the external parts of steam engines is governed by the usual factors of speed, operating temperature, bearing pressure, and method of application. Unfortunately, these factors vary widely not only for different engines but also on the same engine. For example, some bearing pressures in pounds per square inch are as follows: for main bearings, from 150 to 500; crankpins, 400 to 2000 and more; crosshead pins, 1000 to 3000; eccentrics, 60 to 150; crosshead guides, 25 to 80.

26. Methods of Application.—The older open-type engines are equipped with various oiling devices and systems, such as hand, drop-feed, wick-feed, splash, ring, and chain, as well as different combinations of these systems. Modern enclosed engines are with few exceptions lubricated by means of either pressure or gravity-circulation system. Splash is used sometimes in combination with circulation oiling, and more rarely alone. Where full splash is employed, ducts and troughs are provided to conduct the oil to parts not directly exposed to the splash. Some designs use splash in combination with ring, chain, or drop-feed oiling for outboard bearings and other remote parts. Crankpins are frequently equipped with banjo oilers.

Eccentrics may be lubricated either with grease or with oil, the lubricant being supplied by leads from the circulation system, grease cups, or grease-gun fittings. Other parts of the valve gear may also use either grease or oil, the former being the more common. Governors are usually hand-oiled, or the

bearings packed with grease or petrolatum; some, though, are fitted with wick-feed cups, sight drop-feed cups, or grease cups.

A general discussion of all types of lubricating appliances and systems is given in Chap. IX and should be referred to for further details.

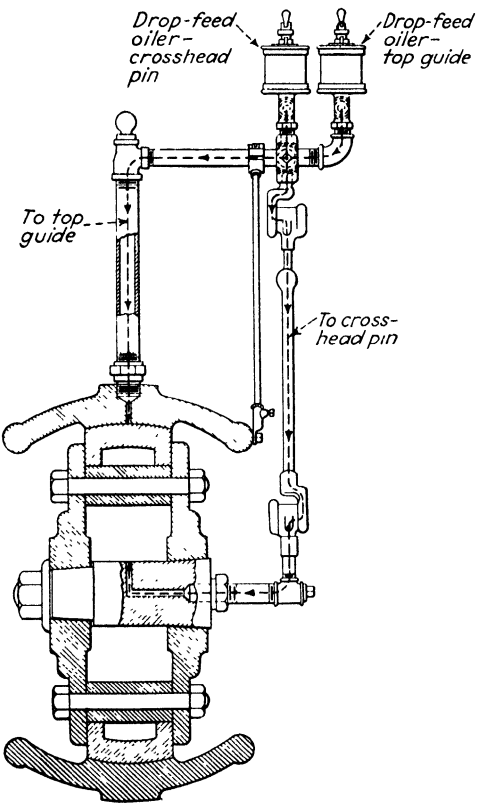


FIG. 260.—Drop-feed oiling applied to crosshead pin and top guide of a horizontal engine.

27. Circulation and Splash Oiling.—Engines provided with circulation or splash systems have enclosed crankcases, and the oil is circulated by a pump in the former case and splashed by the crank or crank disk in the latter to the various parts.

In the case of virtually all machines equipped with circulation or splash systems, certain precautions should be observed to avoid difficulties. Steam engines so equipped are no exception to this rule.

It is virtually impossible to keep all water out of such lubricating systems, and in certain designs the oil is floated on top of the water. Water may enter because of leaking piston-rod and valve-rod packings, scored valve or piston rods, or condensation of atmospheric moisture.

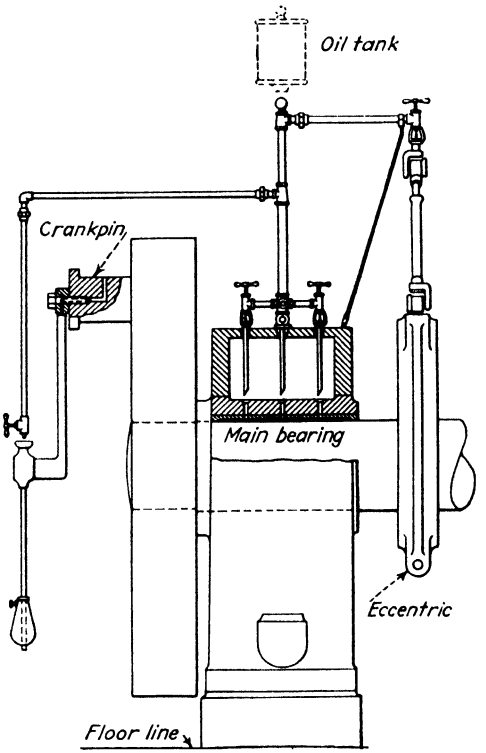


FIG. 261.—Drop-feed oiling applied to crankpin, main, and eccentric bearings of a horizontal engine.

In enclosed engines not equipped with bulkheads, some of the oil is thrown against the hot cylinder head, which tends to oxidize the oil and cause some oil to vaporize and smoke. The portion of the oil not vaporized but that comes into contact with the hot cylinder head is partly carbonized and drains back into the crankcase, thus contaminating the oil.

Some engines have between the cylinder and crankcase a bulkhead that prevents the oil from coming into contact with the hot cylinder head and keeps condensate, caused by steam

leaking past the packing, from entering the crankcase. Bulkheads are a great aid in minimizing oil deterioration and should be kept in good mechanical condition.

The oil in engines operated in dirty or dusty air inevitably collects a certain amount of impurities which aid in forming emul-

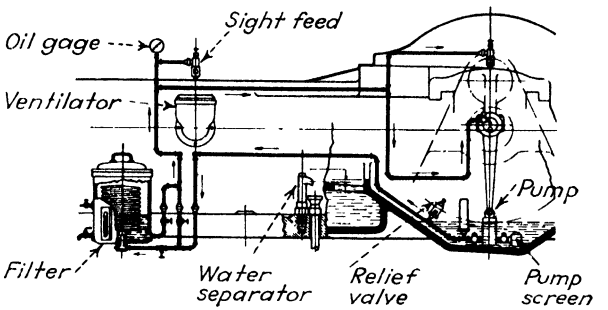


FIG. 262.—Circulation oiling applied to the external parts of a horizontal engine.

sions when water is present and are otherwise objectionable. If the engine is not provided with a purification system, it is good practice to drain the crankcase oil and thoroughly to clean the system at least every 6 months. If exceptionally dirty conditions prevail, it is advisable to drain more frequently. The drained

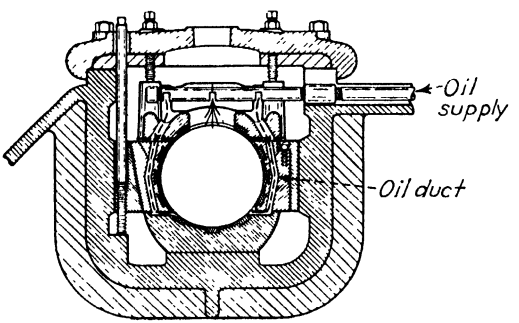


FIG. 263.—Circulation-oiled main quarterbox engine bearing.

oil can be purified by simple gravity settling, or other means, and then re-used.

Some operators unwittingly mix cylinder-oil drip with the bearing oil. This is poor practice because the cylinder oil increases the viscosity and tendency of the bearing oil to emulsify. Every precaution should be taken to prevent the mixing of the two oils.

If automatic devices are not provided for removing the water from the crankcase, frequent and regular draining should be provided for; otherwise, excessive splashing of the oil and water will occur, increasing the danger of emulsions. The proper time

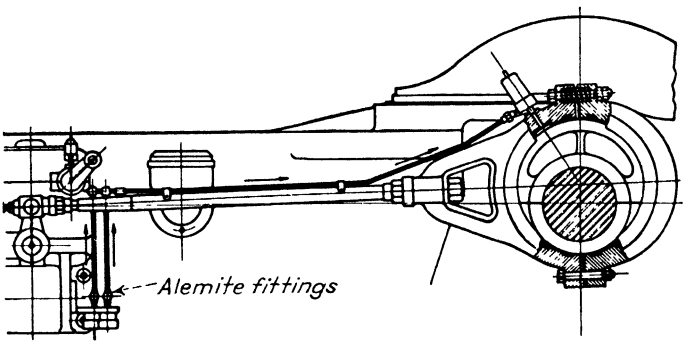


FIG. 264.—Grease-gun lubrication applied to eccentrics and valve cranks of an engine.

for draining is just before the engine is started. Emulsions flow slowly, tending to clog screens and piping and thus endangering the lubrication of the engine.

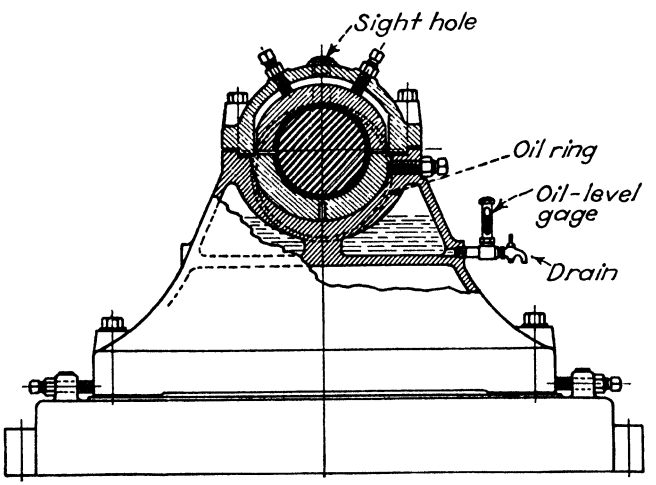


FIG. 265.—Ring-oiled main bearing of an engine.

28. Oil Requirements.—Since the oil is generally not re-used in the case of hand, drop-feed, and wick-feed systems, it is not necessary for it to be of high quality. But since it is not uniformly or copiously supplied, it must be viscous enough to remain

in the bearings for comparatively long periods of time. If it is not re-used, resistance to oxidation, emulsification, and sludging is of little importance.

In splash, ring, chain, and circulation oiling, the oil is used over and over indefinitely and is copiously supplied. It is constantly agitated, usually in the presence of water, air, and impurities,

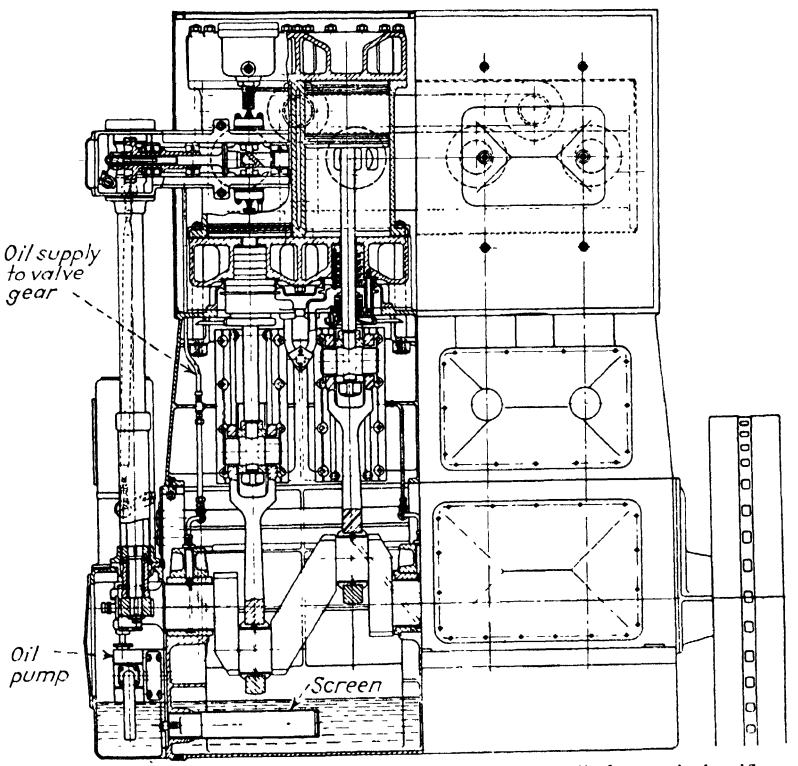


FIG. 266. Half-sectional view of a circulation-oiled four-cylinder vertical uniflow engine.

which tend to promote emulsification, oxidation, foaming, and sludge. Consequently, a pure mineral oil possessing high resistance to oxidation, emulsification, oxidation, foaming, and sludge formation should be used. Because it is copiously supplied and tends to cool the bearings, it need not be of high viscosity.

It is evident from the range of pressures that prevail in the bearings of steam engines that a compromise must be made as to

viscosity. The crosshead-pin and crankpin bearings are the most difficult to lubricate because of the high prevailing pressures. The oil must possess sufficient viscosity to withstand the high pressures prevailing in these bearings but at the same time not be so viscous as to cause excessive friction and temperature in the other bearings.

Enclosed nonreleasing Corliss and uniflow valve gears are usually lubricated with the same cylinder oil used for the cylinder. For governors and valve gears lubricated with grease, a high-grade cup grease of no 2 or 3 consistency should be used. The grease must be of such a character as not to harden or gum under the prevailing temperature conditions.

Although it is impossible to give complete recommendations for all engines operating under various conditions, Table XXXII will serve as a guide in selecting lubricants for the external parts of engines operating under normal conditions.

TABLE XXXII.—GUIDE TO SELECTION OF EXTERNAL-BEARING LUBRICANTS

Method of application	Flash point, °F.	Viscosity, S.U.S. at 100°F.	Remarks
Circulation	385–395	150 min.	Highest quality pure mineral oil
Splash			
Ring or chain		250 max.	
Drop-feed*	425–435	275 min.	Medium quality pure mineral oil
Wick-feed*			
Hand*		375 max.	
Grease gun		No. 2 (soft consistency)	High quality lime-base grease of smooth texture, containing from 10 to 20% soap
Grease cup		No. 3 (medium consistency)	

* For practical reasons, where these methods are used in combination with splash, circulation, ring, or chain oiling, it is recommended that one oil should be used, *viz.*, that used for the splash, circulation, ring, or chain system.

CHAPTER XIV

LUBRICATION OF AIR COMPRESSORS

Virtually every field of industry uses compressed air. It is used for the transmission of power; for the operation of pneumatic tools and machines; for different types of air lifts and hoists; for railway and motor-vehicle brakes; for pneumatic-tube carriers; for air-lift pumps; for electropneumatic signals; etc. It is also widely used for the agitation of liquids; for cleaning, paint spraying, and blasting; for injection and atomization of fuel oil under boilers and in Diesel engines; and for numerous other purposes.

1. Classification of Compressors.—The multifarious uses of compressed air require innumerable types and sizes of compressors. They may, however, be broadly classified as *reciprocating, rotary,* and *centrifugal* types.

RECIPROCATING COMPRESSORS

The reciprocating type of compressor is the most commonly used. These machines operate generally within the speed range of 120 to 350 r.p.m., although the smaller industrial machines may operate at 800 r.p.m. or more. They vary in capacity from 2 cu. ft. per min. for the small single-acting air-cooled units to 8000 cu. ft. per min. for the very large double-acting, water-cooled machines. They are designed for discharge pressures ranging from a few pounds above that of the atmosphere to as high as 5000 lb. They may be direct connected, or they may be indirectly connected by means of a flat or V belt, chain, or gearing to the power unit, which may be a steam, gas, oil, gasoline, or Diesel engine or an electric motor. Large reciprocating compressors designed to deliver air at pressures below 10 lb. are known as *blowing engines* and operate usually at 30 to 70 r.p.m.

2. Parts Requiring Lubrication.—Regardless of the construction and operating conditions, the lubrication of the reciprocating-type compressor resolves itself into a consideration of: (*a*) the cylinder or internal parts, and (*b*) the external parts.

The internal parts requiring lubrication include: (*a*) the piston and cylinder, (*b*) the piston rod, and (*c*) valves if of the Corliss or poppet type.

The external parts that require lubrication are: (*a*) main bearings; (*b*) crankpin and crosshead-pin bearings; (*c*) crosshead and tail-rod guides, where the latter is provided; and (*d*) miscellaneous bearings.

3. Functions of Cylinder Oil.—Air-compressor cylinder oil is required to perform a threefold function:

1. Reduce friction losses to a minimum.
2. Minimize wear.
3. Provide a tight seal between piston and cylinder wall.

4. Factors Affecting Cylinder Lubrication.—The effectiveness of air-compressor cylinder lubrication depends mainly on the following influencing factors:

1. Cleanliness of intake air.
2. Effectiveness of cooling system.
3. Methods of oiling.
4. Oil characteristics.
5. Operating characteristics and requirements.

5. Cleanliness of Intake Air.—More air-compressor operating difficulties are caused by dirty intake air than any other single cause. Thorough cleaning of the intake air pays large dividends on the best and most efficient air filter obtainable.

Atmospheric air is never clean. Impurities that contribute to air pollution include: bits of carbon from the combustion of fuels; fragments of earth, sand, ash, rust, paper; threads of cotton, wool, and silk; and particles of animal and vegetable matter and pollen.

Atmospheric impurities are generally classified, according to size, as dust, fumes, and smoke. Dust consists of particles of solid matter varying from 1.0 to 150 microns in size. Fumes include particles resulting from chemical processes such as combustion, explosions, and distillation and range in size from 0.1 to 1.0 micron in size. Smoke is composed of fine soot and carbon particles less than 0.1 micron in size. Smoke frequently contains, also, unconsumed hydrocarbon gases, sulfur dioxide, sulfuric acid, carbon monoxide, and other gases capable of reacting with unstable hydrocarbons of oil.

The quantity of air impurities varies widely with the locality; however, the following are approximate averages of atmospheric dust concentrations:

Rural and suburban districts	0.2 to 0.4 grain per 1000 cu. ft.
Metropolitan districts	0.4 to 0.8 grain per 1000 cu. ft.
Industrial districts	0.8 to 1.5 grains per 1000 cu. ft.

These quantities may appear insignificant, but actually they are not. For example, approximately 1 lb. of impurities per hour would be taken in by a 1000-cu.-ft. compressor located in an industrial district.

Dirty intake air is a major contributing factor in the formation of the troublesome so-called *carbon deposits* frequently found in air compressors.

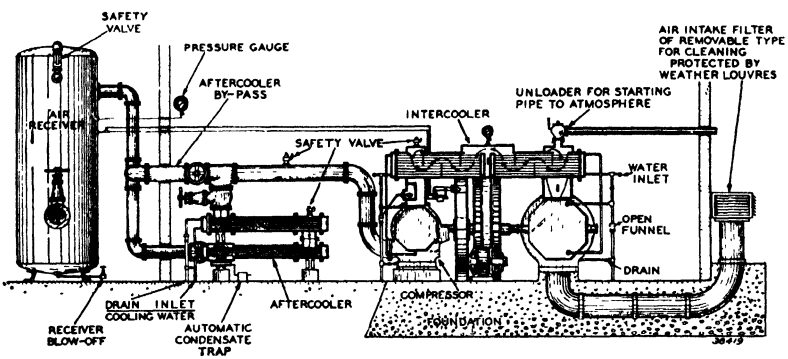


FIG. 267.—Proper installation of a reciprocating air compressor.

Several designs of air filter are available. In general, however, air filters accomplish filtration by the following methods: (*a*) The air is passed in thin layers over oily surfaces of various filtering materials, such as paper, cloth, felt, steel, glass and copper wool, wire ribbon, hair, fiber, and various fabricated metal elements. Such filters obviously operate on the straining principle. (*b*) By the *baffle-impingement* principle the air stream is caused to impinge against various designs of baffles so arranged that it is virtually impossible for any air to flow through the filter without coming into contact with several baffles. The operation of these filters obviously depends on the difference between the density of the impurities and that of the air. (*c*) A sinuous path, which changes direction frequently and abruptly, is provided for the flow of air through the filter. In such filters, the air is caused

to whirl by means of baffles. Like the impingement-baffle type, the operation of these filters depends on the difference between the density of the impurities and that of the air. (*d*) In many filters, filtration is accomplished by a combination of two or more of these methods.

The major factors to be considered in selecting an air filter are: (1) efficiency, (2) ease of servicing, (3) operating costs, (4) dirt

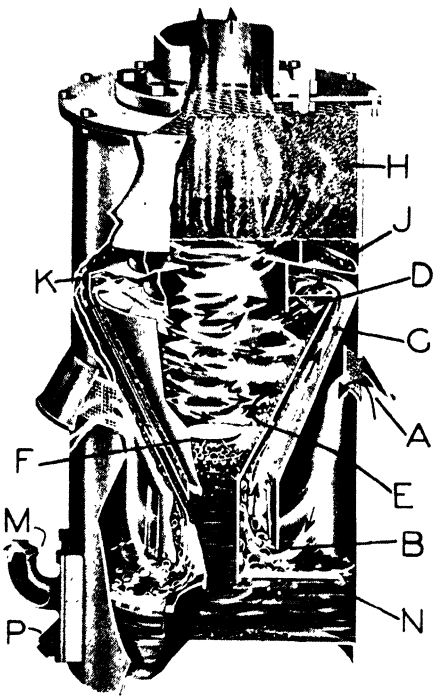


FIG. 268.—Oil-bath type of filter for very dirty air. (*Courtesy American Air Filter Co., Inc.*)

capacity, (5) constructional features and materials, (6) reliability, (7) air restriction, and (8) first cost.

In regard to efficiency, it is more important to consider the time-efficiency characteristics than the initial efficiency. Some filters are very efficient when the element is clean but rapidly lose efficiency when loaded with impurities.

Shown in Fig. 268 is a filter specially designed for very dusty air. The dust-laden air enters ports *A*, which are screened and protected against rain. Sweeping downward and across plates

N, it is intimately mixed with oil at *B* and receives its first cleaning, as the heavier particles of dust are deposited in the oil. Next, it is carried upward through passages *C*, where it is further

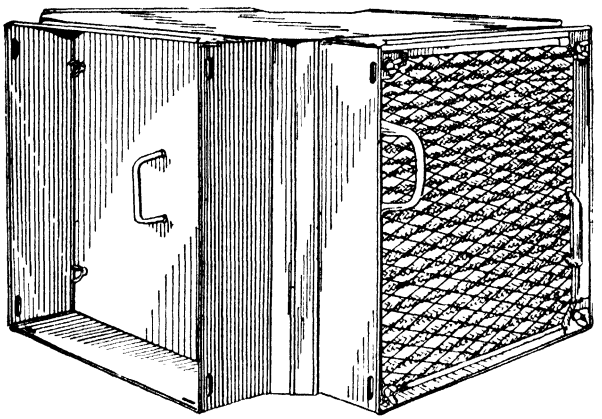


FIG. 269.—Filter suitable for normal air conditions. (*Courtesy Socony-Vacuum Oil Co.*)

cleaned by brushing against the oil-coated walls. Impinging against *D*, the direction of flow is reversed. In its passage down-

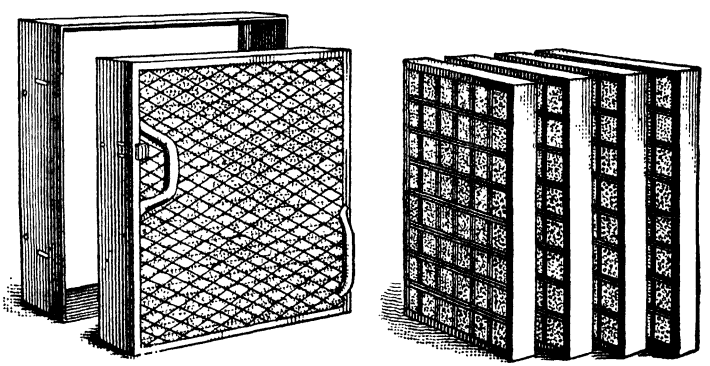


FIG. 270.—Filter units any number of which may be assembled in a common frame to give required capacity. (*From Air Conditioning by Burgess H. Jennings and Samuel R. Lewis, by permission of the copyright owners, the International Textbook Co., Scranton, Pa.*)

ward into the cone-shaped chamber *E*, it is brought in contact with vanes, which give it a whirling motion, thus throwing the heavier particles against the walls whence they fall back into the

oil reservoir through pipe *K*. The air is next caused to spiral upward into and through filter element *H* by means of plate *F*, which also prevents the dust-laden air at the tip of the cone from being swept along into the filter element. The remaining impurities and oil particles are effectively removed by filter element *H*; the dust removed is held in the element while the oil drains through *J* and *K* into the reservoir.

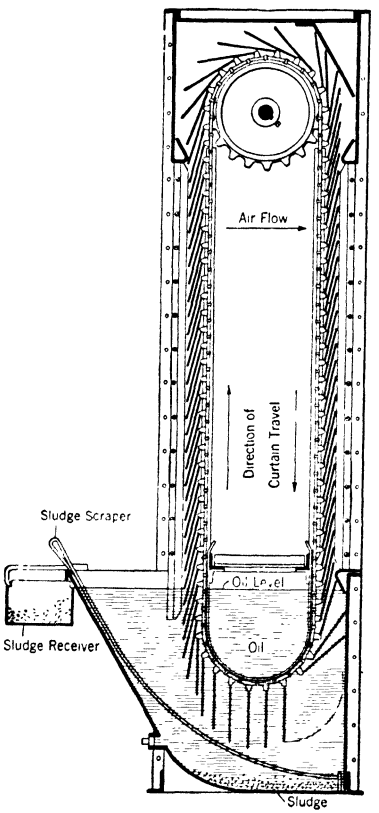


FIG. 271.—Continuous viscous-type air filter. (*From Air Conditioning by Burgess H. Jennings and Samuel R. Lewis, by permission of the copyright owners, the International Textbook Co., Scranton, Pa.*)

Normally, maintenance involves draining the oil reservoir periodically, removing plate *P* to scrape out the sludge, and refilling with clean oil to top of pipe *M*. This type of filter is available in sizes capable of handling 250 to 2000 cu. ft. of air per minute.

Figure 269 shows a design of an air filter that is very effective and widely used. It consists of an outer housing and a viscous impingement-type filter element, which contains continuous strands of galvanized wire, double crimped and packed to give graduated variation in density. The back of the element consists of fine- and coarse-mesh woven-wire screens welded in place. The element is divided by horizontal partitions, which hold the filter mediums in place and provide oil reservoirs.

For compressors having capacities of about 10,000 cu. ft. per min. and above and for certain cases where space will not permit the installation of an integral filter, units and frames of the type shown in Fig. 270 are available. As many as are required of these units are bolted together, and a housing is constructed

around them, which, in turn, is connected directly to the air-intake pipe of the compressor. These units should be protected from the weather by louvers mounted on hinges, which provide accessibility for cleaning and inspection.

The principle of filtering air through oily materials is embodied in the continuous filter, Fig. 271. In this type, the filter curtain passes through the oil bath at the bottom of its travel, the accumulation being thus washed off and the coat of oil continually renewed. In another similiar type, oil is pumped continuously through the filter curtain, which is stationary, thus washing out the dirt and maintaining the curtain thoroughly coated with oil at all times.

Correct air-filter installations will reduce operating expenses and maintenance costs of air compressors. Dirty air not only causes excessive wear but also increases the formation of so-called *carbon deposits*.

6. Effectiveness of Cooling System.—The temperature of air rises during compression, because the work done in reducing the volume and in increasing the pressure of the air is converted into heat. This is known as the *heat of compression*, and both air and water are used to carry away this heat. But it is impracticable to remove all the heat of compression as rapidly as it is generated in air compressors. Consequently, the temperature of the discharge air is considerably higher than that of the intake air. Even though air and water cooling are resorted to, the temperature of the discharge air ranges from 200 to 400°F.

When air is to be highly compressed, the resultant high temperatures, increased cost of operation, and mechanical difficulties render compression in a single cylinder very undesirable. Multistaging was devised to overcome, in part, these factors. In multistage compression, the air is partly compressed in one stage, then cooled in an intercooler, and then further compressed in the second stage, etc., until the final stage, after which it is cooled in an aftercooler. Multistaging results in two major advantages: lower final air temperature, and reduced cost of power for a given compression.

If an air compressor operates for any appreciable period of time above normal temperature, trouble is liable to occur. Normal operation is never assured, as is evident from the following factors that tend to cause overheating:

1. Too warm intake air.
2. Too warm cooling water or air.
3. Insufficient amount of water or air circulated around the cylinder and head.
4. Overloading or forcing compressor beyond capacity.
5. Leaky discharge valves.
6. Deposits in cooling-water jacket or on cooling fins.

All these factors have the effect of increasing the operating temperature of compressors above normal and, ultimately, cause excessive carbon deposits.

For single-stage compression, the temperature of the discharge air roughly increases 2° for each degree increase in the intake-air temperature. It is, therefore, important that the end of the suction pipe should be located in as cool, clean surroundings as possible. Generally, the intake air should be taken from outside the compressor room. Cool, clean air is a most important factor in air-compressor operation.

Repeated leakage of hot air back through the discharge valves may heat the valves to dangerously high temperatures with the ultimate possibility of causing a failure, a fire, or an explosion. Valves may be heated to as high as 700°F. in this manner, which is sufficient spontaneously to ignite lubricating oil.

7. Methods of Oiling Internal Parts.– Cylinders of air compressors require a sparing but uniform oil feed, as is shown in Table XXXIII. Consequently, it is imperative that the method of oiling should be such that the feed can be reduced to the required small amount and at the same time be unfailing. In general, oil is supplied by one or a combination of two of the following methods:

1. Mechanical force-feed oiling.
2. Splash oiling.
3. Drop-feed oiling.

As explained in Chap. IX, mechanical force-feed oiling permits feeding a measured quantity of oil into the cylinder at a rate proportional to the speed of the compressor. The feed can be accurately adjusted and remains so, regardless of temperature variation. This type of lubricator can also be timed to deliver oil to the cylinder at the instant the piston is in such a position that the oil is injected between the piston rings. Such timed delivery results in effective distribution, for the rings spread the

oil evenly over the cylinder surface as the piston moves back and forth. It has become generally recognized that mechanical force-feed oiling is the most reliable and satisfactory means of lubricating air-compressor cylinders, especially for all but the relatively small single-acting machines.

For horizontal compressors, the oil is generally introduced through a single lead at the top center of the cylinder. Very large horizontal cylinders may be provided with two or more

TABLE XXXIII.—APPROXIMATE OIL FEED FOR AIR CYLINDERS

Cylinder diameter, in.	Piston displacement, cu. in.	Rubbing surface, sq. ft.	Oil feed per cylinder	
			Drops per min.	Pt. per 10 hr.
Up to 6	Up to 65	Up to 500	1	0 05
6 8	65– 125	500– 750	1	0 08
8 10	125– 225	750–1100	1	0.11
10 12	225 350	1100–1500	1– 2	0 14
12 15	350– 600	1500–2000	2– 3	0 20
15 18	600–1000	2000–2600	3– 4	0 27
18 24	1000–1800	2600–3600	4– 5	0 36
24 30	1800–3000	3600–4800	5 6	0 48
30 36	3000–4500	4800–6000	6– 8	0 60
36 42	4500–6500	6000–7500	8–10	0.74
42 48	6500–9000	7500–9000	10–12	0.90

Note. Air compressors equipped with Corliss valves require approximately 50 per cent more oil than the quantities shown above.

leads spaced around the cylinder midway of the stroke. In some horizontal double-acting machines, oil is introduced under pressure into the piston-rod stuffing box for the purpose of lubricating and sealing the rod. In some machines, excess oil is also delivered to the stuffing box, from which it passes to the cylinder.

Where more than one point of delivery is required, each lead should connect to a separate pump unit of the lubricator; otherwise, it is impossible to adjust feeds to meet requirements.

Formerly, many compressors were equipped with sight drop-feed oilers, which were provided with means for equalizing the pressure above and below the orifice. Generally, equalizing tubes connect from below the orifice to the space over the oil in the reservoir, thus permitting the oil to flow by gravity into the cylinder. These oilers are manually started and stopped. They

are not inherently susceptible to close feed regulation, nor are they reliable, especially when closely adjusted. Moreover, the feed is markedly affected by temperature and oil-level variations.

Splash oiling is widely used on small, vertical, and horizontal single-acting machines. Usually, the connection rod or an extension of it dips into or strikes the oil in the crankcase and splashes it onto the cylinder wall. The quantity of oil thrown onto the cylinder wall is largely dependent on the level of the oil in the crankcase. The quantity of oil that passes the rings into the cylinder is more or less regulated by the oil-control rings. But if the rings become excessively worn or if the proper oil level is not maintained, practically all control is lost of the amount of oil entering the cylinder. Should the oil level become too low, the parts generally do not receive sufficient oil and excessive friction and wear will result. On the other hand, should the oil level be maintained too high, excessive oil is thrown onto the cylinder wall, this effect usually resulting in an excessive amount of oil in the cylinder. Too high an oil level also causes high consumption and churning of the oil, thus promoting rapid oil oxidation.

Most splashed lubricated compressors have troughs and partitions so arranged as automatically to maintain the oil at the correct height, as shown in Fig. 132.

8. Oil Requirements and Characteristics.—Successful air-compressor-cylinder lubrication depends both on the use of the correct oil and on its proper application. In the operation of most machines, faulty lubrication leads to troublesome difficulties, inefficient operation and, sometimes, costly shutdowns. Faulty air-compressor lubrication, however, involves not only these factors but also the possibility of a serious explosion. For these reasons, cylinder oils for compressors should be *carefully selected* and *properly applied.*

Most operating and maintenance troubles, such as so-called carbon deposits, sticking valves, compression leaks, and high operating temperatures, are directly traceable to overlubrication. The oil fed into the cylinder is not burned, and if it is of high quality the amount evaporated is nil. Consequently, only a small quantity of oil is required to maintain an efficient film on the rubbing surfaces, as is shown in Table XXXIII. Troubles caused by insufficient oil are seldom encountered. Any increase in the feed beyond that required for providing an effective piston

seal and reducing friction to a minimum tends to increase the likelihood of an explosion or fire; moreover, where intercoolers and aftercoolers are provided, the oil tends to deposit on and insulate the cooling pipes, thus reducing the efficiency of the coolers.

The most reliable method of determining whether or not the feed is correct is by an inspection both of the suction and of the discharge valves. If the valves are dry or rusted, the feed is insufficient and should be increased, whereas if oil has accumulated in the ports and clearance spaces, the feed is excessive and should be reduced. If all parts show a uniform and just visible film, the feed is correct.

Air-compressor cylinder oils should be high-quality distillates (not blends) having the highest possible flash point consistent with the required viscosity. They should not contain any cylinder stock, water, sediment, acid, soap, resin, or any other deleterious substances. Where compounded oils are required, the compound should be lard or tallow oil and not rapeseed oil, which is prone to oxidize and form gummy deposits under the influence of hot air.

Because of the many different designs and types of reciprocating compressors, it might be supposed that several oils would be required for their lubrication. But such is not the case, as is shown in Table XXXIV, which is considered a reliable guide for selecting compressor oils.

9. Viscosity.—The correct viscosity is determined by the operating temperature, pressure, and mechanical condition of the cylinder. Under normal operating conditions the temperature of the oil film on the cylinder wall is 125 to 200°F. Consequently, the viscosities of the oil at these temperatures are most important. If the oil is too thin, excessive wear will result and the piston will not effectively be sealed, permitting blow-by. Conversely, if the oil is too thick, operating temperatures and friction increase, and excessive carbon deposits are likely to form.

The viscosity at low temperatures is of importance only when a machine is exposed to cold weather. Under this condition the oil should not thicken to the extent that it will not flow freely when the machine is started.

In regard to pressure, the important consideration is not the maximum discharge pressure but rather the pressure difference

that exists on opposite sides of the piston. It is this pressure difference that tends to cause blow-by and forces the rings against the cylinder wall. As this pressure difference increases, the more

TABLE XXXIV.—GUIDE TO SELECTION OF OILS FOR RECIPROCATING AIR COMPRESSORS

Method of application	Parts	Discharge pressure, lb. per sq. in. gage	Flash point, °F.	Fire point, °F.	Per cent compound	Viscosity, S.U.S.		
						100°F.	130°F.	210°F.
Circulation Splash Ring or chain Drop feed	All	Under 150	385	440	0	320	143	50
Circulation Splash Ring or chain Drop feed	All	Over 150	400	450	½–1	415	175	54

difficult it is to seal the piston effectively and maintain a complete oil film on the cylinder wall. This unbalanced pressure is usually greater in three- and four-stage compressors than in single- and two-stage machines; hence, higher viscosity oils are required for the former machines.

As cylinder and ring wear occur, many operators resort to the use of a heavier bodied oil in order to prevent blow-by. This practice should not be carried too far, for heavy-bodied oils are prone to cause excessive carbon deposits, which are generally believed to promote fires and explosions. If wear becomes excessive, the cylinder should be rebored and new rings installed. In all cases, an oil having the lowest viscosity consistent with effective piston seal and minimum friction should be used.

10. Carbon Residue.—The Conradson carbon-residue test is of some value in selecting a compressor oil; but, as pointed out in Chap. VII, it is not the sole factor in determining the probable amount of so-called *carbon* that will be deposited in an air-compressor cylinder. The concentration of impurities in the air, operating temperature of the compressor, and the viscosity of the oil at the operating temperature are also important factors.

As previously pointed out, mineral oils are composed of many different hydrocarbons, each having a distinct boiling point or

temperature at which it vaporizes. In an air-compressor cylinder as in a still, the low-boiling-point hydrocarbons vaporize first, leaving the high-boiling-point hydrocarbons. These high-boiling hydrocarbons being in intimate contact with hot air are prone to oxidize or decompose to form sticky, tarry material, which acts as a binder for the impurities in the air as well as for the real carbon remaining as a result of the vaporization of the low-boiling hydrocarbons.

This mass, consisting of air impurities, oxidized oil, and some real carbon, bakes under the continued high temperatures in the cylinder into a more or less hard deposit. The average analyses of 10 samples of these so-called carbon deposits is reported by J. A. Vaughan as follows:

	Per Cent
Fixed carbon	22.6
Volatile matter	55.7
Ash	21.7

In some cases these deposits are soft; in others, hard and dry. In general, the real carbon is less than 25 per cent. Bits of silica, iron, copper, and many other materials are always present, which prove that a considerable portion of all so-called carbon deposits consists of air impurities and metal particles worn from parts of the compressor.

The real carbon portion, with few exceptions, depends on the oil. Other factors being equal, the higher the viscosity of an oil and the Conradson carbon-residue value, the greater is the tendency of an oil to form carbon deposits. Likewise, paraffin-base oils are prone to deposit more carbon than other oils, because of their usually higher carbon-residue value.

The real carbon portion of so-called carbon deposits depends on the "make-up" of the oil as well as on the amount fed to the cylinder. If a blended oil consisting of cylinder stock and a comparatively light-bodied distillate is used, the tendency is for the light-bodied distillate to vaporize, leaving the heavy-bodied cylinder stock as a residue to act as a binding agent for air impurities and worn metal particles. Such an oil may have the correct viscosity, but its flash point would be low and not consistent with the viscosity. For this reason, air-compressor oils should always be straight-run distillates.

It is common practice to use motor oils for lubricating many of the small portable compressors so generally used on street, road, and construction works. Most motor oils are blends of distillates and bright stocks and, for the reasons stated in the preceding paragraph, are not considered suitable for air compressors.

Carbon deposits build up not only in the cylinder but also in the valve passages, behind the rings and the discharge passages and piping, and in extreme cases in the intercoolers and receiver.

11. Fire and Flash Points.—It is common practice to overemphasize the importance of flash and fire points of oils for compressors. Many believe erroneously that a high flash point is indicative of high quality, low oil consumption, and the security of freedom from fires and explosions. It is generally true in comparing oils of the same viscosity that the one having the highest flash point will evaporate less and, hence, will deposit less carbon. Consumption, however, is chiefly caused by the air and piston scoring the oil from the cylinder walls and the ultimate ejection of the oil in atomized form with the discharged air. The flash point bears no relation whatever to this action of the air and piston. Viscosity is mainly the governing factor. Regardless of statements to the contrary, flash point is of relatively little importance in so far as explosions and fires are concerned.

12. Pour Point.—Where compressors are exposed to low temperatures, the oil should have a pour point sufficiently low to eliminate any possibility of failure to flow in the lubricator. The pour point should be at least as low as the lowest temperature encountered in operation.

13. Compounded Oils.—Air is never dry. It always contains some moisture, which is never deposited in the first stage but is carried over into the intercooler, where the air is cooled below its dew point and some of the moisture is condensed. Some moisture, however, is still entrained in the air and is carried into the next cylinder. This air-moisture mixture enters the cylinder at a high velocity and tends to wash the oil films from the cylinder walls. To resist this washing effect, slightly compounded oils are generally recommended for the high-pressure cylinder of multistage compressors. Compounded oils form emulsions with water and are more adhesive in the presence of water than pure mineral oils.

When pure mineral oils are used under these conditions, it is generally necessary to increase the feed, which is objectionable, as has been previously pointed out. Moreover, pure mineral oils do not as a rule adhere to the valves, the cylinder walls, and the piston when the compressor is shut down. Consequently, these parts often rust and pit while the machine is idle.

The fixed oils used for compounding, however, are more readily oxidized by the action of hot air than are pure mineral oils. The percentage of compound should, therefore, be just sufficient to counteract the moisture, and no more, and should not be used at all unless necessary. Usually, 1 per cent of compound is sufficient. Lard or tallow oils are preferred to rapeseed oil, which is more prone to oxidize.

14. Fires and Explosions.—Contrary to the generally accepted opinion, the characteristics of the oil have very little to do with air-compressor fires and explosions. Most authorities hold that some faulty condition of operation or installation *must* exist before fires and explosions can occur. When such conditions do exist and fires or explosions take place, it is always found that the operating temperatures have exceeded the flash point of any oil.

Another popular misconception is that explosions are frequent occurrences. As a matter of fact, quite the contrary is true. Fires are much more prevalent and sometimes occur without the knowledge of the operator.

Reports of investigations of explosions show that in most cases the flash point of the oils ranged from 500 to 600°F. In Diesel engines, some of the most successful oils do not have flash points above 450°F., yet the temperatures involved may be as high as 1000°F., these data proving that high-flash-point oils are not required.

The lower the viscosity of the oil, the higher the temperature at which oil vapor and air ignite spontaneously. In general, the more complex and more viscous an oil is, the lower is its spontaneous-ignition temperature. Kerosene, for example, ignites spontaneously in air at a lower temperature than gasoline. For this reason the compression ratio of kerosene engines is lower than that of gasoline engines.

In brief, security from fires and explosions is best secured by observing the following rules:

1. Install compressor properly, as in Fig. 267.
2. Use as clean and cool air as is possible.
3. Use adequate cooling water and as cold and soft water as is possible.
4. Operate compressor in the service for which it was designed, maintain it in good mechanical condition, and do not overload it.
5. Periodically inspect water jacket, valves, discharge pipe, aftercooler, intercoolers, and receiver.
6. Take temperatures of intake and discharge air periodically.
7. Use a high-quality compressor oil, and feed only a sparing but uniform amount.
8. Clean cylinders weekly by feeding for 2 or 3 hr. a soap-water solution consisting of 1 part soft soap and 15 parts of water into the system instead of oil. The feed should be about ten times as great as that of the oil. After using this solution, all drain cocks should be opened to remove any accumulated soap-water solution. The compressor should be operated for a half hour or more after the washing in order thoroughly to cover all surfaces with oil. Kerosene, gasoline, or benzene should never be used for cleaning.
9. Install an aftercooler to cool and condense the oil so that it can be drained from the system.
10. Install a receiver to equalize air pressures.

15. Vacuum Pumps.—There are two types of vacuum pumps, *viz.:* dry-air vacuum pumps and wet vacuum pumps. Only the first type is of interest here. Such pumps are, to all intents and purposes, air compressors that are used to withdraw air and noncondensable gases from vacuum chambers, such as condensers.

In general, dry-air vacuum pumps are lubricated in the same manner and with the same oils as air compressors. Moisture is generally but not always present in the cylinders of these pumps. If it is, however, a slightly compounded oil is usually advantageous.

16. Methods of Oiling External Parts.—Oil is generally supplied to the external parts of reciprocating compressors by one or a combination of two of the following methods:

1. Splash oiling.
2. Gravity-circulation oiling.
3. Force-circulation oiling.
4. Ring and chain oiling.
5. Drop-feed and wick-feed oiling.

The advantages and disadvantages of these various methods of oiling are fully discussed in Chap. IX.

Splash oiling is employed for the complete lubrication of all parts of many small single-acting compressors. But it is also

widely used for the lubrication of the external parts only of many double-acting machines, the internal parts of which are supplied by means of mechanical force-feed lubricators or sight drop-feed oilers.

Because the crankcases of splash-lubricated compressors serve as oil reservoirs, they are closed, except for a breather pipe. The cylinder and crankcase of compressors utilizing splash lubrication

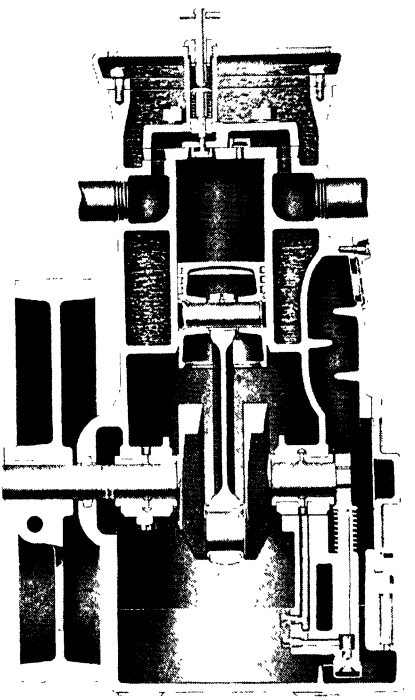


FIG. 272. Circulation-oiled, water-cooled, single-stage air compressor. (*Courtesy Worthington Pump and Machinery Corp.*)

for the external parts only are usually separated by a bulkhead equipped with oil-wiper rings, which prevent crankcase oil from working along the piston rod into the cylinder.

In the gravity-circulation system, the oil is pumped from a bottom reservoir or sump to an overhead tank, from which it flows by gravity, through pipes provided with adjustable feed valves, to all parts. The feeds are generally so restricted as to provide drops only.

In the force-circulation system, a flood of oil is pumped under pressure direct from the reservoir to all parts. A flood of oil, therefore, is supplied to the parts continuously, thereby both lubricating and cooling them.

Both the gravity- and force-circulation systems may be provided with an oil filter, or a cooler, or both. Gear, vane, and plunger-type pumps are used and are generally driven from some part of the machine. The quantity of oil in the system depends chiefly on the size of the compressor. In any case, however, the quantity of oil in the system should be sufficient to allow the oil

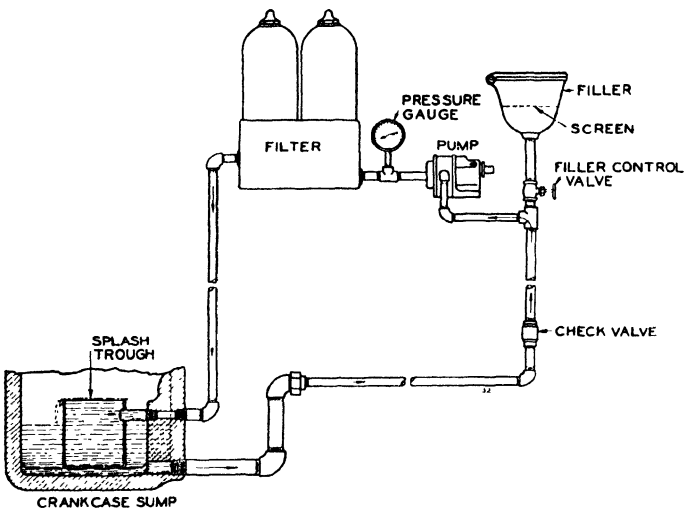


FIG. 273.- Method of filtering and maintaining constant oil level.

to remain quiescent for a period of time during each cycle, impurities and water that may have gathered in the system being thus permitted to settle.

Circulation oiling is an efficient and economical method of applying oils to the external parts of compressors. It is automatic and, hence, requires care and attention only with respect to the condition of the oil and the system itself.

Ring and chain oiling are sometimes used on the bearings of some reciprocating compressors. The operation and principle of these systems are fully explained in Chap. IX.

Drop-feed and wick-feed oiling are restricted to small parts or to parts that are not subject to severe operating conditions. These systems are seldom used nowadays on air compressors.

17. Characteristics of Oils for External Parts.—Because they are used continuously, over and over, oils used in splash-, circulation-, ring-, and chain-oiling systems must possess: (1) correct viscosity, (2) high resistance to oxidation, (3) high resistance to emulsification, and (4) a pour point below the minimum temperature likely to be encountered in service.

On the other hand, oils used in drop-feed and wick-feed systems are not subject to these severe operating conditions. In these systems the oil is used but once and passes quickly through the bearings. There is no agitation or churning of the oil, and it seldom comes into contact with water. Consequently, it need not be highly resistant to oxidation and emulsification.

18. Viscosity.—In many vertical single-acting compressors, one oil serves both the internal and the external parts. In some compressors of this type, and in all horizontal double-acting units, however, independent systems are provided for the cylinders and bearings. In designs provided with a common system for all parts, the viscosity is fixed by the requirements of the cylinder. This viscosity is slightly greater than is required for the bearings, but it is better to favor the cylinder.

Theoretically, a higher viscosity oil should be used in drop-feed and wick-feed oilers than in splash-, circulation-, ring-, and chain-oiling systems because:

1. Bearing temperatures are usually higher, the amount of oil supplied being insufficient to cool the bearings to any appreciable extent.

2. Low-viscosity oils do not adhere so well as high-viscosity oils to rings and chains. Consequently, the use of low-viscosity oil may result in underlubrication.

3. High-viscosity oils are more economical and safer, in that they do not leak out of the bearings so rapidly as low-viscosity oils. A smaller feed, therefore, may be used with safety.

It is, however, desirable to use as few different oils as possible, especially on the same machine, because of the likelihood of mixing. For this and other practical reasons, it is recommended that the cylinder oil should be used for the bearings of units having independent oiling systems for the internal and external parts.

19. Oxidation.—In compressor crankcases, constant agitation of the oil over long periods of time in the presence of air is particularly conducive to oil oxidation. If an oil of poor quality is used,

products of oxidation combine with foreign materials such as water, atmospheric impurities, and carbon to form sludge in the bottom of the crankcase. Sludge, if allowed to accumulate, may clog oil strainers, ducts, pipes, etc., thus interfering with the action of the pump, and, in severe cases, may stop the flow of oil to the bearings. The presence of such materials also increases the tendency of the oil to emulsify; and if emulsions are formed, they are more persistent. Every effort, therefore, should be made to keep the crankcase free from these impurities.

20. Emulsification.—Water sometimes enters the crankcase of a compressor either through leakage from the water jackets or through condensation of atmospheric moisture. When an oil is churned with water, the mixture tends to emulsify and form a thick mass, which collects dirt and oxidized products. These emulsions, or *sludge* as they are frequently inaccurately termed, tend to clog pump screens, oil ducts, pipes, and drains and to insulate cooler coils where these are used. In this respect, emulsification and oxidation combine, and the result is an accumulation of harmful material in the system. The oil, therefore, should have a high demulsibility rating in order that water may have the least possible effect on it.

21. Pour Point.—Most compressors are operated in comparatively warm surroundings; but some, particularly portable machines, are often operated under extremely cold temperatures. In these cases, the oil should have a pour point at least as low as the surrounding temperature; otherwise, the oil will not flow to the pump, or through the orifice of drop-feed oilers, or through the wicks of wick-feed oilers. Congealed oil will also tend to channel in the splash-oiling system. In any of these cases, therefore, oil having too high a pour point will not be promptly, properly, or adequately supplied to the bearings.

ROTARY-DISPLACEMENT AND CENTRIFUGAL COMPRESSORS

Rotary-displacement compressors comprise a group of small machines designed usually for pressures less than 125 lb.; they are generally driven direct by moderate- to high-speed electric motors. They generally have one or more rotating parts fitted closely within a circular or partly circular housing. The variations in the design of these compressors are numerous.

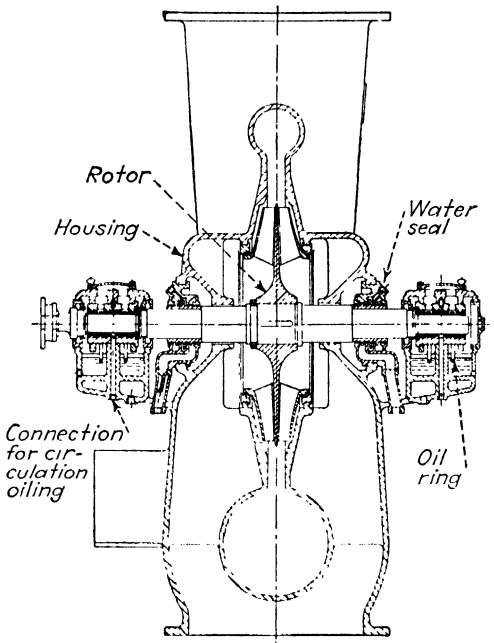


FIG. 274.—Single-stage, double-flow centrifugal compressor equipped with ring-oiled bearings and water seals.

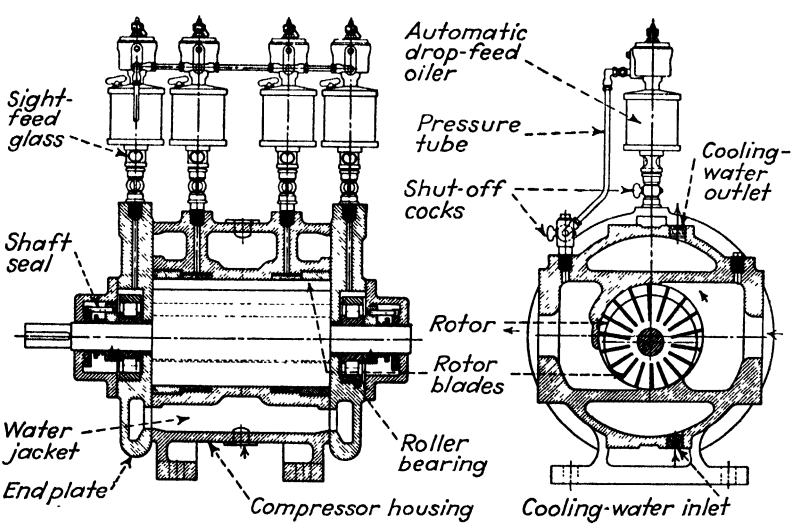


FIG. 275.—Rotary sliding-vane compressor equipped with automatic drop-feed oilers.

Centrifugal compressors are usually classified as turboblowers and turbocompressors. Generally, turboblowers are units in which the discharge pressure is 40 lb. or less, and turbocompressors are those in which the discharge pressure is greater than 40 lb. Either type may be uncooled or water-cooled, depending on the pressure and operating speed. In general, they are driven by a direct-connected electric motor or steam turbine.

In some cases, however, they are driven through speed-increasing gears by steam or internal-combustion engines. They seldom operate at less than 1200 r.p.m. and sometimes at as high as 20,000 r.p.m. They are essentially large-volume machines, being available in capacities varying from 1000 to 100,000 cu. ft. of free air per minute. They are built in a number of stages, the number varying from 1 in the smaller, low-pressure machines to as many as 28 in the large units.

22. Parts Requiring Lubrication.—Parts of these compressors that require lubrication are fewer, simpler, and better adapted

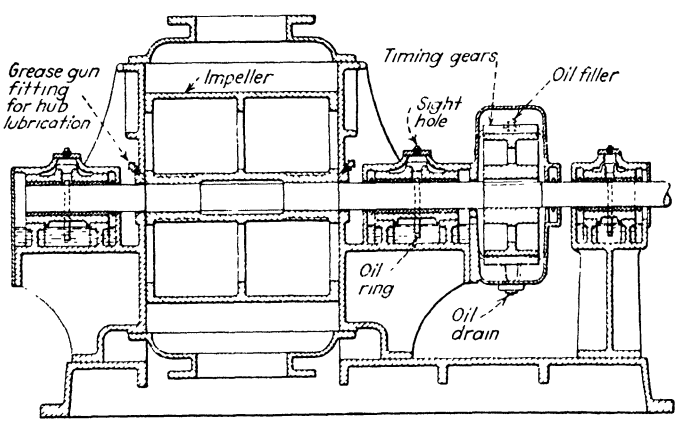


FIG. 276.—Two-lobe, rotary-displacement compressor with ring-oiled bearings.

to the formation and maintenance of oil films than those of reciprocating compressors. In the rotary-displacement type, parts requiring lubrication are the external bearings and timing gears, on some designs, and the rotating impeller or rotor. Bearings may be either of the antifriction or of the sleeve type. Some vane-type units are so constructed that the sliding vanes make contact with the housing, whereas in others there is a clearance of a few thousandths of an inch. In the first type, the oil acts as a

lubricant and a seal, whereas in the second type it acts only as a seal, to prevent loss of compression.

In centrifugal compressors, shown in Figs. 274 and 279, no internal lubrication is required; thus, the only parts requiring lubrication are the external bearings. Small- and medium-sized centrifugal compressors usually have ring-oiled bearings, whereas forced-circulation oiling is generally used on the larger units. When these units are driven by a steam turbine, frequently a common circulation system serves both the turbine and compressor.

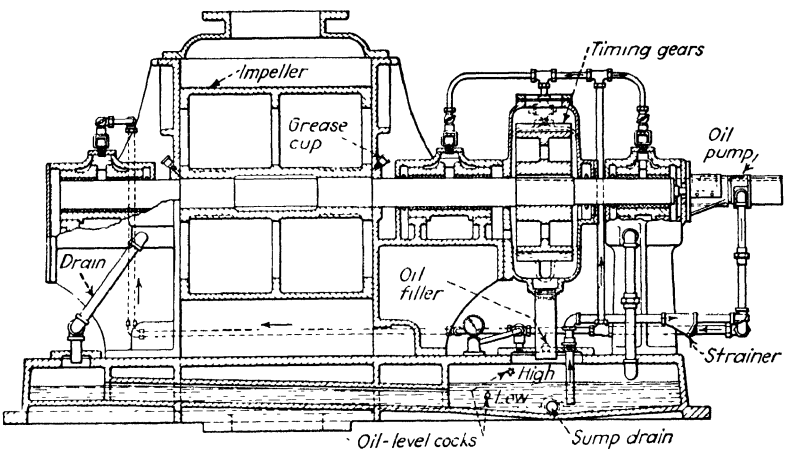


FIG. 277.—Two-lobe rotary compressor with circulation-oiling system.

Pressures and temperatures are generally lower in the rotary type than in the reciprocating type of air compressor. For the rotary-displacement type, speeds are relatively low but the bearing loads pulsate, as they depend on the angular position of the impeller. In the centrifugal type, speeds are high and bearing loads are uniform. In general, operating conditions are, however, less severe than in the reciprocating-type compressor.

23. Methods of Application.—In the sliding-vane type of rotary-displacement compressor, the oil is usually applied to the bearings and internal parts by a mechanical force-feed lubricator or sight drop-feed oilers. Figure 275 shows the automatic drop-feed oiler of Fig. 100 applied to a sliding-vane type compressor.

In the gear-type compressor, the oil is generally picked up from a reservoir by the gears and distributed to the bearings through

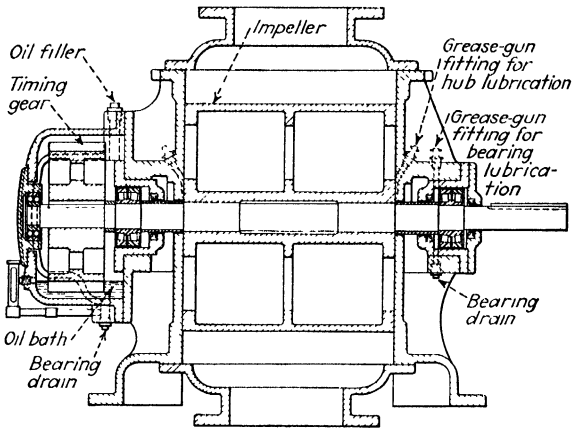


FIG. 278.—Two-lobe, rotary-displacement compressor with roller bearings.

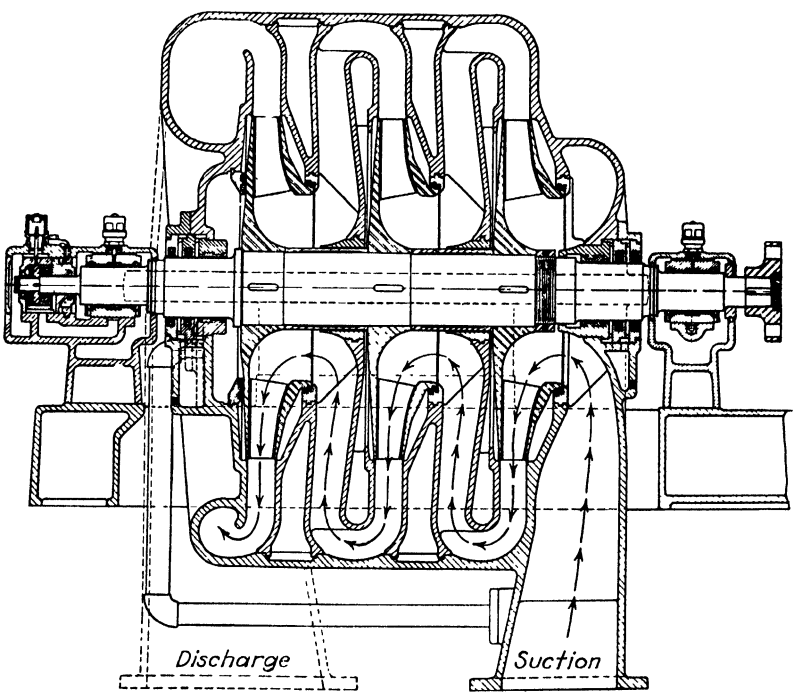


FIG. 279.—Circulation-oiled, three-stage turbocompressor.

ducts and grooves. In some designs, ring and drop-feed oilers supply the bearings.

The lobe or cam type, shown in Fig. 276, is provided with timing gears, which require lubrication as well as the bearings and

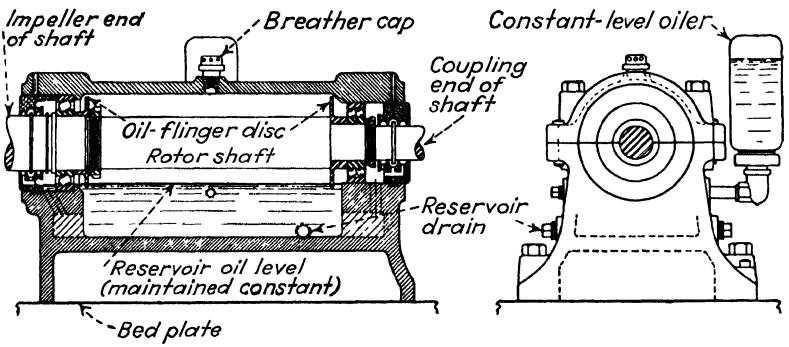


FIG. 280.—Ballbearing stand for overhung impeller centrifugal blower.

impellers. The impellers are generally lubricated by means of grease cups or grease-gun fittings. Bearings, if of the sleeve type, are circulation- or ring-oiled, as in Figs. 276 and 277; gears on the smaller units are generally bath-oiled, as in Fig. 276; and circulation oiling is commonly used on the larger units, as in

TABLE XXXV.—GUIDE TO SELECTION OF LUBRICANTS FOR ROTARY COMPRESSORS

Type	Parts	Method of application	Size, hp.	Flash point, °F.	Fire point, °F.	Viscosity, S.U.S.		
						100°F.	130°F.	210°F.
Rotary—sliding vane	All	Any	Any	385	440	320	143	50
Rotary—lobe, gear.	All	Circulation splash	25 and under	400	455	535	210	56
Rotary—lobe, gear.	All	Circulation splash	Over 25	415	465	650	266	65
Centrifugal	All	Circulation ring	Any	385	440	150	85	42
Rotary—lobe, gear, vane.	All	Grease gun, grease cup	Any	No. 2 (soft consistency) or no. 3 (medium consistency)			High-quality lime-base grease of smooth texture, containing 10 to 20% soap.	

Fig. 277. Units equipped with ball or roller bearings may be grease or oil lubricated, as in Fig. 278.

The bearings of the centrifugal type are either circulation-, ring- or collar-oiled, as in Figs. 279, 274, and 280.

24. Oil Characteristics.—Experience shows that lubricants for rotary compressors of all types should possess the same general high-quality characteristics as those for reciprocating compressors. Table XXXV may be used as a guide in making proper selections for normal operating conditions.

CHAPTER XV

LUBRICATION OF REFRIGERATING MACHINES

Mechanical refrigeration is concerned chiefly with the production and control of temperatures lower than atmospheric. Mechanical refrigerating plants are used in all parts of the civilized world and in nearly all industries. The preparation, transportation, and storage of many meats, fruits, and dairy and poultry products are virtually impossible without mechanical refrigeration.

The largest single application of mechanical refrigeration is in the manufacture of ice, of which over 65 million tons are produced annually in the United States. It is indispensable in the manufacture of mercerized cotton, celluloid, rubber, lubricating oils, sugar, soap powders, matches, golf balls, chewing gum, glue, candles, and hundreds of other products. It has been comparatively recently adapted to the air conditioning of homes and, especially, public buildings and to the process of quick freezing of food products.

1. Principles of Refrigeration.—Cooling may be accomplished mechanically by the evaporation of any volatile liquid. The basic principles involve:

1. Expansion and evaporation of the volatile liquid (refrigerant), whereby heat is absorbed by the refrigerant.
2. Compression and condensation whereby heat is first added and then abstracted from the refrigerant.

2. Refrigeration Systems.—Broadly, mechanical refrigerating systems are of two types: (1) compression and (2) absorption system.

The compression system, as shown in Fig. 281, consists essentially of a positive-displacement type (reciprocating or rotary) or impeller type (centrifugal) compressor, a condenser, an expansion valve, and an evaporating or cooling coil. The compressor draws the low-pressure refrigerant, which is in the vapor state, from the evaporator and compresses and then discharges it to the con-

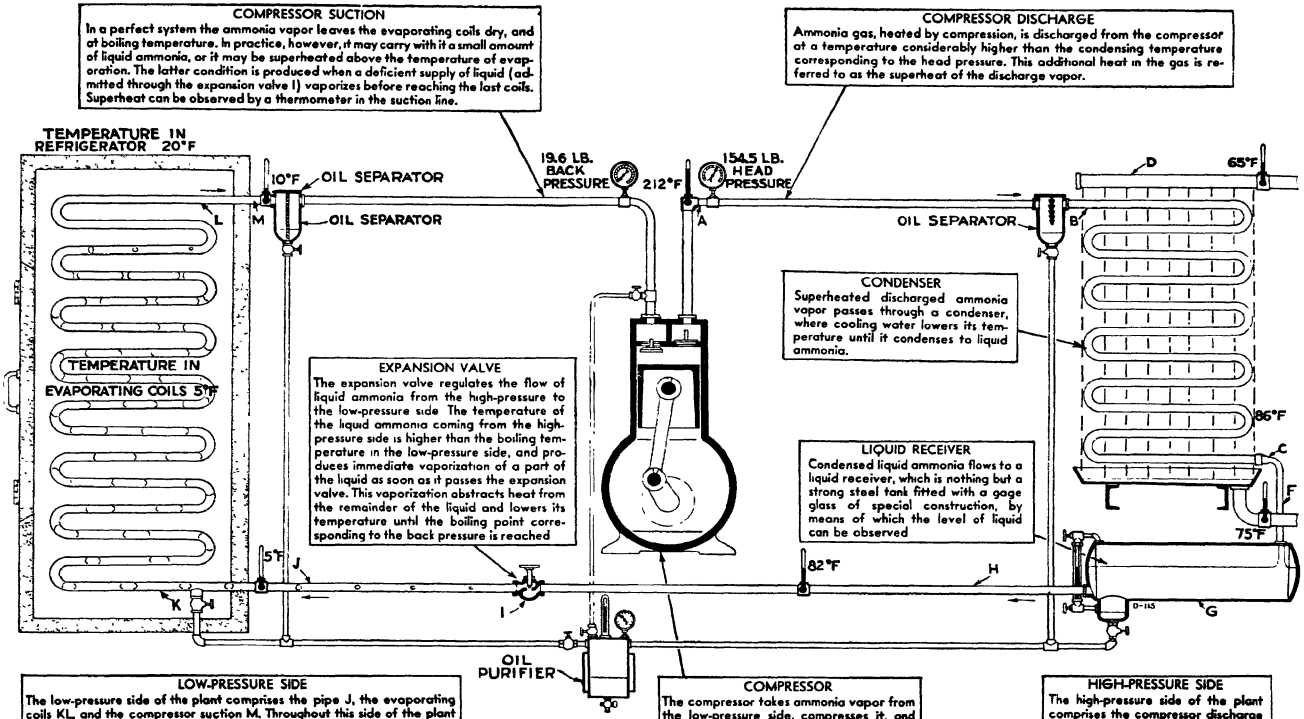


FIG. 281.—Diagrammatic layout of a simple ammonia-compression plant. (*Courtesy Socony-Vacuum Oil Co.*)

denser. This increase in pressure raises the boiling temperature (condensing temperature) of the refrigerant so that it is condensed on coming into contact with the cool surfaces of the condenser. From the condenser, the liquid refrigerant flows through the expansion valve, which reduces its pressure. This reduction in pressure lowers the boiling point of the refrigerant, causing it to evaporate and drop to a very low temperature. From the expansion valve the vapor refrigerant flows through the evaporator and into the compressor, thus completing the cycle. That part of the system from the discharge side of the compressor, through

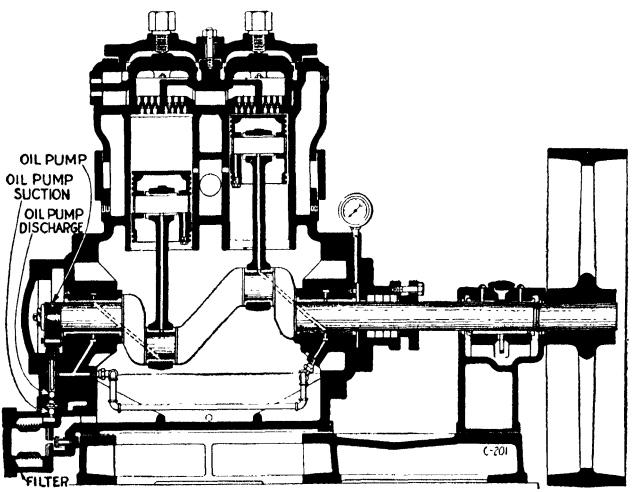


FIG. 282.—Circulation-oiled enclosed ammonia compressor. (*Courtesy Socony-Vacuum Oil Co.*)

the condenser to the expansion valve, is called the *high-pressure side;* that part from the expansion valve, through the evaporator to the suction side of the compressor, is known as the *low-pressure side* of the system. The pressure existing in the high-pressure side is called the *head pressure,* and that in the low-pressure side is referred to as the *suction pressure.* The head and suction pressures depend, respectively, on the efficiencies of condensation and evaporation for any particular refrigerant.

The absorption system depends on the solubility of the refrigerant in water. The refrigerant, which is usually ammonia, passes from the evaporator in the gaseous state to an absorber, where it is absorbed by water. This concentrated liquid solution

(strong aqua ammonia) is pumped into a generator, where heat is applied and the refrigerant is driven off as a vapor, which passes next through a rectifier to remove entrained water. From the rectifier the refrigerant passes to the condenser, where it is liquefied. It then flows through the expansion valve, which reduces its pressure and lowers its boiling temperature, causing it to evaporate. From the expansion valve, it flows through the evaporator and then again into the absorber. This cycle is continuously repeated.

The only mechanical power required in the absorption system is that needed to pump the refrigerant from the absorber to the generator. The only part of this system, therefore, that requires lubrication is the pump, which offers no difficulty.

3. Refrigerants.—Neither a perfect nor a universal refrigerant has yet been discovered. The selection is usually a compromise, the choice being influenced by the specific conditions encountered. The problem of correlating and adapting the refrigerant and machine to meet the conditions to the best advantage is often complex.

Under certain conditions a very large number of liquids might be satisfactory as refrigerants, but only a few are able to meet the restrictions sufficiently exactly to be of importance commercially. The principal controlling factors are:

1. Boiling and condensing temperatures; pressure relationship.
2. Toxicity.
3. Chemical stability in service.
4. Inflammability.
5. Odor and ease of detection of leaks.
6. Reaction with materials of construction.
7. Latent heat.
8. Cost.
9. Behavior toward lubricants.

Some of the important properties of the more commonly used commercial refrigerants are given in Table XXXVI.

Ammonia (NH_3) is the oldest and still the most generally used refrigerant. It does not react with iron and steel but readily attacks brass and bronze in the presence of water. It has a pungent, irritating odor and is toxic and very soluble in water and explosive when mixed with air in volumes of 13 to 27 per cent.

TABLE XXXVI.—CHARACTERISTICS OF COMMON REFRIGERANTS
(Standard ton conditions)

Characteristics	Freon-12 (CCl_2F_2)	Freon-11 (CCl_3F)	Freon-21 ($CHCl_2F$)	Carbon dioxide (CO_2)	Ammonia (NH_3)	Methyl chloride (CH_3Cl)	Iso-butane ($(CH_3)_2CH$)	Sulfur dioxide (SO_2)	Methyl formate ($H.COOCH_3$)	Methylene chloride (CH_2Cl_2)
Boiling point, °F.	−21 7	74.67	48 0	−108.4	−28.0	−10 6	13 6	14.0	89.2	103.7
Gage pressure, lb. per sq. in., 86°F.	93 2	3.6	15.8	1024.3	154 5	80.83	44 8	51.75	1.84*	9.44*
Gage pressure, lb. per sq. in., 5°F.	11.81	23.9*	18.8*	319.7	19.57	6.19	3.3*	5.87*	26.335*	27.30*
Heat content of saturated vapor in 5°F. evaporator, B.t.u. per lb.	78.79	91.2	117.1	102.14	613.35	195.3	162.0	183.49	233.55	163.8
Heat content of liquid leaving 86°F. condenser, B.t.u. per lb	27.72	25.8	32 5	45.45	138 9	46.6	50.5	42.12	44.32	29.75
B.t.u. refrigerating effect per lb.	51 07	65.4	84 6	56.69	474.45	148.7	111 5	141.37	189.23	134.05
Lb. refrigerant per minute	3 916	3 058	2 364	3.528	0.4215	1.345	1.794	1.414	1.056	1.492
Cu. ft. liquid per lb., 86°F.	0.0124	0.01097	0 0119	0.0267	0.02691	0.01793	0.0294	0.01184	0.0164	0.01198
Cu. in. refrigerant per min.	83.9	57.968	48 61	162 8	19.6	41 7	91.1	28.9	29.926	30.88
Cu. ft. vapor per lb., 5°F	1.485	12.1	8.83	0.2673	8.150	4.529	6.41	6 421	47.25	49.9
Cu. ft. piston displacement per min.	5 815	37.00	20.874	0.943	3.436	6.091	11.497	9.084	49.9	74.45
B.t.u. refrigeration per cu. ft. piston displacement.	34 4	5 4	9 58	212 0	58 2	32 8	17.4	22 0	4.01	2 686

* Inches of mercury below atmosphere.

Pure and moisture-free ammonia has no chemical effect on pure mineral oils but is slightly soluble in them. Ammonium hydroxide (aqua ammonia), formed when it comes into contact with water, readily emulsifies with mineral oils.

Carbon Dioxide (CO_2), if pure, is only slightly soluble in mineral oil and has no effect on mineral oil or grease. It is colorless, odorless, nonexplosive, and nontoxic. It is entirely inert to metals except in the presence of water.

Methyl chloride (CH_3Cl) is slightly toxic and inflammable, colorless, and soluble in water, has no appreciable effect on metals, and has a mild sweet odor. Acrolein, which is an eye, nose, and

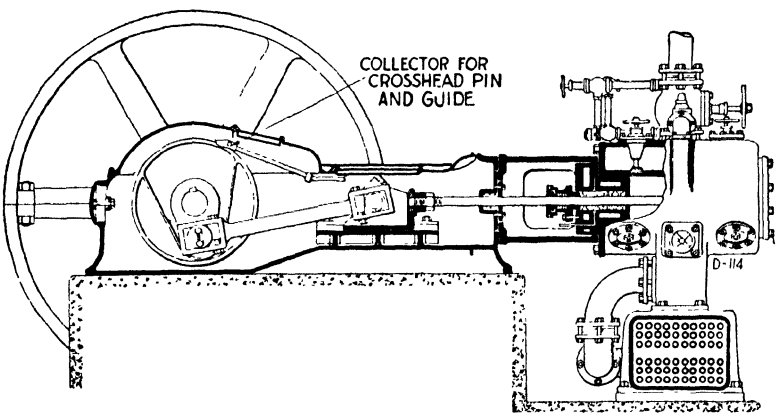


FIG. 283.—Ammonia compressor with mechanical-force feed to cylinder and splash to bearings. (*Courtesy Socony-Vacuum Oil Co.*)

throat irritant, is frequently used (in the larger systems) in the proportion of about 1 per cent as a warning agent. It does not react chemically with pure, dry mineral oil but is miscible with oil in all proportions, thus diluting it. It also lowers the pour point of the oil, making it generally unnecessary to use an oil of low pour point.

Sulfur dioxide (SO_2) is colorless, nonexplosive, and very toxic and has a strong pungent odor. In the complete absence of moisture, it is noncorrosive, but even in the presence of 20 parts per million of water it becomes corrosive, as sulfurous acid is formed. Mineral oil is only slightly soluble in it, but it has a strong tendency to dissolve the unsaturated color-bearing hydrocarbons of oil, which may precipitate as sludge, especially if any moisture is present. Sulfur dioxide used in refrigerating systems

contains about 0.001 per cent by weight water. The system itself is usually baked at a temperature of 275°F. for 4 hr. under a vacuum of less than ¼ in. of mercury. It possesses in the liquid state some lubricating properties, which is a distinct advantage in a virtually dehydrated system.

The Freon group is comprised of halogen derivatives of certain aliphatic hydrocarbons of which Freon-12 (dichlorodifluoromethane (CCl_2F_2), Freon-11 (trichloromonofluoromethane (CCl_3F), and Freon F-21 (dichloromonofluoromethane ($CHCl_2F$) are the most important. Freon-12 is the most widely used of this group and is employed extensively in air-conditioning refrigera-

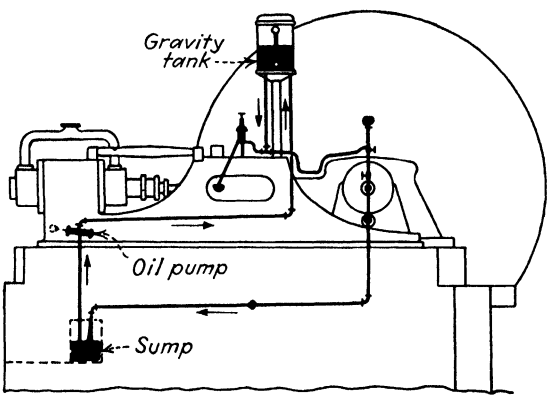


FIG. 284.—Carbon dioxide compressor with gravity circulation to bearings and mechanical-force feed to bearings and packing gland. (*Courtesy Socony-Vacuum Oil Co.*)

tion because it is odorless, nontoxic, virtually noninflammable, and noncorrosive. It has no ill effects on animals in concentrations up to the point where suffocation results. It is miscible with water to only a slight extent. It does, however, mix with mineral oil in all proportions, thus diluting it. Its solubility in mineral oil depends on temperature and pressure, increasing with pressure and decreasing with temperature.

Methylene chloride (CH_2Cl_2), known commercially as Carrene no. 1, is a chlorinated hydrocarbon refrigerant especially suitable for use in the rotary and centrifugal compressors used widely in air-conditioning systems. Like other chlorinated hydrocarbons, such as methyl chloride, it is virtually inert to metals used in refrigerating equipment. Under ordinary atmospheric conditions, it is a colorless liquid and has a pleasant, sweet odor similar

to that of chloroform. It readily mixes in all proportions with mineral oil; therefore, it has a pronounced diluting effect.

Hydrocarbons, such as isobutane ($(CH_3)_3CH$), propane (C_3H_8), ethane (C_2H_6), and butane (C_4H_{10}) are used to a very limited extent as refrigerants. They are highly inflammable and explosive and for this reason are not safe for most purposes. They dilute but have no chemical effect on mineral oils.

4. Compressors.—The compressors, aside from the power-driving unit, are the only unit of a refrigerating system that requires lubrication. Compressors range in size from the very small fractional-tonnage household machine to the very large commercial machine capable of producing thousands of tons of refrigeration per day. The design of compressors used in the refrigerating industry has largely paralleled that of air compressors and to some extent that of the steam engine. Like air compressors, they are broadly classified as *reciprocating, rotary,* and *centrifugal.*

RECIPROCATING COMPRESSORS

The reciprocating compressor is by far the most usual type and, also, the type that requires the most consideration from the standpoint of lubrication. Although this type of compressor has been built in a wide variety of designs, the present-day machine is confined to virtually two designs: (1) the enclosed vertical single-acting machine, as in Fig. 282; and (2) the horizontal double-acting machine, as in Fig. 283.

Power may be applied by a steam, Diesel, gas, or an oil engine or by an electric motor. It may be transmitted by direct connection or indirectly by a flat or V belt or a silent or roller chain or gearing. The vertical enclosed compressor is generally divided into three groups: the fractional-tonnage units, which may have from one to four cylinders, those of a size having 1 to 8 tons of capacity, and the industrial machines, which have a capacity of more than 8 tons. Speeds as high as 800 r.p.m. have been used, but usually they are under 600 r.p.m. for this type of machine. Speeds of horizontal double-acting machines are generally less than 170 r.p.m. Cylinder sizes of the enclosed machine range from about 1½ by 1½ in. to 12½ by 15 in.; for the horizontal machine, cylinders as large as 30 by 48 in. have

been made. Valves are of the plate or ribbon type or the poppet type and are located either in the cylinder or in the piston head.

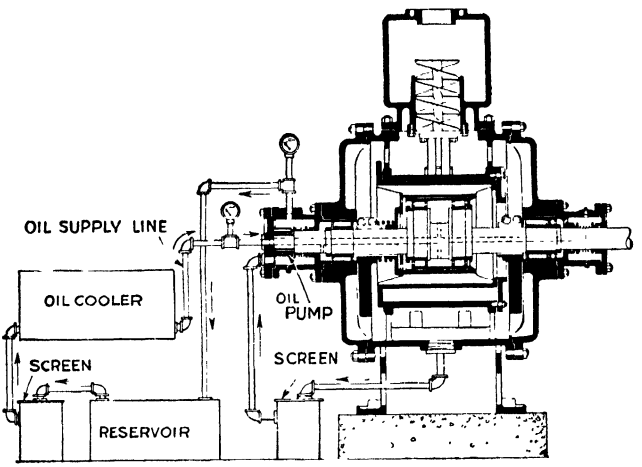


FIG. 285.—Rotary compressor with circulation oiling. (*Courtesy Socony-Vacuum Oil Co.*)

5. Parts and Objects of Lubrication.—The lubrication of the reciprocating-type compressor is concerned with supplying lubricating oil to the internal parts—cylinder, piston, valves, and packings—and to the external parts—bearings and guides.

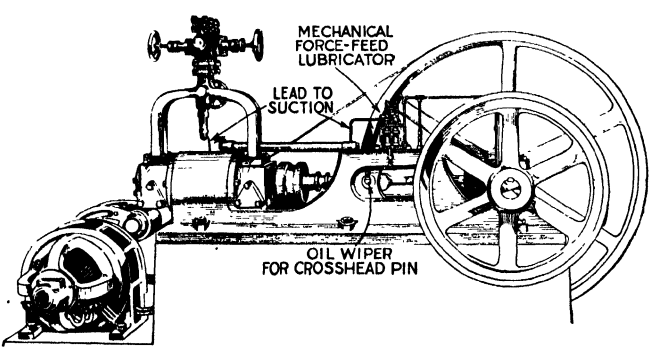


FIG. 286.—Small carbon dioxide compressor with mechanical-force feed to bearings and cylinder. (*Courtesy Socony-Vacuum Oil Co.*)

The object of lubrication is to minimize wear and friction and to provide a tight seal between the piston and cylinder wall, blow-by being thus prevented.

6. Methods of Lubrication.—Nearly all conceivable methods of lubrication have been applied to refrigerating compressors at one time or another, as indicated in Table XXXVII. The modern practice is to use mechanical force feed or splash for the internal parts and circulation or splash for the external parts.

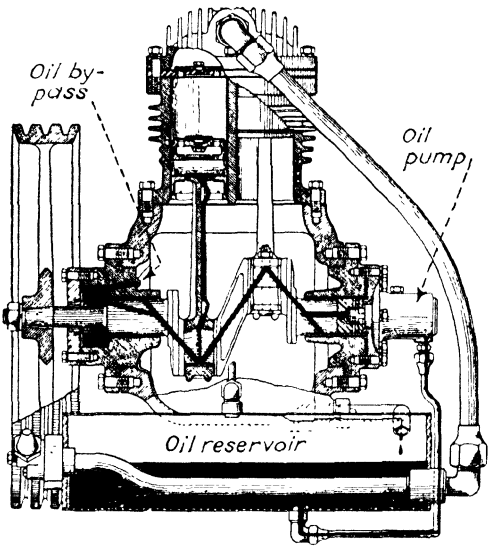


FIG. 287.—Small circulation-oiled compressor with dry crankcase.

7. Factors Affecting Lubrication.—The lubrication of refrigerating compressors is similar in many respects to that of air compressors. It differs, however, in that consideration must be given to the effects of the various refrigerants on the oil and the action and effects of the oil on parts not requiring lubrication. In nearly every case the refrigerant has some undesirable effect

TABLE XXXVII.—METHODS OF LUBRICATING REFRIGERATING COMPRESSORS

Application to Cylinder	Application to Bearings
Drop feed	Drop feed
Splash	Splash
Splash	Splash; dip oilers
Pump circulation	Pump circulation
Mechanical force feed	Drop feed
Mechanical force feed	Pump circulation
Mechanical force feed	Gravity circulation
Mechanical force feed	Mechanical force feed
Mechanical force feed	Splash

on the oil. It may cause the oil to sludge, it may dilute the oil, or it may cause corrosion, especially if moisture is present; only in a few instances does it have no effect. The pressure and temperature in the cylinder, method of application, temperature in the evaporator, kind of refrigerant used, and location, type, and efficiency of the oil separator are important factors in the selection of the correct oil.

OIL CHARACTERISTICS AND REQUIREMENTS

Briefly, a refrigerating oil should possess the following general characteristics:

1. Correct viscosity at the temperature and pressure existing in the cylinder.

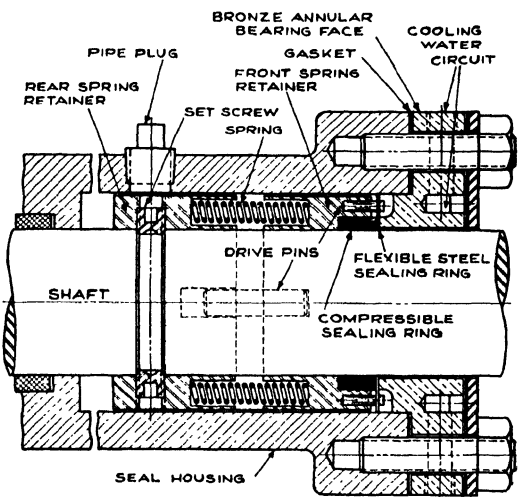


FIG. 288.—Patented shaft seal used on some Freon compressors.

2. A pour point at least as low as the lowest temperature to which it may be subjected during operation. This temperature will be encountered in the evaporating coils.
3. A high resistance to emulsification.
4. A low carbon residue.
5. A color varying from water white to pale straw.
6. Freedom from impurities, especially moisture.

8. Viscosity.—The viscosity of the cylinder oil of reciprocating compressors using ammonia, carbon dioxide, and sulfur dioxide is determined by the pressure and temperature in the cylinder.

The temperature of the oil film on the cylinder walls is usually moderate, rarely exceeding 120 to 150°F. The temperature of the discharge valves, however, is from 200 to 250°F. Under extreme conditions, higher temperatures prevail. Head and suction pressures depend on the refrigerant and the operating conditions. For all commercial refrigerants, with the exception of carbon dioxide, the head pressure is normally less than 200 lb. per sq. in. and the suction pressure rarely exceeds 25 lb. per sq. in. For carbon dioxide, the head and suction pressures may be, respectively, as high as 1000 and 350 lb. per sq. in. The oil films coating the surfaces of the cylinder, piston, and rings are subjected to only the difference of the head and suction pressures, which is not excessive, even in the case of the carbon dioxide machine. The viscosity of the oil must, however, be sufficient to prevent excessive metallic contact and provide a gas-tight seal between the rings and wall and between the rings and grooves.

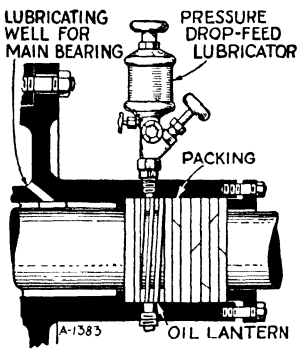


FIG. 289.—Drop-feed oiler applied to lantern of vertical compressor. (*Courtesy Socony-Vacuum Oil Co.*)

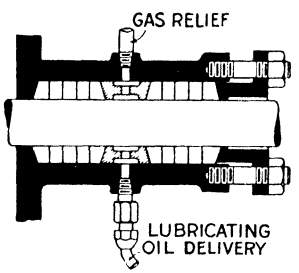


FIG. 290.—Overfeeding oil to single lantern introduces excess oil into compressor suction. (*Courtesy Socony-Vacuum Oil Co.*)

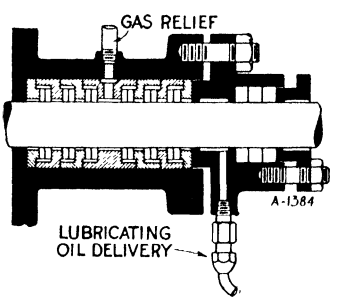


FIG. 291.—Oil loss to suction is minimized by separating gas relief and oil lantern. (*Courtesy Socony-Vacuum Oil Co.*)

For compressors using Freon, methyl chloride, propane, Carrene, and other refrigerants that tend to dilute the oil, the viscosity depends on the diluting effect of the refrigerant.

9. Pour Point.—Refrigerating oil may be carried from the compressor into the coils of the condenser and evaporator; thus, it

should have a pour point sufficiently low to flow freely at the temperature in the evaporator. Otherwise, it will congeal in the coils, insulating them and reducing the rate of heat transfer. As shown in Fig. 294, the main effect of congealed oil in the con-

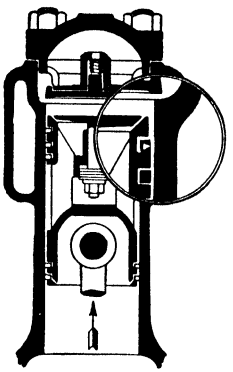


FIG. 292. Pumping action of worn piston rings. (*Courtesy Socony-Vacuum Oil Co.*)

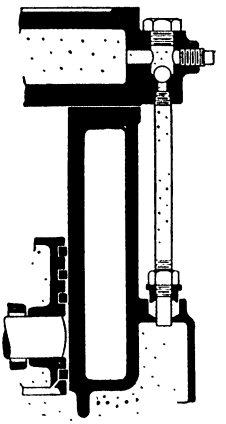


FIG 293.—Blow-by forcing oil mist into suction. (*Courtesy Socony-Vacuum Oil Co.*)

denser is to increase the head pressure without increasing the capacity of the compressor. And that of congealed oil in the evaporator is to reduce the capacity of the unit without any appreciable change in the power consumption, as in Fig. 295.

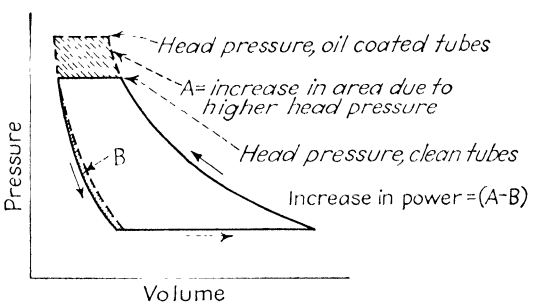


FIG. 294.—Oil in condenser increases power consumption.

In other words, the effect in both cases is a reduction in the efficiency of the system.

The development of quick freezing of fruits, meats, vegetables, poultry, etc., has brought about the use of: stage compression;

the combined ammonia and carbon dioxide systems (binary system); the rotary-booster system; and the flooded ammonia system in which temperatures as low as −40 to −50°F. are maintained in the evaporator. It is not practicable to produce oils that will flow freely at such low temperatures. In such

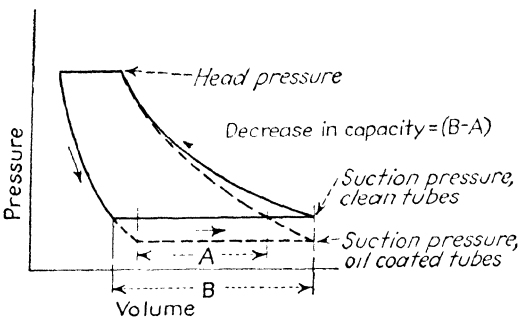


FIG. 295.—Oil in evaporator decreases capacity.

cases, the oil used should have the lowest possible pour point but mechanical means should also be provided to minimize the amount of oil reaching the evaporator. An efficient oil separator should, therefore, be installed. Oil can be more effectively removed from the refrigerant in the gaseous state than in the liquid state. Moreover, the larger the oil particles and the lower the velocity of the refrigerant, the more complete will be the separation. For these reasons, oil separators are more efficient if placed near the point of entry of the discharge into the condenser. The capacity of the oil separator should be ample, not only so that the velocity of flow through it will be low, but also so that it can handle efficiently an overload should an excessive amount of oil be fed to the compressor.

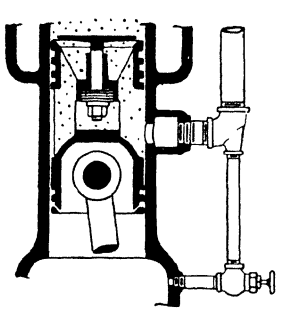


FIG. 296.—Blow-by past double-trunk piston forcing oil mist into suction. (*Courtesy Socony-Vacuum Oil Co.*)

Another mechanical means of reducing the amount of oil carried into the evaporator is to install baffles in the liquid receiver and provide an oil sump, as in Fig. 298. The baffles arrest the motion of the refrigerant and permit the oil to settle into the oil sump. For best results the receiver should be tilted slightly.

Bent pipes serve very efficiently as baffles and may be easily installed by burning a small hole in the end of the receiver, inserting the pipes, and then welding the hole shut.

10. Emulsification.—Emulsions are likely to form, especially if any moisture is present, in certain compressors, particularly in single-acting splash-lubricated ammonia and sulfur dioxide machines. Emulsions may eventually find their way into the condenser and evaporator, where they collect in the coils, insulating them much in the same manner as does congealed oil. When such a condition comes about, it is generally necessary to shut down the compressor and thoroughly clean the complete system. The formation of such emulsions is usually due to some mechanical fault, such as cooling-water leakage. To guard against such

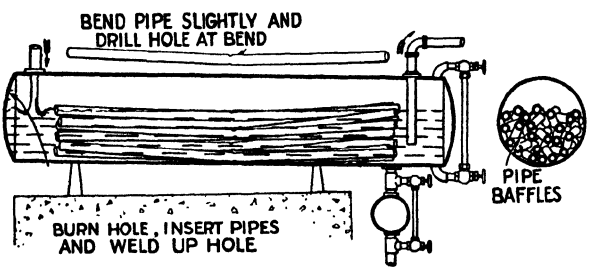


FIG. 297.—Liquid receiver with improvised baffling. (*Courtesy Socony-Vacuum Oil Co.*)

difficulties, all impurities, especially moisture, should be excluded from the system and the oil used should possess high resistance to emulsification.

11. Carbon Residue.—All refrigerating systems are closed so that, under normal operating conditions, air does not come into contact with the oil or the refrigerant. Consequently, since there is virtually no air (oxygen) present to support oxidation or combustion, there is little likelihood of troublesome carbon deposits forming. Sometimes, in ammonia and sulfur dioxide systems, moisture is present and a so-called *carbon deposit* forms. Such deposits are not pure carbon but products of the chemical action of the refrigerant with the oil.

12. Color.—In general, the color of refrigerating oils ranges from water white to pale straw. Water-white or nearly water-white oils are used for sulfur dioxide systems because this refrigerant readily reacts with the color-bearing parts (unsaturated

hydrocarbons) to form sludge. Though color is not indicative of the lubricating value of an oil, yet it does, other things being equal, indicate the degree of treatment and filtering that an oil has been given.

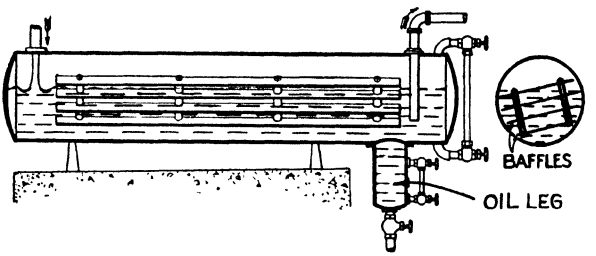


FIG. 298.—Baffles in liquid receiver aid in separating oil from refrigerant. (*Courtesy Socony-Vacuum Oil Co.*)

13. Impurities.—Refrigerating oils must be free from foreign impurities, such as dust, dirt, scale, and, especially, water. Solid impurities cause undue wear and increase the tendency of an oil to emulsify. Water has a strong affinity for ammonia and forms with it an emulsion that may be very persistent if solid impurities are present. Carbon dioxide is only slightly soluble in water but may react with it to form carbonic acid, which may cause corrosion. Sulfur dioxide reacts readily with water to form sulfurous acid (H_2SO_3), which is a weak acid but corrosive. Regardless of whether or not water reacts with the refrigerant, it is harmful, as it will freeze out in the expansion valve and thus restrict the flow of refrigerant and reduce the efficiency of the system. Some authorities regard the moisture content of refrigerating oils as one of their most important characteristics.

Since a pure, dry mineral oil is a nonconductor of electricity and its dielectric strength is greatly reduced by the presence of impurities, perhaps the most satisfactory method of determining its dryness and purity is by measuring its dielectric strength. An oil having a dielectric strength of 21,000 v. per mm. when tested in accordance with the A.S.T.M. method D 117-33 is considered sufficiently pure and dry for refrigerating purposes.

If a refrigerating system is maintained in good condition, there is little likelihood of water entering the system. However, the following are some of the possible ways water might enter the system: from leaking cooling-water connections; from air left in the system at the time of charging; with air drawn into the

compressor through the packing gland; and with the oil. Refrigerating oil rarely contains water in harmful quantities when shipped from refineries, but sometimes it absorbs moisture in storage. It should be kept at all times in an airtight container and should not be purchased in too large quantities.

14. Recommendations.—In Table XXXVIII are given general specifications of oils that have been used successfully for refrigerating units. These should be highly refined pure mineral oils containing no fatty oils, fatty acids, resins, soaps, or other non-hydrocarbon materials. They should preferably be straight distilled and not blended.

For the following reasons, compounded oils should never be used for the lubrication of compressor cylinders or the bearings where there is any possibility of the oil getting into the system: (*a*) They react chemically with most refrigerants to form sludge and other deposits. (*b*) They have relatively high pour points. (*c*) They have a decided tendency to absorb moisture.

Refrigerating-compressor cylinders, like air compressors, require very little oil. In the case of splash-lubricated units, especial care should be taken not to raise the oil level too high. Where a force-feed or drop-feed lubricator is used, the correct feed can be determined only by an inspection of the interior of the cylinder, but Table XXXIII may be used as a guide.

15. Bearing Oils.—For compressors employing splash lubrication, all parts are lubricated with one oil, the selection of which is governed by the requirements of the cylinder. Some compressors are so designed that the external and internal parts are lubricated by means of separate systems. Where external lubrication is thus isolated, the bearing oil may be selected on the basis of the bearing requirements alone. Cylinder oils generally meet bearing requirements, and it is advisable to use one oil in all cases, if possible. Ordinary bearing oils should not be used if there is any possibility that they will reach the internal parts of the compressor.

16. Reclaiming Oils.—It is usually practicable to recover oil from a compression refrigerating system by installing an oil purifier, as in Fig. 281. Such a purifier performs the dual function of recovering the oil and purifying the refrigerant without interfering with the continuous operation of the plant. It should be equipped with a water or steam jacket or other means of

TABLE XXXVIII.—GUIDE TO SELECTION OF REFRIGERATING OILS

Refrigerant	Type of compressor	Temperature in evaporating coils, °F.	Pour point, min., °F.	Flash point, min., °F.	Acidity max.	Carbon residue, %	Viscosity, S.U.S., 100°F.	V. I.
Ammonia and carbon dioxide	Reciprocating	5 and above	0	340	0.1	0.2	200–250	75
		Under 5	−10	325	0.1	0.1	125–150	75
Carrene nos. 1 and 2	Centrifugal multi-stage	Any	−10	380	0.1	0.3	300–350	75
	Centrifugal single-stage	Any	−10	340	0.1	0.2	200–250	75
Freon group	Centrifugal rotary	Any	−10	380	0.1	0.3	300–350	75
	Reciprocating	5 and above	0	400	0.1	0.3	450–550	75
		Under 5	−10	380	0.1	0.3	300–350	75
Methyl chloride	Reciprocating	5 and above	−10	380	0.1	0.3	300–350	75
		Under 5	−10	340	0.1	0.2	250–250	75
Sulfur dioxide	Reciprocating	Any	−10	350	0.1	0.1	100–200	75

heating, a pressure gage, thermometer, gage glass, and drain connection.

Oil recovered by the separator may be re-used if properly filtered, which can be done by filtering it through specially dried blotting paper. It is good practice to use the reclaimed oil, particularly if not well filtered, for the external parts, employing new oil only for the cylinder.

ROTARY COMPRESSORS

There are two types of rotary compressor: positive rotary displacement, which requires internal lubrication, and centrifugal, which requires no internal lubrication. Both types are simply constructed, operate at high speed, and are usually direct-connected to an electric motor or a steam turbine.

17. Positive Rotary-displacement Type.—This type compresses the refrigerant by entrapping it between vanes carried in the slots of a rotor eccentric with the casing or in pockets, separated by a sliding blade in the casing, formed by the eccentric motion of the rotor in the casing. In either case, there are only three major parts: the casing, rotor, and bearings. It is essential, however, that such compressors should be accurately constructed to prevent excessive leakage of the refrigerant from the high- to the low-pressure side. The rotor generally operates in a bath of oil, which provides a seal between it and the casing. The viscosity of the oil depends mainly on what refrigerant is employed, but the oil should always be thoroughly dehydrated. Its general characteristics are similar to the characteristics of the oils used for reciprocating machines. The responsibility for the lubrication of these machines rests largely with the manufacturers, for these machines are generally hermetically sealed at the factory.

18. Centrifugal Type.—This type of compressor comprises a rotating steel shaft to which are fastened one or more impellers (depending on the number of stages), a casing, and bearings. It operates on the same principle as the centrifugal air compressor and centrifugal water pump. It is used chiefly in air conditioning where Carrene, Freon, and water vapor are used largely as refrigerants.

The rotor is supported at each end by either plain or antifriction bearings, and a thrust bearing holds it in the correct axial posi-

tion. In general, the parts that require lubrication are: the main radial bearings, thrust bearing, oil-pump gearing, and shaft seal. Additional parts requiring lubrication are the bearings of the motor or steam turbine and, where provided, the step-up gear set. No internal lubrication is required. Bearings of small- and medium-size units are usually ring-oiled, whereas circulation oiling is frequently applied to the larger machines.

The lubrication of the unit shown in Fig. 299 is typical of these units. This system is equipped with oil cooler, filter, gage, and the necessary check and pressure-regulating valves. The two

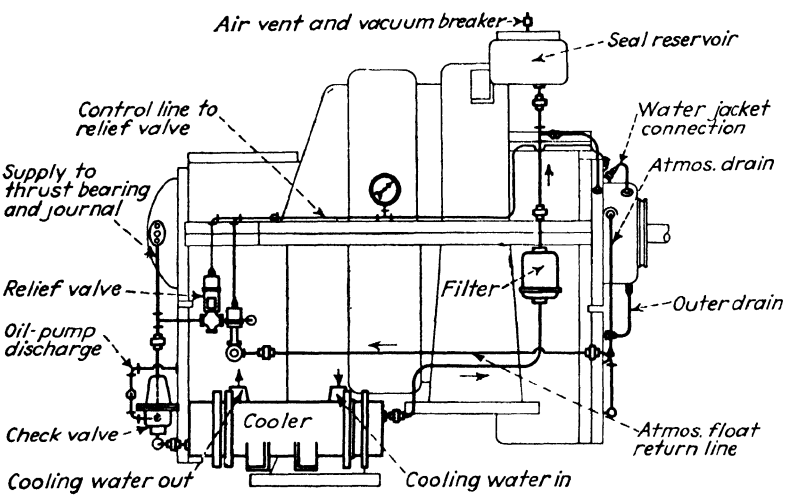


FIG. 299.—Oil-piping diagram for a multistage Carrene compressor.

main bearings are provided with oil rings. In this unit the lubricating oil is used to maintain a seal at the drive end where the shaft extends through the casing. Loss of vacuum is prevented by an automatic device actuated by oil pressure while the unit is operating and by springs when it is at rest. The seal comprises a rotating and a stationary disk, held in position by oil pressure, during operation, and separated by an oil film. When the unit is stopped and the oil pressure ceases, springs automatically press the two disks together, effecting a seal.

Regardless of construction, design, and method of lubrication, centrifugal compressors require oils of high quality, similar to those recommended for reciprocating machines.

19. Operating Notes.—Excessive head pressure is common and is due to inefficient cooling, which may be caused by scale on the water side of condenser pipes, deposits on the refrigerant side of condenser pipes, inadequate cooling water, or air in the system.

In virtually all instances, so-called *foreign gas* in a refrigerating system is air, which has leaked into the system at some point on the suction side where the pressure is less than atmospheric, was left in the system when charged, or has leaked through the stuffing box. Either unstable oil or impure ammonia may decompose to form more or less permanent gases, but rarely does this occur.

Sudden loss of oil from the crankcase of compressors having trunk-type pistons and operating on variable back pressure is generally caused by the sudden release (boiling) of the refrigerant absorbed by the oil. This causes the oil to froth, in which state it passes rapidly through the compressor into the system. This difficulty can usually be remedied by changing the back pressure more gradually and/or the use of a less viscous oil that permits the refrigerant to escape quickly at low temperature. Gradual loss of oil is usually due to worn piston and oil-scraper rings that permit oil pumping.

The use of unsuitable oil—chemically unstable, too viscous, or containing impurities, especially moisture—or the use of too much oil, even if of high quality, will be likely to cause excessive wear, friction, and deposits, resulting in decreased plant efficiency.

CHAPTER XVI

LUBRICATION OF INTERNAL-COMBUSTION ENGINES

An internal-combustion engine is an engine in which pressure energy is produced by the burning or exploding in its cylinder of a mixture of air and fuel, such as natural gas, gasoline, and fuel oil.

1. Development.—Although records of the seventeenth century describe crude experiments dealing with engines of this type, yet it was not until 1860 that J. J. E. Lenoir, of Paris, developed the first commercially successful internal-combustion engine. It was a double-acting slide-valve machine having a crank and flywheel, and resembled very much the steam engine of that time.

Beau de Rochas, a Frenchman, in 1862 proposed the four-stroke cycle; but no practical use was made of this cycle until 1876 when Dr. Nicholas A. Otto, of Germany, used it in his so-called *silent engine*. In 1874, G. B. Brayton, an American, invented the first liquid-fuel engine; and in 1881, Dugald Clerk, of England, produced the first two-stroke-cycle internal-combustion engine. In all these engines the fuel was ignited by an open flame. Stuart Ackroyd, of England, in 1892 introduced the first hot-bulb or surface-ignition engine. At about this same time, Dr. Rudolf Diesel, of Germany, built his "rational heat motor," which was designed to operate on coal dust but was not successful. In 1897 and 1898, however, commercial engines designed by Diesel were produced by M. A. N. and shortly afterward by Krupp and others. In 1898, Adolphus Busch manufactured the first Diesel engine in the United States.

Since 1900, the development of the internal-combustion engine has been phenomenal. Today, it is the only successful engine for aircraft, submarines, tanks, and tractors. It is preeminent in the automotive field and finds wide application in marine and industrial services.

2. Classification.—To meet a wide range of conditions in many different services, internal-combustion engines are built in many

varied types and designs. They may be classified according to: *cycle of operation*—two-stroke cycle and four-stroke cycle, depending on the number of strokes required to complete an energy cycle; *number of cylinders*—one, two, three, four, etc., or single cylinder and multicylinder; *arrangement of cylinders*—vertical, horizontal, radial, in line, inverted, opposed, and V; *cycle of combustion*—Otto cycle (combustion at constant volume) and Diesel cycle (combustion at constant pressure); *commercial uses*—stationary, portable, marine, industrial, truck, tractor, tank, automobile, aircraft, etc.; *operating speed*—low speed, moderate speed, and high speed; *method of cooling*—liquid cooled and air cooled; *valve arrangement*—L head, in head, modified L head, T head, F head, overhead, etc.; *type of fuel*—gas, gasoline, oil, and kerosene.

No single classification is adequate for all engines, or even a particular engine, because of the overlapping of the various groups. For example, an automobile engine may be more or less completely described as a single-acting vertical in-line eight-cylinder high-speed four-stroke-cycle gasoline Otto engine.

However, the essential features, affecting lubrication, of all internal-combustion engines are: (1) cycle of operation; (2) cycle of combustion; (3) fuel-induction system; (4) mechanical construction; and (5) size and speed.

3. Cycles of Operation.—To understand fully the lubricating problems associated with and to select suitable lubricating oils for internal-combustion engines, it is essential that the operating principles are fully understood.

The process of introducing the fuel and air into the cylinder, compressing, igniting, and removing it from the cylinder after having done work is accomplished either by the four-stroke cycle or by the two-stroke cycle.

In the four-stroke-cycle engine, the cycle of operation is completed in four strokes of the piston or two revolutions of the crankshaft. The strokes of a four-stroke cycle are named after the corresponding events that they produce or in some way control, *viz.*, *suction*, *compression*, *power*, and *exhaust*, as in Fig. 300.

In the two-stroke-cycle engine all events occur during two successive strokes of the piston; these are called the *compression* and *power* strokes, and are shown in Fig. 301. Since in the two-stroke-cycle engine the exhaust gases and recharging mixture are

respectively driven out of and admitted to the cylinder during the latter part of the power stroke and the first part of the compression stroke, it is necessary for efficient operation to purge the cylinder of the exhaust gases. This scavenging effect is accomplished by the use of fresh air supplied usually by a compressor

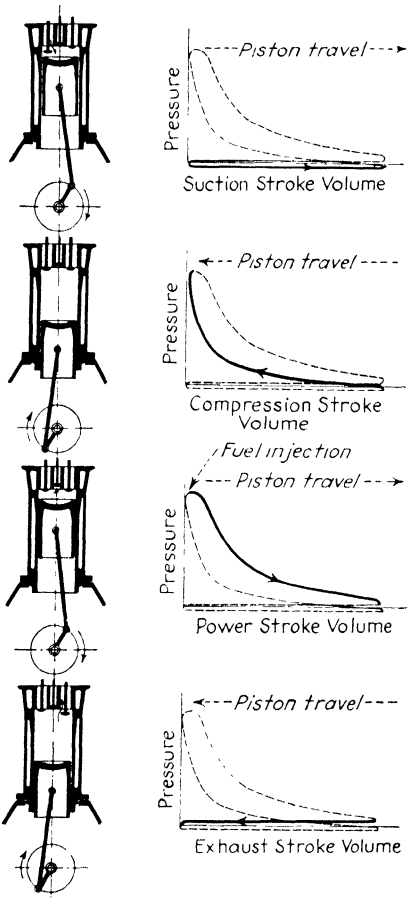


FIG. 300.—Diagrams, showing order of events in a four-stroke-cycle Diesel engine.

driven by an additional crank or an independently driven turbo-blower, the air being nearly always introduced through ports in the cylinder walls. In some designs there are two rows of scavenging ports, one above the other, which prolong the scavenging period. The flow of air through the top row of ports is con-

trolled by a valve. In some two-stroke-cycle engines, however, the scavenging air is admitted through valves in the cylinder head instead of through ports in the cylinder.

The four-stroke cycle is better suited for high-speed engines, whereas the two-stroke cycle is suitable for medium and slow-speed engines.

4. Cycles of Combustion.—Virtually all internal-combustion engines operate either on the Otto or on the Diesel cycle. Many other cycles have been proposed and tried, but these are the only two that have proved practicable.

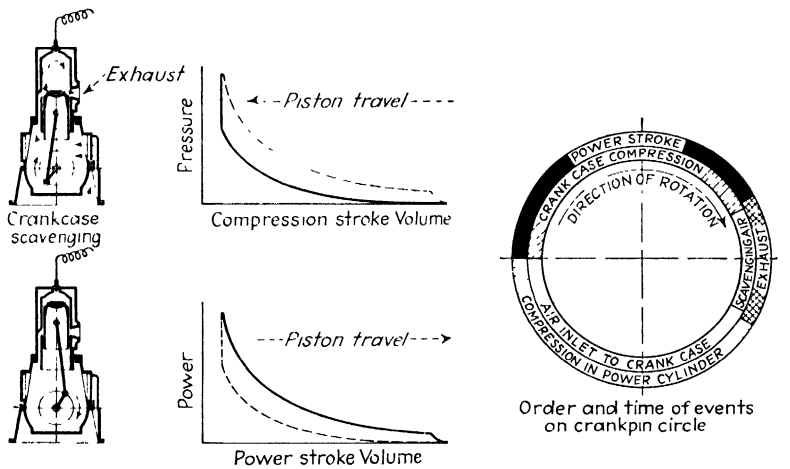


FIG. 301. Diagrams, showing order of events in a two-stroke-cycle Otto engine.

Otto Cycle.—In this cycle, air, intimately mixed with a suitable amount of fuel in gaseous or vaporized form, is compressed on the compression stroke to a pressure between 75 and 200 lb. in the cylinder. Slightly before the piston reaches top dead center, the charge is ignited by an electric spark or some other ignition device; the resulting rise of pressure occurs virtually instantaneously at constant volume, as shown in Fig. 302.

The essential features of the Otto cycle are as follows: (1) The fuel must be in gaseous form at the time of ignition. (2) The fuel and air are proportioned and mixed while passing through the intake valve or chamber external to but near the cylinder. (3) The fuel-air mixture is drawn into the cylinder during the suction stroke and is in intimate contact during the compression stroke. (4) The fuel-air mixture is ignited near the end of the compression

stroke of the piston, which is moving very slowly, with the result that combustion, which is very rapid, occurs at virtually constant volume, resulting in a large and rapid increase in both pressure and temperature.

Diesel Cycle.—In the Diesel cycle, air only is compressed in the cylinder during the compression stroke, the compression being

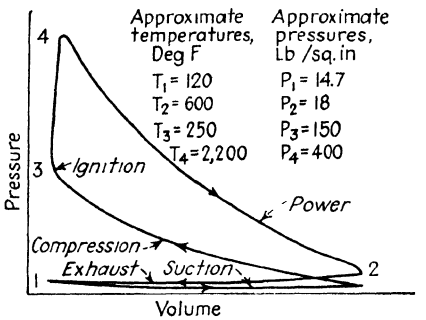


FIG. 302.—Approximate temperatures and pressures of the gas in a four-stroke-cycle Otto engine.

carried to approximately 500 lb. with a resulting temperature of about 1000°F., which is sufficient to ignite the fuel when injected or sprayed into the cylinder near the end of the compression stroke. Subsequent combustion of the fuel tends further to

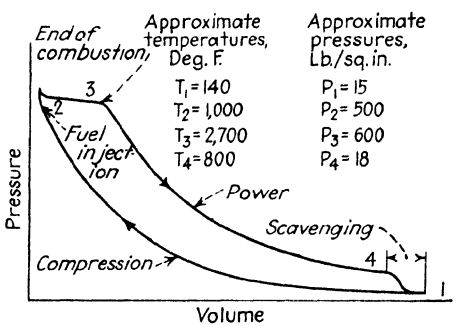


FIG. 303.—Approximate temperatures and pressures of the gas in a two-stroke-cycle Diesel engine.

increase the temperature, resulting in nearly constant pressure burning, as shown in Fig. 303. At the instant the fuel-injection valve closes, the resulting temperature is about 3000°F. After the fuel-injection valve closes and combustion ceases, the gases expand during the remained of the power stroke, and the tem-

perature drops to about 900°F. at the instant the exhaust valve opens, which is a little before bottom dead center is reached by the piston.

Combustion in Diesel engines occurs during three distinct periods: (1) a delay period, during which the fuel is heated by compression to its autoignition point; (2) a rapid burning period of the fuel droplets; (3) a period of burning during which there is nearly complete control of the rate of burning, and therefore pressure, because these depend virtually entirely on the manner in which the fuel is injected into the cylinder. To these, some authorities add a fourth period, the afterburning of the fuel that is not sufficiently atomized and mixed with air and fuel and that dribbles or leaks into the cylinder after the injection valve cuts off.

The delay period should be as short as possible; for the greater the accumulation of fuel during this period, the greater is the rate of pressure rise during the second period, and the greater is the tendency of the fuel to knock or detonate. The delay period depends primarily on engine design, location of hot spots, and ignition quality of the fuel as indicated by the cetane number. The second period of burning cannot be controlled directly but only through control of the first or delay period.

Afterburning is aggravated by the use of fuel containing high self-ignition temperature constituents. It is definitely undesirable, because it tends to increase fuel and lubricating-oil consumption and causes incomplete combustion, dirty exhaust, odor in the exhaust, ring sticking, and formation of carbon on injection nozzles.

The essential differences between the Otto and Diesel cycles are that, in the Diesel cycle, the cylinder during the compression stroke contains only air that is compressed to a high pressure, with a resulting temperature above the autoignition point of the fuel, and the injection of the fuel into this highly heated air produces autoignition of the fuel.

Considerable confusion exists in regard to the term *oil engine* because during the time in which the use of the true Diesel cycle was denied to all except regular licensees, several builders constructed so-called *semi-Diesel engines.* These engines, though similar in appearance to true Diesels and burning fuel oil, did not, however, depend on the heat of compression for ignition. On

the compression stroke of these engines, the air was compressed to about 150 lb. per sq. in., which is far below the autoignition temperature of fuel oil. Consequently, they were equipped with a separate ignition device, such as a hot bulb, plate, or tube, which were maintained at a red heat simply by not water-cooling them. The fuel was injected into the cylinder far in advance of the top dead center and, owing to the high temperature prevailing in the cylinder, was vaporized. A combustible fuel-air mixture was thus formed, and near the end of the compression stroke the temperature was so increased that ignition occurred.

Actually, the term *oil engine* applies to any internal-combustion engine that uses fuel heavier than kerosene, *i.e.*, fuel oil. Oil engines, therefore, include Diesel engines as well as hot-bulb or surface-ignition engines. The last-named engines were quite successful, and several different types are still manufactured under the more fitting title of surface-ignition engines. The true Diesel engine is now frequently called by the appropriate title *compression-ignition engine.*

5. Internal-combustion-engine Fuels.—Because the fuel is always burned in the combustion chamber of an internal-combustion engine, its character profoundly affects the operation of the engine. Moreover, the fuel and the lubricant are intimately associated, especially so within the cylinder where they come into contact. Often, when trouble arises, it is difficult and sometimes impossible to determine if the fault lies primarily with the fuel or with the lubricant. For these reasons, it is advisable to state briefly the salient characteristics of the various fuels used in internal-combustion engines.

6. Gas-engine Fuels.—A gas engine is any internal-combustion engine in which the fuel is a mixture of air and any permanent gas that is ignited by an independent source, such as an electric spark, a hot bulb, or a hot tube. The most commonly used gases are natural gas, blast-furnace gas, coke-oven gas, producer gas, illuminating gas, sludge or sewage gas, and refinery or still gas. As a rule, the gas engine is not so finicking about its fuel as are the Diesel and gasoline engines, chiefly because its fuel is a gas, readily mixed with air. Though a specific modern Diesel is limited to certain fuels, a given modern gas engine is likely to be able to burn a wide range of fuels with only slight changes in the setting of the mixing valve.

Natural Gas.—This gas is found in the oil districts of the United States and Canada, and to some extent in several European countries. It is the commonest and most desirable of any of the gaseous fuels for use in internal-combustion engines because of its cleanliness and its freedom from moisture, sulfur, and other acid-forming constituents. Its heating value is high, ranging from 800 to 1200 B.t.u. per cu. ft. and averaging about 900. It is mainly methane (50 to 98 per cent) and usually contains some ethane (0 to 20 per cent), varying small percentages of carbon dioxide and nitrogen, and possibly some oxygen, carbon monoxide and hydrogen.

Blast-furnace Gas.—Blast-furnace gas, or "downcomer" gas, is a by-product of the blast furnace. Its heating value is low, ranging from 90 to 120 B.t.u. per cu. ft. The principal combustible gases contained in it are carbon monoxide (27 per cent) and hydrogen (3 per cent). The remainder is chiefly the inert gases, nitrogen and carbon dioxide.

As it comes from the blast furnace, it contains considerable amounts of lime dust, iron oxide, soot, moisture, and sulfur. It contains sometimes as much as 225 grains of impurities per cu. ft. Because of the impurities, it is not suitable for gas-engine use until cleaned, which is done by dry cleaning or wet scrubbing, or both. Most engine builders specify that the dust and other solid impurities contained in the gas shall not exceed 0.02 grain per cu. ft. and that the moisture shall not be in excess of 10 grains per cu. ft.

Coke-oven Gas.—This gas is produced from bituminous coal during the production of coke. Coke was formerly prepared in beehive ovens, in which all the by-product gases were burned to furnish heat for the coking of the coal. Coke is now made in by-product ovens, and the volatile gases are led away and cooled and then washed or scrubbed, after which they may be used as gas-engine fuel. Coke-oven gas contains about 50 per cent hydrogen, 35 per cent methane, and small percentages of carbon monoxide, carbon dioxide, nitrogen, and, possibly, other volatile gases.

Coke-oven gas contains, as it comes from the coke oven, coke dust, tar, sulfur, and ammonia, which will cause serious operating difficulties if not removed before use in an engine. If thoroughly cleaned, however, it makes an excellent fuel. Its heating value ranges from 450 to 600 B.t.u. per cu. ft.

Producer Gas.—This gas is formed with a deficient air supply by combustion in a producer of any grade of coal, coke, peat, or charcoal. Incomplete combustion results, with the formation of a considerable quantity of carbon monoxide. Gas producers are of three general types, suction, pressure, and balance draft, depending on whether the pressure in the producer is below, above, or equal to atmospheric pressure. Usually, a producer and engine are installed as a unit, the suction of the engine drawing air and steam into the producer. The gas is thus generated as it is required by the engine, and no storage is required.

Producer gas has a heating value ranging from 110 to 175 B.t.u. per cu. ft. It always contains some moisture and more or less impurities, such as soot and fine dust, but no sulfur. Where lignite or peat is used as a fuel, it is not necessary to introduce steam into the producer, for these fuels contain sufficient moisture. But when coal or charcoal is used, steam is always introduced into the producer to improve the richness of the gas. Regardless of the fuel used in the producer, however, the cleaning process of producer gas involves washing and as a result it always contains more or less moisture.

Illuminating Gas.—Illuminating or water gas is made by passing steam over white-hot coke or coal, coke being the more generally used. Gas made from coke is more uniform in composition and is cleaner than that made from coal. Its heating value ranges from 450 to 600 B.t.u. per cu. ft., and it contains approximately 12 per cent hydrogen, 14 per cent carbon monoxide, 25 per cent methane, 10 per cent ethylene, the remaining content being chiefly the inert gases, nitrogen and carbon dioxide.

Although this gas is an excellent gas-engine fuel, it is too expensive for extensive use, being economical only for small or infrequently operated engines.

Sludge Gas.—Sludge or sewage gas is a product of the sludge-digestive tanks of sewage-disposal plants. It averages 600 to 750 B.t.u. per cu. ft. and contains about 65 per cent methane and 30 per cent carbon dioxide, with small percentages of other gases, including, sometimes, hydrogen sulfide.

It burns slowly, because of the high carbon dioxide content, and may be used in the conventional high-compression gas or gasoline engine. It has a narrow air-fuel-mixture-ratio range. The

hydrogen sulfide content affects the potential compression ratio, increases maintenance, and tends to cause detonation. If the hydrogen sulfide content is in excess of 0.5 per cent, the compression ratio must be decreased. Because of the formation of sulfuric acid from the hydrogen sulfide, severe corrosion is likely to occur unless the valves, cylinder, piston, and exhaust manifold are made of corrosion-resisting alloys.

Several cities are using this gas as an engine fuel; and the operation of the engines indicates high reliability, low maintenance, and virtually no fuel cost.

Refinery Gas.—Refinery or still gas is a by-product obtained when crude petroleum is distilled. It consists mainly of light hydrocarbon gases, such as methane, ethane, propane, butane, and pentane. It nearly always contains some hydrogen sulfide, of which, if above 0.25 per cent by volume, the gas has to be cleaned. Usually, a simple scrubbing will clean it satisfactorily. The heating value averages about 1500 B.t.u. per cu. ft.

7. Gasoline-engine Fuel.—All gasoline internal-combustion engines operate on the Otto cycle and may be of either the two- or four-stroke type. Virtually all aircraft and passenger-car automobile engines and the majority of truck, tractor, and bus engines in this country use gasoline and are of the four-stroke Otto-cycle type.

Gasoline is defined by the A.S.T.M. as "a refined petroleum naphtha which by its composition is suitable for use as a carburant in internal-combustion engines." This society has established tentative specifications for three motor gasolines, as in Table XXXIX. Type A is provided for use under normal conditions; type B for use where a gasoline of greater over-all volatility than type A is desired; type C for use where a relatively nonvolatile fuel is desired.

The federal government has established specifications for two aviation and two motor gasolines, as in Table XL.

8. Oil and Diesel-engine Fuels.—Early Diesel and oil engines were heavy-duty slow-speed units with large cylinders and air injection of the fuel. They would operate on virtually any type of liquid fuel, but the modern oil and Diesel engine is nearly as exacting in its fuel requirement as is the modern high-speed gasoline engine. For many years the fuel oils were satisfactory as internal-combustion engine fuels. Relatively a short time

TABLE XXXIX.—A.S.T.M. GASOLINE REQUIREMENTS

Gasoline	Distillation temperature, max., °F.					Distillation residue, max., %	Vapor pressure, max., lb. per sq. in., 100°F.			Octane no., min.	Corrosion	Gum, max., mg. per 100 ml.
	For 10% evaporated			For 50% evaporated	For 90% evaporated							
	Winter	Fall	Summer				Winter	Fall	Summer			
Type A	140	149	158	284	392	2	13 5	11 5	9 5	67 or 75	Passes	7*
Type B	140	149	158	257	356	2	13 5	11 5	9 5	67 or 75	Passes	7*
Type C	167	167	167	284	392	2	13 5	11 5	9 5	45	Passes	7*

Note.—75 octane number, minimum, corresponds to premium-priced gasolines. 67 octane number, minimum, corresponds to regular-priced gasolines. 45 octane number, minimum, corresponds to less than regular-priced gasolines.

* In the case of gasoline containing added nonvolatile material, the gum requirement shall apply to the base stock. The technical data available do not afford an adequate basis for specifying maximum sulfur content. At the present time (1937), gasolines containing up to 0.25 per cent sulfur are distributed within the United States.

TABLE XL.—FEDERAL GOVERNMENT GASOLINE SPECIFICATIONS

Specifications	Aviation gasoline		Motor gasoline	
	Fighting grade	Domestic grade	Motor fuel V	Motor gasoline
Water content	None	None	None	None
Suspended content	None	None	None	None
Distillation range, °F.:				
10 per cent evaporated	167	167	158	167
50 per cent evaporated	212	221	257	284
90 per cent evaporated	275	311	356	392
96 per cent evaporated		347		
Residue, max. per cent	2	2	2	2
Vapor pressure, max. at 100°F.	6.5 lb.	6 5 lb.	10 lb.	12
Sulfur, max. per cent	0.10	0 10	0.10	0.10
Freezing point, not above, °F	−76	−76		
Antiknock value, not less than an octane number of	87			

ago, however, manufacturers and users of these engines, as well as petroleum refiners, felt the need for some classification differentiating types of fuel oils suitable for Diesel and oil engines. In consequence, the A.S.T.M. has presented the classification of Table XLI, out of which will probably evolve a series of Diesel-fuel-oil specifications.

The use of a suitable fuel is one of the most essential considerations in the operation of any internal-combustion engine; its importance cannot be stressed too highly. The use of an unsuit-

TABLE XLI.—A.S.T.M. DIESEL-FUEL-OIL CLASSIFICATION

Grade of Diesel fuel oil	Flash point, °F.	Water and sediment, % by vol.	Viscosity, S.U.S., 100°F.		Carbon residue, % by wt.	Ash, % by wt.	Pour point, °F.	Sulfur, % by wt.	Alkali and mineral acid
	Min.	Max.	Min.	Max.	Max.	Max.	Max.*		
No. 1-D	115 or legal	0.05	33	50	0.2	0.02	35	†	None
No. 3-D	150	0.10	33	70	0.5	0.02	35	†	None
No. 4-D	150	0.60	..	250	3.0	0.04	35	†	None

* Lower pour point may be specified whenever required by local temperature conditions to facilitate storage and use.

† So far as known, sulfur content need not be considered as regards combustion characteristics. However, when sulfur content is of consequence—as, for instance, in fuel for engines in intermittent service—the following limits are suggested: grade no. 1-D, 1.5 per cent maximum; grade no. 3-D, 1.5 per cent maximum; grade no. 4-D, 2.0 per cent maximum.

Ignition quality is determined by either the cetane number and/or Diesel index number. The following are minimum values. Cetane number—grade no. 1-D, 45; grade no. 3-D, 35; grade no. 4-D, 30: Diesel index number—grade no. 1-D, 45; grade no. 3-D, 32; grade No. 4-D, 25.

In many cases the Diesel index may prove more convenient than the cetane number and equally as satisfactory. It is reliable for hydrocarbon fuels that have 50 per cent boiling between 490 and 575°F. It cannot apply in case of fuel containing an ignition promotor ("doped" fuel).

Cetane number is the percentage by volume of cetane in a mixture of cetane and α-methylnaphthalene that the fuel matches in ignition quality when compared by a standard procedure given by the A.S.T.M. Thus, by definition, α-methylnaphthalene has a cetane-number rating of zero and cetane of 100. Diesel index number is calculated from the aniline point and A.P.I. gravity by the following formula:

$$\text{Diesel index number} = \frac{\text{A.P.I. gravity at 60°F.} \times \text{aniline point, °F.}}{100}$$

Aniline point is the lowest temperature at which equal parts by volume of freshly distilled aniline and the test sample of oil are completely miscible. It is determined by heating such a mixture in a jacketed test tube to a clear solution and noting the temperature at which turbidity appears as the mixture is cooled.

able fuel tends to cause overheating, excessive carbon deposits, ring sticking, increased fuel and oil consumption, and detonation, with probable damage to pistons, rings, cylinders, and other parts.

9. Parts Requiring Lubrication.—In basic design, all internal-combustion engines are alike. Regardless of the type of engine, the parts that require lubrication are the main crankshaft bearings, crankpin and piston-pin bearings, camshaft bearings, cylinder walls and pistons, valve stems and guides, and various miscellaneous bearings, such as those of the water pump, fan, and starting motor. Often, these miscellaneous bearings are fitted with grease cups or grease-gun fittings or with simple oil cups.

10. Methods of Lubrication.—Various methods are employed for applying lubricating oils to the bearings and cylinders of internal-combustion engines, as in Figs. 304 to 310. The method employed depends on many factors, some of which are: make; model; speed; type of service for which engine is designed; and type, *i.e.*, gasoline, gas, oil, Diesel, and two- and four-stroke cycle.

Large Diesel, gas, and oil engines are generally equipped with two independent oiling systems, one for the cylinders and the other for the bearings, as in Fig. 304. With but few exceptions, bearings of the modern internal-combustion engine are supplied by means of a force-feed circulation system, as in Figs. 305, 306, and 308. Stationary Diesel and aircraft engines are usually provided with the so-called *dry-sump system*, which comprises in addition to the usual equipment an external reservoir and, generally, two oil pumps, as in Figs. 311, 312, and 315. One of the pumps takes its suction from the external oil reservoir and delivers oil either to an overhead tank or under pressure through a network of pipes and ducts to the various bearings, from which it drains by gravity to the crankcase or sump. The other, called the *scavenging pump*, takes its suction from the crankcase or sump and returns the oil to the external reservoir.

High-speed single-acting engines, such as motor-vehicle and inboard-motorboat units, are generally equipped with a force-feed circulation system that serves both the bearings and cylinders, the crankcase serving as an oil reservoir, as in Figs. 309 and 310. The cylinders are usually supplied with oil thrown from the crankpins.

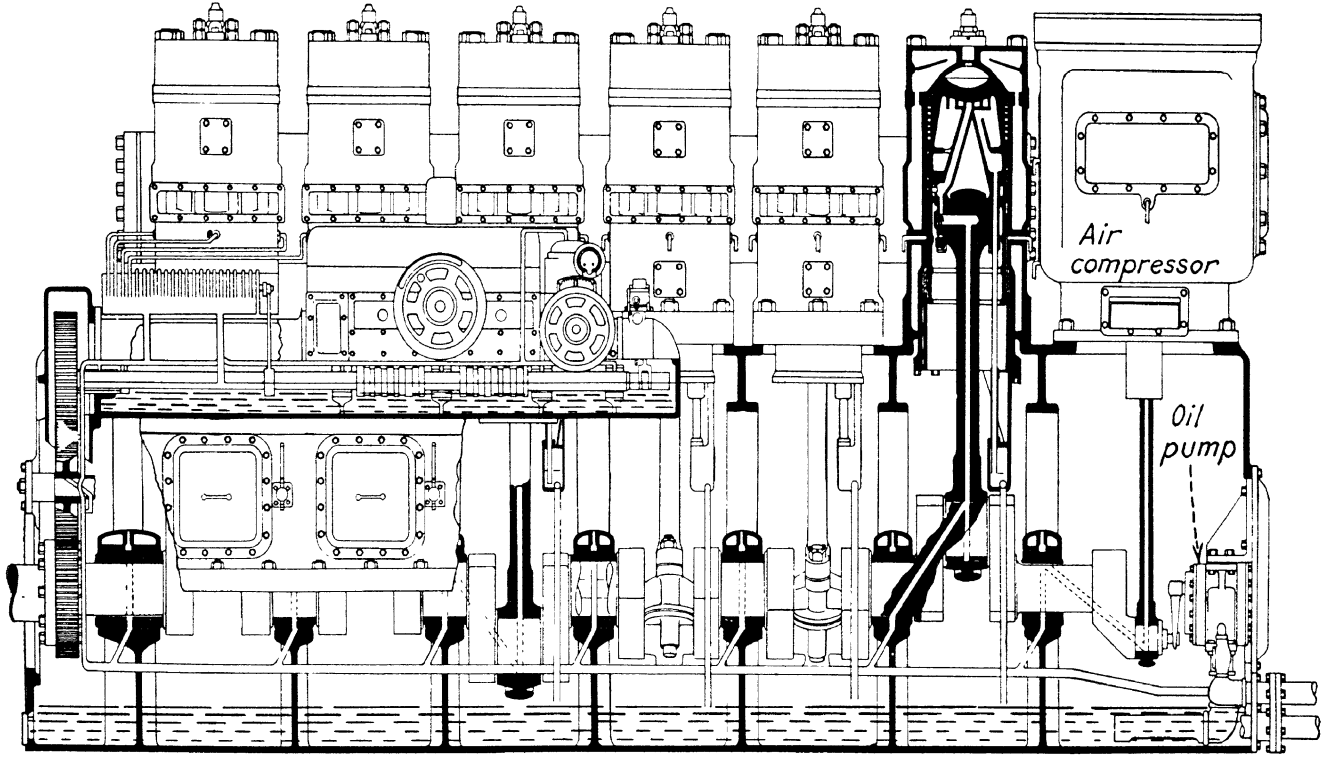


FIG. 304.—Lubricating system of a two-stroke-cycle, single-acting Diesel engine. (*Courtesy Socony-Vacuum Oil Co.*)

The oil pressure in force-feed-circulation systems ranges from about 20 to 90 lb. gage.

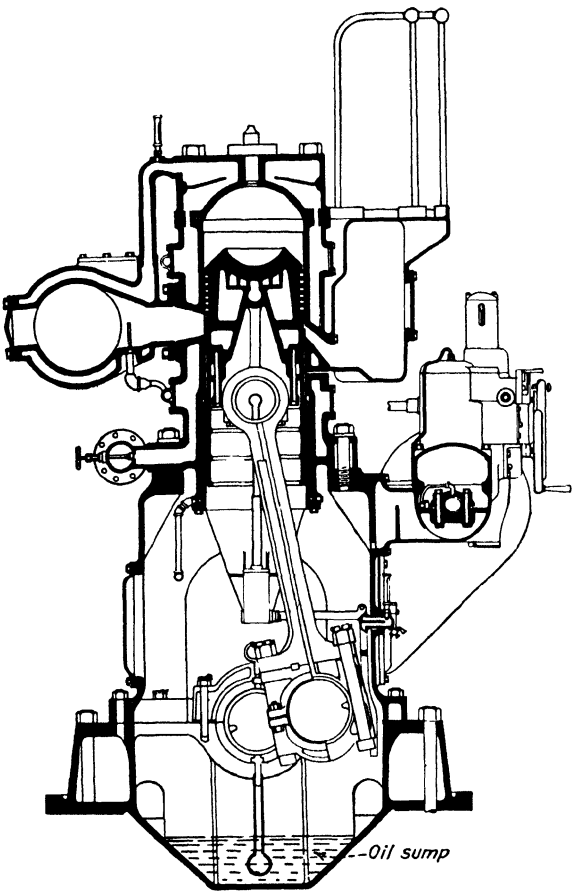


FIG. 305.—Transverse section of Diesel engine shown in Fig. 304. (*Courtesy Socony-Vacuum Oil Co.*)

11. Duties of Lubricating Oil.—Progress in the design and manufacture of internal-combustion engines has been phenomenal in recent years. This progress is reflected in engines of higher specific-power output, reduced weight, higher piston speeds, and higher mean effective pressures. These improvements have constantly made the lubrication problem more difficult until it can be truly said that "lubrication is the lifeblood of an engine." Formerly, the sole duty of the oil was to provide adequate

lubrication and thereby minimize both friction losses and heat generated. It is required now to perform not only this first duty but also the duty of carrying away heat generated and of thus maintaining temperatures within practical limits. This added duty is the major reason for builders equipping their engines nowadays with the costly force-feed-circulation system, which is virtually standard.

12. Cylinder Lubrication.—The lubrication problems associated with internal-combustion engines divide naturally into two groups: (1) lubrication of the cylinder, and (2) lubrication of the bearings.

The ideal would be to provide over the entire cylinder wall a complete unbroken oil film capable of acting as a lubricant for the piston rings and as a seal to prevent blow-by. Although piston rings are essential to the operation of internal-combustion engines, they have scarcely a single feature either in principle or in operation that is not inimical to good lubrication. They are the most difficult of all parts to lubricate. They account for approximately 70 per cent of the total friction losses of the engine, and it is estimated that 80 per cent of the heat dissipated by the pistons passes through the ring belt. They move with nonuniform sliding motion and are subjected to maximum pressure and temperature conditions during the period of minimum velocity and actual reversal of motion.

13. Perfect and Imperfect Lubrication.—Although there is some question as to the type of lubrication that prevails between the rings and cylinder walls, an analysis of the conditions indicates that probably both perfect and imperfect lubrication exist. Since motion is essential to the formation of oil films and since the velocity of a piston is very slow near the ends of the stroke and actually reverses its direction of motion at the dead centers, it appears that imperfect lubrication prevails at and near the ends of the cylinder, especially at the combustion end of the cylinder of single-acting engines. For intermediate positions of the piston where the speed is higher, the probabilities are that perfect lubrication prevails most of the time after the engine has warmed up and is operating under normal conditions.

The quantity of lubricant actually supplied to the cylinder walls is undoubtedly an important influencing factor. A copious supply of oil to the cylinder walls tends to extend the region of

perfect lubrication and thereby reduce bore and ring wear. Unless a copious supply of oil is furnished to the cylinder during each stroke, the reciprocating motion of the piston will remove

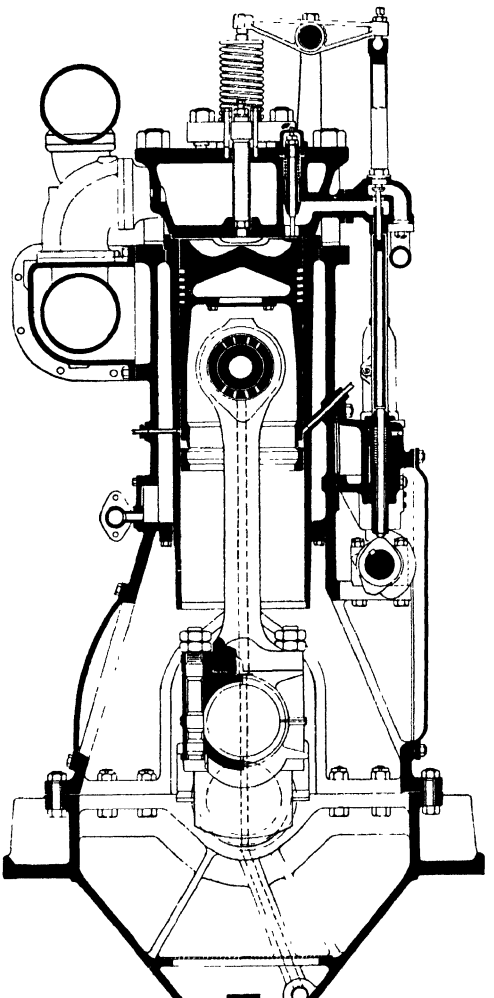


FIG. 306.—Four-stroke cycle, single-acting, solid-injection Diesel engine. (*Courtesy Socony-Vacuum Oil Co.*)

the oil and the rings will eventually make metal-to-metal contact with the cylinder walls. There is more likelihood of inadequate lubrication in two-stroke-cycle engines than in four-stroke-cycle

engines, not only because in the former piston temperatures are higher, but also because the scavenging and exhaust ports tend to scrape the oil film off the piston skirt.

The lower the viscosity of the oil, the greater, generally, is the gas pressure behind the ring; and the slower the speed, the less is the tendency for the oil film to form and the more easily is it squeezed from between the ring and cylinder wall. Although a copious supply of oil tends to promote perfect lubrication, it is impossible to reduce bore and ring wear below a certain minimum, even with a large excess of oil.

14. Ring Sticking.— Although ring sticking is encountered in air compressors, steam engines, and other machines, it is much more prevalent in internal-combustion engines. It is one of the major difficulties met with in the operation of such engines, particularly high-speed Diesels and aircraft engines.

Briefly, ring sticking is caused by deposits in the ring grooves. There are four possible sources from which these deposits may originate: (1) the fuel, (2) lubricating oil, (3) atmospheric air, and (3) the engine itself.

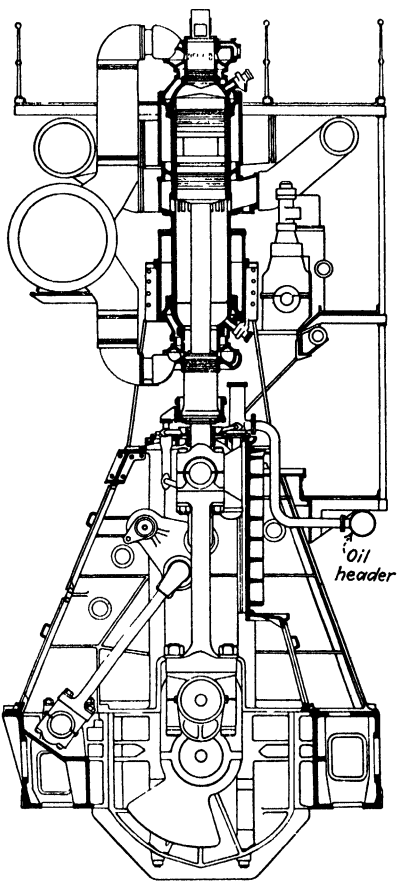


FIG. 307.—Two-stroke-cycle, double-acting, solid-injection Diesel engine. (*Courtesy Socony-Vacuum Oil Co.*)

Fuels vary widely in their ability to burn free from residues. Some fuels contain few or virtually no foreign impurities, such as suspended solid matter, water, sulfur, and nitrogen, whereas others contain relatively large amounts. Ordinarily, gasoline and light fuel oils do not contain these impurities in harmful amounts. It is not uncommon, however, for destructive

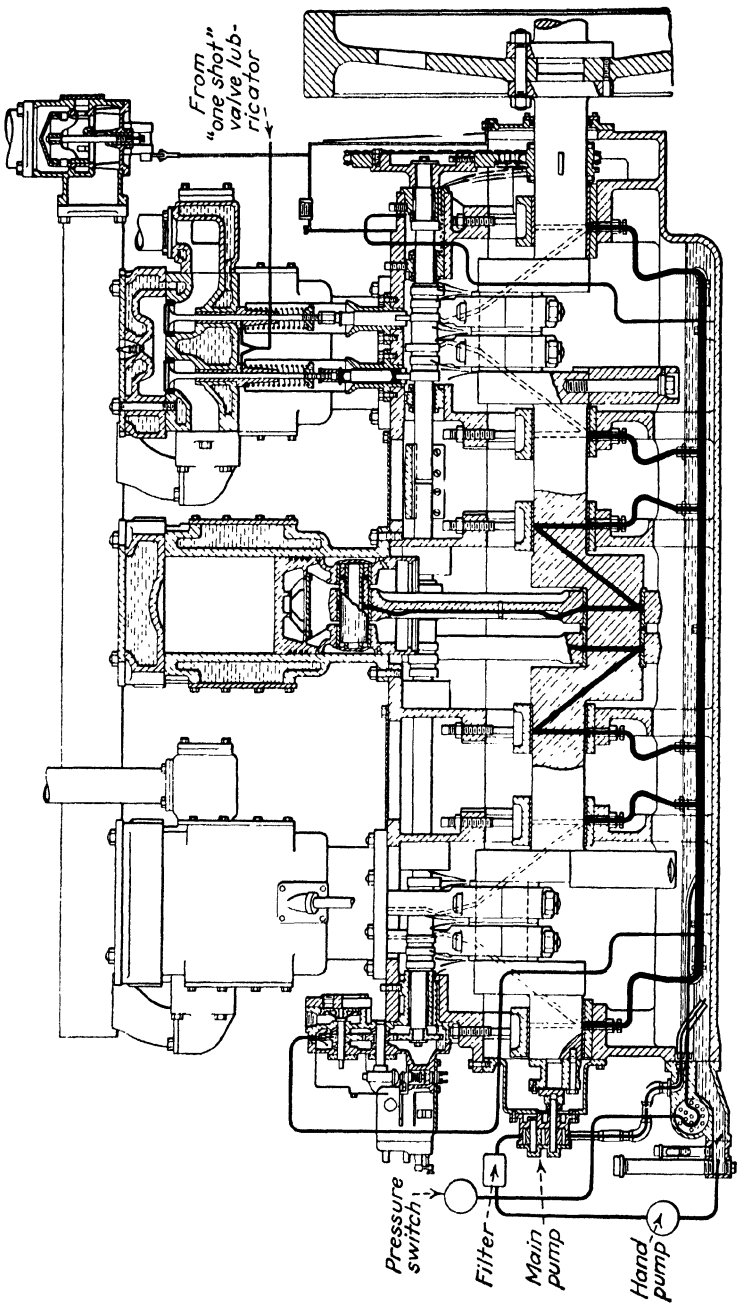


FIG. 308.—Six-cylinder, V-type gas engine equipped with force-feed circulation oiling to bearings and oil throw to cylinder walls. (*Courtesy Ingersoll-Rand Co.*)

amounts of them to be in the heavier fuel oils and gaseous fuels.

Though all internal-combustion-engine fuels are hydrocarbons and contain approximately the same ratio of carbon to hydrogen, yet their efficiency to burn free from residues, aside from foreign impurities, is largely a matter of their chemical structure. Just as the character of lubricating oils depends chiefly on the arrangement of the atoms comprising the molecule, so does the ignition

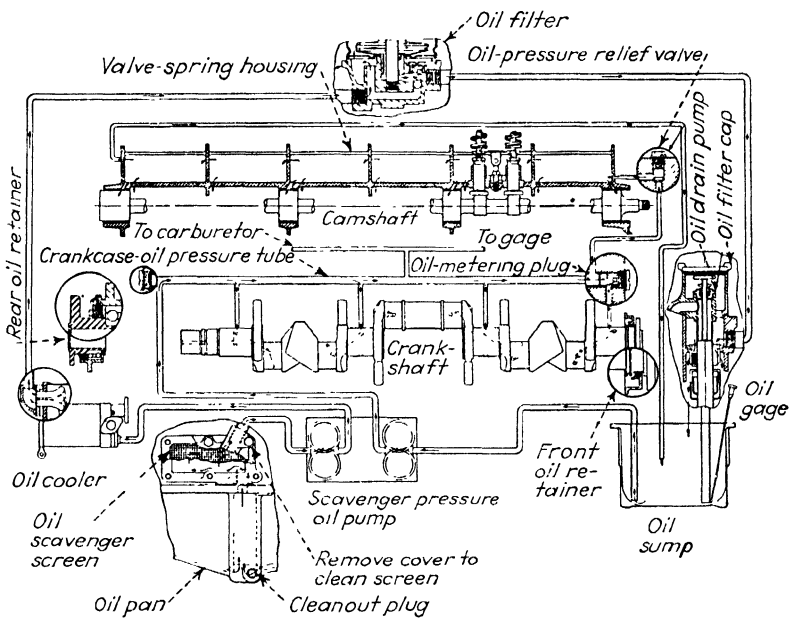


FIG. 309.—Oiling diagram for inboard motorboat engine having force feed to bearings and oil throw to cylinder walls.

quality of fuels. Some fuels upon burning leave a hard, abrasive carbon deposit, and others leave a gummy deposit.

The nature of fuel deposits depends not only on the fuel itself but also on the conditions under which it is burned. A given gasoline, for example, may be entirely satisfactory for one engine but decidedly unsuitable for another engine of different but similar design. Compression ratio, timing, combustion-chamber design, fuel-air ratio, effectiveness of cooling system, and operating conditions are some of the more important factors, aside from the fuel, that affect the character of fuel deposits.

Approximately 14,000 gal. of air are taken into an internal-combustion engine for each gallon of fuel burned. Further, a 14- by 17-in. two-stroke-cycle Diesel engine running at 257 r.p.m. requires about 3,361,000 cu. ft. of air every 24 hr. As explained in Chap. XIV, air always contains more or less dirt, much of which is noncombustible and of an abrasive nature. Atmospheric impurities are often a large percentage of deposits found in piston-ring grooves. In all cases where air must be taken from dusty surroundings, it is profitable to provide the engine with an efficient air cleaner.

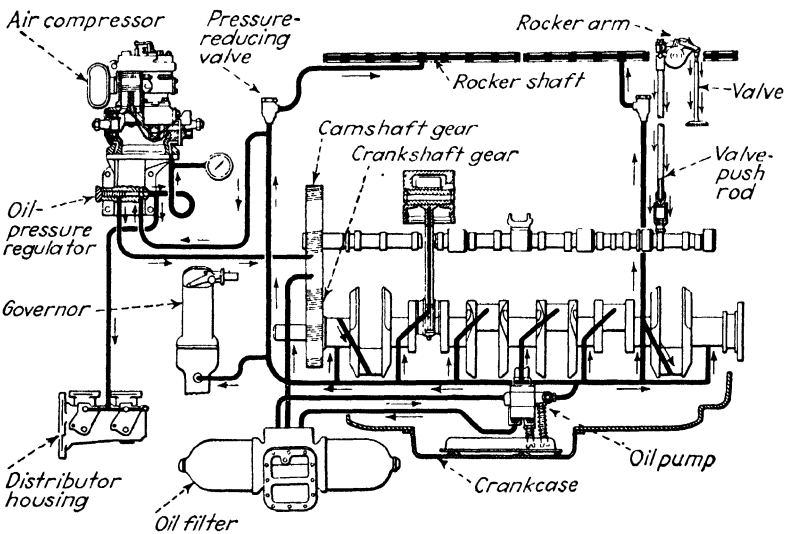


FIG. 310.—Lubricating system of heavy-duty bus engine having force feed to bearings and oil throw to cylinder walls.

The engine itself contributes such impurities as rust, worn bits of metals, core sand, filings, and drillings to ring-groove deposits. Usually, the quantity of such materials is small in proportion to the whole; often, however, the metallic particles act as powerful catalyzers to promote rapid and substantial oil deterioration. Thus, indirectly, these materials may be responsible for a considerable portion of the deposit in ring grooves.

The attitude of mind is still predominantly in agreement with the expression "It's the fault of the oil." This attitude is fast becoming extinct, as a better appreciation is gained of the influence of certain details of design and operation on lubrication.

From the foregoing discussion, it is evident that ring sticking can be and often is caused by factors other than the oil.

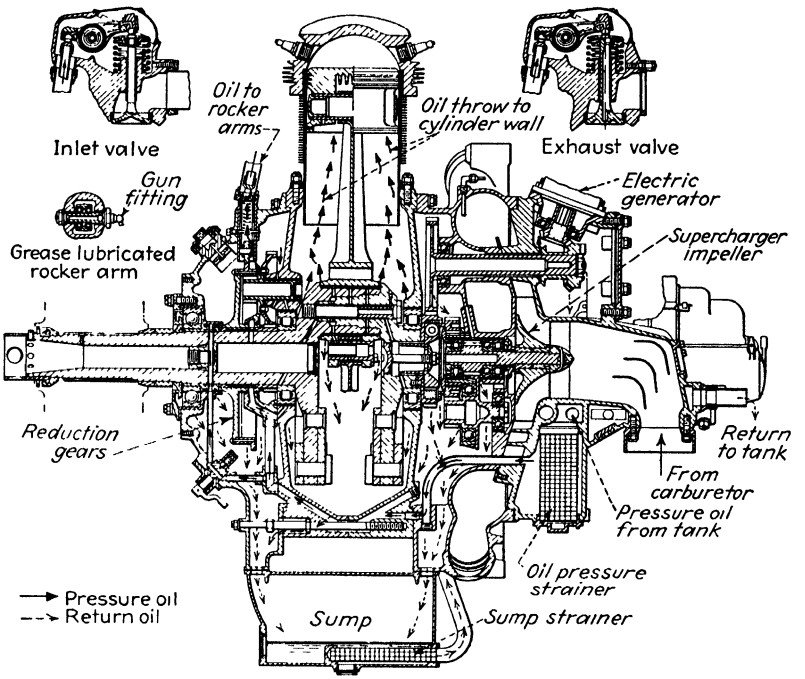


FIG. 311.—Aircraft engine having force feed to all bearings and oil throw to cylinder walls. (*Courtesy Pratt and Whitney Aircraft.*)

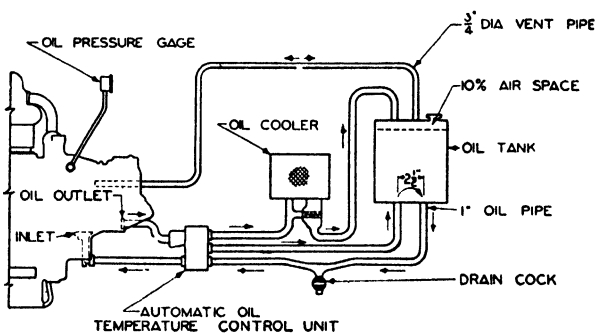


FIG. 312.—External oil piping and equipment for engine shown in Fig. 311. (*Courtesy Pratt and Whitney Aircraft.*)

In most cases, analyses of ring-groove deposits indicate that the oil is the major contributor. But the fact should not be lost sight of that oil deterioration and carbonization are often has-

tened through faulty design and poor maintenance and operating practices. The piston assembly, finish of the cylinder bore, effectiveness of the cooling system, and method of lubrication are important constructional features that affect oil deterioration. The temperature of the ring belt of the piston (which depends chiefly on the design of the piston, rings, and cooling system) and operating conditions, in particular, affect ring-groove deposits.

Lubricating oils in internal-combustion engines are exposed to the usual deteriorating factors of air, heat, foreign impurities, and agitation common to nearly all machinery. In the internal-combustion engine, however, these factors are of much greater intensity. The tendency, therefore, is for the oil to deteriorate at a very rapid rate, especially if it contains unstable compounds. When engine conditions change, the effects of these various deteriorating factors on oil oxidation, polymerization, and carbonization also change.

In recent years, many improvements have been made in oils with respect to their tendency to cause ring sticking. The greatest improvement has been accomplished through better refining processes. Some improvement has also been effected through the addition of metallic soaps and other purging compounds, which may or may not reduce the amount of carbon deposit formed in ring grooves, but which act as a detergent to flush deposits out of the ring grooves.

To summarize: Deposits in ring grooves comprise mainly the following products:

1. Deposits, resulting from the oxidation, polymerization, and carbonization of the lubricating oil and consisting mainly of resins, asphaltenes, lacquer, and carbon.
2. Deposits, resulting from the combustion of the fuel and consisting chiefly of soot, gum, lacquers, carbon, and ash.
3. Deposits, composed of worn bits of metal and atmospheric impurities.

The composition and consistency of ring-groove deposits vary widely in internal-combustion engines. Analyses of these deposits show that they can be separated according to their solubility in various solvents, such as carbon tetrachloride, carbon disulfide, chloroform, alcohol, benzol, benzene, and petroleum naphtha. In general they are within the following percentage ranges:

1.	Oil.	0–50 per cent, soluble in benzene (60–80)
2.	Lacquer.	1– 5 per cent, insoluble in benzene (60–80); slightly soluble in benzol; soluble in alcohol
3.	Asphaltenes.	1– 5 per cent, insoluble in benzene (60–80) and alcohol; soluble in benzol
4.	Carbon and soot . .	40–80 per cent, insoluble in benzene (60–80), alcohol, and benzol
5.	Ash.	2– 5 per cent, insoluble in benzene (60–80), alcohol, and benzol

15. Blow-by.—The word *blow-by* is used to describe the leakage of combustion gases from the combustion chamber, past the rings, into the crankcase. The pressure in the combustion cham-

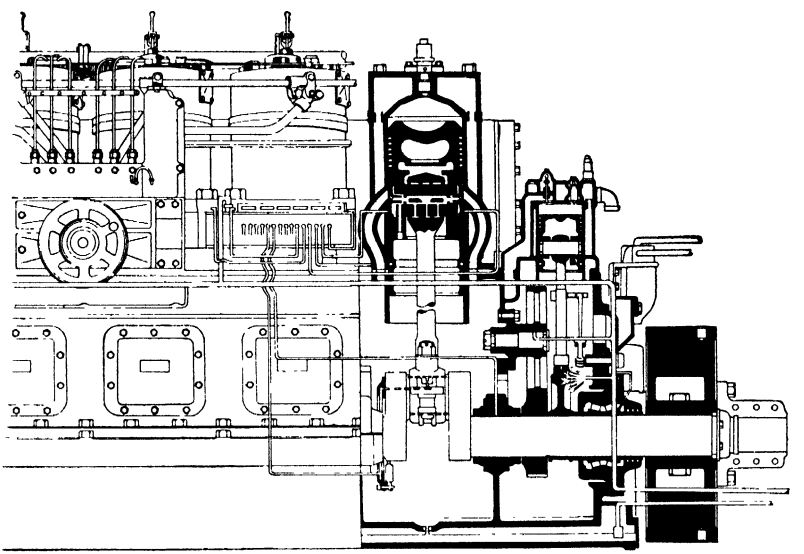


FIG. 313.—Two-stroke-cycle, single-acting, marine Diesel engine with solid injection. (*Courtesy Socony-Vacuum Oil Co.*)

ber tends to force the compression rings against the cylinder walls and ring grooves. Occasionally, however, pressures are so high or clearances are so large because of wear or cylinder distortion that the oil seal is broken at the first two or three rings, and blow-by occurs.

The quantity of oil supplied to the cylinder walls and the wiping action of the rings are vital in the maintenance of an oil seal between the rings and cylinder wall. During the compression stroke the wiping action of each piston ring tends to build up an

oil wave at the leading edge, which wave forms a seal against gases escaping downward. Blow-by results if for any cause this seal is destroyed, and there are a number of related and frequently quite serious consequences.

1. If much leakage occurs during the compression stroke of Diesel engines, the resulting pressure and temperature in the combustion chamber will be so low that incomplete or no combustion or misfiring may occur.

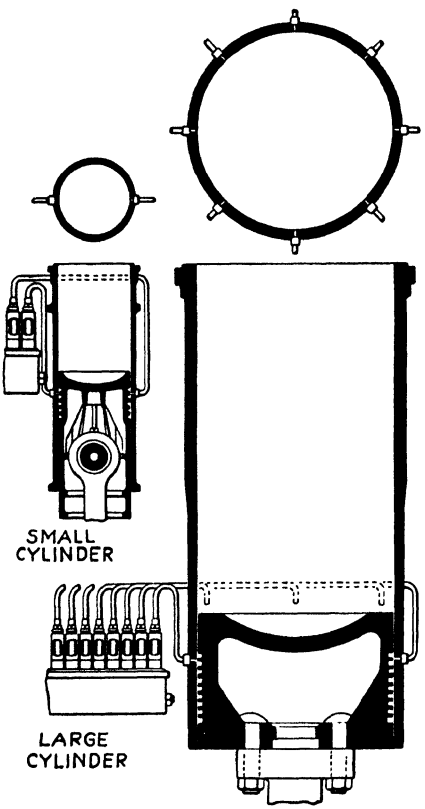


FIG. 314.—Application of oil by mechanical-force-feed lubricator. Note the increased number of points of application required by a large cylinder in order to secure distribution. (*Courtesy Socony-Vacuum Oil Co.*)

2. Incomplete combustion in turn results directly in power loss, and additional power loss results indirectly, due to the carbonization of the fuel. The resulting carbon deposits lead to ring sticking and ineffective lubrication.

3. Blow-by during the power stroke leads directly to power loss and to destruction of the oil film on the cylinder wall owing to the high temperature and velocity of the gases blowing past.

4. Combustion gases leaking into the crankcase, condense and mix with the oil, thus forming acids and sludge.

In order to prevent blow-by and maintain an effective oil seal, it might appear that a very viscous oil would be preferable. This is true to a certain extent only, as a viscous oil is not so readily distributed over the cylinder wall as is a less viscous oil. Moreover, a viscous oil usually leaves more carbon when burned. A less viscous oil, being more easily distributed over the cylinder walls, will effectively lubricate the parts; but it burns more readily than a viscous oil, and it may fail to form an effective seal.

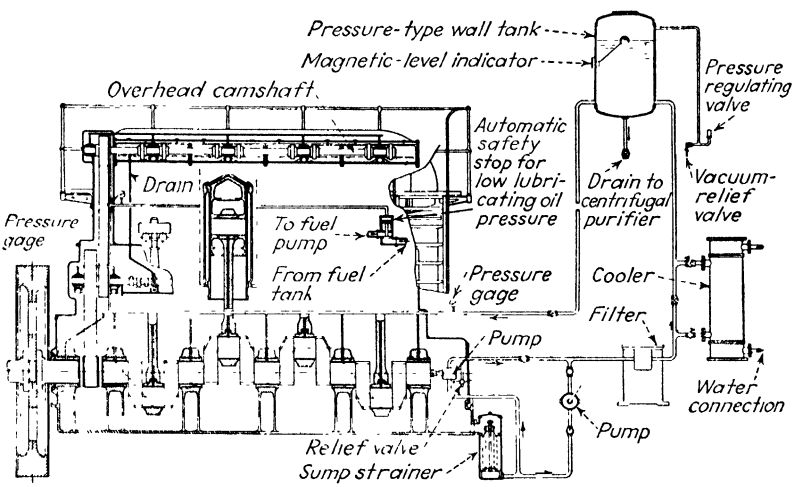


FIG. 315.—Diesel engine with dry crankcase and elevated pressure tank.

16. Cylinder and Ring Wear.—The greatest bore wear occurs at the top of the cylinder, where pressure and temperature conditions are severest and the oil film thinnest, tapering virtually to nothing at the bottom, as in Fig. 317. Maximum pressures range usually from 400 to 700 lb. per sq. in., which is also approximately the pressure behind the top ring. The maximum temperature of the top land of the piston and head is usually between 500 and 600°F., whereas cylinder-wall temperatures vary from 200 to 600°F., being highest at the top. Flame temperatures are, of course, much higher, as shown in Figs. 302 and 303. Temperatures of small localized hot spots on the cylinder walls and faces of rings are sometimes 1200°F., or more, as is evidenced by the formation of iron carbide.

Wear results because the oil film fails. Factors that tend to destroy the oil film, therefore, cause increased wear. The difficulties of maintaining an oil film over the surfaces of the rings and

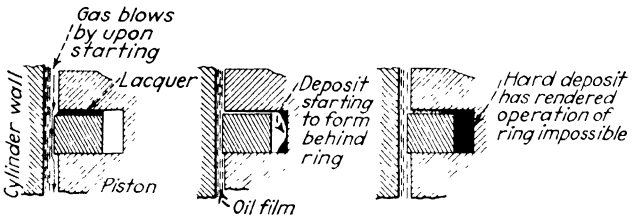


FIG. 316.—Deposit formations in piston-ring grooves.

cylinder walls in the face of conditions met with in internal-combustion engines are self-evident. The reciprocating motion of the piston makes it difficult even to establish an oil film, especially at and near the ends of the strokes.

Generally, the rate of bore and ring wear is greater in Diesels and oil engines than in gas and gasoline engines. This is not

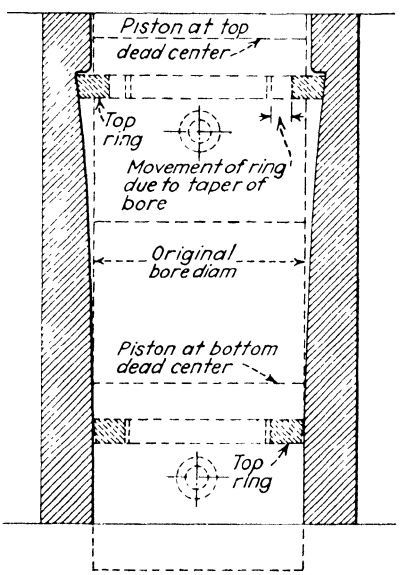


FIG. 317.—Exaggerated cylinder-bore wear.

entirely due to the slightly higher average pressure and temperature conditions that prevail in these engines, as many believe. An important contributing factor is that of the duration of the

high temperature and pressure conditions. The oil film is exposed in these engines to high temperatures over a considerable period, and, as a result, it may be destroyed.

Although the cause of ring and bore wear is simple, the factors affecting it are numerous and complex. Some of these are: nature of combustion; quality of fuel; operating temperature; pressure and temperature conditions in cylinder; design of piston, cylinder and rings; finish of cylinder bore and rings; materials of construction; effectiveness of cooling system; mechanical condition of engine; purity of air; method of lubrication; and the chemical and physical properties of the lubrication oil.

Briefly, wear can be minimized by observing the following points: using efficient air cleaner; suitable fuel; correct viscosity oil of high chemical stability; proper amount of oil; maintaining the engine in good mechanical condition and in correct adjustment as to timing, fuel-air ratio, etc.; and use of engine in service for which it was designed.

17. Oil Consumption.—Oil charged against an internal-combustion engine rightly should include that which is thrown away because it is judged unfit for further service and that which is actually burned, leaked, sprayed, or otherwise consumed in the operation of the engine.

Consumption due to draining oil and discarding it because it is thought unfit for further use will not be discussed here, as the subject of oil purification is taken up in Chap. X.

An internal-combustion engine is adequately lubricated when a film of oil is maintained on the cylinder wall just thick enough to prevent metal-to-metal contact. A film thicker than this results in excessive oil consumption and wear. A thinner film results, also, in excessive wear of rings, pistons, and cylinder walls.

A thick film is desirable only from the standpoint of preventing blow-by. On the power stroke the oil film on the cylinder wall becomes exposed to the flames of combustion. Because of the poor heat conductivity of oil, the exposed surfaces of thick films reach higher temperatures than do those of thin films. As a result, more oil is burned to carbon in the case of thick films than in that of thin films. The carbon thus formed mixes with the oil that is spread over the cylinder wall on the succeeding stroke and eventually is mixed with the crankcase oil. Not only is the oil consumption increased, but the crankcase oil is contaminated.

Since carbon so formed is somewhat abrasive, wear is also increased.

To maintain on the cylinder wall an oil film of the proper thickness is a difficult problem, especially over long periods of time. The problem is generally solved by overfeeding oil to the cylinder wall and scraping the excess off, rather than controlling the supply to the cylinder walls. Whenever the excess exceeds the volume that can be handled by the oil-control rings, excessively thick film is formed and the oil consumption increases.

Many factors affect the quantity of oil supplied to the cylinder walls and, in turn, the consumption of oil by an internal-combustion engine. These may be grouped under four main headings:

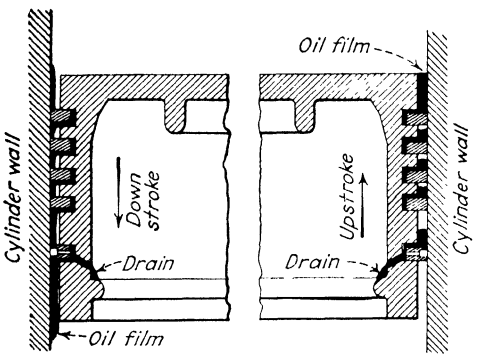


FIG. 318.—Showing pumping action of worn piston rings.

(1) mechanical design of engine, particularly that of piston assembly; (2) operating conditions, particularly loads and speeds; (3) wear of piston assembly and other parts; (4) oil characteristics, especially viscosity at the operating temperature.

In an engine free of oil leakage, nearly all the oil consumed is that which passes the rings into the combustion chamber. Speed of the engine is, apart from the design and mechanical condition of the piston assembly, the most important factor affecting oil consumption. Doubling the speed may increase consumption from two to twenty times, depending on engine design and condition. Increasing the speed results, in nearly all engines, in a greater supply of oil to the cylinder walls. Frequently, the capacity of the oil-control rings is not sufficient to remove the excess of oil, and more oil finds its way into the combustion chamber. Moreover, if the rings are badly worn, as in

Fig. 318, a considerable quantity of oil is actually pumped by the rings into the combustion chamber. Increased speed is generally associated with an increased operating temperature, which reduces the viscosity of the oil, producing increased consumption.

Probably because they tend to increase blow-by, preignition and detonation cause an increase in oil consumption. Indirectly, some fuels are responsible for increasing oil consumption because they release, upon burning, deposits which tend to interfere with free operation of the rings. The design of the combustion chamber, also, affects oil consumption, owing to its effect on the completeness of the combustion of the fuel.

In engines in which the bearings are supplied by a circulation system and the cylinder walls by oil thrown from the crankpin and main bearings, the clearances of these bearings largely govern the amount of oil thrown onto the cylinder walls. Excessive wear of these bearings allows too much oil to be thrown onto the cylinder walls, resulting usually in excessive consumption. The wear may not be excessive from the standpoint of the bearing but still it may cause high oil consumption.

The oil characteristics that have a bearing on oil consumption are viscosity and volatility. Other characteristics, such as gravity, pour point, carbon residue, flash and fire point, etc., do not affect oil consumption except as they affect viscosity, volatility, and service changes. In general, oil consumption decreases with increased viscosity. This is probably because as viscosity increases the amount of oil thrown onto the cylinder walls decreases. In some high-speed engines, however, this relationship has been observed to hold only up to some critical viscosity depending on engine design, and then consumption increases with increased viscosity. This is probably because when the oil becomes too viscous the oil-control rings do not effectively remove it from the cylinder walls.

Tests indicate that oil consumption is not affected by the volatility of oils which are virtually nonvolatile at engine temperatures. If, on the other hand, oils are volatile at or below engine temperatures, volatility affects oil consumption and, with the exception of viscosity, probably is more closely associated with oil consumption than is any other property of an oil.

18. Dilution.—As explained on page 130, in the operation of internal-combustion engines, some of the less volatile portions of

the fuel may pass unburned from the combustion chamber into the crankcase. Dilution as a factor affecting lubrication is confined to engines that operate under widely varying temperature conditions and to those using liquid fuels. It is most pronounced in engines of motor vehicles that are intermittently operated in cold weather. It is virtually nonexistent in Diesels and aircraft engines because they usually operate at normal temperature, regardless of weather conditions.

Excessive diluent in crankcase oil is undesirable, as it lowers the viscosity, increases the volatility, and brings about other undesirable changes. With the introduction of crankcase ventilators, higher temperature thermostats, and higher average operating temperatures, excessive dilution is the exception nowadays rather than the rule. Consequently, dilution is seldom if ever a serious problem in the operation of internal-combustion engines.

19. Bearing Lubrication.—Lubrication of the bearings is relatively simple as compared with that of the cylinder. Although

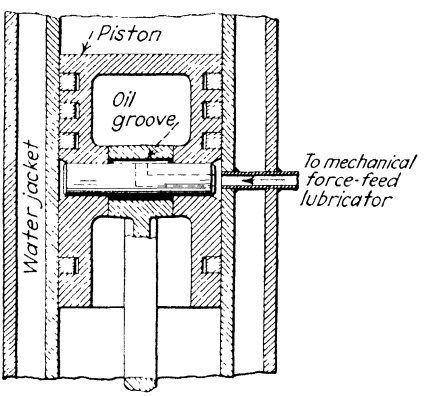


FIG. 319. Oil feed to piston pin.

bearing pressures are high as compared with those of machinery in general, yet the loads fluctuate and the average seldom exceeds 400 or 500 lb. per sq. in. of projected area. Piston pins are heaviest loaded and operate at the highest temperature because of the proximity to the combustion chamber. Moreover, the relative motion of the pin and bearing is oscillatory rather than continuous. As explained in Chap. VIII, this type of motion is not conducive to oil-film formation and maintenance.

Lubrication of this bearing is, in general, accomplished by one of the following four methods: (1) drilling a hole through the connecting rod, as in Fig. 304, or providing a separate tube, through which oil is fed under pressure from the crankpin; (2) scraping from the cylinder wall some oil, which flows through the hollow pin to the bearing; (3) registering the end of the hollow pin with an inlet port in the cylinder wall, through which oil is supplied by a mechanical force-feed lubricator, as in Fig. 319; (4) in single-acting engines, by drilling one or more holes in the connecting rod, into which oil is thrown from the crankpin bearings, as in Fig. 320. This and method 1 are most generally used for high-speed engines.

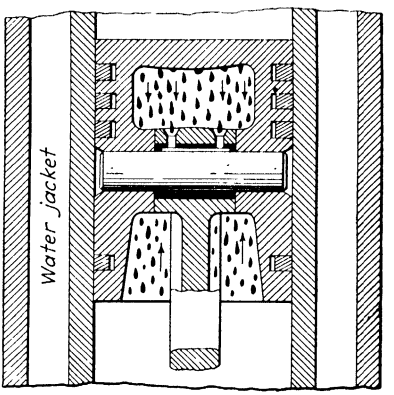


FIG. 320.—Splash lubrication to piston pin.

Mechanical force-feed lubricators and circulation systems are both widely used to supply oil to the main and connecting rod bearings. Connection between the main bearings and the crankpin bearings is made by drilling the crankshaft, as in Fig. 308. Ring oiling is applied to the main bearings of some small units.

TABLE XLII.—MAXIMUM ALLOWABLE BEARING PRESSURES WITH FORCE-FEED LUBRICATION

Type of engine	Main bearings, lb. per sq. in.	Crankpin bearings, lb. per sq. in.	Piston-pin bearings, lb. per sq. in.
Automobile and aircraft	600–1800	1500–2500	2000–4000
Diesel, two-stroke cycle	400– 600	1000–1200	1200–1600
Diesel, four-stroke cycle	500–1000	1000–1500	1200–1800
Diesel, high speed, two-stroke cycle	500–1000	1000–1500	1200–1800
Diesel, high speed, four-stroke cycle	600–1200	1200–1800	1500–2000
Double acting, two-stroke cycle	600–1000	1200–1800	1500–2000
Gas, two-stroke cycle	500–1000	1200–1800	1200–2000
Gas, four-stroke cycle	600–1000	1200–1800	1500–2000
Oil, surface ignition	600–1000	1000–1600	1800–2000

Crosshead guides of double-acting engines present no particular difficulties; for the bearing pressure is low, and they are generally oil- or water-cooled. Oil is usually supplied by direct leads from the circulation system or the mechanical force-feed lubricator.

If bearings are in line, properly fitted, and a correct oil is used, wear is extremely low. In erecting or overhauling an engine, care must be taken properly to align and fit the bearings. Alignment of the main bearings is not always an easy matter in the case of large stationary engines because of the slight flexibility of the long crankshaft. It is necessary to check alignment by measuring with micrometers the distance between adjacent cheeks of each crank as the shaft is rotated. This distance should be the same for all positions of the crankshaft when main bearings are in alignment.

20. Required Oil Characteristics.—Oils for internal-combustion engine service should possess the following two main characteristics: (1) correct viscosity for type of engine and operating conditions, and (2) maximum chemical stability.

Viscosity.—In engines equipped with separate oiling systems for bearings and cylinders, the bearing oil can be selected on the basis of bearing requirements alone. On the other hand, when one system serves both bearings and cylinders, the cylinder requirements govern the selection. The bearings, in general, do not require so heavy an oil as do the cylinders. This difference is greater for large than for small cylinders because large cylinders operate at higher average temperatures. In small engines the same viscosity oil is more or less suitable for lubrication both of bearings and of cylinders. As the size of cylinders increases, the necessity for heavier cylinder oil likewise increases. This is not only because large cylinders operate at higher temperatures than do small cylinders but also because clearances are necessarily greater in large cylinders. For these reasons, medium- and large-size engines are generally equipped with separate oiling systems for the bearings and cylinders.

An oil of high viscosity index is always desirable for internal-combustion engine service. Unless an oil possesses a high viscosity index, it may become too thick to spread quickly and uniformly over the cylinder walls and bearing surfaces, especially at low temperatures. An oil not having a high viscosity index becomes very thin at high temperatures. Since oil in an internal-

combustion engine is subjected to high temperatures, one of low viscosity index may become excessively thin and, as a result, not only would be consumed rapidly but may not possess sufficient viscosity to prevent blow-by and metal-to-metal contact between the rings and cylinder walls.

Oils of high-viscosity index are less affected by temperature variations than ones of low-viscosity index. Consequently, high-viscosity index oils are more satisfactory under both operating and starting conditions.

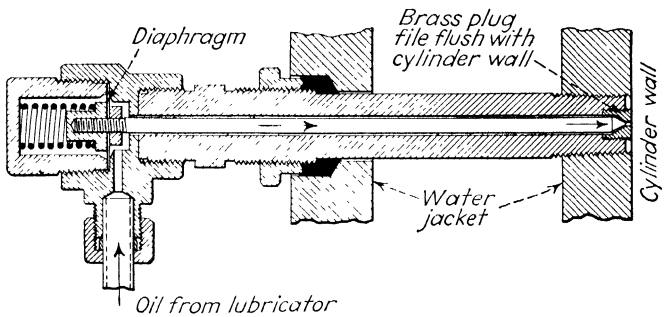


FIG. 321.—Diaphragm check valve for timed cylinder lubrication. This check valve is used in conjunction with a mechanical-force-feed lubricator for timed lubrication of Diesel, gas, and other engines. The lubricator and piston of the engine are synchronized so that oil is delivered at any predetermined position of the piston. In a four-stroke-cycle engine best results are secured by injecting the oil onto the piston between the first and second rings at the end of the power stroke. For a two-stroke-cycle engine most efficient results are secured by injecting the oil onto the piston at the beginning of the compression stroke, at a point just above the exhaust ports.

Oils of lower viscosity are required for operation in cold surroundings than in warm surroundings. It is universal practice to use lighter oils in motor-vehicle engines in the winter than in the summer. Air-cooled engines, as a rule, operate at higher temperatures than liquid-cooled ones; consequently, heavier oils are generally used.

Table XLIII gives viscosities and other data of oils suitable for the lubrication of internal-combustion engines. Tables XLIV, XLV, and XLVI will be found to be useful guides in selecting lubricating oils for Diesel, oil and gas engines. Table XLVII gives two typical specifications for aircraft engines.

Flash Point.—As explained in Chap. VII, flash point in itself has no direct bearing on the performance of a lubricating oil; yet it is, to a certain degree, indicative of the comparative

TABLE XLIII.—PROPERTIES OF OILS SUITABLE FOR INTERNAL-COMBUSTION ENGINES

Oil	Specific gravity	Pour point, °F.	Flash point, °F.	Fire point, °F.	Viscosity, S.U.S.		
					100°F.	130°F.	210°F.
A	0.910	25	425	480	660	270	66
B	0 905	10	390	445	320	143	50
C	0 905	40	450	500	950	390	85
D	0 895	40	500	565	1550	605	118
E*	0 905	10	400	450	425	178	58
F*	0 910	10	400	450	415	175	53
G	0 910	30	415	465	650	266	65

* Contain approximately 1 per cent compounding for wet cylinder conditions.

TABLE XLIV.—GUIDE TO SELECTION OF LUBRICATING OILS FOR DIESEL ENGINES

Methods of application		Viscosity, S.U.S. at 100°F.					
		Up to 151 hp. per cylinder		151 to 350 hp. per cylinder		Over 350 hp. per cylinder	
To cylinders	To bearings	Cylinder	Bearing	Cylinder	Bearing	Cylinder	Bearing
Mechanical force feed, no oil throw, 20" and under between points of application	Circulation	660	320	950	660	1550	660
Mechanical force feed, no oil throw, over 20" between points of application	Circulation	660	320	950	660	950	660
Mechanical force feed	Mechanical force feed	660	660				
Mechanical force feed	Ring or drop-feed oiling	660	660				
Mechanical force feed and oil throw	Circulation	660	660	950	660	1550	660
Oil throw	Circulation	660	660	660	660		
Circulation	Circulation	660	660	660	660		
Splash and oil throw	Circulation	660	660				

resistance to burning of oils. An oil having a low flash point will generally show a higher consumption in an internal-combustion engine than one having a high flash point. In all cases, the flash point should be consistent with viscosity.

TABLE XLV.—GUIDE TO SELECTION OF LUBRICATING OILS FOR OIL ENGINES

Method of application		Viscosity, S.U.S., 100°F.*			
		Up to 20 hp. per cylinder		Over 20 hp. per cylinder	
To cylinders	To bearings	Cylinders	Bearings	Cylinders	Bearings
Mechanical force feed—no oil throw.	Mechanical force feed, ring oiling, wick feed, drop feed, or splash	320	320	420	420
Mechanical force feed—oil throw	Splash			660	660
Drop feed or wick feed	Ring oiling, drop feed, or wick feed	320	320	420	420
Splash	Splash	420	420		

* Where water injection is employed, an oil of the same viscosity but containing approximately 1 per cent compound should be used.

Pour Point.—Pour point is only of importance where operation is carried on under low-temperature conditions. For example, the operation of motor vehicles and aircraft in the winter. In all instances, the pour point should be sufficiently low so that the oil will flow freely at the lowest temperature encountered in operation.

Foaming.—This is the rapid absorption of air by the oil and the resulting formation of bubbles. It is caused always by a mechanical fault, such as: (1) leakage of air into the pump suction line; (2) oil level in reservoir too low, pump suction being thus allowed to become partly uncovered and to draw in air with the oil; (3) excessive fall of oil from return line into sump or reservoir, air being thus beaten into the oil. These conditions are not due to the oil, and the remedies are simply mechanical.

Chemical Stability.—Chemical stability has to do with the chemical changes that occur in an oil while in service. Virtually

TABLE XLVI.—GUIDE TO SELECTION OF LUBRICATING OIL FOR GAS ENGINES

Methods of application		Viscosity, S.U.S., 100°F.											
		Up to 20 hp. per cylinder				21 to 200 hp. per cylinder				201 to 750 hp. per cylinder		Over 750 hp. per cylinder	
		Dirty gas		Clean gas		Dirty gas		Clean gas		Clean gas		Clean gas	
To cylinders	To bearings	Cylinder	Bearing	Cylinder	Bearing	Cylinder	Bearing	Cylinder	Bearing	Cylinder	Bearing	Cylinder	Bearing
Mechanical force feed—no oil throw	Circulation	....	....	...	...	420*	420	420	420	650*	320	650*	650
Oil throw from circulation	Circulation	....	....	...	...	650	650	650	650				
Splash	Splash	..	..	...	...	650*	650*	650	650				
Mechanical force feed—no oil throw.	Mechanical force feed, ring, drop feed, splash, wick feed	320*	320*	320	320	420*	420*	420	420				
Drop or wick feed	Drop feed, wick feed, ring	320*	320*	320	320	420*	420*	420	420				

* Where water injection is employed, an oil of the same viscosity but containing approximately 1 per cent compound should be used.

all oils on the market are sufficiently pure when new satisfactorily to lubricate internal-combustion engines. Not all, however, possess sufficient resistance to heat, impurities, air, water, and rapid agitation—agents that promote chemical changes—satisfactorily or even safely to lubricate internal-combustion engines for any appreciable time. As yet no satisfactory method short of actual engine testing has been devised for determining this characteristic of internal-combustion engine oils. Carbon-residue, demulsibility, and oxidation tests are among the more important ones used at this time.

TABLE XLVII.—TYPICAL AIRCRAFT-ENGINE-OIL SPECIFICATIONS

Characteristics	Temperate	Torrid
Flash point, °F. min	475	500
Viscosity, S.U.S., 210°F	100 ± 5	120 ± 5
Viscosity, S.U.S., 100°F	Not over 12.5 times viscosity at 210°F.	Not over 14.5 times viscosity at 210°F.
Viscosity index (V.I.) min	95	95
Pour point, °F. max	10	10
Carbon residue, %, max	1.00	1.25
Neutralization number, max	0.10	0.10
Precipitation number	None	None
A.P.I. gravity, min		26.6
Emulsion test, Herschel	60 min. maximum time to settle out, using distilled water at 180°F.	
Flash point, °F. min	450	475
Viscosity, S.U.S., 210°F	90–100	115–125
Viscosity S.U.S., 100°F	Not over 12.5 times viscosity at 210°F	Not over 14.5 times viscosity at 210°F.
Pour point, °F. max	10	20
Carbon residue, % max	1 50	1.50
Neutralization number, max	0.10	0.10
Precipitation number, max	None	None
Ash, %, max	0.01	0.01
Evaporation loss, %, max	0 50	0.50
Emulsion test, Herschel	The oil shall separate completely in 1 hr. from an emulsion with distilled water at 180°F.	

Carbon Residue.—As in Table XLVII, carbon residue is generally included in specifications for internal-combustion engine oils. Because of the extremely high temperatures and the inevitable burning of the oil film on the cylinder walls, oils for

internal-combustion engines should have low carbon-residue values. Oils having high carbon content leave, upon burning, heavy carbon deposits on the ports, cylinder walls, and piston heads and in the piston-ring grooves. Some of these deposits gradually work past the rings into the crankcase and mix with other impurities to form sludge. The undersides of pistons in internal-combustion engines are well above the cracking temperature of many of the hydrocarbons of the oil. Consequently, some of the oil splashed against these hot surfaces carbonizes, and deposits are formed, which deposits eventually drop into the crankcase and mix with the oil.

Valves are sometimes held open by the formation of deposits under them. This causes a loss of compression and power and, often, burned and warped valves. Carbon deposits also form sometimes in the valve guides and cause the valves to stick open, rendering them inoperative.

Carbon deposits in piston-ring grooves may cause the rings to stick, loss of power and excessive blow-by thus resulting. Carbonization of oil around the oil-control rings leads to excessive oil consumption and added carbon formation in the cylinders.

Demulsibility.—Water is sometimes present in crankcases of some internal-combustion engines. It may come from several sources, as follows;

1. Condensation of water vapor in the exhaust gas that blows by the piston rings.
2. Condensation of water vapor from the air that passes through the crankcase ventilators or breathers.
3. Leakage from water-cooled pistons and crosshead guides.
4. Leakage from water jackets, particularly at the cylinder-liner joints.
5. Water sometimes used to suppress detonation in oil engines.

Oil and water in the crankcase tend to emulsify and act as a binding agent for dirt, carbon, oxidized hydrocarbons, etc., to form sludge. Sludge, usually slimy in character, may clog oil lines and coolers. Clogging of lines reduces oil flow to the bearings and, in extreme cases, may stop the flow altogether. Sludge deposits in oil coolers decrease their efficiency and lead to increased bearing temperatures, with increased oil oxidation and sludge formation.

Oxidation.—Temperature conditions that prevail in internal-combustion engines are quite sufficient to cause oil oxidation.

This causes an increase in the acidity of the oil and usually a precipitation of resinous or asphaltic material.

Any appreciable amount of acid developed through oil oxidation is likely to cause pitting or corrosion of the highly polished bearing surfaces and an increase in the rate of sludge formation, which further accelerates oxidation by restricting oil flow to the cooler and bearings.

The bulk of internal-combustion engine oils now in use are high-quality solvent-refined pure mineral oils. At the present time, however, considerable experimental work is being carried on with oils containing various addition agents, such as those discussed in Chap. II.

CHAPTER XVII

STORING AND HANDLING OF LUBRICANTS

Industry is faced constantly with the problem of minimizing and preventing waste. Power and maintenance costs, which depend to a large extent on lubrication, are large items in the operating budgets of plants. Regardless of how well a design has been thought out and executed, no machine can render trouble-free service unless properly lubricated at all times. Quantity and quality products cannot be secured from poorly lubricated machines.

1. Scope of Correct Lubrication.—The correct lubricant must obviously be chosen and correctly applied. It is no exaggeration to say that today's lubricants are better and more securely packed than those of even a few years ago. New and more exacting and scientific refining processes are being employed by the refiner; greater care is exercised to make certain that containers are thoroughly clean before filling. The reputable refiner makes every effort to supply the consumer with clean products especially suitable for his purposes. This is obviously the end of the refiner's responsibility and authority. But, on the other hand, it is the beginning of the responsibility of the user.

Since correct lubrication is vital to the operation of mechanical equipment, it seems reasonable that lubricants should be given the same meticulous care that is usually accorded spare parts. This, however, is the exception rather than the rule. Too often, oil and grease drums are set in the most convenient dark corner with lids off and bungs out, contamination by dust, other foreign matter, and often water being thus allowed. Containers for dispensing lubricants often never receive the benefit of a periodic cleaning. The best oil ever refined is useless if it is stored and handled carelessly. Even a little dirt and contamination will impair the lubricating quality of an oil or a grease and take its toll in excessive wear, loss of power, and per-

haps even shutdown. Storage in too hot or too cold a place, exposure to weather, or transfer into contaminated containers also spoil a lubricant.

Though refinement and proper application are salient factors in realizing benefits of correct lubrication, yet these go for naught unless lubricants are properly stored and handled prior to use. The most perfect turbine oil or refrigerating oil or stainless textile lubricant, for example, will cause difficulties if stored or handled in such a manner as to invite contamination.

2. Factors Involved.—The proper storing and handling of lubricants will generally involve a careful consideration of the following factors:

1. Construction, size, and location of storing facilities.
2. Storage tanks and accessories.
3. Handling equipment.
4. Measuring equipment.
5. Method and manner of distributing lubricants to units or departments.
6. Character of lubricants.
7. Extent to which records are to be kept.

3. Construction of Oil House or Room.—To minimize fire hazard the oil house or room should be of fireproof construction, as in Figs. 322 and 323. The added cost of fireproof construction is usually a good investment because of lower insurance rates. Adequate drains should be provided in the floor so that it can be easily cleaned or hosed out. In addition, cleanliness is more easily maintained in such a building or room than in one constructed of wood, which soon becomes oil soaked.

The handling of filled containers from one level to another is an item that should be given careful consideration both in designing the oil-storage space and in selecting the storage tanks. Not only is hoisting expensive, but it also entails a certain amount of rough handling, which may lead to contamination of the lubricant through sprung seams, broken seals, etc.

To guard against such occurrences and minimize cost of handling, "one-level" handling should be planned wherever possible. The platform of the oil house or storage room should be as nearly as possible on a level with the floor of cars, docks, or trucks. Such construction permits drums to be rolled, trundled on hand trucks, or handled by a portable conveyor, directly to the filling hatches of the storage tanks where basement tanks

FIG. 322.—A well-designed and well-arranged oil-storage room.

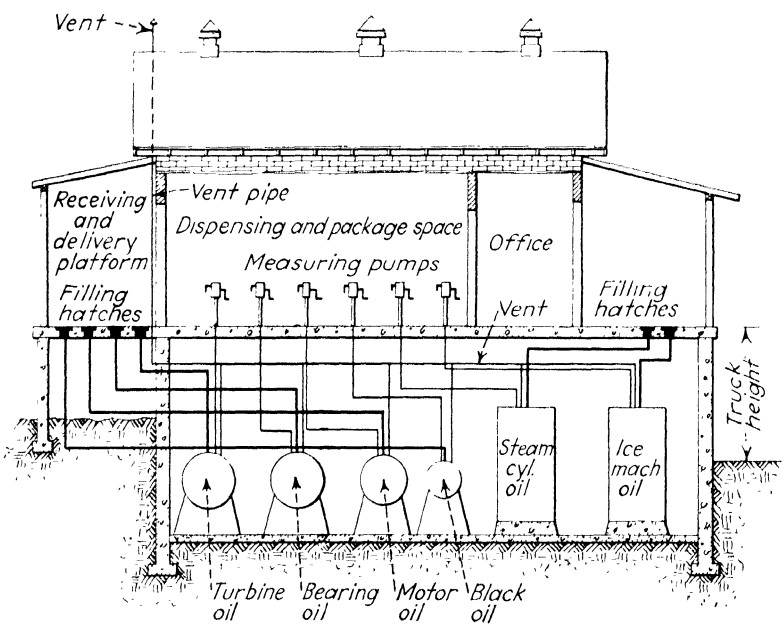


FIG. 323.—Sectional elevation of a central oil-storage house, showing location of tanks, pumps, filling hatches, and other equipment.

are used, or to the hoist above the tanks if the tanks extend above or rest on the floor.

4. Size and Location.—There are so many factors involved in determining the size and location of storage facilities that each case must be given separate consideration.

Whether or not an independent oil house should be constructed or a special room should be set aside for storage depends largely on the quantities of lubricants used per year. An independent house entails considerable expense; if the amount of lubricant used is not large, the cost of such a building may be prohibitive. In deciding this question, it should be kept in mind that considerable savings can usually be realized by purchasing lubricants in large quantities, such as tank-car lots. Plants close to oil-supply depots need not in general provide so much storage as those more remote from such depots. Many small plants thus favorably located find it more economical to set apart a portion of the engine room or general storehouse for lubricants, which are kept in the shipping drums or packages or in small storage tanks provided with pumps, as in Fig. 324.

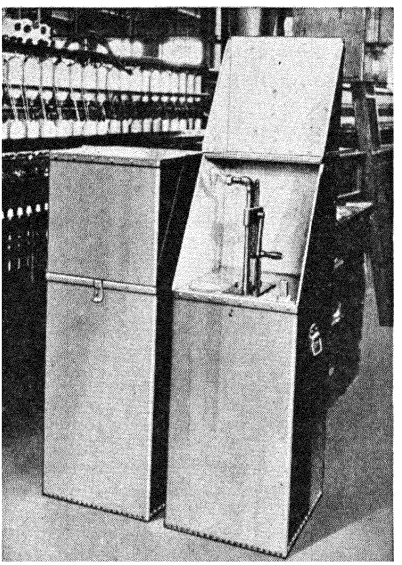


FIG. 324.—Cabinet-type tank with hinged cover and measuring pump.

Storage facilities may be planned not only for storage but also for storage and dispensing purposes. The capacity of tanks that should be provided depends chiefly on the following factors:

1. Quantities of lubricants used per year.
2. Types of lubricant used, *i.e.*, greases, lubricating oils, cutting oils, core oils, processing oils, etc.
3. Daily consumption.
4. Space available.
5. Availability of steam for heating tank-car shipments in cold weather.
6. Factors governing proper location of storage facilities.

5. Tank-car Storage.—Conditions are not always such that the most desirable space can be used for tank-car storage. Preferred locations and some of the factors that should be considered are:

1. To avoid excessively long unloading lines, tank-car storage should be as close to the unloading point as is practicable.
2. Also, tank-car storage should be located as close as possible to the center of distribution, so that the distributing lines or routes are as short as possible. Rarely can requirements 1 and 2 be met in full. Consequently, it is generally necessary to make a compromise, which should usually be in favor of the location that permits simple and inexpensive distribution of the lubricants through the plant.
3. Pumping oil both into and out of storage tanks is expensive and should be avoided. Storage tanks, therefore, should be so located that the oil will flow by gravity either out of the tank car into the storage tanks or else from the storage tanks into the portable dispensing tanks or to points of use.
4. Since all lubricants become very viscous at low temperature, it is advisable to provide in most locations storage-tank heating facilities, which may be either steam or hot-water coils. Better temperature control can usually be secured with hot-water coils than with steam coils. Heating coils may be placed directly in the tanks, in which case they should be of one-piece construction to avoid leakage, or they may be located on the outside, preferably underneath.

The oil should generally be heated between 70 and 100°F., which is sufficient to permit easy pumping. Some oils, if continuously heated above these temperatures, undergo harmful changes. Indoor storage spaces are usually sufficiently warm so that only the very viscous oils require heating. As a general rule, outdoor storage spaces are undesirable because of the rapid and wide variation in temperature, which causes excessive contamination brought about by the breathing of the tanks, especially pronounced during cold weather. To avoid this, if outdoor storage tanks are used, oils for winter use are often purchased in drums, or else transferred to them before cold weather sets in, when the drums are stored indoors where a more even temperature prevails. Lubricants in storage should not be exposed to extreme temperatures. Compounded oils, such as steam cylinder oils, for example, may separate if kept at too low temperature, and fluid greases are prone to separate if exposed to high temperature.

When tank cars are unloaded, the hose and connections should be clean. The same hose should not be used for fuel and black oils as for lubricating oils.

6. Drum and Package Storage.—Factors that influence the size and location of tank-car storage are of equal importance in considering storage space for lubricants in drums and packages.

Such storage should be near the receiving platform and centrally located to reduce trucking distances to points of use. In general, it should be located in the same building or adjacent to the tank-car storage tanks so as to simplify supervision. Drums and other packages should be stored indoors so that they will not be subjected to wide variations in temperature and so that brand names will not become obliterated by weathering. If drums have to be stored outdoors, a sheltered place should be provided and the drums placed on their sides to avoid the collection of water and dirt on the heads. Under these conditions, a minimum of supply should be kept on hand, and it is good practice to use the oldest stock first.

All lubricants are combustible; thus, oil-soaked rags, waste, and other material should be kept in approved fire-underwriter's containers. Fire extinguishers should also be kept at strategic points.

7. Storage Tanks.—Sheet iron or sheet steel should be used for the fabrication of storage tanks. Galvanized iron should never be used, for the zinc is likely to react with oils, especially if they are compounded.

The type, number, and size of storage tanks to be installed depend on the volume and nature of lubricants to be stored. Where an independent oil house is provided, it is usually practicable to provide a basement for the bulk storage tanks and to use the main floor for receiving, delivering, and storing package products. Basement tanks may or may not extend above the main floor level. Many plants prefer, however, to have all bulk tanks below the main floor level, which is kept free for delivery pumps, other necessary accessories, and office space, as in Fig. 323.

All tanks should have vents, to take care of breathing, away from dirt and moisture-laden air. Even with such precautions, a tank will in time accumulate some moisture and contamination. For that reason, storage tanks should have sloping bottoms, as in Fig. 325, or be set at a slight angle, with drain plugs at lowest level. The end of the oil-removal pipe should be fitted with a check valve and located several inches above the bottom of the

tank, so that it will tap clean oil. Underground tanks should be cleaned with a suction pump not less than twice a year. Large tanks, with manhole openings, should be thoroughly cleaned by hand. A rope should be securely tied around under the armpits of the man who enters the tank, and two men should be stationed at the manhole to lift him out should he be overcome by fumes. He should be provided with a gas mask and not strike any sparks. The watchers should communicate with him at frequent intervals, and he should come out into the air every 15 min. Small tanks should be regularly cleaned by flushing with kerosene, which must all be removed before refilling with oil. Because of the fire hazard, gasoline should not be used.

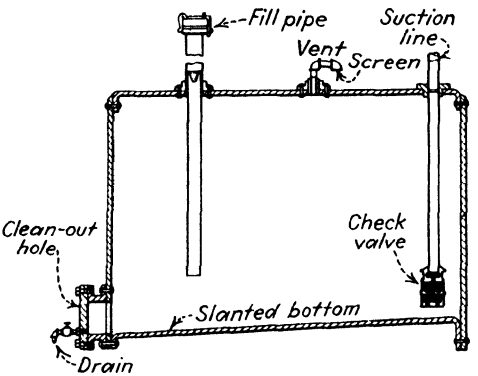


FIG. 325.—A well-designed oil-storage tank.

For handling lubricant containers and the lubricants themselves, accessories, such as pumps, meters, and portable elevators for handling drums, are always necessary. Seal measuring pumps should be used wherever practicable for pumping oils out of storage tanks into dispensing equipment. Pumps for this purpose are available having a built-in meter that indicates the amount of oil withdrawn. A measuring device is always advisable so that records can be accurately kept and the oil consumption of the plant or any department determined. Measuring pumps save time and labor, enable orders to be promptly filled, and ensure that the oils are free of contamination, at least until they are withdrawn into the distributing containers.

8. Handling Equipment.—Where drums and other heavy containers have to be hoisted to the top of storage tanks, it is advisable to install portable elevators, the probability of damage due

to rough handling being thus eliminated. The approved practice is to extend a suitable track along the tops of all tanks at a sufficient height above them for the bungs to be located directly over the filling hatches, as in Fig. 326.

If compressed air is used to transfer oil from drums to storage tanks, it should be dry to eliminate the possibility of contamination with water, and care should be taken not to use excess air pressure, which might rupture the drum.

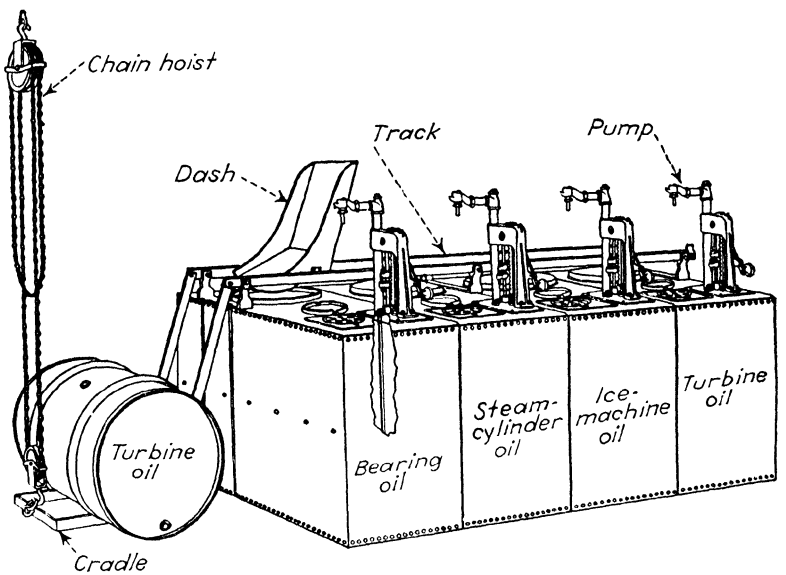


FIG. 326.—Battery of four tanks equipped with gravity-drum emptying device. (*Courtesy S. F. Bowser and Co.*)

9. Distributing.—Lubricants may be distributed to the points of use in a number of ways, depending on the type and quantity of lubricant used, distance from central storage to points of use, availability of storage space, and method of application.

If systems are large and the machines are grouped together, it may be best to provide pipe lines from the central storage to the machines. On the other hand, if the machines are scattered or if the distance is too great for piping, a portable tank, as in Fig. 330, may be used.

In large plants where individual operators are responsible for the lubrication of the machines, it is usually best to have several conveniently located substations where lubricants can be

obtained. The type, size, and location of these substations depend on many factors. If several different types and brands of lubricants are required, it is generally advantageous to provide small storage rooms with an attendant. Usually, however, the amount of lubricants handled in such a room does not warrant a full-time attendant, but it is generally possible to arrange a schedule whereby the attendant can look after several such rooms.

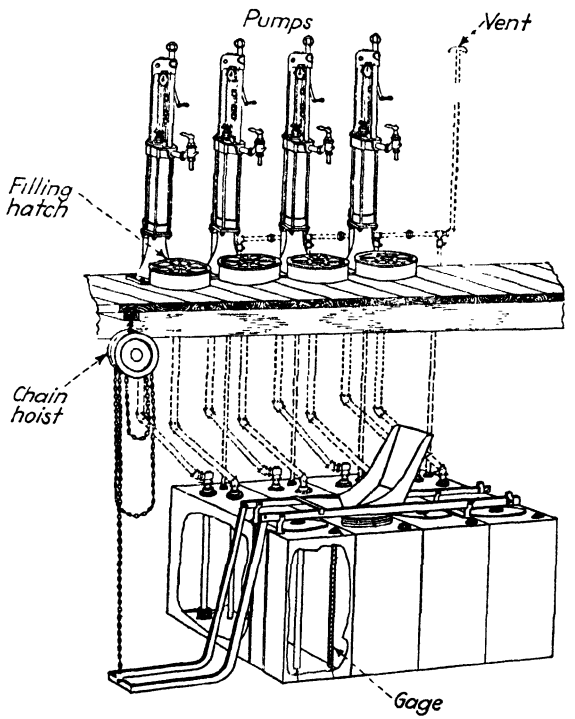


FIG. 327.—Battery of four tanks located in basement and pumps mounted on floor above. (*Courtesy S. F. Bowser and Co.*)

Where room substations are practicable, suitable storage tanks and dispensing equipment should be provided. On the other hand, if space is limited and the quantity of lubricants handled is small, shipping containers may be used for dispensing purposes. Such containers should be equipped with pumps or placed on racks on their sides and provided with faucets and drip pans. It is better to provide pumps, as heavy drums need not be lifted onto racks and the oil can be easily and accurately measured. Pumps

also provide added protection against contamination and fire hazard.

Where the quantity of lubricant handled is small, individual containers, such as in Fig. 324, may be located at convenient points throughout the plant. If the cabinet-type tank is not warranted, shipping drums may be set on suitable supports, as in Fig. 331, and provided with faucets and drip pans or set on end on the floor and provided with barrel pumps.

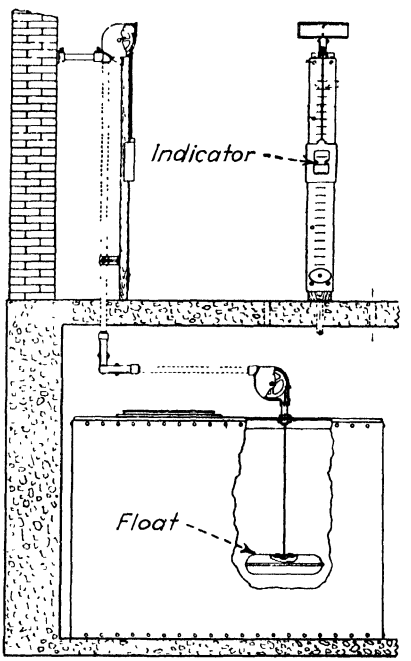


FIG. 328. Level indicator located on floor above tank.

Where an oiler takes care of all lubrication, a truck, as shown in Fig. 332, should be provided. Such trucks are specially made; they should be equipped with tanks for the most frequently used oils, racks for bottle oilers and grease guns, containers for waste and rags, drawers for oil and grease cups, grease-gun fittings, and hand tools for making minor repairs to oiling appliances.

Greases in general are less stable than oils and for this reason require more careful handling in storage and dispensing. They separate relatively easy if exposed to high temperatures, which renders them virtually useless. Despite the fact that they

should be given greater consideration than oils, the usual practice is to accord them less attention. They are generally used in

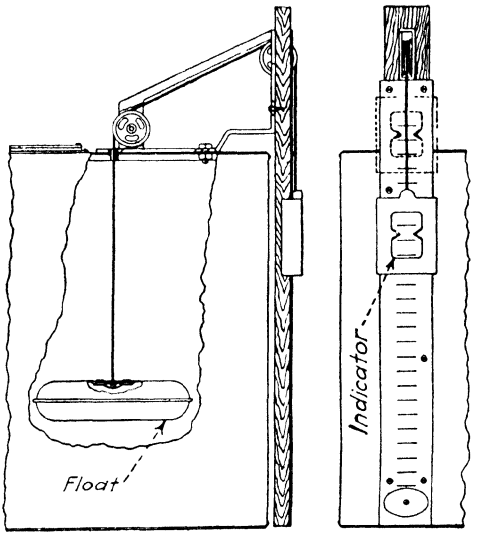


FIG. 329.—Level indicator applied to tank.

smaller quantities than oils, and it is a frequent practice to provide the operator with a small can which he keeps near the machine. It is the usual thing to find the cover off or missing from such cans, the grease being thus exposed to dirt, dust, and, frequently, water. If it is necessary to dispense grease in this manner, the container should be provided with a tight cover and the operator should be required to keep the cover on at all times. A better plan is to provide a system, such as is shown in Fig. 166, which protects the grease from contamination.

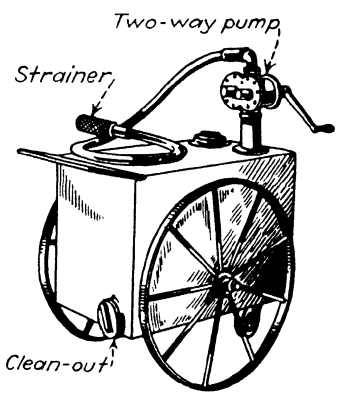


FIG. 330.—Portable tank with two-way pump.

10. Supervision and Records.—The greatest economy and efficiency in the storage, handling, and use of lubricants can best be realized by having a competent man in complete charge. Many large plants have found it profitable to provide a lubricat-

ing engineer who has direct charge of all matters pertaining to lubrication. The duties of such an engineer are, briefly, as follows:

1. To issue instructions for the proper lubrication of all equipment.
2. To fix the responsibility for the proper lubrication of each machine.
3. To inspect regularly all machines to make certain that instructions are carried out.
4. To make arrangements for the proper storage and dispensing of all lubricants.
5. To provide proper lubricating appliances and filtering equipment and see that all such equipment is maintained in good operating condition.
6. To set up the necessary system of records from which accurate lubrication costs for each department and for each machine can be ascertained.

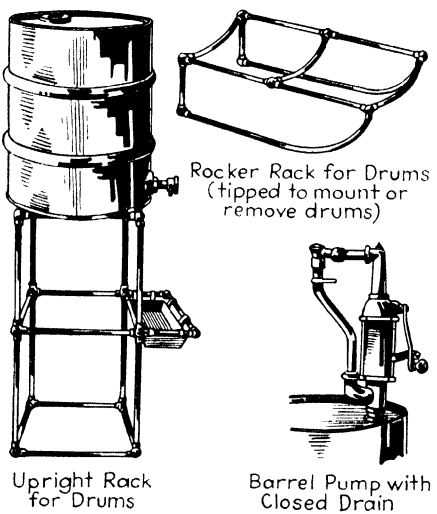


FIG. 331.—Various oil-dispensing equipment.

In order to have definite information on lubrication costs, accurate records of all quantities purchased and of where and how the lubricants were used must be kept. Individual records should be kept for large steam turbines, Diesel engines, steam engines, and other large machines.

Regardless of how efficiently and economically lubricants are selected and used, if prior to use they are improperly stored and handled, all potential benefits are likely to be lost. Many serious difficulties occur daily because of improper storing and handling of lubricants. Cleanliness is the most important factor; such accessories as funnels, measuring cans, grease guns, and oil cans,

should periodically be cleaned and, when not in use, be stored in dustproof closets or boxes. Dirt or dust present in such equipment leads to contamination and, often, serious difficulties.

Many plants would find it profitable to investigate thoroughly their whole lubrication program. Often, too many different brands and types of lubricants are stocked. Surprisingly large savings can often be realized by the standardization of both lubricants and lubricating devices.

Frequently, worth-while savings can be had by providing proper oil-reclaiming equipment. Nearly all oils can be

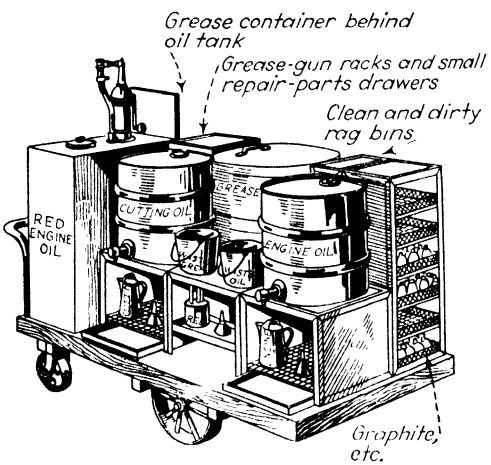


FIG. 332. Portable oil and grease truck.

reclaimed, and usually at a profit. A reduction in direct lubrication costs and in maintenance expense can often be effected through the installation of appliances that economize on lubricant consumption and through substitution of common types of lubricants for high-priced specialties, which are generally not necessary. In most instances, special lubricants furnished through the equipment builders are expensive; in nearly all cases a substitute, equally as good and often better, can be purchased at a much lower price from an oil manufacturer.

Among the potential benefits that may be expected through the establishment of a well-planned and -organized lubrication program are reductions in machine shutdowns, maintenance costs, spoilage of products through contamination with lubricants, oiling-labor costs, power consumption, and lubrication costs.

APPENDIX

TABLE I.—OIL-MEASUREMENT TABLE AT 60°F.

Gravity, °A.P.I.	Sp. gr.	Lb. per gal.	B.t.u. per lb.	B.t.u. per gal.	Lb. per 42-gal. barrel	Weight, lb. per cu. ft.	Cu. ft. per ton, 2240 lb.	Gal. per ton, 2240 lb.
3	1.0520	8.76	18,190	159,340	368.00	65.54	34.17	255.65
4	1.0443	8.69	18,240	158,500	365.31	65.07	34.42	257.54
5	1.0366	8.63	18,290	157,840	362.62	64.59	34.68	259.48
6	1.0291	8.57	18,340	157,170	359.98	64.12	34.93	261.37
7	1.0217	8.50	18,390	156,320	357.37	63.65	35.18	263.26
8	1.0143	8.44	18,440	155,340	354.81	63.19	35.44	265.15
9	1.0071	8.39	18,490	155,130	352.46	62.78	35.68	266.91
10	1.0000	8.33	18,540	154,620	350.15	62.36	35.91	268.67
11	0.9930	8.27	18,590	153,740	347.71	61.93	36.16	270.56
12	0.9861	8.22	18,640	153,220	345.28	61.50	36.42	272.50
13	0.9792	8.16	18,690	152,510	342.88	61.07	36.67	274.39
14	0.9725	8.10	18,740	151,790	340.53	60.65	36.93	276.28
15	0.9659	8.05	18,790	151,260	338.22	60 24	37.18	278.17
16	0.9593	7.99	18,840	150,530	335.91	59.83	37.43	280.06
17	0.9529	7.94	18,890	149,980	333.64	59.42	37.69	281.99
18	0.9465	7.89	18,930	149,360	331.42	59.03	37.94	283.88
19	0.9402	7.83	18,980	148,610	329.23	58.64	38.19	285.77
20	0.9340	7.78	19,020	147,980	327.05	58.25	38.45	287.66
21	0.9279	7.73	19,060	147,330	324.91	57.87	38.70	289.55
22	0.9218	7.68	19,110	146,760	322.81	57.49	38.95	291.44
23	0.9159	7.63	19,150	146,110	320.71	57.12	39.21	293.37
24	0.9100	7.58	19,190	145,460	318.65	56.75	39.46	295.26
25	0.9042	7.53	19,230	144,800	316.59	56.39	39.72	297.15
26	0.8984	7.49	19,270	144,330	314.58	56.03	39.97	299.08
27	0.8927	7.44	19,310	143,670	312.60	55.68	40.22	300.97
28	0 8871	7.39	19,350	142,990	310.63	55.32	40.48	302.86
29	0.8816	7.35	19,380	142,440	308.70	54.98	40.73	304.75
30	0.8762	7.30	19,420	141,770	306.81	54.64	40.98	306.64
31	0.8708	7.26	19,450	141,210	304.92	54.31	41.24	308.53
32	0.8654	7.21	19,490	140,520	303.03	53.97	41.50	310.46
33	0.8602	7.17	19,520	139,960	301.18	53.64	41.75	312.35
34	0.8550	7.12	19,560	139,270	299.37	53.32	42.00	314.24
35	0.8498	7.08	19,590	138,690	297.57	53.00	42.26	316.18
36	0.8448	7.04	19,620	138,120	295.80	52.68	42.51	318.07
37	0.8398	7.00	19,650	137,550	294.04	52.37	42.76	319.96
38	0.8348	6.96	19,680	136,970	292.32	52.06	43.02	321.85
39	0.8299	6.92	19,720	136,460	290.64	51.76	43.26	323.69
40	0.8251	6.87	19,750	135,680	288.91	51.46	43.52	325.63
41	0.8203	7.83	19,780	135,090	287.23	51.16	43.78	327.52
42	0.8156	6.79	19,810	134,510	285.55	50.86	44.04	329.45

(Courtesy of Power).

For each 10°F. above 60°F., add 0.7°A.P.I.

For each 10°F. below 60°F., subtract 0.7°A.P.I.

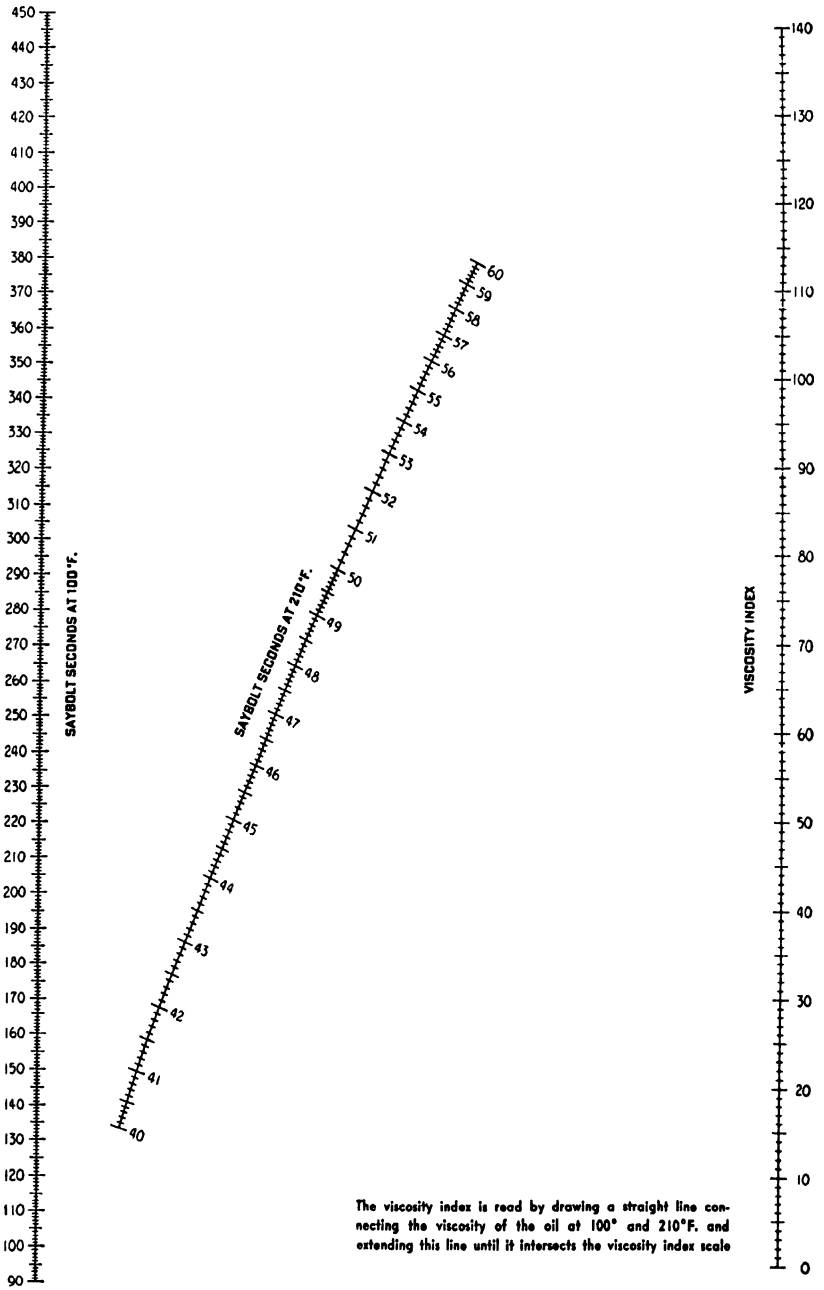


FIG. 1.—Viscosity index of lubricating oils. (*Reproduced by permission of the copyright owner, Penola, Inc.*)

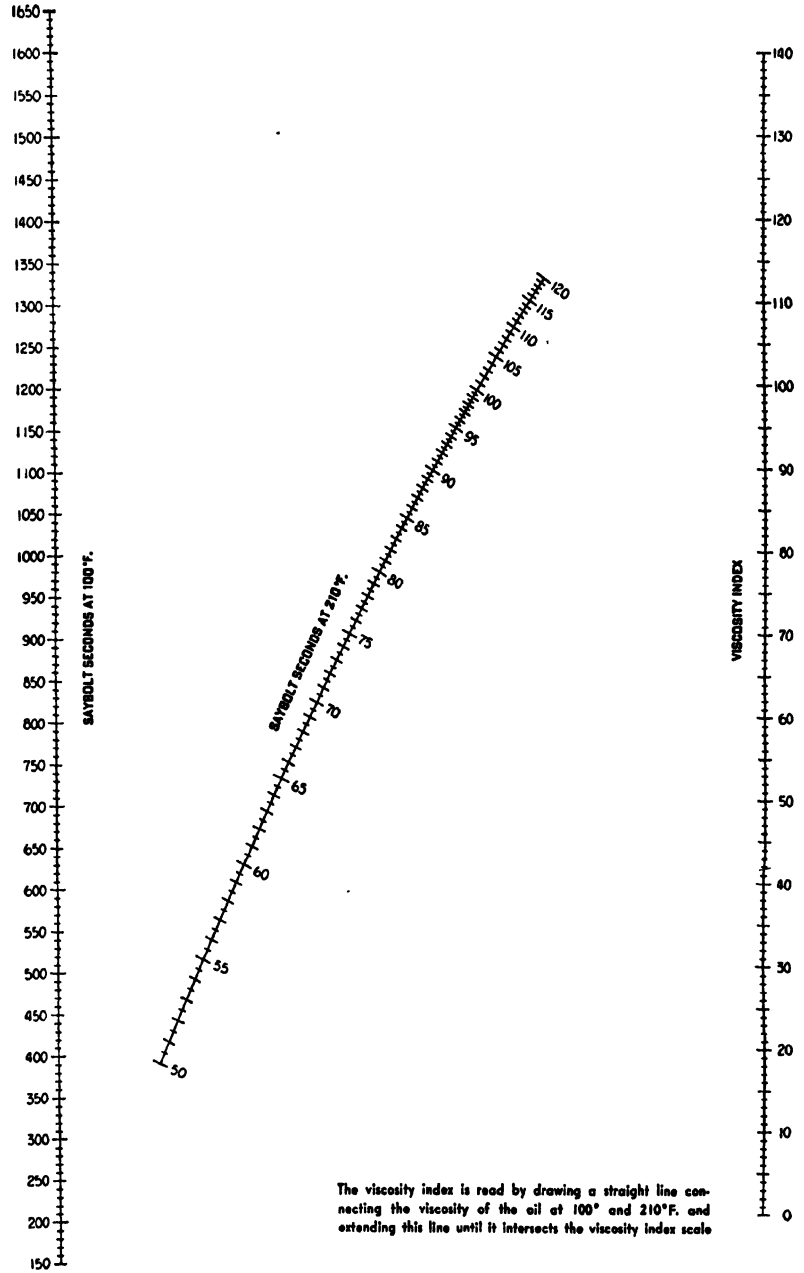


FIG. 2.—Viscosity index of lubricating oils. *(Reproduced by permission of the copyright owner, Penola, Inc.)*

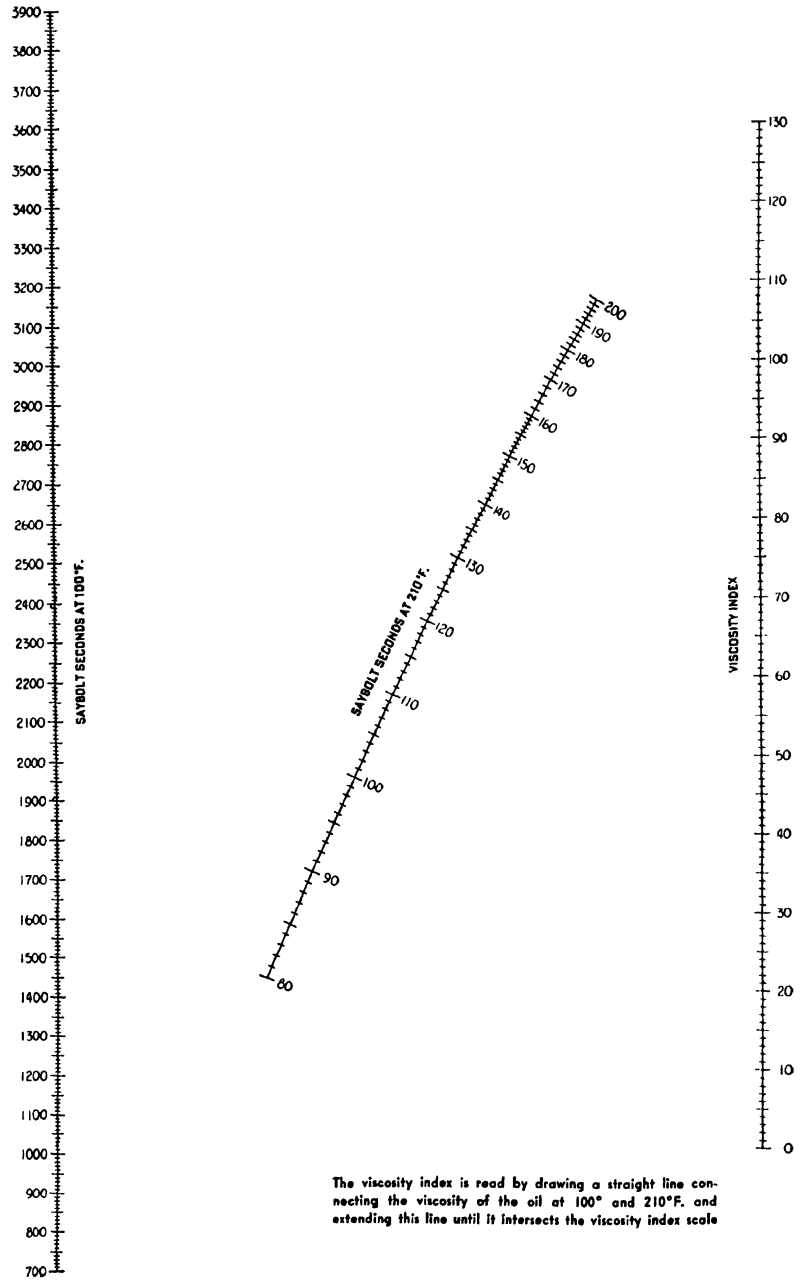


FIG. 3.—Viscosity index of lubricating oils. (*Reproduced by permission of the copyright owner, Penola, Inc.*)

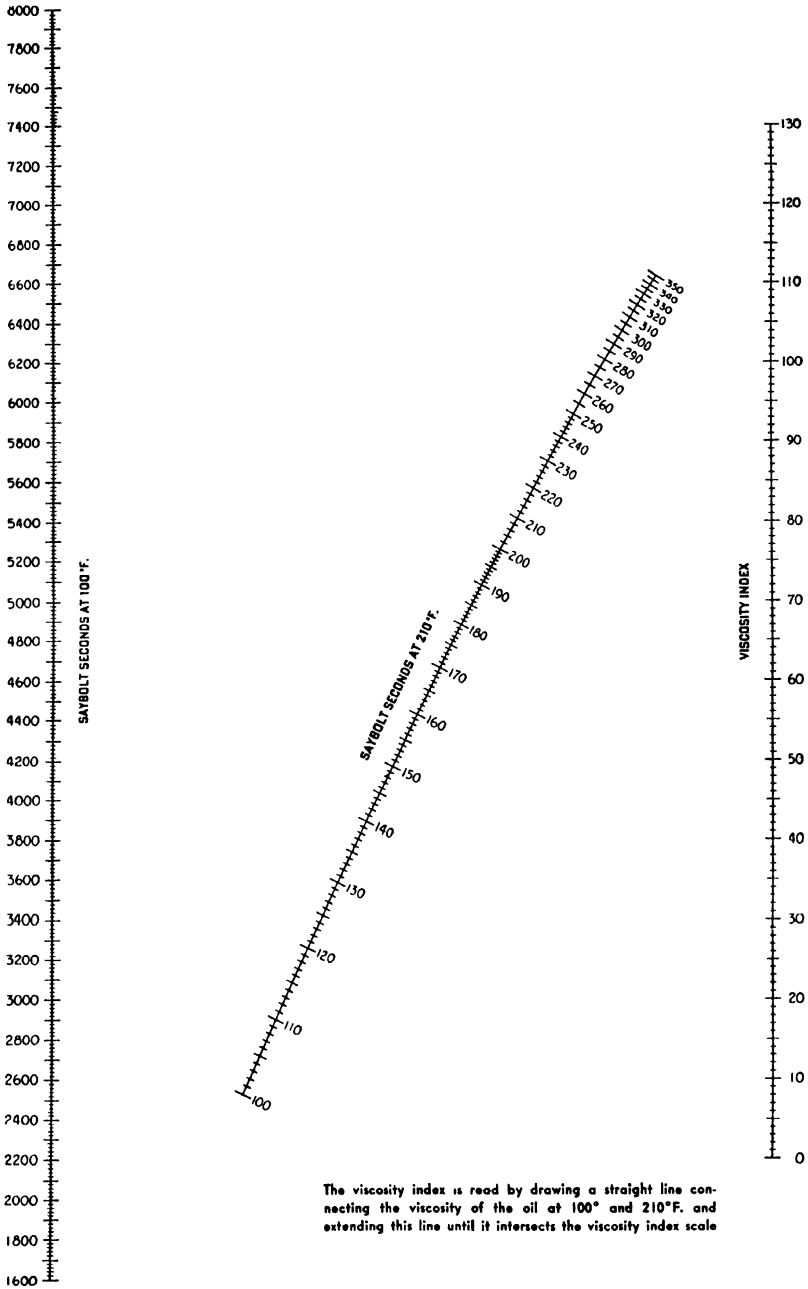


FIG. 4.—Viscosity index of lubricating oils. (*Reproduced by permission of the copyright owner, Penola, Inc.*)

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