The modern Diesel engine is required to give reliable service over long periods of varying conditions. Correct lubrication ensures this reliability of operation.

Lubrication is a science in which specialisation of two types is necessary. Co-operation between the engineer and the chemist is necessary. Hit or miss methods of lubrication will not do where Diesels are concerned. The cost of a miss is too serious. The use of the best possible oil means decreased consumption, less wear, increased power output, a cleaner engine, and therefore a saving in maintenance costs. It should be emphasised that there is a wide gulf between "no trouble" in operation and perfect lubrication.

The correct lubrication must possess "oiliness," or the property of molecular adhesion. It must also have a viscosity sufficient to comply with the maximum and minimum conditions of temperature, pressure, and speed. Too high a viscosity means loss in power due to unnecessary fluid friction, while too low a viscosity may mean squeezing out of the oil from between metal surfaces under high pressure, resulting in unnecessary wear. The most suitable viscosity is the lowest which will stand up to the maximum overload conditions.

The viscosity of the oil is an important factor, but it is not always the most vital. The correct lubricant must possess the power to withstand contamination during use. Contact with air, fuel-gas, water, or other foreign substances which it meets whilst doing its duty may produce undesirable deposits if unlimited attention is not given to a careful selection of crudes and a diligent watch kept over refining methods.

The correct oil must suit the type of lubricating system employed. Especially must this be studied where oil-cooled pistons with their particular type of cooling gears are in use.

Oil for Diesel lubrication can be divided into two classes—

(1) Cylinder lubrication.

(2) Crankcase lubrication.

Taking cylinder lubrication first, in order to select a correct cylinder oil the following points must be given consideration—

Type of engine.

Piston clearance.
Piston speed,
Type and number of piston rings.
Compression pressure.
Temperature of the water jacket.
Method of lubrication.

Grade of fuel burnt and the completeness of combustion.

These are only a few of the important points that a lubricating-oil engineer must consider before he can put forward a correct recommendation.

If the piston clearance is too big piston rock will be set up, and the oil suitable for a fine clearance must not be too viscous or excessive fluid friction will result. If friction and wear are to be reduced to a minimum, the piston clearances should just be sufficient to allow a sliding movement of the piston under conditions of maximum load. Piston rings are usually softer than the liner and the outer edges are rounded off, otherwise the ring will function more as a scraper than a sealing ring. "Pegging" is not essential, but it prevents the gaps working into line, and the products of combustion blowing past the rings, so charring the lubricating oil and setting up excessive wear. Piston rings should be numbered and replaced in the same grooves after examination. The rings must be a good fit in their respective grooves, or a high-pressure gas will get between the rings and increase the ring pressure against the cylinder wall.

Liner wear is a most formidable problem, and is not confined to lubrication alone, but correct oil and its method of application are exceedingly important. Oil should be introduced under pressure, preferably timed so that the oil is injected on the piston and its rings. Oil feeds should be independent, as if two or more points are fed from the same source the lubricant will take the line of least resistance, and the supply cannot be sensitively controlled. With trunk type pistons note should be made of the line of the piston thrust, due to the obliquity of the communicating rod, and provision made for the oil to be forced in on the thrust sides. The final hole in the cylinder lining must be small, as it is not possible to get satisfactory timing effect with a large aperture.

The position and number of holes in the cylinder are of considerable importance, and the old conventional position of drilling these, so that the oil enters between the first and second ring when the piston was on its bottom dead centre, is now giving way, where large powers are concerned, to a position...
nearer where the wear is greatest, and smaller quantities of oil are delivered at an increased number of points. Lubricating oil is often blamed for the amount of carbon deposited during use, but to a large extent this is due to the method of application, which should be improved and the carbon formation reduced. Mechanical lubricators are employed to distribute the cylinder oil under pressure, and should be so fed that the amount of oil supplied is in direct proportion to the speed of the engine. In cold weather oil in the lubricator becomes more sluggish, and for a given speed fewer but bigger drops pass the sight glass per minute. As the viscosity of the oil rises so the adhesive power increases, and the globules of the oil which appear on the discharge jet hang for a longer period and accumulate into a large drop.

Many engineers consider they must see a certain number of drops of oil pass per minute, and increase the stroke of the lubricator pump to change this. This is erroneous; every movement of the delivery stroke discharges an equivalent amount of oil where it is needed. It must not be thought that the sight feed is no use; it is indispensable. In the interpretation of the sight feed, the engineer will use his own judgment in regard to the number and size of drops passing per minute. If too few drops it may mean the pump section or delivery valves are leaking, or the plunger needs attention. A careful glance at the sight feed glass will give the engineer the right clue to any change in normal conditions.

With a new engine the cylinder oil lines should have oil well pumped through them to ensure that the pipes are thoroughly clean and clear, and this should be done by hand with the final joint of the cylinder uncoupled. It also ensures that every line is fully charged with lubricant before starting the motor. The problem of cylinder lubrication consists of having satisfactory oil and just sufficient quantity to give a perfect film of oil, and these conditions are best attained by separate feeds of four, or in large engines to even eight, points on the cylinder. Any cylinder oil must spread readily and evenly and not in streaks, and in the case of two-stroke cycle engines the injection point must not be in line with any of the exhaust or other ports, or excessive consumption will result.

It is often asked if a cylinder lubricant will stand the high temperature and pressures encountered in a Diesel engine where the flame has a maximum temperature of about 3000° F., and the pressure may exceed 500 lbs. per square inch. It must be remembered here that the oil film is on the cylinder wall, and the temperature mentioned only refers to the gases, and many
experiments carried out to determine the temperature on the
cylinder wall have given, as a result, that of approximately 30°
higher than the temperature of the cooling water measured at
the point of water contact of the liner opposite the section of
oil film under survey. Thus the heat in the greater part of the
oil film corresponds to a temperature which can never exceed
under normal conditions 250° F., and this figure is a long way
removed from the flash temperature of a good lubricant, which
is usually well over 400° F. Also, the oil film is only exposed
to the high temperature of gases for a fractional part of a
second of time, and in a four-stroke engine, running at 100
revolutions per minute, the lubricated surface is exposed to the
flame for less than .25 of a second, and the time ruling in a
high-speed engine is so short that excellent economies can be
effected if proper attention is paid to the method of application
of the lubricant.

The cylinder oil must have a suitable viscosity. If too heavy
it will not spread, and the friction will be high owing to "oil-
drag," also any impurities in the combustion gas will cling and
may bake to form undesirable deposits. Too thick an oil or too
thick a film (overfeeding) will also interfere with the heat flow
through the liner to the cooling medium. On the other hand,
too low a viscosity will cause a break down of the oil film, and,
under the conditions of high temperatures met, the lubricant
will lose its sealing power. Excessive friction will result.
Where viscosity has been too low the carbonaceous deposits are
always found to contain large percentage of iron and iron
oxide, an indication of excessive friction. Carbonaceous
deposits, if excessive, will cause the piston rings to cement in
their grooves, in which case the gases will inevitably blow past
and again give excessive friction and wear. The cylinder oil
must not evaporate too quickly or consumption and wear will
be high; neither must evaporation be too slow, or the high tem-
perature will soon cause the oil to oxidise. In the case of
horizontal engines the cylinder oil must be light enough to
spread round the piston to the under side. If the oil is too
heavy, it will have the under side of this type of piston quite
dry, or will become so sticky as to cause the piston to seize; and
it is amazing how sticky a deposit can be formed by oil alone.

Bearing Lubrication—Low-speed Engines.—The problem
here with main bearings, crank pins, cross heads, guides, or
gudgeon pins is the sudden rise of pressure tending to break
down the oil film. The chief object is to hold this film intact,
even at the expense of fluid friction. It must also be borne in
mind that journal and crankcase pins are also subject to inertia
pressure and centrifugal force which in some cases are more serious problems than rise in temperature.

The bearing requirements of an engine have to be considered as follow:

- Type of engine,
- Bearing pressure,
- R.P.M.,
- Metals in use,
- The grooving of the bushes,
- Oil pressure,

and the temperature of the surrounding machinery should be considered.

Whilst cylinder lubrication in Diesel and semi-Diesel engines is similar, the oiling of the crankshaft, etc., differs considerably. With the semi-Diesel two-stroke engine as little oil as possible must be retained in the crankcase, otherwise it may subsequently be carried into the combustion cylinder with the scavenge air. The oil is fed directly to each main bearing, and centrifuge or banjo oilers usually supply the oil to the pin, after which any oil that drains to the bottom of the crankcase is drawn off. The oil is then filtered for further use, but the question of filtration needs to be carefully watched owing to contamination of carbonised oil, fuel, etc.

In the full Diesel type the crankcase has no dual purpose to perform, and the oil is fed freely by forced feed pumps and is usually in continuous circulation. This not only provides an efficient lubricating film, but the oil acts as a cooling medium by carrying away heat from the bearings. It is essential that the Diesel with the forced feed system should have an oiltight crankcase to prevent loss of oil either in the form of splash or vapour, and incidentally to prevent the possibilities of dust obtaining entrance to the crankcase.

When working clearances are to be set for any bushes, the oil which will eventually pass through them must be considered. Too great a clearance will do as much, often more, damage than too little. When the clearance is too large the shock taken on the power stroke may easily destroy the film and squeeze the oil from the pressure side of the bush. If large clearances are worked to, a heavy-bodied oil must be used, but if the limits are fine, a lighter-bodied oil can be employed, resulting in less fluid friction and more efficient lubrication surface.
At the point at which oil enters the bearing, the edges of the hole are chamfered. Oil distributing grooves should be cut with their edges well chamfered, otherwise the sharp edges would have a scraping action, and destroy the oil film. Oil grooving must not be overdone, as large grooves often remove bearing surfaces. The channels should only act as distributors, and should not be taken too near the ends of the bearing or the oil will escape from the sides.

Bearing and bottom end bushes are usually lined with white metal. It is the hard grain in the metal which holds the load, and if the load becomes excessive these hard grains will yield owing to the plastic nature of the metal as a whole. This assists the oil to maintain a good film everywhere, but the quality of the white metal must be considered. With too hard a metal the hard grains knit together and develop a brittle skin, and it has been found that tri-metal alloys usually give better service than those composed of two metals only, but the resultant metal must not be too soft or it will run too easily.

In the trunk type engine, with enclosed crank, heat is radiated from the piston and cylinder walls, which results in bearing temperatures being from 90 to 170° F. For normal running temperatures 140° is the maximum if the life of the oil is to be extended and oxidation reduced. In trunk type pistons, and even some cross head type, the crankcase chamber oil becomes contaminated with the carbonised oil from the cylinder walls, and this is pronounced in the majority of engines when crankcase oil is splashed on the lower and practically hot cylinder walls. In such cases it is preferable to use one oil for all parts of the engine and to remove the oil from circulation. At regular intervals clean the crankcase thoroughly and replenish the system. Splash guards are even fitted and runways made for the carbonised oil to escape, and this reduces the contamination to a minimum and gives longer life to the circulating oil.

Careful examination of worn crankshafts indicate that the relatively high bearing pressure during the short time when the piston is under its power period gives far less wear than the less intense but longer sustained pressure due to inertia and centrifugal force. This shows that an oil film can hold a heavy load for a short period, but is more likely to break down under sustained pressure. Very little trouble is experienced in four-cycle main bearings, as the pressure of the journals is frequently reversed, and allows a constant film of oil to be maintained.

With the Doxford engine approximation of perfect lubrication takes place, as, owing to the design of the engine, the crankshaft
constantly floats, and bearings inspected after three years of running have shown the original scraper marks.

With two-cycle, single-acting engines the lubrication is more complex, and there is no reverse pressure possible, but as long as peripheral speed is low the oil film will be stable, and it is desirable to keep the bearing pressures lower in two-cycle engines in order to facilitate the maintenance of a constant film.

The gudgeon pins of two-stroke trunk type pistons is usually the most difficult problem. This can be surmounted in large engines by employing a high-pressure pump to supply oil to this member at approximately 250 lbs. per square inch, which ensures that the oil will get to the loaded side of the pin. As this point is in metallic contact with the hot piston, a high working temperature is reached, and a high pressure forced feed therefore helps to keep the small end cool, ensuring reliable operation.

Oil tends to increase in viscosity after continual circulation. The contact with impurity tends to form acidity and sludge which, if allowed to develop for any length of time, may cause emulsification. The higher the grade of oil used the more free it will be from these tendencies, and as the closed circulation system is now the usual practice, the life of the oil is important.

*General Lubricating Details.*—Inlet and exhaust valve spindles should be sparingly oiled, and special care should be taken with the exhaust valve spindle to ensure not only a sparing quantity but a uniform flow; if too much oil is fed it will only burn and carbonise, and may quite easily cause a seizure of the valve stem; too little is just as bad, as the oil film will crack, due to the heat, and again carbonise. On some types of engines to-day the valve rocker arms are oiled from the circulating system, and hand oiling practically done away with. The method certainly entails a slightly higher initial cost, but the life of the moving parts is considerably extended.

Cam-shafts follow the usual lines of modern practice, many being fed off the main circulating system. Owing to the very low peripheral speed of this component, and the intermittent loads that are carried, the lubrication is not of a complex nature. Where force feed is employed the design of the bearings should allow a good dirt proof save-all draining back to the sump.

The cam-shaft is usually gear or chain driven, and as the lubricant for these drives is necessarily the same as that used for the crank chamber, note of the drive must be made when selecting a suitable crank-case lubricant. For gearing and chain drive an oil of good body should be employed, as it will
need to stand up to the big pressures set up between the teeth, or the link and the chain tooth, as the case may be. Especially is this desirable where quietness of running is important. The oil should be applied freely as no waste will result, the overflow falling back into the crank pit.

Piston cooling by oil is now a common practice, and from a practical standpoint is far more efficient than water for a four-stroke engine. The piston is subjected to very high temperatures, and the desirability of getting away a certain portion of this heat quickly and efficiently is obvious. With the enclosed type of engine the advantages over water cooling are considerable, as it means elimination of hinged pipe joints for the supply and discharge of the oil, and the fact that the leakage will not give rise to contamination of oil in the crank pit must also be borne in mind. Of course many engine builders still utilising water-cooled pistons are placing the cooling gear outside the engine to prevent as far as possible any likelihood of leakage of water into the circulating oil. As the heat transfer per minute through the crown of a two-stroke piston is necessarily higher than that of the four-stroke, water, which has a capacity for heat nearly twice that of oil, is still customary for piston cooling in this type of machinery.

When the engine has been at rest for some time the oil films on the various working parts have more or less completely broken down. They have been squeezed out by the sustained pressure, due to the weight of the parts, and a certain amount of metallic contact takes place. As a result the starting effort of an engine is very considerable, and the static coefficient of friction may quite easily approach that of solid friction. Of course the starting effort will depend upon the condition and nature of the surfaces in contact and the pressure between them.

Just as the surfaces begin to move the kinetic coefficient of friction comes into play, and as the speed increases an oil film is formed. The kinetic and solid frictions decrease until perfect film formation is attained. The high values of the static coefficient easily explain the great effort often required to start an engine from rest; hence we find the introduction of ball and roller bearings, where there is practically no difference between the static and kinetic coefficients.

Oil purifiers are now considered a necessary auxiliary for all Diesel plants of any size, and this economic and practical method has been found to keep the oil more or less free from carbon, fine metallic dust, water, or any other impurities which it must inevitably pick up on its journey through the system. The
whole-time employment of these separators cannot be too strongly emphasised.

Generally speaking, an oil having a fairly low viscosity and specific gravity gives a better result as a circulating oil, as it more readily separates from water, dirt, and other foreign matter. Circulating oil is in more or less continual contact with air, and if the correct lubricant is not chosen it may quickly become oxidised. Therefore one cannot advocate too strongly the need for the selection of high-grade lubricants.

In conclusion, the author stressed the necessity of calling in the lubrication engineer in order to safeguard the operation of such valuable plant as the Diesel engine. With his advice, although it would entail the use of the highest qualities of oils, there would result an incalculable saving from excessive maintenance costs.