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# "The Lubrication of Prime Movers"

by

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In the introduction to his paper the Author reminded his listeners that he gave a paper on "Lubrication" to the Swindon Engineering Society nearly twenty years ago. At that time, the oils available to engineers and the methods of lubrication used, were much the same as they had been during the previous twenty years, and that state of affairs continued until the mid-1930s, but then came two important advances, these being:—

1. The adoption of the Solvent Process method of refining for the manufacture of high grade lubricating oils,

and several years later—

2. The introduction of "Chemical Additives," which are chemical compounds added to mineral lubricating oils to give certain properties which are highly desirable in lubricants for specific purposes. These additives are dealt with later in this paper, particularly in connection with the lubrication of Diesel engines.

Recalling that he described the refining processes in some detail in his 1928 paper, the Author stated that he did not want to repeat all that information. However, it was necessary for him to say something about refining and types of oil, in order that his later remarks dealing with certain lubrication problems should be fully understood.

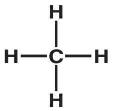
## Refining and Types of Oils.

As most people are aware, crude petroleum is obtained from deep oil wells. This crude oil is pumped to a fractionating tower and heat is applied. The light gasoline (called petrol in this country) boils off first and is condensed and collected; then the kerosene (called paraffin in the United Kingdom) comes off, followed by the gas oil—which is also used as Diesel fuel oil, and after that, the lubricating oil. When all these have boiled off, the heavy residue remaining in the still—always provided that the refiner started with a suitable crude—is the dark, heavy cylinder oil used for the lubrication of the locomotive cylinders. An unsuitable crude will only give a residue of asphalt or heavy, crude fuel oil.

Some knowledge of the chemistry of petroleum is useful for the engineer, for the kind of molecules of which the lubricating oil is composed has a considerable effect on the use of the oil as a lubricant.

Petroleum is composed of compounds of carbon and hydrogen, known as hydrocarbons.

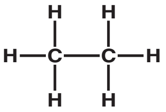
The first hydrocarbon series is the paraffin hydrocarbons with a formula $C_nH_{2n+2}$ the simplest of which is methane, which has a formula $CH_4$, the molecule being drawn like this:—



$$\begin{array}{ccccc} & & H & & \\ & & | & & \\ H & - & C & - & H \\ & & | & & \\ & & H & & \end{array}$$

($CH_4$)

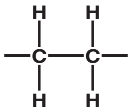
The second hydrocarbon in this series would be $C_2H_6$, and the molecule would be drawn:—



$$\begin{array}{ccccccc} & & H & & H & & \\ & & | & & | & & \\ H & - & C & - & C & - & H \\ & & | & & | & & \\ & & H & & H & & \end{array}$$

($C_2H_6$)

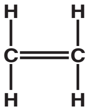
It should be noted that each carbon atom has four arms. If this hydrocarbon is going to be stable and resist oxidation and sludging, it has to have each of these arms attached to another atom. Otherwise, it would have a free arm to grab an atom of oxygen or another element and so cause the lubricating oil to deteriorate. A hydrocarbon compound of the paraffin series—where all the carbon arms are attached—is called a saturated hydrocarbon, and these hydrocarbons are very stable. An example of an unsaturated hydrocarbon—and therefore more unstable—is ethylene, which is the simplest member of the olefine series, and has the general formula $C_nH_{2n}$, the molecule being drawn like this:—



$$\begin{array}{ccccccc} & & H & & H & & \\ & & | & & | & & \\ & - & C & - & C & - & \\ & & | & & | & & \\ & & H & & H & & \end{array}$$

($C_2H_4$)

It will be seen that the carbon atoms have spare arms ready to catch hold of an atom of an impurity; actually the above formula should be written:—



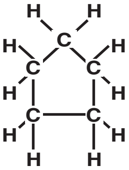
$$H_2C{=}CH_2$$

$(C_2H_4)$

But the double bond between the two carbon atoms is readily broken, so that an arm reaches out for another element.

All the above hydrocarbons are known as chain compounds, and the stable, saturated paraffin series is found in petroleum in what are described as paraffinic crudes. Speaking generally, the best lubricants are manufactured from these crudes. They are almost entirely found in the U.S.A., although it is anticipated that future Middle-East crudes will give a high yield of paraffinic hydrocarbons.

Another important type of crude from which lubricating oils are obtained is known as naphthenic crude, and this is made up of naphthenic hydrocarbons, or cycloparaffins, as they are called. These are saturated hydrocarbons, which are stable, though not quite so much as the paraffin series. The molecular structure of these naphthenes is a ring, an example of which is given below:—



Cyclopentane

It should be noted that each carbon atom has its four arms occupied, and therefore the molecule would be expected to be reasonably stable.

Crudes exist which are a mixture of paraffinic and naphthenic hydrocarbons, and these are known in the oil industry as mixed crudes.

Speaking very generally, any hydrocarbons which do not come in the paraffin or naphthene series are unsaturated and unstable, and are not wanted. A certain quantity of these unsaturated compounds are always present even in the best crudes, and the refiner has always sought for improved methods of removing them from his valuable paraffinic and naphthenic oils. Solvent refining, which was introduced in the mid-1930s, largely solved this problem, and therefore very much improved lubricants have been available during the past ten years.

Solvent refining is the process of adding certain solvents to the lubricating oil fraction, which have an action of scrubbing or combing out the unsaturated hydrocarbons, and so leaving the valuable paraffins and naphthenes purer and considerably improved. The great advantage of solvent refining lies in the improvement that has come about in purifying oils which were once considered inferior. By means of solvent refining many oil bearing crudes which were once thought to be low grade, now form the source of supply for a major portion of the world's requirements of high grade lubricating oils.

Before dealing with actual lubrication problems, it is necessary to define two terms which will be used later, these being (1) Viscosity, and (2) Viscosity Index.

Viscosity—which is the measurement of resistance to flow—is probably the most important property of a lubricating oil. An oil with a low viscosity is thin; an oil with a high viscosity is thick. Viscosity is determined by measuring the time required for a definite quantity of oil to flow through a small orifice at a certain temperature. The instrument used is called a viscometer, the Redwood viscometer being the commercial instrument in this country, while the Americans use the Saybolt viscometer. Both of these instruments report the results in seconds. i.e., the number of seconds required for a definite quantity of oil to flow through the small orifice at the bottom of the viscometer. The tendency now in the oil industry is towards measuring kinematic viscosity in a U tube viscometer, which is quicker and more accurate than the Redwood or Saybolt instruments. By means of conversion tables, the kinematic viscosities can be converted to Redwood or Saybolt seconds.

All lubricating oils get thinner—that is, the viscosity decreases—when the temperature is raised. The more an oil maintains its viscosity when heated, the better it is as a lubricant for most purposes. For example, below are given the viscosities of two lubricating oils which could be used for lubricating an ordinary automobile engine:—

| | *A*<br>made from<br>*Paraffinic Crude* | *B*<br>made from<br>*Naphtaenic Crude* |
|---|---|---|
| Viscosity at 70° F. ... | 1,300 seconds | 2,490 seconds |
| ,, ,, 140° F. ... | 175 ,, | 193 ,, |
| ,, ,, 200° F. ... | 66½ ,, | 62½ ,, |

It will be noted that the viscosities of both oils tend to approach one another at the higher temperatures, and consequently they have approximately the same carrying power when the bearings have warmed up. But when starting up at atmospheric temperature, much more "drag" from the oil will have to be overcome if oil "B" is used than would be experienced when using oil "A." In other words, oil "A" will give much easier starting, and if these two oils were both locomotive lubricants, oil "A" would syphon through trimmings much more readily at lower temperatures.

The relationship between viscosities of an oil at the lower and higher temperatures used to be referred to as "Viscosity Ratio," but in recent years the term "Viscosity Index," or usually the abbreviation "V.I." is used for expressing the relative change in viscosity with temperature. Naphthenic oils thin out more rapidly than paraffinic base oils as the temperature rises; conversely, naphthenic oils thicken more rapidly as the temperature drops. Therefore, the paraffinic base oils are superior for most purposes to the naphthenic base oils. For the purpose of giving various oils a Viscosity Index rating, a Pennsylvanian paraffinic type oil was given the arbitrary value of Viscosity Index of 100, and a Gulf Coast U.S.A. naphthenic base oil was given the value of 0. Any oil can therefore be rated between these two values according to a formula. Due to recent improvements in refining methods, it is now possible to obtain solvent processed paraffinic type oils with Viscosity Index of 110, or even higher. As an item of interest, the Viscosity Index of oil "A" mentioned above is 105, and that of oil "B" is 38.

As a general rule, high Viscosity Index oils are superior for the lubrication of internal combustion engines, circulating oiling systems where heat is a factor, and similar applications. On the other hand, naphthenic oils which have a low Viscosity Index usually give a lower and softer carbon content. The principal disadvantages of the naphthenic low Viscosity Index oils are the rapid thinning effect of elevated temperatures and lower resistance against oxidation and sludging.

## Lubrication of Steam Engines.

The lubrication of the steam engine cylinder is probably the most difficult of all lubrication problems, and unfortunately less progress has been made in recent years with the lubrication of the steam engine than with other prime movers.

To explain steam engine cylinder lubrication under superheat conditions, it is helpful to draw conclusions from the behaviour of lubricating oils in the cylinders of other types of engines.

In the cylinders of any internal combustion engine, over-all temperatures of the burning and expanding gases are much higher than in steam engines. In Diesel engines the maximum temperature of combustion is approximately 3,000° to 3,500° F., which is sufficient to vaporise and destroy the heaviest oils made, while that of the exhaust is approximately 1,500° F. just prior to the opening of the valve or port. Yet there is very little difficulty in lubricating the cylinders of average internal combustion engines with comparatively thin oils. In fact, engines of this type never require lubricants comparable in viscosity to the thick steam cylinder oils.

In the cylinders of most petrol and Diesel engines, the lubricating oil is spread over a water-cooled surface. Hence an oil film of microscopic thickness survives these high temperatures because it is maintained on a comparatively cool surface. Experiments show that the average surface temperature on the cylinder walls of internal combustion engines is about 300° to 350° F. Even if the average temperature is 350° F., it is still comparatively cool because the lubricating oil is being replenished with each stroke of the piston.

Operation of a steam engine is just the opposite of that of an internal combustion engine. Instead of the cylinder walls being cooled, they are insulated against heat losses to reduce condensation, and are sometimes equipped with steam jackets to maintain the highest possible operating temperature on the internal surfaces. Hence, steam cylinder walls are maintained at higher operating temperatures than the walls of internal combustion engine cylinders. For wet-steam operation, the temperatures can be handled with comparative ease with the cylinder oils available, but it is a very difficult problem to lubricate the cylinder under high superheat conditions.

Earlier in this paper in connection with the refining process, it was mentioned that the heavy residue remaining in the still at the end of the distillation was the viscous oil used for the lubrication of the steam engine cylinder. (Incidentally, the highest grade cylinder oils are the residue from the distillation of a paraffinic crude). If this residue is not treated in any way, the oil will be dark in colour. By careful refining and filtering through Fuller's Earth, certain high boiling constituents which tend to cause carbonisation are removed, and the colour of the oil is lightened. These filtered cylinder oils are known in the oil industry as Bright Stocks, and as would be expected, they tend to form less deposits than the Dark Cylinder Oils. However, at temperatures from about 600° F. upwards, the high boiling constituents of the Dark Cylinder Oils are very valuable for lubrication, even if they do cause higher carbon.

Both the Dark Cylinder Oils and the Bright Stocks are very heavy oils; but nature has placed a limit on the temperatures which the heaviest bodied cylinder oils can withstand.

The film between the moving surfaces in the cylinder is extremely difficult to maintain for the following reasons:

(*a*) The backwards and forwards motion of the piston and valves tends to scrape the lubricant from the bearing surface, particularly at the point where the motion is reversed.

(*b*) The high temperature in the cylinder reduces the viscosity of the oil, which becomes thin and liable to be squeezed out.

(*c*) The oil evaporates at the high temperature and the oil vapour is carried away in the exhaust. As distinct from evaporation, small liquid particles may be carried bodily away by the steam into the exhaust.

(*d*) Any moisture of condensation will tend to wash the oil film from the cylinder walls.

(*e*) Chemical changes in the oil caused by its distillation under high temperature. These changes produce "carbonisation," or formation of black sticky deposits consisting of carbon, mineral oxides, and the thicker hydrocarbons which block the passages and blast pipe, and eventually bake hard.

A frequent cause of carbonisation and deposits, particularly in the superheated engine, is excess of oil, and that is perhaps, the major complication of steam cylinder lubrication. It is so easy to lose the oil out of the cylinder in the ways mentioned above; yet if the lubricant is supplied lavishly, the deposits are almost certain to increase. With the steam engine cylinder the aim should always be to get a satisfactory lubricating film on the walls of the cylinder with the minimum quantity of oil, although it is readily admitted that that sounds like a counsel of perfection.

Mention has only been made so far of the mineral lubricating oils obtained from petroleum; but reference must now be made to the fatty oils such as Rape Oil, Lard Oil, and Acidless Tallow, which are of vegetable or animal origin. Under the effect of high temperatures and pressures, fatty oils (which are composed of what are known as fatty esters) will split up into alcohols and free fatty acids. These free fatty acids will corrode metal surfaces and form metallic soaps, with the consequent formation of unwanted deposits, but against this disadvantage must be balanced the fact that the fatty oils possess a higher degree of oiliness than mineral oils. In the paper given to the Society in 1928, the theory of oiliness was explained in some detail; the Author only wishes to repeat that the film of fatty oil on a metal surface is much more resistant to rupture that a similar film of mineral oil, and it will be realised that this property of oiliness becomes very important under conditions which are called boundary lubrication, when the lubricating oil film separating the metal surfaces is very thin, perhaps only one layer of molecules thick.

To increase the oiliness of a mineral cylinder oil, a small percentage of fatty oil—usually about 5 per cent.—is added. Apparently there are no objectionable results from free fatty acids when the cylinder lubricant only contains this small percentage of rape, lard or acidless tallow oil. With wet steam, the fatty oil will tend to form an emulsion with the condensate, and so resists the washing of the film of lubricant from the cylinder walls. These oils, which are blends of mineral oils and fatty oils, are known as compounded oils.

The oil may be fed to the cylinders and valves by means of the Sight-Feed Condensation Lubricator (of which type the G.W.R. lubricator is considered one of the best), or the Mechanical Lubricator driven from the engine mechanism, which pumps a definite feed when the engine is running. The mechanical lubricator appears to be steadily superseding other types, due to its more positive action and independence of the steam supply.

The oil may reach the cylinder by three methods:—

(*a*) Atomised into the steam line and carried by the steam to the valves and cylinders.

(*b*) A direct feed of cylinder oil from the mechanical lubricator to the valves and cylinders.

(*c*) A feed like (*b*), but the oil is mixed with steam just before entering the valve chest and cylinder.

With (*b*), i.e., the direct feed of oil pumped to the cylinder, there is a possibility of getting an excess of oil at one point with the danger of increased carbonisation. If the temperature allows it, the Bright Stock type of cylinder oil with its lesser tendency to carbonise, is more suitable for direct feed. It has been suggested that with direct feed the oil should be applied at several points round the circumference of the cylinder, thus delivering a small quantity of oil at several points rather than supplying at one or two points and allowing the thin hot oil to work round the cylinder.

## Future Prospects.

There appears to be little prospect of any revolutionary developments in steam cylinder oils in the immediate future. In consequence, better lubrication of the steam engine cylinder will largely depend on improvements in the methods of feeding the oil to the cylinder. The possibility of using the low carbon-forming Bright Stocks compounded with a small percentage of fatty oil in conjunction with direct feed, is probably worth investigating, but it must be mentioned that the heavier Bright Stocks are at present in short supply.

A possible source of improvement is the inclusion in the cylinder oil of an additive which was developed for certain other purposes shortly before the war. This is a special hydrocarbon known as a polymer, which, when added to a lubricating oil, gives the oil a "tackiness" without interfering with the lubricating properties of the oil. It has been used very successfully for "non-spattering" oils such as are required in textile mills and for food processing machinery and apart from the "non-spattering" property, the consumption is considerably reduced. In the U.S.A. it is claimed that the inclusion of this additive in the cylinder oil for stationary steam engines has given a stronger, more "clinging" lubricating film on the cylinder walls, and thus allowed the supply of cylinder oil to be cut down, with the lessening of deposits, but whether this polymer additive will retain its molecular structure at the high temperature and under the slogging conditions in the cylinder of the express locomotive, is still a matter for practical experiment. There seems little doubt however that this same additive could be applied successfully to axle and motion lubricating oils, and its inclusion should give a stronger film and cut down consumption. Fortunately, the bearing oil containing this additive will syphon quite satisfactorily through trimmings.

## The Lubrication of the Steam Turbine.

In comparison with the problem of lubricating the steam engine cylinder, the lubricating problems in steam turbines are not complicated, provided that the correct high quality oil is used and maintained in good condition.

As previously stated, the lubrication conditions in the steam engine cylinder are those of thin oil film or boundary lubrication; but the design and layout of turbine bearings enables the turbine to be fitted with a lubricating oil circulating system. A plentiful supply of oil is fed continuously to the bearings, which therefore operate in a condition of fluid lubrication. When running, the turbine rotor is floating in the bearings on a film of oil, the only friction being the "drag" of the oil which should therefore be as thin as practicable.

Full circulating systems for the lubricating oil are universally employed in all but the small turbines. These systems fall into two groups which will now be described.

(1) *The Gravity System*, in which pumps deliver oil to an overhead tank from which it flows by gravity to all parts requiring lubrication. The oil pump takes suction from a drain tank below the turbine or gear case, and passes the oil through a suction filter, and it is then discharged through a discharge filter to an oil cooler. From the oil cooler it passes to the overhead gravity tank, and then flows by gravity to the bearings, gearing, etc. It then drains from the bearings to the drain tank, and again starts on the circuit. Sight glasses are frequently fitted to each bearing to enable the operator to ascertain that each bearing is receiving an adequate supply of oil.

The pressure on the bearings is dependent on the head of oil (2.3 feet is equivalent to 1lb. per square inch). The gravity tank is always kept overflowing to ensure a constant head and therefore constant pressure of oil to the bearings. Low level alarms and warning lights are usually fitted, which come into operation when the oil in the gravity tank falls to a pre-determined level. Bearing pressures are usually 10/15 lbs. per square inch. This system gives a constant, steady flow of oil to the bearings, and in addition, the oil in the tank itself serves as a reserve supply in the event of a pump failure. This usually gives the operator time to stop the turbine before damage is caused through lack of lubricating oil.

(2) *Direct Pressure System.* This is similar to the gravity system except that it does not use the overhead tank, the oil being pumped direct to the bearings. This system is in general use where head room is limited and where a higher bearing pressure is required. The two main drawbacks to this system are (a) discharge pressure is inclined to fluctuate, and (b) there is no reserve supply in the event of pump failure.

Oil leaves turbine bearings in modern sets at 140/150° F.; the temperature of oil entering is 110/120° F. Oil adjacent to a hot rotor has been measured by thermo couples and found to be 250° F., although temperature of the oil outlet was only 140° F.

As implied above, the steam turbine should be one of the easiest pieces of machinery to lubricate. Shaft speeds are high, therefore there is a pumping action of the journal itself which carries the oil into the bearing area. Bearing loads are relatively light, and the volume of oil supplied to each bearing is such as to float the spindle on the oil and so provide fluid film lubrication.

If it were possible to stop and dismantle the turbine and clean its lubrication system at, say, weekly intervals, any well refined light bodied lubricating oil might be used successfully; but a turbine must often operate continuously for months, and even for a year or more, at full speed and load without adjustment or cleaning. Therefore the requirement becomes more complicated than that of just providing a lubricating film in the bearings. The lubricant itself must be of such a character that it maintains the entire lubrication system in a clean and trouble-free condition throughout the length of time the oil is used.

A further complication is the fact that turbine designers have given the oil which lubricates the bearings a large number of additional functions to perform. Many times the volume of oil must reach the bearing than is required for actual lubrication, and the major portion of the oil circulated acts as a cooling medium for the bearings. (One American investigator estimates the heat extracted by the bearing oil in a large turbine as 2,000,000 B.T.U.s per hour. This is, of course, mainly conducted heat from the turbine along the shaft, and not due to any friction in the bearing.) The lubricating oil is also required to be the hydraulic medium in the elaborate governing apparatus and other mechanisms incorporated in the modern turbine; and it must be emphasised that the critical nature and close tolerances of such devices impose the necessity for stability and cleanliness on the part of the lubricant. When the turbine drive is transmitted through gearing, the oil must also provide the lubricant for the gears, which are almost always of the double helical type. The high tooth loading increases the arduous demands already made on the lubricant.

The requirements of a satisfactory turbine oil are therefore:—

(a) It must be a thin oil to minimise fluid friction or “viscous drag,” due to the oil itself.

(b) It must have a high viscosity index so that it does not thin out excessively with rise in temperature. This is particularly important when the turbine oil has also to operate hydraulic mechanisms.

(c) It must separate readily from water and have a high resistance to emulsification.

(d) As the oil has to circulate in the lubrication system almost indefinitely, it must be very stable and have a high resistance to oxidation and the development of acidity, otherwise sludge and deposits will be formed in the circulation system which will foul the governor and have other adverse effects.

(e) The oil must have surface “oil wetting” ability to resist rusting and corrosion on internal parts of the turbine with which it comes into contact.

(f) The oil must be of such a nature that it can be readily cleaned and maintained.

If such an oil is used, the operation of the turbine is comparatively trouble free; if not, trouble is certain.

Now to link up the above points with the improvements which have been made in turbine oils during the past few years.

Up to about ten years ago the high grade turbine oils were manufactured by blending a Paraffinic Neutral Spindle Oil with a Paraffinic Bright Stock. Both oils came from the U.S.A. Pennsylvanian oil fields and were refined by what is known as the conventional process, i.e., the method of refining used before the development of the solvent process of refining. The blended oil was usually filtered through Fuller's Earth to give it a good factor of demulsibility, that is, a quick separation from water.

The development of the modern turbine with higher steam pressures and temperatures called for improved turbine oils; the modern turbine with its complicated system of oil piping, and the present practice of placing much of the oil piping within the turbine and its oil reservoir, makes it very necessary that the lubricant provides trouble free, continuous operation without the necessity for cleaning deposits from the system. The invention of the solvent process method of refining gave the refiner the opportunity of making the necessary improvement in turbine lubricating oils.

Early experiments with solvent process oils were not very successful, but after the early teething troubles had been overcome, the desired results were obtained. Solvent process turbine oils were produced with high viscosity indexes and good demulsibility; but it was found that after a certain time in use these oils developed acidity due to oxidation, which in due course would lead to sludging and deposits. This was overcome by blending certain chemical compounds with the solvent process mineral oil, and these chemical "additives," or "inhibitors," as they are called, retard the oxidation and development of acidity.

The principal factors which have a deteriorating effect on turbine oils are:—

(1) Heat.

(2) Oxygen in the air.

(3) Catalytic effect of impurities and contact with metals.

Due to the presence of oxygen in the air and the catalytic effect of various metals, oxidation of even the highest grade turbine oil will slowly but surely take place. It is impossible to prevent oxidation, but it can be retarded by the use of a highly refined paraffinic oil containing the special chemical additives. Oxidation causes the viscosity of the oil to increase (that is, the oil thickens), the formation of acids and eventually sludge, and other harmful effects which will lead to the breakdown of the oil.

Water is almost always present in turbine oils to a certain extent, due to vapour from turbine glands, condensation, etc. A neutral oil kept free from solids has no water retention properties so that emulsions cannot be formed. With a clean oil, water has no harmful effect on bearings, but it can be very serious with contaminated oils when emulsions are formed. In passing through the close clearances of the governing apparatus, or in the pressure area between the journal and its bearing, the pressures and temperatures in turbine service tend to drive the moisture out of the emulsion. This causes the solid products in the emulsion to precipitate and permits them to adhere to these areas, forming hard deposits, with the possibility of bearing failure.

The most suitable method of judging the rate of breakdown in a turbine oil is the measurement of Neutralisation Number. This is the laboratory test which estimates the milligrams of potassium hydroxide necessary to neutralise one gram of the oil, and this evaluation therefore measures the total acidity in the oil. When oil breaks down as a result of oxidation, it develops organic petroleum acids, complex in structure, generally distinguishable by a slightly pungent odour. An excessive amount of this acidity is almost invariably the forerunner of sludge. The test for acidity should be carried out at monthly intervals, and the acidity will increase steadily. A sudden rise will indicate that sludging can be expected and breakdown may take place at any time.

It must be specially emphasised that apart from the quality of the turbine oil used, the life and satisfactory operation of the oil depends on the maintenance of the oil in good condition by the removal of water and impurities. Practically all modern large installations are fitted with a centrifuge, which is a highly effective method of removing impurities and water from the oil system. The majority of centrifuges operate at too high a flow rate; they are much more effective if the rate of flow is reduced to approximately 50 per cent. of the maximum claimed by the makers. Fortunately, centrifuging does not remove additives.

In tabulating the qualities required in a turbine oil, it was mentioned that the oil had to possess the ability to "wet" the internal parts of the turbine with which it came into contact, and so resist the formation of rust. The modern turbine oil includes an anti-rust additive.

The rusting of non-oil bathed parts of the lubrication system may be a serious problem, and with the realisation that some water will inevitably be encountered in any turbine lubrication system, research has been undertaken in an effort to develop coatings which might be readily applied to the interior parts of the oil reservoir, bearing and governor housings, etc. The coating applied must last a very long time, prevent rusting, while itself remaining unchanged, and not peel or flake off to form particles which would be carried in the oil stream. It must obviously be impervious to both oil and water at elevated temperatures. Such a material has been found which is a hard-drying paint type product having a synthetic carrying vehicle and pigmented with aluminium. After application it dries on, leaving a thin coat of aluminium. This prevents the steel or cast iron from corroding, and thus reduces the oxidation of the oil, as iron oxide is an active catalyst which accelerates oxidation.

Summing up, the ideal turbine lubricating oil will be a light bodied oil produced from a paraffinic crude by solvent refining, containing a chemical additive to resist oxidation, and another additive to resist rusting and corrosion.

## The Lubrication of Diesel Engines.

The Diesel engine is another prime mover with its own special lubrication problems. These problems have received particular attention during the past ten years in view of the development of the Diesel engine during that period. For instance, the Diesel engine is now so well established that it is rapidly superseding the steam locomotive on the U.S.A. railways.

There are many different sizes and designs of Diesel engines, which can roughly be divided into three types.

(1) The high speed Diesel engines of the automotive and rail traction type. These usually have a lubricating oil circulating system very similar to that of the petrol engine.

(2) Medium size, medium speed Diesel engines, usually of the stationary type. These use the same oils for the lubrication of the cylinders and bearings, and employ either a spray or force feed of oil to the cylinders.

(3) Large, slow speed, stationary and marine Diesel engines. The cylinders of these engines are now usually lubricated with a separate oil from that of the bearings, by means of a mechanical lubricator.

Apart from the above classification, there are four stroke and two stroke cycles. The high speed, four cycle engine may be supercharged by blowing pressure air into the cylinder with a pump or turbo blower; the exhaust of the two cycle engine may be just scavenged by air from the crankcase, or air may be blown in under pressure to perform the scavenging much more efficiently. This development of blower scavenging has had the effect of staging a " come back " for the two cycle engine. For instance, in the U.S.A. two of the most efficient Diesel engines used for main line rail traction are both two cycle with blower scavenging. These are the General Motors engine, and the Fairbanks Morse opposed piston engine.

Speaking generally, Diesel engines are more difficult to lubricate than petrol engines. In a Diesel engine, operating temperatures are higher at the end of the air compression stroke owing to greater pressures. These pressures average 450/550 lbs. per square inch, in comparison with 90/ 120 lbs. in spark ignition engines. In general, there is an increase in temperature of about 2° F. for each pound of compression pressure. Thus 500 lbs. per square inch compression in a Diesel engine would generate a temperature of about 1,000° F. if heat losses are left out of consideration.

The peak temperatures of combustion may reach, and even go above, 3,500° F. and the temperature of the expanding and burned gases may average around 1,500° F. just prior to the opening of the exhaust valves.

Owing to the method of charging fuel to the cylinders, the spark ignition type engine is cooled during the suction stroke by vaporisation of the fuel, but this effect is absent in Diesels.

The net result of these differences is that piston temperatures in Diesel engines are higher than in spark ignition engines. In high speed Diesels equipped with aluminium alloy pistons the average maximum temperature at the top of the piston is about 650° F. The temperature of the top compression ring generally ranges from 475°/500° F., and in the four ring type of piston the temperature of the bottom compression ring will be about 350° F. Temperatures in spark ignition engines are about 50°/100° F. lower. Diesels equipped with cast iron pistons operate with higher piston temperatures, the average range being possibly 700/750° F. at the crown of the piston. Cylinder wall surface temperatures in the Diesel engine reflect the higher operating temperatures and average about 350° F.

Since the rate of oxidation of lubricating oil roughly doubles with each 20° F. increase in temperature, one American authority suggests that the Diesel engine may subject the lubricating oil within the cylinder to as much as ten times the oxidising tendency occurring in petrol engines. In petrol engines a full charge of air is fed into the cylinders only when the engine is under maximum load, and as a result, there is normally little excess of oxygen in the gas mixture after combustion. The Diesel engine always operates with excess air; Diesel engines compress a maximum amount of air at all loads, and excess oxygen is always present which probably aids oxidation of the cylinder lubricating oil.

Owing to these operating conditions, crankcase sludge resulting from deterioration of the lubricating oil is generally formed at a comparatively high rate in Diesel engines of the trunk piston type where the pistons enter the crankcase relatively close to the crankcase oil. These deposits are carried in the oil stream and adhere to the hot metal piston surfaces, where they generally tend to form a distinctive, varnish-like type of deposit. Such deposits tend to collect and bake behind and around the rings, and sometimes clog the oil grooves and passages through which the lubricating oil returns to the crankcase.

Another source of deposits in Diesel engines is the formation of soot particles resulting from incomplete combustion. The particles are present around the top of the piston, and because of the high operating pressure during the compression and power strokes, some of these particles are probably forced back of and around the rings. These deposits are in addition to the normal deposits formed by oxidation of the lubricating oil at high temperatures.

Another adverse effect of carbon deposits is their interference with heat transfer. In all types of internal combustion engines a considerable portion of the heat absorbed by the head of the piston is passed through the rings to the oil film, and through the oil film to the cylinder wall and into the cooling water. Any deposits collecting around the rings retard this necessary heat transfer and causes a further rise in piston temperatures. This will probably lead to seized rings, power loss, and blow-by past the rings.

In large engines it is possible to control the operating temperatures of pistons by methods which are not considered practical for small engines on account of the extra equipment required. Piston cooling has a marked effect in retarding the formation of ring deposits. To cool the pistons in large engines, it is common practice to circulate a liquid through them. Water is sometimes used, but it has the disadvantage that it carries oxygen which materially assists in causing corrosion, and if any leaks develop, the lubricating oil becomes contaminated with water. For these reasons, oil is preferred as the circulating cooling medium in many engines, this being either the crankcase oil or a lighter oil which will circulate more rapidly.

Another method which is sometimes installed on smaller engines of the trunk piston type is to direct jets of oil on the inside area of the piston, and for this purpose the crankcase oil is generally used. While the over-all working temperature of the oil is raised, the compromise favours the operation of the engine because piston ring deposits are reduced as a result of the lower operating temperature of the piston head.

The design of piston heads and location of rings is a very important factor in the operation and lubrication of Diesel engines. In fact, a change in the design of the pistons will sometimes alter lubricating results to a marked extent. As a simple example—if the piston heads are designed too thin in an endeavour to cut down weight, there is a point where the amount of metal becomes insufficient to transfer the surplus heat from the centre of the pistons to the rings, and thence to the cylinder walls. This excessive heat produces carbon which results in lubricating difficulties, and breakdown of the oil charge is correspondingly rapid as the charge strikes excessively hot pistons.

The question of deposits has been dealt with at some length, as the formation of these due to the high operating temperatures which must prevail, is the problem of Diesel engine lubrication. A good Diesel engine lubricating oil has to fulfil three conditions:—

(1) It must reduce sliding friction and wear to a minimum, and therefore possess an adequate viscosity (or body) at the working temperature of the cylinder.

(2) It must form a good piston seal, preventing “ blow-by ” past the rings from the combustion chamber, with consequent loss of compression.

(3) It must leave as little, and as soft a deposit as possible.

Perhaps a fourth should be added—that the oil should not corrode modern bearing metals.

Conditions (1) and (2) are reasonably easily satisfied, but—as stated previously—(3), i.e., the question of deposits, is a problem.

Seized rings is the high-speed Diesel engine operator's nightmare, and until the modern lubricating oils were invented shortly before the outbreak of the recent war, it appeared as if this ring problem would hold up the development of this prime mover. Deposits on the piston, accumulating behind and on top of the rings, bake there and cause sluggish action, and finally prevent movement. In two-cycle engines additional trouble is caused by the carbon building up in the scavenge and exhaust ports, resisting the passage of the gases and still further reducing the engine efficiency.

From the remarks made earlier in this paper, it will be realised that there are two types of oils available for lubricating the Diesel engine: (a) the paraffinic type, and (b) the naphthenic type.

*Paraffinic Oils* are superior in the fact that they thin out less than the naphthenic oils as the temperature rises; they also have greater heat resisting properties than the naphthenic type and are less liable to oxidation; they strongly resist sludging and emulsification, but unfortunately, the carbon formed by the paraffinic oil in the ring belt, and in the ports of the two cycle engines, is of a hard, slatey type.

*Naphthenic Oils*, while being neither so stable, nor retaining their body so well under heat, form a much softer type of carbon, and there is less likelihood of ring seizing. Hence naphthenic base oils have been somewhat favoured for Diesel engines on account of the lower initial carbon content and the softer type of carbon formed when decomposition takes place. The consumption of lubricant is, however, higher with naphthenic than with paraffinic type oils.

Two cycle engines designed with crankcase scavenging, generally operate better when supplied with the naphthenic type of oils, because in this design, oil mist from the crankcase is drawn into the cylinders with the scavenging air and burned with the fuel. Under these conditions, the lower carbon content and softer type of carbon produced by naphthenic oils is advantageous in overcoming the disadvantage of partially burning a small but continuous quantity of lubricating oil.

Diesel engines operating on the four-stroke cycle approach the conditions which prevail in petrol engines, and providing the conditions are not severe, naphthenic and paraffinic oils both give reasonably satisfactory service. When the engine cylinders are lubricated by oil splashed from a reservoir in the crankcase, the oil scraper ring located near the bottom of the piston skirt, must be maintained in good working condition when using paraffinic base oils; otherwise the benefits of the higher heat resisting qualities possessed by this type of oil are not only lost, but the excessive supply passing the scraper rings will tend to produce carbon.

The older Diesel engines were not too difficult to lubricate; but the development of the high speed Diesel engine has brought problems in lubrication which could not be solved by the use of ordinary mineral lubricating oils of either paraffinic or naphthenic types. In the mid-1930s, ring seizing became a serious problem on some new types of American engines, and at one time appeared likely to set a limit to further improvement in performance. In 1936 the Caterpillar Tractor Company approached the oil companies with regard to this problem. Considerable research work led to the solution of adding chemical additives to the mineral oil, which have the property of largely preventing the deposition of undesirable products within the engine. Such compounds are usually described as "detergents," and they disperse the carbon and solid contaminants throughout the oil and prevent them from coagulating to any appreciable extent, and therefore prevent deposits from building up on the piston head and in the ring grooves. etc. The mineral oils containing these detergent additives are known as "H.D. Oils." i.e. "Heavy Duty Oils."

From mid-1943 the British and American armies used only H.D. oils for the lubrication of internal combustion engines, and the invasion of Europe and sweep into Germany took place with H.D. oils lubricating every tank and all the mechanised transport. From the experience gained, the British Admiralty since the war terminated, has standardised on H.D. oils for lubricating internal combustion engines.

The introduction of chemical additives into lubricating oils was a revolutionary development which opened up a completely new field for research. In addition to the detergent additives there are now additives which resist oxidation of the lubricating oil, additives which resist bearing corrosion, and additives to improve oiliness and increase film strength, etc. When normal conditions are restored to this country, H.D. oils will be available to the ordinary motor car user, and the use of these oils will allow the engine to run for a longer period without decarbonising.

It should not be inferred that H.D. oils are necessary for all high speed Diesel engines. British Diesel engines at their present stage of development appear to be less prone to ring seizing than American Diesel engines, and satisfactory results can usually be obtained without the use of H.D. oils.

However, it can be stated that H.D. oils generally show superiority over mineral oils in:—

(1) Anti-ring seizing properties.

(2) Anti-wear properties, particularly in respect of lubrication in the ring belt area under high temperature high load.

(3) Freedom from accumulation of sludge in ring grooves and scraper ring slots and consequent tendency towards lower oil consumption.

(4) General piston and crankcase cleanliness.

Additive type oils are not yet a definite cure-all for every type of internal combustion engine trouble. Earth or chemical filters will remove the additive, and so care has to be taken when proposing to use H.D. oils, to ensure that the filters used are suitable. This difficulty of the additive being removed, means that the additive type oils cannot be simply reclaimed, and are therefore often not economical for the larger engines in power plants. As would be expected, the additive oils are more expensive than the straight mineral oils; but it is undoubtedly a comfort to the modern high speed Diesel designer to know that there are H.D. oils to fall back on if necessary.

Finally, a thought about the future. Undoubtedly much of the trouble with deposits and ring seizing in the Diesel engines arises from the type of fuel used in them. The continued increasing popularity of the Diesel engine, such as is shown by the turnover of American Railways to Diesel traction, has produced an enormously increased world demand for Diesel fuel oil. There is no guarantee that the present quality of this oil can be maintained in view of the increasing demand; and it may present very serious problems in the future were it not for the invention of H.D. oils with their ability to scour deposits from pistons and rings.