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"MINERAL OILS AND LUBRICATION"

BY

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To endeavour to cover a small part of the subject of lubrication in one evening is a matter of considerable difficulty. Various aspects have already been treated in previous lectures before this Society, and therefore an effort will be made to-night to treat the subject from a more commercial aspect, and shew what products are actually produced from the wells, and how and why they are refined into the definite grades on the market to meet the lubricating demands of the modern engineer.

CRUDES.

Crude petroleum, from which lubricating oils are produced, is a highly complex liquid product which is found very abundantly in various parts of the world, and is obtained in commercial quantities from wells by natural pressure or forcing. The greatest volume is obtained from the United States, Mexico, Venezuela and in the neighbourhood of Baku in the Caucasus.

The crudes of different districts have varying characteristics. However, broadly speaking, the crude oils of the world fall into two distinct classes, paraffin base crudes and asphaltic base crudes. As will be shewn later, the type of crude from which the lubricating oil is derived largely governs the choice of a lubricant, and much of the argument to-day with regard to lubrication matters is on the relative merits of the paraffin and asphaltic base oils as lubricants.

Paraffin base crudes are largely composed of what are known as paraffin hydrocarbons, that is, compounds of hydrogen and carbon belonging to the paraffin series CnH_2n+2. These crudes are practically free from asphalt or bituminous matter, but contain paraffin wax. As the sulphur content is very low, the process of refining is comparatively simple, for sulphur is one of the refiners greatest obstacles. The most important supplies of paraffin base crudes come from Pennsylvania and Ohio in the United States, and for many years the term "Pennsylvanian" was synonymous with "quality."

Asphaltic base crudes are so called because they contain a high percentage of asphalt or bituminous matter. Crudes from the newer fields of California, Mexico, Texas and South America belong to this class; they are usually very viscous, dark brown or black in colour, and have a high specific gravity and often contain complex sulphur compounds which are very difficult to extract.

In some localities, crude oil is found with some of the characteristics of each class. These are known as mixed crudes, Mexican mixed crudes being the most important.

The wells which were drilled in the earlier years of the petroleum industry gave largely a yield of paraffin base crudes. The development of the fields yielding asphaltic base lubricants has taken place in recent years.

DISTILLATION OF CRUDES.

Petroleum crude is a mixture of many hydrocarbons, all having different boiling points. The first step in the separation of crude oil into its various products is fractional distillation, which is carried out by heating in a cylindrical still, the vapours escaping through a dome at the top of the still and passing into a condenser. The process may be modified according to the nature of the petroleum and the products required. Some crudes are, however, of such poor quality that they are only suitable for fuel oil.

The value of distillation depends on the fact that the different constituents of the crude oil boil at different temperatures, and the hydrocarbons distil over as their boiling points are reached. The naphtha and gasolines distil over first, then the kerosenes or illuminating oil (commonly known as paraffin), next a high flash point heavy burning oil known as mineral colza, and then the oil which is used for gas making, leaving the heaviest hydrocarbons (unless the distillation is continued to dryness) as a residue or residuum in the still. When the process is carried out with a suitable crude, this residuum contains the valuable lubricating stock, and is further distilled to give the various grades of lubricating oils.

The distillation process varies with the different kinds of crude. With a paraffin base crude, the distillation is continued until the residue in the still is suitable for use as a steam cylinder oil.

In the case of the asphaltic base crude, the distillation is taken down to dryness, or to use the technical phrase, "run to coke." This is due to the residuum in this case being useless for the manufacture of cylinder oil, owing to the high percentage of asphalt. The asphaltic base residuum is, however, sometimes blended with a lighter oil and used as a dark machinery oil for rough purposes, or it may be used as a fuel oil.

Usually the crude is split into only a few fractions which may be further separated into a greater number of fractions by redistillation. For example, crude gasoline (or petrol, as it is called in Britain) is redistilled by steam distillation into light and heavy gasoline, and the residue may be used as first grade turpentine substitute or kerosene stock. Crude kerosene is similarly redistilled into the particular grades of kerosene desired, and if the crude kerosene contains too light fractions, these may be utilised as a second grade turpentine substitute, whereas too heavy fractions are mixed with gas oil distillates.

Lubricating oil distillates are also redistilled by fire and live steam distillation, and separated into heavier and lighter lubricating oils.

CRACKING.

When hydrocarbons are heated suddenly to a temperature above their boiling point, and not given time to distil in the normal manner, they decompose into lighter hydrocarbons, which possess lower boiling points. This process is called cracking, and was developed owing to the ever-increasing need for light hydrocarbons as fuel for internal combustion engines. Therefore, if the manufacturer desires to obtain a large yield of petrol or other light hydrocarbons, he may crack any of the heavier fractions, and during the process the heat will be violently applied. When a maximum yield of lubricating stock is required, heat is more gently applied and steam introduced into the still, so that the oil will vaporise at a much lower temperature and overheating at the bottom of the still is avoided, with less likelihood of cracking. Another method to avoid cracking is the use of a partial vacuum when distilling.

BY-PRODUCTS AND SPECIAL GRADES.

Many refinery products must be purified by chemical treatment. In general, the objectionable bodies to be removed are the unsaturated hydrocarbons (that is hydrocarbon compounds which tend to be unstable), sulphur compounds and other minor impurities.

Colour and odour imparting bodies in cheaper grades are usually removed with sulphuric acid, the amount of acid used depending on the stock to be treated. This operation is carried out in an agitator, which is a steel cylinder with a cone-shaped bottom, the apparatus being lined with lead to resist the action of sulphuric acid. The oil and acid are thoroughly mixed by means of an air blast, and the sulphuric acid forms a sludge with the impurities, which settles out at the bottom of the tank and is withdrawn. The oil is now transferred to a wash agitator and soda solution is added to neutralise the excess of acid, care being taken to avoid any excess of soda, on account of the liability of emulsion. After heating to about 180° F. the mixture is allowed to settle for eight or ten hours and then is washed by means of open steam sprays in the cone to dissolve any further traces of soda. After settling, the sludge is drawn off and air is blown through the warm oil to remove all traces of moisture, this operation clarifying the stock.

Another method of removing impurities and improving the colour of better grades of lubricating oils is by filtration or percolation through fullers earth or animal charcoal. There is much controversy as to the relation between colour and value in lubricating oils. Except as an indication of the possibility of the presence of unsaturated compounds which are liable to break down under heat and release free carbon, colour bears no apparent close relation to the quality of a lubricant.

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

When refined from paraffin base crudes, the lubricating oil fractions will contain wax. The oil is therefore chilled to about 20° F. to 25° F., and in the wax filter press the oil is squeezed out and the wax left in the press. Lubricating oils, that is excluding cylinder oils when made from paraffin base crudes, therefore, have setting points of about 20° F. to. 25° F., unless they are specially treated to remove more of the wax.

The wax, when removed from the press, contains as much as 50% of oil which is removed by sweating, that is, slow prolonged heating. The melting points of the sweated wax range from 100° F. to 150° F., according to the degree of sweating.

The product is generally yellow in colour: it may be melted, filtered, crystallised in moulds and sold as white paraffin wax.

Reference has already been made to the dark cylinder oil as the residue in the still from the distillation of paraffin base crudes. Filtered refined cylinder oils are produced from dark cylinder stock by filtration. The colour becomes green, the heavy gravity tarry matter is removed, the viscosity is reduced 15% to 25%, and the specific gravity is also reduced. The setting point is, however, increased.

Petroleum jelly, or petrolatum, is an amorphous wax produced by slow cooling of dark cylinder stock diluted with gasoline. The petroleum jelly, or vaseline, separates out and is afterwards decolourised by hot filtration.

The petroleum coke, which is the residue from the distillation when cracking takes place with a paraffin base crude, may also be used for electric arc carbons.

Heavy liquid asphaltic residues are used as road spraying materials in place of coal tar. Petroleum pitch, or bitumen, has found a most important use in the making of wearing surfaces for modern roads, and also in the manufacture of rubber substitute.

CHEMICAL AND PHYSICAL TESTS.

Chemical and physical tests, though not necessarily infallible tests as an indication of the lubricating properties of an oil, are very necessary for controlling the quality of supplies. A few words will be said about the tests which are most commercially important, these being an indication of the crude, and which thanks to the good work of standardisation by the Institute of Petroleum Technologists, can be accurately reproduced in all laboratories.

Specific Gravity is a good guide to the source of lubricating oils. Oils from Pennsylvanian crudes have gravities up to .910; those from asphaltic base crudes from .930 up to .960 or even higher. Commercially, the chief use of the specific gravity is for converting weight to gallonage, and has no direct relation to the performance of an oil as a lubricant except in special circumstances, such as for use with syphon trimmings.

Flash Point is the temperature at which the oil gives off an inflammable gas under certain definite test conditions. This may be either the open flash, which is carried out by heating the oil in an open crucible and applying the flame at regular intervals; or the closed flash, in which the oil is heated in a closed standard vessel which is opened at regular intervals for the application of the small flame. The standard apparatus of the oil industry is the Pensky-Martin. For consistent results the heating must be carried out at a uniform rate. The open flash is used much more largely in the United States of America than in Europe, and is about 20° F. above the closed flash. As a general rule lubricating oils of equal body made from the paraffin base crudes have much higher flash points than those manufactured from the asphaltic base crudes.

VISCOSITY is perhaps the most important property of lubricating oils for it largely determines the choice of a lubricant. The viscosity of an oil is a measure of its resistance to flow or its internal friction. To put it in everyday language, a viscous or high viscosity oil is thick and flows with difficulty, a low viscosity oil is thin and flows readily. For commercial purposes the viscosity is usually determined by measuring the time taken in seconds for a certain volume of oil to flow through a standard orifice under known conditions of temperature and pressure.

Three viscometers are in popular use—the Saybolt in America, the Engler on the Continent, and the Redwood (which is by far the best instrument) in this country.

Lubricating oils are usually classed according to their viscosity at 140° F.; that is the time for 50ccs. of the oil to flow through the Redwood viscometer at that temperature. Determinations are also made at 70° F. and in some cases at 60° F. to determine the thickness of the oil at ordinary temperatures. The viscosity of oils for steam cylinder lubrication is taken at much higher temperatures, usually 140° F. and 200° F. or 250° F.

It is generally considered that the oil with the lower viscosity at the lower temperature for the same viscosity at the upper temperature, that is, with the lowest viscosity ratio or the flatter temperature viscosity curve, is the better oil for most purposes. Oils from paraffin base crudes have lower viscosity ratios (that is they do not lose body on heating) than the oils from asphaltic base crudes, as the following figures shew:—

	Paraffin base.	Asphaltic base.
Specific gravity at 60° F.	.905	.930
Appearance, colour	Red	Red
Closed flash point	425° F.	365° F.
Open flash point	440° F.	375° F.
Viscosity at 60° F.	2000″	3000″
Viscosity at 70° F.	1230″	1800″
Viscosity at 140° F.	140″	146″
Cold test, fluidity	30° F.	0° F.

So far it has been shewn that the paraffin type oil has generally a lower gravity, a higher flash point and a lower viscosity ratio than the asphaltic base oil; there is, however, one very important test where the asphaltic base oil is the better oil, the cold test being much lower for this type of oil than for the Pennsylvanian type, owing to the presence of paraffin wax in the latter.

When lubricating oils are cooled they do not congeal suddenly, as does, for instance, water when it turns into ice, but being mixtures of products of different natures they gradually become more and more viscous until they finally set solid. The temperature at which they congeal is called the setting point. The lowest temperature at which the oil will flow is usually taken as being 5° F. above the setting point, and is called the pour point or cold test.

The setting point of an oil must be low enough so that the oil will flow readily under working conditions and so that a sufficient amount will reach the bearings or parts to be lubricated. Many mishaps have been caused by the oil solidifying in the lubricators or refusing to run through exposed oil pipes to the bearings. While, therefore, in tropical or warm climates the setting point of lubricating oils is comparatively of little importance, this feature is certainly important in temperate climates, such as the British Isles, and particularly so in colder climates like Canada, Northern Scandinavia, Northern Russia, etc.

These are the chief tests in commercial use. There are several others of importance, and reference will be made to some of them when dealing with oils for definite purposes.

USES AND APPLICATIONS OF THE GRADES.

Before dealing with the uses and applications of the various grades of lubricating oils on the market, it may be advisable to say a few words with regard to friction and the fundamental laws of lubrication.

Much light has been shed on the theory of lubrication films in recent years by the work of Sir William Bragg, and among others, the American chemists, G. N. Lewis, Irving Langmuir and W. D. Harkins.

Before the recent investigations, although the results obtained by Beauchamp Tower on behalf of the Institute of Mechanical Engineers had proved that the friction of well lubricated bearings was entirely due to the viscosity of the oil, it was well known to engineers that when the supply of oil was insufficient, or the conditions of load and speed were unfavourable to the formation of the liquid oil film, that is, when the solid surfaces tended to come into close contact with one another, lubrication depended on some property other than viscosity and the flow of oil forcing the surfaces apart. Due to the absence of any better term, this property of maintaining a lubricating film under very difficult conditions was called oiliness. The existence of this property has been continually confirmed, for on many occasions two oils of similar physical tests have been known to give quite different results in a bearing where the supply of lubrication was restricted. The general experience of engineers has been confirmed by F. W. Lanchester, of worm gear fame, who states as his experience when in charge of the testing of gas engines, that if a new bearing ran hot when on test with a mineral oil lubricant, the trouble was always removed by the substitution of castor oil for the mineral lubricant.

For a considerable period friction was almost entirely attributed to the interlocking of minute corrugations on the faces of the surfaces in contact. To-day, there is the molecular adhesion theory, which appears to be a solution to many of the problems of the theory of friction and lubrication.

In a paper on "The Relation between Viscosity and the Chemical Constitution of Lubricating Oils" read before the Institute of Petroleum Technologists, Dunstan and Thole remark, "In recent years the progress of organic chemistry has largely been due to the realisation that unsaturation, or the possession of residual affinity, plays an all-important part in the reactivity and the personality of a compound. Colour, odour, taste, and, in a word, all the characteristic properties of bodies are influenced by this condition. It appears now that we may add lubricating ability to the already long list of effects proceeding from this one prime cause."

From investigations with regard to surface tension it is assumed that the molecules in the surface layers of liquids are chemically unsaturated, that is, in non-chemical language, they have a free force with a tendency to exert attraction on other molecules approaching the surface. This hypothesis has been carried further and applied to solid surfaces.

There are two types of lubrication, namely, boundary and fluid lubrication.

When clean surfaces are placed together, the molecules on both surfaces attract each other with a very large force which tends to weld them into a continuous solid. Since the molecules in both surface layers attract each other and a state of equilibrium is soon reached, any force tending to cause slipping will have to move the molecules out of this state of equilibrium, and also to rotate them. The friction would be composed of the resistance of the molecules to motion in a straight line and to rotation. The tendency of a force to create relative motion between clean surfaces is to produce a re-arrangement of the molecules in the surface layers such that the force of attraction is increased, so that seizure takes place.

When a lubricant is placed on one of the surfaces it saturates the attractive forces of the molecules in the surface layer of the solid, and the molecules of the lubricant take up a position so that the most active part of the molecule is in combination with the active part of the molecule of the solid, and the more neutral part of the lubricant molecule is now furthest from the solid face, so that when another surface is placed on it, the capacity for cohesion is considerably lessened, and so solid surfaces do not weld if they are contaminated in any way. The friction now depends on the internal friction between the layers of the contaminant.

When the film is thin, perhaps only one layer of molecules thick, the solid surfaces tend to come into close contact and rub against one another. This may be termed solid film or boundary lubrication. When solid surfaces become completely separated by a film of liquid oil, which forces itself between them, the condition may be termed fluid film or viscous lubrication. With boundary lubrication the friction depends on the chemical nature of the lubricant and of the solid surfaces, a good lubricant being one with molecules which are strongly attracted by the molecules of the solid, and so maintaining the film. This property of a lubricant of attaching itself to a solid surface and resisting rupture is the mysterious property known as oiliness, and varies considerably even between oils of similar physical and chemical tests.

With fluid film lubrication, that is, when the surfaces are entirely separated by an oil film, the friction entirely depends on the viscosity or internal friction between the molecules of the film, the oil film remaining between surfaces which have been pressed together without tangential motion for some time, is a superficially absorbed surface film.

When the shaft of a bearing is at rest, a comparatively heavy pressure is exerted, tending to rupture the film of lubricant and give metal to metal contact. As a result the starting effort, when the surfaces are brought into motion, is much greater than the running effort. When the speed of the rubbing surfaces is very low, the kinetic coefficient of friction may be even higher than the static value, as there is added to the solid friction the resistance caused by the presence of a lubricant, it being understood that the speed of rubbing is too slow to allow the lubricant to produce any appreciable separation of the rubbing surfaces. As the speed increases the lubricant begins to produce a film, the solid friction quickly decreases and the kinetic coefficient of friction is likewise reduced, until perfect film formation is brought about. As the speed of the journal increases, oil enters the low pressure area of the bearing and is dragged into the high pressure area, so that under ideal conditions, the shaft is now completely separated by the film of the lubricant; solid friction disappears and the resistance to motion is that of the internal friction of the lubricant layers situated midway between the two surfaces, and is proportional to the viscosity of the oil.

The problem the engineer has to face is to find an oil which will form and maintain a film under the specific conditions of speed, pressure and method of lubrication and keep friction at a minimum. With high speeds and light pressures, or with a force feed and a plentiful supply of oil, it is a comparatively easy task to completely separate the surfaces of the bearing and abolish solid friction. The problem under these conditions is to find the lowest viscosity oil that will stand up to the work, so that the minimum of power is lost in overcoming the internal friction of the lubricant itself. In practice the correct viscosity for the lubricant is entirely a matter of experience and experiment.

In order to cope with the numerous demands of the modern engineer, it is necessary for suppliers to select a wide range of grades, so that the most common requirements may be satisfied. One well known oil company, for example, carries a stock of more than 60 grades of varying viscosities. Lubricating oils of commerce (exclusive of cylinder oils) are classified according to their viscosity at 140° F., which is the average bearing temperature. These oils range from very light pale-coloured spindle oils with viscosities of from 40 seconds Redwood upwards, red oils with viscosities at 140° F. up to 260 seconds and dark machinery oils with viscosities at 140° F. up to 330 seconds. Red oils represent the larger portion of the medium and heavy viscosity oils of commerce, and are used for the general lubrication of engines, shafting and machinery of all kinds. Very heavy red oils for various purposes can be obtained by blending with a little filtered cylinder oil to hit up the viscosity, especially in the production of the heavier motor oils. Red oils from asphaltic base crudes are usually used to blend with filtered cylinder oils to produce oils for internal combustion engines, as it is an accepted fact that oils from an asphaltic base produce less carbon deposit and that it is of a very soft crumbly nature, whereas the red oils from paraffin base crudes produce a great deal of hard and brittle carbon. It has, been mentioned previously that oils from the asphaltic base crudes have very low cold tests or congealing points. This again makes them very suitable for use in the petrol engine owing to the ease of starting in the cold weather, for the asphaltic base oil will still flow freely at a temperature some twenty degrees below that at which the usual paraffin base oil has congealed.

Red oils, unless specially treated, should not be used for circulation service, because of their tendency to emulsification and the formation of objectionable deposits, owing to their containing a certain proportion of unsaturated compounds which are liable to oxidation. For example, in steam turbines, in addition to causing trouble through deposits in the oil circulating system, the bearing oil with a tendency to emulsification may come into contact to some degree with the steam, which, after passing through the condenser plant, is utilised again for steam raising.

There is a standard test for emulsification by passing steam through oil under definite conditions, and then timing the separation of the emulsion.

Pale oils, which vary from a light straw to amber in colour are prepared by acid treatment and filtration. They are of light to medium viscosity and are used for lubricating quick running machinery such as high speed shafting, electric motors, dynamos and textile machinery. They make good lubricants for the smaller internal combustion engines, either alone or mixed with a little filtered cylinder oil, and produce less carbon than the red oils. Pale oils have little tendency to emulsification.

A separate class of pale oils are the neutral bloomless oils. These are not acid treated, but are highly filtered through Fullers Earth. They are very suitable for circulating oils for enclosed type steam engines and steam turbines, as they separate readily from water and have little tendency to oxidise and darken. For the latter reason, these are the best oils for self-oiling bearings, and all purposes when the same oil is used over and over again.

Dark lubricating oils are the undistilled residues in the still after the distillation process, which are either too thin or too high in asphalt for use as steam cylinder oils. They are usually mixed with low viscosity lubricating oils to produce the required viscosity. Dark machinery oils, as they are known, are the cheapest lubricating grades on the market and are used for rough machinery in collieries and steel works and for making the black lubricating grease for rough service. The better class dark oils are used very successfully for the lubrication of the axles of railway carriages and wagons using underfeed pad or waste lubrication and, blended with a small percentage of fatty oil, for locomotive axles and motion.

This is the first mention to be made of the use of fatty oils for lubricating purposes. In the early days of engineering, before the development of the American oilfields, animal and vegetable oils were generally used as lubricants. Mineral lubricating oils were received with considerable distrust when first placed on the market, but began to gain favour when the results of the work of Beauchamp Tower became more generally known, and the engineering world accepted that the friction in well lubricated bearings almost entirely depended on the viscosity of the oil. Here is the great advantage of the mineral oil, for by suitable refining and blending, mineral oils of a very wide range of viscosities can be prepared. As an example of this, and as previously mentioned, a well-known oil company, without resorting to blending, carries a stock of over 60 grades of varying viscosities.

The modern practice is to use a mineral oil whenever possible, which practice has been forced upon users by the facts

1. That the supply of fatty lubricants is not nearly adequate to meet present day demands.

2. That the chemical properties of mineral oils are more suitable than the fatty oils to meet the conditions required by modern engines and machinery.

3. That the mineral oils are considerably cheaper. This is not only in the initial cost but in the life of the lubricant. Not only is the tendency of the lubricant to thicken and gum by oxidation very much less when mineral oils are used, but the mineral oils used in ordinary bearings do not, to any great extent, deteriorate by continued use, and if occasionally filtered to remove impurities, their life appears to have no limit. The risk of fire from spontaneous ignition of oily waste and pads is also eliminated when mineral oils are used as lubricants.

The older fatty lubricants, have not, however, been by any means entirely displaced. They are still needed to augment the property of oiliness in which the mineral oils as a class are deficient. As mentioned earlier, when the supply of lubricant is restricted or the bearing is so designed that fluid lubrication cannot be obtained, then the formation of the lubricating films depends on the chemical nature of the lubricant. It is under these conditions that the use of fatty oils, or a percentage of fatty oil compounded with the mineral oil, is found to give the best results, for the molecules of the fatty oil appear to have a much stronger power of attraction for the surface molecules of the solid than is apparent with the mineral oils, and so the film has much less tendency to rupture.

Fatty oils are generally used in admixture with mineral oils, the small percentage of fatty oil being sufficient to give the requisite oiliness or power of adhesion to the mixture. For some special purposes fatty oils are still used unmixed, as for example, castor oil, which is used for aircraft rotary engines and racing automobile engines.

Before considering any special cases, the following broad principles may be stated with regard to the use of the straight mineral or compounded oil.

For bearings running continuously at high speeds, seldom stopping and restarting and provided with an ample supply of oil by pumping, ring or bath lubrication, pure mineral oils are the most suitable and, as in this case, all the friction is fluid friction, the viscosity of the mineral oil used should be no greater than is required to carry the load. For bearings running intermittently, stopping and starting at intervals, pure mineral oils are generally suitable for light loads and for high speeds, and compounded oils for heavy loads and for low speeds; the general principle being to use a compounded oil where the amount of solid friction is so great as to make it necessary to increase the oiliness of the mineral oil.

Any pressure below 70lbs. per square inch may be regarded as a light load, and any journal surface speed below 100 feet per minute may be termed a low speed.

Opinions appear to vary considerably with regard to compounding, especially in connection with steam cylinder oils. The problem of the lubrication of steam cylinders is extremely difficult, for although it is possible so to lubricate the cylinders and valves of the steam engine that there shall not be any excessive wear, it is impossible to obtain anything like the results, so far as friction is concerned, given by a well lubricated journal. The pistons and valves move to and fro in straight lines and do not tend to place themselves automatically in such positions as to trap the oil properly and keep the surfaces from touching. Neither can the large extent of surface exposed be kept flooded with the oil, the passage of live steam through the valve chest and cylinders not admitting the presence of large quantities of lubricant. The engineer must therefore be content with the presence of a lubricating film of no great thickness and either make the loads on the bearing surface small or cause them to move somewhat slowly.

When the steam is wet it has a tendency to wash away the oil film on the internal surfaces. In compound or triple expansion engines, even if the steam is dry on entering the high pressure cylinder, the fall in pressure and expansion taking place produces condensation, so that the steam arriving at the low pressure cylinder is very wet. In order to lubricate cylinders satisfactorily under wet steam conditions, the cylinder oil must readily combine with the moisture and cling to the cylinder walls. It should therefore be a compounded oil, as the fatty oil tends to emulsify with the moisture present and so resist the washing action on the bearing surface of the cylinder.

The above theory certainly appears correct, but the fact remains that two of the British Railway Groups use a straight mineral oil for the lubrication of the cylinders of all the engines using saturated steam with complete satisfaction.

Judging from the many specifications against which an oil company has to quote, there appears to be again a difference of opinion as to the composition of the cylinder oils for the lubrication of the cylinders of superheated steam engines, some engineers compounding with rape, lard or tallow oil, others using a straight mineral oil. The evidence will be examined for and against the compounded oil.

All fatty oils are composed of fatty esters, formed by the union of alcohol radicles with fatty acid radicles and all fatty esters by hydrolysis (that is, by the action of water under certain conditions) are split up into alcohols and free fatty acids. The change can be effected in several ways: by heating with water under pressure, by superheated steam and by heating with sulphuric acid. In the case of olein, which is the chief constituent of lard, tallow, neatsfoot and olive oils, the complete change is represented by the following equation, namely:—

$$C_3H_5(C_{17}H_{33}COO)_3 + 3H.OH = C_3H_5(OH)_3 + 3C_{17}H_{33}COOH.$$

that is

$$\text{OLEIN} + \text{WATER} = \text{GLYCEROL} + \text{OLEIC ACID}.$$

This change takes place in steam cylinders when fatty oils are used as lubricants, with the result that the fatty acids set free corrode the metal and form metallic soaps which tend to choke the steam passages.

In the days before the present mineral cylinder oils were on the market and tallow was used almost exclusively as a cylinder lubricant, the use of the fatty oils resulted in the cylinder metal being rendered quite spongy or porous in the course of a few years. According to Archbutt, bolts, valve spindles, studs and other parts have been cut quite through and cylinder joints, etc., rendered leaky. The steam passages also became choked with metallic soaps, oxides of iron and free carbon resulting from the chemical action of the free fatty acids upon the cylinder metal and the destructive decomposition effected by the heat and high pressure steam. In locomotives the oil thrown against the hot blast pipes, and even that adhering to the ports, undergoes destructive distillation, with the formation of a carbonaceous deposit, which accumulates and gradually blocks up the passages.

Fatty oils, however, when mixed with mineral oils in quantities not exceeding 5% to 20% do not seem to produce these objectionable results so readily and the free fatty acids seem to assist in the lubrication of parts which have to carry heavy loads. H. M. Wells and J. E. Southcombe have shewn that a small percentage of fatty acids dissolved in mineral oil, which they term their "Germ Process," has a marked effect in increasing the lubricating power of an oil and this has been confirmed by many independent experimenters. The addition of the small percentage of fatty acids appears equivalent to the addition of a much higher percentage of fatty oil.

Some users of the compounded cylinder oils, though admitting a larger amount of deposit, claim that the deposits are much softer and easier to remove when the compounded oil has been used for superheat conditions.

In certain circumstances it is essential for mineral oils only to be used. When surface condensers are used, as in marine engines, and the condensed water is again passed into the boilers, great care must be exercised to prevent the passage into the boilers of the oil used for the lubrication of the cylinders. Fatty lubricants should not be used in such cases, even in small quantities, as they tend to emulsify with the water and cannot be separated by ordinary means. The acids liberated by the action of heat and water vapour passing into the boiler will cause serious corrosion and other troubles. Even with mineral oils care should be taken that deposits do not form in the boiler, as local heating will be set up and may have serious results, such as the failure of tubes by collapsing.

So disastrous at various times have been the effects produced by the action of the lubricant on marine boilers when surface condensers have been used, that it has been common practice for the saturated cylinders of marine engines to run without any direct lubrication, the marine engineers confining themselves to swabbing the piston rods and valve rods only with a liberal supply of cylinder oil when acute trouble made it necessary to apply this remedy. There is, however, no need for this drastic step, with the attendant frictional losses, providing that a high grade straight mineral oil is chosen, with little tendency to emulsification, and is used in conjunction with an efficient oil separator. The filtered cylinder oils separate much more readily from water than the dark cylinder oils, but are, of course, higher in price.

While the marine engine cylinder should always be lubricated with a straight mineral oil, it is essential that a compounded oil with a definite tendency to emulsify should be used for the bearings.

There is always a greater or less amount of condensed steam finding its way down the piston and valve rods and dropping all over the external moving parts, and in the case of a hot bearing, the cold water hose is frequently applied. Sometimes a small trickle of water is allowed to run into or on to those bearings which are inclined to run rather warm. When oils, pure mineral in character, are used, the water will displace the mineral oil and the bearing will heat and may seize.

Marine engine oils should, therefore, be compounded with a suitable percentage of good quality fixed oil, so that they will emulsify freely with water and form a rich creamy lather.

The bearings of large marine steam engines require oils of great oiliness to give the necessary margin of safety under the severe operating conditions. Pure mineral oils of the required oiliness do exist, but they are so viscous that they will not syphon properly and they feed irregularly owing to poor cold tests. The admixture of fixed oils having great oiliness is, therefore, dictated not only by the presence of water, but also by the necessity of keeping the cold test and the viscosity of the finished oil reasonably low.

An interesting case of the use of compounded oils is in the textile industry, where, of necessity, oils are needed that will leave the minimum of stain. Perfectly stainless oils are non-existent, for any oil will in time produce a visible stain. There are, however, oils whose stains will disappear during the scouring or washing process.

Mineral oils, even the neutral bloomless oils, which are almost water white, give, after considerable time, permanent stains to the fabric. The longer the interval before scouring, the deeper the colour will become, due to oxidation. If only a short time has elapsed these stains may be removed by dabbing with a fatty oil, such as olive oil, which blends with the mineral oil, and can be removed by scouring with soda lye. Therefore, in the manufacture of high grade fabrics, where there is any danger of oil splashes, a compounded oil is used, about 15% of good quality non-drying fatty oil, such as olive oil, neatsfoot, lard oil or pale.

Fatty oils are considerably dearer than mineral oils and, as an oil sufficiently stainless for most purposes.

THE CHOICE OF A LUBRICANT AND THE MAKING OF SPECIFICATIONS.

It has been said that the successful engineer is the man who can make the best compromise. Perhaps in no branch of engineering is this statement more true than when dealing with lubrication. It is comparatively easy to get satisfactory lubrication by neglecting cost, but thought and judgment are required to keep the cost of lubricants at an economical figure and still obtain efficient results. It would be, of course, folly to economise on lubricants and get high power losses and exceptional wear of the machinery.

It is possible, however, by correlating the need with the supplies available, and by efficient design of bearings, to considerably reduce the cost of lubricants.

Fatty oils are considerably dearer than mineral oils, and, as previously stated, this was the chief reason that led to the adoption of mineral oils for lubricating purposes.

In a well designed bearing, where it is possible to have a plentiful supply of lubricant and approximate to fluid friction, it is almost always possible to use the straight mineral oil with success, not only securing a cheaper lubricant, but avoiding the oxidation troubles, such as gumming, associated with the fatty oil. It is always possible, and in fact preferable, to use the mineral oil in force feed lubrication.

Sometimes when the mineral oil is used, as for instance with syphon trimmings, there is not the same margin of safety should anything go wrong, as when a certain amount of fatty oil is mixed with the mineral oil. Should the supply of lubricant cease for any reason, the bearing lubricated with mineral oil would soon run hot and seize, whereas when using the fatty oil, owing to the greater resistance to rupture of the fatty oil film, it may be possible to carry on until the supply has been adjusted. For this reason many engineers prefer to add varying percentages of fatty oil to the mineral oil. It is, however, often possible to get this margin of safety by the use of a very small quantity of fatty oil and it is therefore hardly worth while bearing the extra cost of say 20% fatty oil, when a satisfactory result can be obtained with 5%, if the bearing is well designed.

Lubricating oils from asphaltic base crudes are cheaper than those from the paraffin base crudes. The choice between these two types must, however, be governed by the operating conditions, but this is not quite so simple as it may appear.

As an example the case of the ordinary petrol engine will be taken.

With the high temperatures in the cylinder, it appears to be essential to have an oil that will retain its viscosity well under heat, without being too viscous at the lower temperatures, especially as the same oil is usually used for both the cylinder and the bearings. Paraffin base oils meet these requirements.

Again it is essential that sulphur compounds shall be entirely absent in a motor oil and due to the fact that there is usually little sulphur in the original crude, it is more likely that the paraffin base oil will be entirely free from these compounds.

As the paraffin oils contain a lower proportion of unsaturated hydrocarbons, they should last much longer in the circulating oil system of the petrol engine and have less tendency to darken and sludge.

Offset against these factors serious consideration must be given to the cold test of the lubricant, which must be low enough to ensure easy starting and good circulation when the engine is set in motion from cold and usually a low cold test is only associated with an asphaltic base oil. Also as previously mentioned, from practical experience it is generally conceded that asphaltic base oils give less carbon actually remaining in the cylinder and that it is of a crumbly nature, fairly easily removed.

The ideal lubricant would seem to be manufactured from a high grade paraffin crude, from which the wax had been pressed to give a low cold test and yet retain the good ratio. Such an oil would, however, be prohibitive in price, the gain in practical use being in no way equal to the increased cost. A compromise is often made by blending oils of each type, which will, of course, improve the cold test of the paraffin base oil and better the ratio of the asphaltic base oil.

A large amount of blending is carried out by the various oil companies to meet the various specifications issued by the consumers, chiefly to meet the viscosity requirements. This is carried out in tanks heated by an internal steam coil, the capacity of the tanks varying with the demand. In the case of mineral oils, the constituents of the blend are mixed by blowing with compressed air, but as this method would oxidise the fatty oils, resource is made to mechanical paddling when compounding mineral and fatty oils.

The cost of blending materially increases the price of the lubricant and it is by careful choice of a specification that the consumer can save money.

All the important oil companies carry in bulk at their depots a range of what are known as straight grades. These are a series of oils which are refined to definite tests, which are (within commercial limits) rigidly adhered to, year in and year out. The tests of the grades carried by the various firms tend to approximate to the same range of viscosities at 140° F., excluding cylinder oils, being usually a range of paraffin base oils and a range of asphaltic base oils with similar viscosities at 140° F. With some exceptions, such as where both a comparatively low cold test and viscosity ratio are required, for which the oils from either base must be blended, it is possible to find a straight grade to meet every purpose and so take advantage of the lower price of oils which are imported and handled in bulk, and avoid the expense of blending charges.

The paper has been confined as far as possible to the lubricants themselves and little mention has been made of methods of applying the lubricant. To develop that subject would, of course, need an evening to itself, but the Author would be pleased to hear during the discussion the opinions of members on such controversial subjects as the comparative merits of the hydrostatic sight feed and the mechanical lubricator for the lubrication of the locomotive cylinder; whether the cylinder oil should enter with the steam or be applied direct to the cylinder and the relative merits of force feed and syphon trimmings for the lubrication of the locomotive axle boxes.

DISCUSSION.

The CHAIRMAN (Mr. K. J. Cook), opening the discussion, said that the Author had given a very interesting paper, and had dealt very clearly with a large number of points concerned with the distribution and uses of oils.

There were several points of particular interest to locomotive engineers and perhaps one which might come in for a certain amount of criticism was the question of carbon deposit in cylinders. This was a matter always present with locomotive engineers and was of paramount importance. It was stated that the carbon deposit was primarily due to the splitting of the oil and the high temperatures encountered in the cylinders. It was possibly so, or, at any rate, it was a partial cause. Possible others present would have something to say of the entry of that deposit. There were points mentioned in connection with saturated steam and superheated steam which were of great interest. He thought that it was, to a certain extent, contended that with saturated steam a lubricant had to have a greater clinging power in order to prevent being separated from the cylinder wall by the moisture. That raised the query as to whether moisture itself did not form a lubricant and, in that respect, one was apt to lose sight of the coasting properties of the old locomotives which were run on saturated steam. It was not possible to coast to the same extent with the modern superheated engine.

Regarding the question of the necessity for an absolutely smooth surface, to a certain extent practice had gone against theory in saying there should be numerous oil pockets, but as the Author had outlined in his theory, it meant that those pockets should be as few as possible in order to prevent, or diminish, any possibility of an uneven surface commencing to break down the film. That was an important point that had only recently been incorporated in practice. The Author had outlined a theory that, with a certain proportion of bearings, the latter tended to produce the film, but until recently, practice had always aimed at introducing cavities in the bearings with the object of getting oils, which, in practice, 'had been the first agent in breaking down that film.

Mr. T. C. DAVISON congratulated the Author on a most interesting and comprehensive paper: he had covered so much ground that difficulty was experienced in knowing what points could be most usefully discussed, apart from the points the Chairman had raised.

Crude oils were obtained from very varying sources on the earth's surface, or below the surface, and one wondered sometimes, as to when this country would have its own oil fields, especially when one remembered that oil, in lubricating, was not used up; it did not cease to be oil and the enormous quantities of oil at present coming into this country must go somewhere. The oil that the Great Western Company used in the course of a year, for instance. One was bound to feel that a very large proportion of it must go back into the earth somewhere and it was only a matter of time before there would be a sufficient accumulation to start oil fields and distilling works. However, he was afraid that it would not be in the near future.

The engineer knew, or thought he knew, what he wanted in a lubricating oil, and the Author had tried to shew what oils the suppliers could provide. He had divided the mineral oils into two general classes, those with a paraffin base and those with an asphaltic base. Each class of oil had its own characteristics. The engineer told the oil supplier, in the form of a specification, that he wanted a certain quality and that he wanted that quality at a very cheap rate. The Author rightly said that the engineer could be satisfied at a price, but that price the engineer was not prepared to pay; but by judicious blending, the requirements of the engineer could be very largely met, but he had to accept a compromise. The requirements of the engineer were originally based upon the characteristics of fatty oils, the vegetable and the animal oils. They had certain characteristics with which the engineer was familiar and he looked askance at mineral oils when those were introduced and was only inclined to use them in-so-far as their characteristics were similar to the fatty oils, and not until quite recent years had he begun to realise that he must not gauge mineral oils by the characters of fatty oils. The engineer always wanted an oil which had a very flat viscosity curve, that was, one which lost the lowest amount of body by changes of temperature. That was a quality that the fatty oils possessed in a larger degree than the mineral oils; but now the engineer realised that this was not the predominant characteristic because the mineral oils which would give him the best viscosity within the ordinary temperatures would often become solid at temperatures which the bearings might reach in cold weather, so that now more attention was given to the fluidity of the oil at low temperature; that was, the good ratio of viscosity at 140° F. and at the ordinary temperature of 60° F., was sacrificed in order to secure an oil which would still remain fluid at such temperatures as might be reached in the winter time. That was a point of considerable importance in the lubrication of rolling stock and also of gear box oil.

The property of oiliness, which one could define shortly as the capacity to reduce friction to a minimum, did not vary very much among the various available mineral lubricating oils. What was of importance was that the body, the fluidity of the oil, should be sufficient for the particular purpose in view; that was, it should have sufficient body to maintain a lubricating film; and the selection beyond that depended upon the other qualities desired, i.e., whether an oil was wanted that would not emulsify with water or whether an oil with a low cold point was wanted. On the other hand, the oil which would resist change on exposure to the air was yet another thing and so on; so that the engineer had to realise that at the best he had to accept a compromise and the art lay in making the best selection possible at the lowest possible price.

The Chairman had referred to carbon deposits. That was a very big subject and might occupy almost the whole evening in discussing it, so he did not propose to start. It might be of interest to mention that the average locomotive cylinder deposit always contained a very large proportion of smokebox ash and perhaps, also, the water solids from the boiler. This was an interesting fact and a fact that should always be borne in mind in considering this deposit, as it indicated that the oil which remained in the cylinder had some binding action. It acted as an agent in fixing the smokebox ash which found its way into the cylinder and also the water solids which passed in with the steam. He (the speaker) had always held the view that if the admission of foreign solids, such as smokebox ash and water solids due to priming, could be excluded, one of the great difficulties would be overcome.

With regard to the relative merits of compound and simple mineral oils, considerable divergence of opinion existed. The Great Western considered that a compound oil was essential for saturated steam engines; i.e., something was needed in the oil to make it emulsify with the mist of water in the steam, so that the emulsion would wet the cylinder walls. Pure mineral oils, if projected in the form of a spray, simply ran away and there seemed to be a kind of repulsion between the oil and the metal surfaces. The presence of the fatty oil broke down that repulsion and enabled the oil to stick and so do its work. With regard to whether plain mineral oil or blended mineral oil was the better for superheated steam, he thought it was still a moot point, and a point for future discussion.

Mr. Kay said that the Author had mentioned shore tanks: for small purposes they contained about 60 barrels, but the large ones contained anything up to 52,000 barrels. The capacity of a barrel was about 35 gallons.

Mr. I. R. Richards said that oil with an asphaltic base would leave in internal combustion engines an apparently soft carbon deposit, whereas oils with a paraffin base gave a hard deposit. The Author had mentioned the deposit that is left, but he would like to know where that portion of the oil which was not left in the cylinder went.

The Author replied that it went out of the exhaust.

Mr. A. W. J. Dymond said that he had been listening with interest to the Author's paper, and would like to congratulate him on having covered a field about which he had to confess considerable ignorance.

There were several points of importance in regard to cylinder and piston valve lubrication. Mr. Davison had referred to the change that had taken place in the fatty acid proportion of G.W.R. cylinder oils. As he understood it, the function of that proportion of fatty acid was to form emulsion on the cylinder walls, but apparently the use of superheated steam instead of saturated steam altered the conditions. Experience of superheated steam previous to two years ago apparently had not caused the G.W.R. to alter their practice with cylinder oils, but recently some difficulties had presented themselves and the whole question had come up again. One of the difficulties might be that of higher initial temperatures. Previous to the "King" class engines, the initial temperature corresponded to 225lbs. sq. in. gauge and about 140° superheat, but with the introduction of the "Kings" the pressure went up to 250lbs. sq. in., with an increase of temperature and a certain slight increase in the superheat temperature, the total temperature therefore being greater. It was a moot point whether that slight increase in the initial temperature might not, in this case, entirely alter the conditions which occurred immediately the oil entered the cylinders, because as expansion proceeded, cooling took place, and with the cooling, condensation, and subsequently adhesion of the oil to the cylinder walls. In the case of the earlier superheated engines the conditions were not so severe, but with an increase in the total temperature, the oil might have been destroyed in the early stages of the expansion in the cylinder.

Another interesting point was that of carbon in the cylinders, and he regretted to hear Mr. Davison talk about water solids in the cylinders because it indicated a lamentable state in the steaming of the engines. In the superheated engines this was unlikely, as these solids should have been deposited in the superheater tubes. The introduction of smoke box ash had recently caused considerable trouble owing to "pumping" when coasting and drawing smokebox gasses and ash into the steam chest. Enginemen were instructed that, when coasting, the gear should be in such a position (generally about 45% cut-off) that "pumping" should be as small as possible.

The question of what the Author had very aptly termed solid friction was very interesting, and one might almost wish that more time had been given to it because there was the germ of a fuller explanation of that very mystifying phenomenon known as oiliness. He had heard definitions which had left him entirely in the air, but it certainly did seem to be very sound that if the surfaces of a cylinder were in such a state that they could combine in some kind of physio-chemical form with the lubricant, it was up to the engineer to find the lubricant which had the most affinity for, and was the most enduring on, that surface.

Mr. E. H. Gooderson said that the question of lubrication was very interesting to those who had to deal with lubricating problems in the design of bearings. The Author had mentioned the film of oil; any data relating to the thickness, etc., and how to supply the oil, would be of great interest. He would like to know what kind of bearings the Author would use in order to get the film over the centre of pressure.

With regard to the oil freezing or getting solid through the lengths of supply pipes, many years ago the men in the shops discovered how rape oil and certain classes of fatty oils acted and they ran for the rape oil can when the oil in bearings became solid.

Mr. C. T. Roberts stated that mineral oil had a prohibitive viscosity for some things and he would like to know whether it could be inferred that oiliness varied with the viscosity. If that were so, it would seem that the bad viscosity oil would give difficulty at low speeds.

Mr. T. R. Hall said that the Author had stated that sulphur should be absent from motor oil, and also that lubricating oils from a paraffin base contained very little sulphur. He enquired why, in the motor trade, when bearings became hot, sulphur was added and this had the effect of rapidly cooling them. Also, at one time in the shops, the men put sulphur on the lubricating pads.

Mr. T. M. Walker referred to the fact that the Author had mentioned that the addition of a small amount of vegetable oil had the effect of causing emulsification. He enquired if that would help to remedy the heating of axleboxes due to water being added to them in washing out boilers.

Mr. J. F. Cuss thought that fatty and vegetable oils were the only oils to which the men looked in cases of emergency. He knew that before starting out on trials, engine drivers added cylinder oil to the coupling rod bearings. He had read that all oils at high temperatures had practically the same viscosity. He enquired if that were correct. If so, it seemed that any kind of oil would be suitable for cylinder oil. Mr. Dymond had expressed the hope that should any solids be carried through from the boiler in the steam, that the steam would be evaporated in the superheater tubes and the solids deposited. He thought that if this were so, the steam would carry the solids through with it.

With regard to solid friction and the affinity of the molecules of the oil for the metal, he noticed that most bearings were of dissimilar metals, say one of steel and one of bronze. He enquired if the Author had any theory on the use of similar metals from the point of view of lubrication, and what would be the effect on the viscosity of a mineral oil of adding fatty oil.

Mr. W. Floyd thanked the Author for his paper. The oil question was so pre-eminently the question of to-day that he thought perhaps the Author might reveal the great secret that would take a load off the mind of the engineer, but the only secret revealed was that if the money were paid, the oil company had the oil, but even that, with his experience, he was bound to doubt. There were conditions prevailing which varied so much that he could see an engineman going round an engine with about 26 oil cans. It was one thing to tell a locomotive engineer that the oil could be given him, but the trimming had also to be given him. It appeared that when one started dealing with the oil, one must also deal with the trimming which was used in the siphon, as in the case of hot boxes, all the evidence was destroyed before one reached the cause. He often found that there was a certain amount of water which had caused the trimming to "steel," so that it did not soften, so that whatever oil was used it would not get to the bearing.

The Author, replying to the question as to where to introduce oil into the bearings, said that he thought it was a mistake to have anything disturbing the pressure area; for this reason he was not in favour of having any grooving. However, opinions differed on this subject. He regretted he was unable to give from memory the figures relating to the thickness of the oil film in relation to the load.

Regarding the relation between viscosity and oiliness, there were no definite relations between them.

With regard to the question of using sulphur as a lubricant, the general idea was to add a little sulphur which would fill up the minute holes, and so help to fill up the film and make a closer surface. Graphite was, however, used more than sulphur.

"Oil-dag" composed of very fine particles of graphite suspended in the oil was on the market: this filled up the holes and formed a perfect surface.

As to the question of trailing axlebox lubrication, he thought it was advisable to use a combined oil where there was much water present.

With regard to oils being of the same viscosity, he did not consider that viscosity was the biggest characteristic with regard to cylinder oils; an asphaltic content was one of the most important items about a cylinder oil.

Regarding the price of oil, he would not go so far as to say that a better oil could be obtained if more is paid for it; he was not in agreement with buying the dearest lubricant in all cases. Bearings should be designed to take the cheaper lubricants.

In reply to the question about the trimmings, he said that in the course of his paper he stated that when a fatty oil was combined with a mineral oil, there was a higher margin of safety. In using mineral oils once the oil supply failed the bearing would seize up very quickly, but if this oil were mixed with a fatty oil, warning would be given and the bearing would carry on a little longer.