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# Lubrication and Lubricants

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Additional information is available at the end of the chapter

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## 1. Introduction

### 1.1. Lubrication

The primary purpose of lubrication is to reduce wear and heat between contacting surfaces in relative motion. While wear and heat cannot be completely eliminated, they can be reduced to negligible or acceptable levels. Because heat and wear are associated with friction, both effects can be minimized by reducing the coefficient of friction between the contacting surfaces. Lubrication is also used to reduce oxidation and prevent rust; to provide insulation in transformer applications; to transmit mechanical power in hydraulic fluid power applications; and to seal against dust, dirt, and water.

#### 1.1.1. *The lubrication regimes*

The modern period of lubrication began with the work of Osborne Reynolds (1842-1912). Reynold's research was concerned with shafts rotating in bearings and cases this show in Fig. 1. When a lubricant was applied to the shaft, Reynolds found that a rotating shaft pulled a converging wedge of lubricant between the shaft and the bearing. He also noted that as the shaft gained velocity, the liquid flowed between the two surfaces at a greater rate. This, because the lubricant is viscous, produces a liquid pressure in the lubricant wedge that is sufficient to keep the two surfaces separated. Under ideal conditions, Reynolds showed that this liquid pressure was great enough to prevent direct contact between the metal surfaces. Fig.2 taking a plain journal bearing as example, Fig.3 which is known as Stribeck curve summarizes the lubrication regimes by describing the relationship between speed, load, oil viscosity, oil film thickness, and friction.

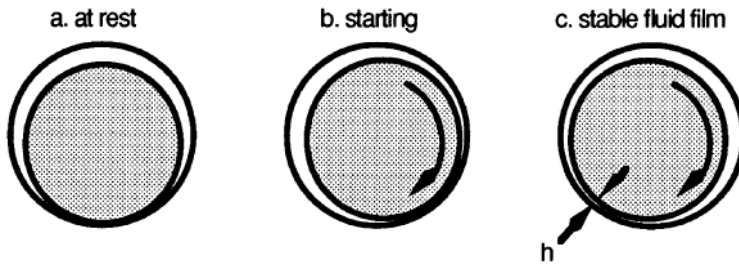


Figure 1. Three positions of shaft in a bearing

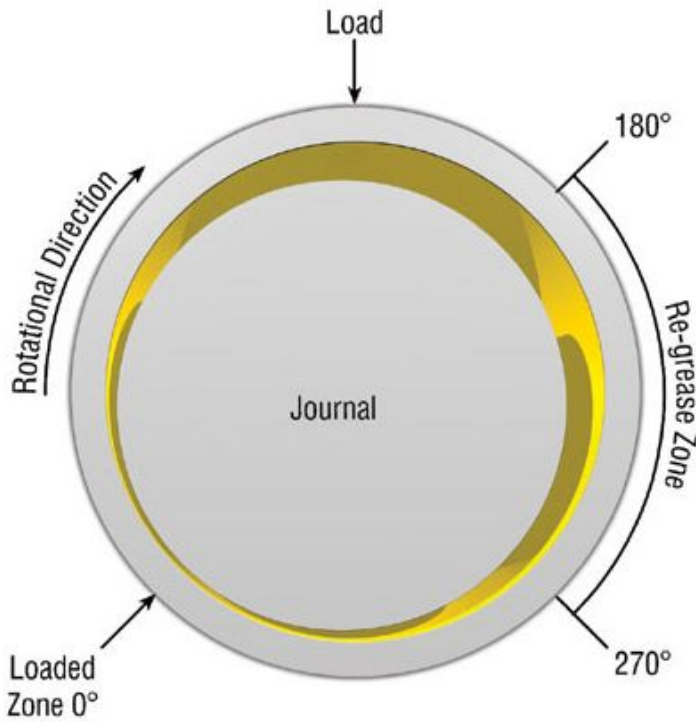


Figure 2. Plain Journal bearing

In this graph, the coefficient of friction is plotted against the expression  $ZN/P$  (sometimes referred to as the Hersey number)

$$\text{Where } ZN/P = \frac{\text{oil viscosity} \times \text{shaft speed}}{\text{bearing pressure}} \quad (1)$$

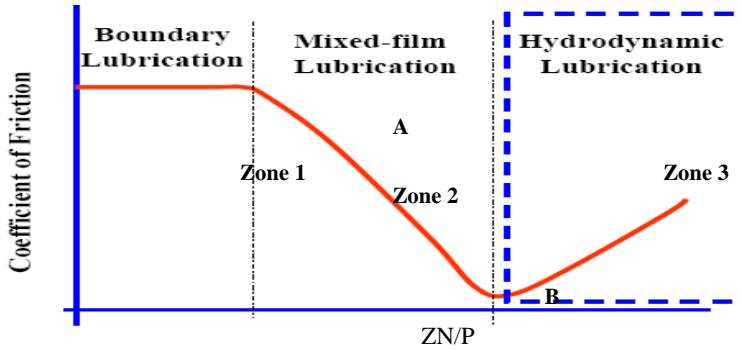
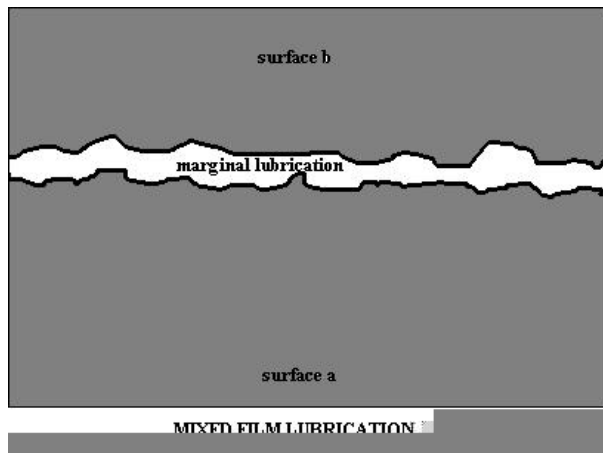


Figure 3. Stribeck curve



Scheme 1. Mixed-film lubrication

As shown there are three distinct zones separated by points A and B. At B the oil film is just thick enough to ensure that there is no contact between asperities on the shaft and bearing surfaces. Smoother surfaces shift B to the left, while at point A the oil film thickness reduces virtually to nil. Zone 2, between A and B is known as the zone of mixed lubrication. Mixed-film lubrication is unstable at which increase in lubrication temperature causes further increases in lubrication temperature.

### 1.1.2. Hydrodynamic lubrication

Basically, lubrication is governed by one of two principles: hydrodynamic lubrication and boundary lubrication. In the former, a continuous full-fluid film separates the sliding surfaces. In the latter, the oil film is not sufficient to prevent metal-to-metal contact. Hydrodynamic lubrication is the more common, and it is applicable to nearly all types of continuous sliding

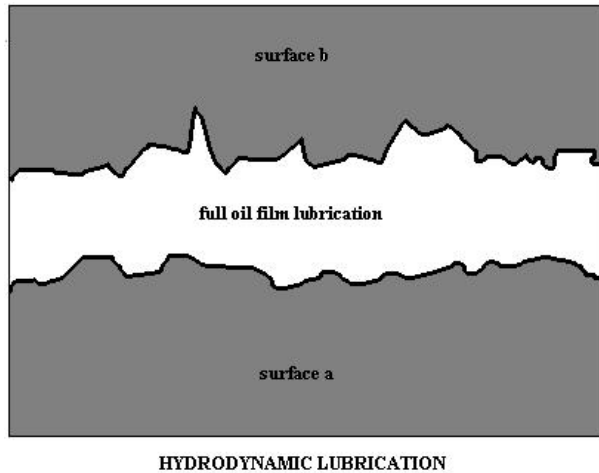
action where extreme pressures are not involved. Whether the sliding occurs on flat surfaces, as it does in most thrust bearings, or whether the surfaces are cylindrical, as in the case of journal (plain or sleeve) bearings, the principle is essentially the same.

It would be reasonable to suppose that, when one part slides on another, the protective oil film between them would be scraped away. Except under some conditions of reciprocating motion, this is not necessarily true at all. With the proper design, in fact, this very sliding motion constitutes the means of creating and maintaining that film.

In zone 3 is the zone of hydrodynamic or fluid film lubrication where there is no wear because there is no contact between the surfaces. Hydrodynamic Lubrication is often referred to as stable lubrication. There are four essential elements in hydrodynamic lubrication, a liquid, relative motion, the viscous properties of the liquid, and the geometry of the surfaces between which the convergent wedge of fluid is produced. Only friction present in a hydrodynamic lubrication system is the friction of the lubricant itself, it would make sense to have a less viscous fluid in order to minimize friction: the less viscous a liquid the lower the friction. Too low of a viscosity jeopardizes our system though. We have to be very careful that the distance between the two surfaces is greater than the largest surface defect. The distance between the two surfaces decreases with higher loads on the bearing, less viscous fluids, and lower speeds. The surface geometry is also very important. The surfaces have to be such that a converging wedge of fluid can develop between the surfaces, allowing the hydrodynamic pressure of the lubricant to support the load of the shaft or moving surface. Hydrodynamic lubrication is an excellent method of lubrication since it is possible to achieve coefficients of friction as low as 0.001, and there is no wear between the moving parts. Special attention must be paid to the heating of the lubricant by the frictional force since viscosity is temperature dependent. One method of accomplishing this is to cycle the lubricant through a cooling reservoir in order to maintain the desired viscosity of the fluid. Another way of handling the heat dissipation is to use commercially available additives to decrease the viscosity's temperature dependence which are known as viscosity index improvers.

The formation of fluid film is influenced by the following factors:

- The contact surfaces must meet at a slight angle to allow formation of the lubricant wedge.
- The fluid viscosity must be high to maintain adequate film thickness to separate the contacting surfaces at operating speeds.
- The fluid must be adhering to the contact surfaces for conveyance into the pressure area to support the load.
- The fluid must be distributing itself completely within the bearing clearance area.
- The operating speed must be sufficient to allow formation and maintenance of the fluid film.
- The contact surfaces of bearings and journals must be smooth and free from sharp surfaces that will disrupt the fluid film.



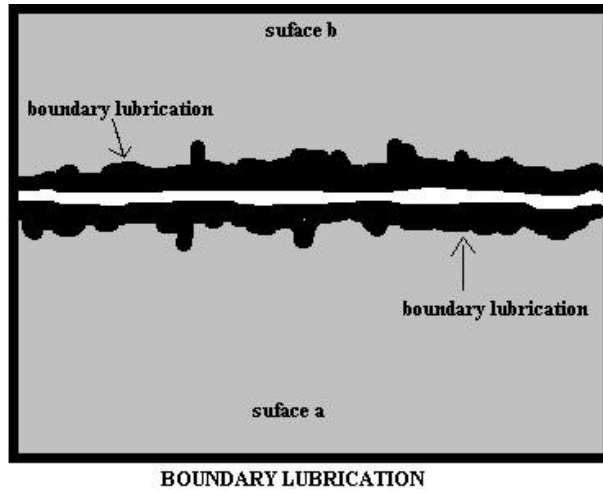
**Scheme 2.** Hydrodynamic lubrication

### 1.1.3. Boundary lubrication

The oil film has become so thin in Zone 1 that there is no hydrodynamic contribution and only boundary lubrication which is defined by Campbell in 1969 as the lubrication by a liquid under conditions where the solid surfaces are so close together that appreciable contact between opposing asperities is possible. The friction and wear in boundary lubrication are determined predominantly by interaction between the solids and between the solids and the liquid. The bulk flow properties of the liquid play little or no part in the friction and wear behavior.

As mentioned, boundary lubrication is effective when a complete fluid film does not develop between potentially rubbing surfaces, the film thickness may be reduced to permit momentary dry contact between wear surface high points or asperities. Boundary lubrication occurs whenever any of the essential factors that influence formation of a full fluid film are missing. The most common example of boundary lubrication includes bearings, which normally operate with fluid film lubrication but experience boundary lubricating conditions during routine starting and stopping of equipment. Other examples include gear tooth contacts and reciprocating equipment.

A brief explanation of what needs to be added to basic mineral oil in order to create an effective boundary lubricant. Generally, the best additives are active organic compounds with long chain molecules and active end groups. These compounds bind tightly and intricately with each other, forming a film that builds up on the surface of the metal itself. This results in a thin film that is very difficult to penetrate. When two surfaces, each covered with a boundary layer, come in contact with each other they tend to slide along their outermost surfaces, with the actual faces of the surfaces rarely making contact with each other. Liquids are rarely good boundary lubricants. The best boundary lubricants are solids with long chains of high inter-chain attraction, low shear resistance so as to slip easily, and a high temperature tolerance. The



**Scheme 3.** Boundary lubrication

boundary lubricant should also, obviously, be able to maintain a strong attachment to the surfaces under high temperatures and load pressures.

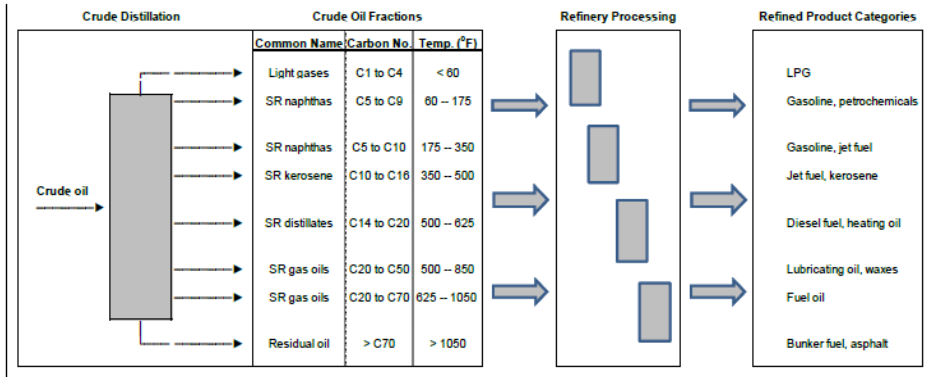
The most common boundary lubricants are probably greases. Greases are so widely used because they have the most desirable properties of a boundary lubricant. They not only shear easily, they flow. They also dissipate heat easily; form a protective barrier for the surfaces, preventing dust, dirt, and corrosive agents from harming the surfaces

## 1.2. Base stock

Petroleum is one of the naturally occurring hydrocarbons that frequently include natural gas, natural bitumen, and natural wax. The name "petroleum" is derived from the Latin *petra* (rock) and *oleum* (oil). According to the most generally accepted theory today, petroleum was formed by the decomposition of organic refuse, aided by high temperatures and pressures, over a vast period of geological time.

Although petroleum occurs, as its name indicates, among rocks in the earth, it sometimes seeps to the surface through fissures or is exposed by erosion. The existence of petroleum was known to primitive man, since surface seepage, often sticky and thick, was obvious to anyone passing by prehistoric animals were sometimes mired in it, but few human bones have been recovered from these tar pits. Early man evidently knew enough about the danger of surface seepage to avoid it.

The petroleum remaining from the distillation is thick like pitch; if the distillation has been pushed far, the residuum will flow only languidly in the retort, and in cold weather it becomes a soft solid, resembling much the maltha or mineral pitch Fig. 4 shows that the distillation of crude oil.



**Figure 4.** Schematic View of Crude Oil Distillation

Base stocks are refined from crude oil to obtain products with the best lubricating properties. Base stocks generally make up 80-95% of a typical engine oil and 5% additives [1]. Base stock is used to describe plain mineral oil. The physical properties of an oil depend on its base stock. In most cases it is chemically inert there are three sources of base stock: biological, mineral and synthetic. The oils manufactured from these sources exhibit different properties and they are suitable for different applications. For example:

- a. Biological oils are suitable in applications where the risk of contamination must be reduced to a minimum, for example, in the food or pharmaceutical industry. They are usually applied to lubricate kilns, bakery ovens, etc. There can be two sources of this type of oil: vegetable and animal. Examples of vegetable oils are: castor, palm and rape-seed oils while the examples of animal oils are: sperm, fish and wool oils from sheep (lanolin).
- b. Mineral oils are the most commonly used lubricants throughout industry. They are petroleum based and are used in applications where temperature requirements are moderate. Typical applications of mineral oils are to gears, bearings, engines, turbines, etc.
- c. Synthetic oils are artificially developed substitutes for mineral oils. They are specifically developed to provide lubricants with superior properties to mineral oils. For example, temperature resistant synthetic oils are used in high performance machinery operating at high temperatures. Synthetic oils for very low temperature applications are also available [2].

### 1.3. Lubricants

All liquids will provide lubrication of a sort, but some do it a great deal better than others. The difference between one lubricating material and another is often the difference between successful operation of a machine and failure. For almost every situation, petroleum products have been found to excel as lubricants. Petroleum lubricants stand high in metal-wetting

ability, and they possess the body, or viscosity characteristics, that a substantial film requires, these oils have many additional properties that are essential to modern lubrication, such as good water resistance, inherent rust-preventive characteristics, natural adhesiveness, relatively good thermal stability, and the ability to transfer frictional heat away from lubricated parts. What is more, nearly all of these properties can be modified during manufacture to produce a suitable lubricant for each of a wide variety of applications. Oils have been developed hand-in-hand with the modern machinery that they lubricate; indeed, the efficiency, if not the existence, of many of today's industries and transportation facilities is dependent upon petroleum lubricants as well as petroleum fuels.

The basic petroleum lubricant is lubricating oil, which is often referred to simply as "oil." This complex mixture of hydrocarbon molecules represents one of the important classifications of products derived from the refining of crude petroleum oils, and is readily available in a great variety of types and grades.

Any description of lubricating oils would be incomplete without consideration of oils for vehicle engines. These oils are used in greater quantity than all other lubricants combined, and are of interest to more people than any other lubricants. Engine oils are generally recommended by automotive builder according to the Society American of Automotive Engineers (SAE) viscosity classification.

Engine oil lubricants make up nearly one half of the lubricant market and therefore attract a lot of interest. The principal function of the engine oil lubricant is to extend the life of moving parts operating under many different conditions of speed, temperature, and pressure. At low temperatures the lubricant is expected to flow sufficiently in order that moving parts are not starved of oil. At higher temperatures they are expected to keep the moving parts apart to minimize wear. The lubricants reduce friction and removing heat from moving parts.

### *1.3.1. General classification of the lubricating oils*

The term lubricating oil is generally used to include all those classes of lubricating materials that are applied as fluids [3]. Lubricating oils are made from the more viscous portion of the crude oil which remains after removal by distillation of the gas oil and lighter fraction [4-8]. Although crude oils from various parts of the world differ widely in properties and appearance, there is relatively little difference in their elemental analysis. Thus, crude oil samples will generally show carbon content ranging from 83% to 87 %, and hydrogen content from 11% to 14%. The remainder is composed of elements such as oxygen, nitrogen, and sulfur, and various metallic compounds. An elemental analysis, therefore, gives little indication of the extreme range of physical and chemical properties that actually exists, or of the nature of the lubricating base stocks that can be produced from a particular crude oil.

An idea of the complexity of the lubricating oil-refining problem can be obtained from a consideration of the variations that can exist in a single hydrocarbon molecule with a specific number of carbon atoms. For example, the paraffinic molecule containing 25 carbon atoms has 52 hydrogen atoms. This compound can have about 37,000,000 different molecular arrangements [3]. The hydrocarbons of the crude oils are:



#### 1.3.1.1. *Paraffinic components*

The paraffinic components, show in Fig. 5 (a, b), which determine the pour point, contain not only linear but also branched paraffins. The straight chain paraffins of high molecular weights raise the pour point of oils (waxy compounds) and should be removed by dewaxing processes.

The branched paraffins are chemically interesting hydrocarbons and they are found in large quantities in lubricating oil fractions from paraffinic crudes. Oil rich in paraffinic hydrocarbons have relatively low density and viscosity for their molecular weight and boiling range. Also, they have good viscosity/ temperature characteristics. In general, paraffinic components are reasonably resistant to oxidation and have particularly good response to oxidation inhibitors [9, 10].

#### 1.3.1.2. *Naphthenic components*

They have rather higher density and viscosity for their molecular weight compared to the paraffinic components. An advantage which naphthenic components have over the paraffinic ones is that they tend to have low pour point and so do not contribute to wax. However, one disadvantage is that they have inferior viscosity/ temperature characteristics. Single ring alicyclics with long paraffinic side chains, however, share many properties with branched paraffins and can in fact be highly desirable components for lubricant base oils. Naphthenic components, Fig. 5 (c), tend to have better solvency power for additives than paraffinic components but their stability to oxidative processes is inferior [9, 10].

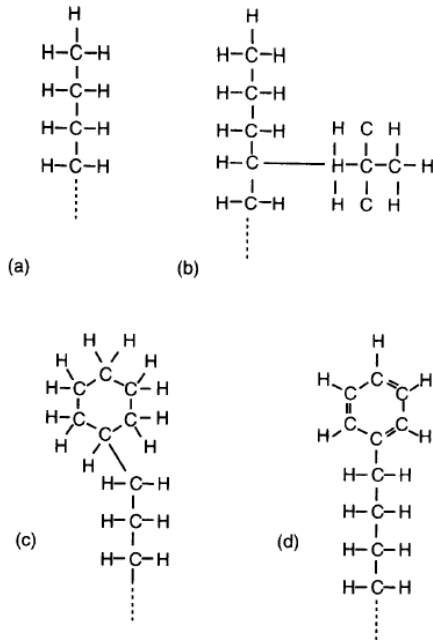
#### 1.3.1.3. *Aromatic components*

They have densities and viscosities which are still higher viscosity/ temperature characteristics are in general poor but pour point is low, although they have the best solvency power for additives, their stability to oxidation is poor. As for alicyclics, single ring aromatics with long paraffinic side chain may be very desirable base oil components, Fig. 5 (d). The classifying of hydrocarbon as paraffinic, naphthenic and aromatic groups which are generally used for characterizing the base oil should not be taken as absolute but as an expression of the predominating chemical tendencies of the base stocks [11].

#### 1.3.1.4. *Non hydrocarbon components*

The non hydrocarbons in lubricating oil are analogous in many ways to the hydrocarbons. Sulfur and nitrogen compounds are found almost entirely in ring structures such as sulfides, thiophene, pyridine and pyrrol types. More complex molecules are also thought to exist in lubricating oil in which nitrogen and sulfur atoms are found in the same molecule. As in the case of hydrocarbons, these compounds will probably also have paraffinic side chains and possibly be condensed with naphthenic and aromatic ring structures [11]

Although these non hydrocarbons may be present in only trace amounts, they often play a major role in controlling the properties of lubricating oils. In general they are chemically more active than the hydrocarbon, and hence they may markedly affect properties such as oxidation



**Figure 5.** Chemical Structure of Lubricating oil

stability, thermal stability and deposit forming tendencies. In refining the general tendency is to reduce the non hydrocarbons content to a minimum.

Naphthenic acid account for most of the oxygenated compounds found in petroleum. These are removed in the refining processes by neutralization and distillation. The naphthenates are retained in the residue from the distillation and can be removed by deasphalting process. Modern refining methods generally remove most of resins, asphaltenes, polycyclic aromatic, di aromatic and their analogous non hydrocarbons, so that the final lubricant consists chiefly of saturated and monocyclic aromatic fraction [12].

### 1.3.2. Main properties of lubricating oils

The main properties which a lubricating oil must possess to full performance are :

#### 1.3.2.1. Physical properties of lubricating oil

##### a. Viscosity

Viscosity is the measure of the internal friction within a liquid; the way the molecules interact to resist motion. It is a vital property of a lubricant because it influences the ability of the oil to form a lubricating film or to minimize friction [8]. Newton defined the absolute viscosity of a liquid as the ratio between the applied shear stress and the resulting shear rate.

## **b. Viscosity index**

The most frequently used method for comparing the variation of viscosity with temperature between different oils by calculation of dimensionless numbers, known as the viscosity index (VI). The kinematic viscosity of the sample is measured at two different temperatures (40°C, 100°C) and the viscosity compared with an empirical reference scale. VI is used as a convenient measure of the degree of aromatics removal during the base oil manufacturing process, but comparison of VI of different oil samples is only realistic if they are derived from the same distillate feedstock [8].

## **c. Low temperature properties.**

When a sample of oil is cooled, its viscosity increases in a predictable manner until wax crystals start to form. The matrix of wax crystals becomes sufficiently dense with further cooling to cause an apparent solidification of the oil. Although the solidified oil does not pour under the influence of gravity, it can move if sufficient force is applied. Further decrease in temperature cause more wax to form, increasing the complexity of the wax/oil matrix. Many lubricating oils have to be capable of flow at low temperatures and a number of properties should be measured.

### **• cloud point**

It is the temperature at which the first sign of wax formation can be detected. A sample of oil is warmed sufficiently to be fluid and clear. It is then cooled at a specified rate. The temperature at which haziness is first observed is recorded as the cloud point, the ASTM D 2500/IP 219 test. The oil sample must be free of water because it interferes with the test.

### **• pour point**

It is the lowest temperature at which the sample of the sample of oil can make to flow by gravity alone. The oil is warmed and then cooled at a specified rate. The test jar is removed from the cooling bath at intervals to see if the sample is still mobile. The procedure is repeated until movement of the oil does not occur, ASTM D 97/IP 15. The pour point is the last temperature before the movement ceases, not the temperature at which solidification occurs. This is an important property of diesel fuels as well as lubricant base oils. High-Viscosity oils may cease to flow at low temperatures because their viscosity becomes too high rather than because of wax formation. In these cases, the pour point will be higher than the cloud point.

## **d. High temperature properties.**

The high temperature properties of oil are governed by distillation or boiling range characteristics of the oil.

### **• volatility**

It is important because it is an indication of the tendency of oil to be lost in service by vaporization.

### **• flash point**

It is important for oil from a safety point of view because it is the lowest temperature at which auto-ignition of the vapour occur above the heated oil sample. Different methods are used, ASTM D 92, D93, and it is essential to know which equipment has been used when comparing results.

**e. Other physical properties**

Various other physical properties may be measured, most of them relating to specialized lubricant applications. Some of the more important measurements are:

- **density**

Important, because oils may be formulated by weight, but measured by volume.

- **demulsification**

Ability of oil and water to separate.

- **foam characteristics**

Tendency to foam formation and stability of the foam that results.

- **pressure/viscosity characteristics**

- **thermal conductivity**

Important for heat transfer fluid.

- **electrical properties**

Resistively, dielectric constant.

- **surface properties**

As surface tension, air separation.

*1.3.2.2. Chemical properties of lubricating oils*

**a. Ease of starting rapidity of warming up.**

The ease of starting depends chiefly on the cranking speed which is influenced by oil viscosity at the temperature of the crankcase. The major factor in the usage of a lubricant is its viscosity. It's not enough that the lubricants should have the proper viscosity but also they should maintain the little viscosity change within the temperature range during and after the appertain. So, viscosity controls not only frictional and thermal effect but also oil flow as a function of the load speed, temperature and design of the device lubricated. In other words, if the equipment will often have no make a cold start, it's also important that the viscosity at starting temperature is not so high that the machine can not be started. The rapidity with which an engine can be put to work is dependent on the speed of circulation and supply of oil to vital components, all forms of wear and even the safety of the engine are influenced by rapidity of circulation of the lubricants.

**b. Low Carbon Forming Tendency.**

This property is important for high compression ratio petro engine where carbon deposit will adversely affect combustion quality. The extent and also the composition of such formed deposits are causing noisy and rough burning which subjects the engine to high thermal and mechanical stresses resulting in lowering of performance and reduction of engine life. The typical symptoms will be knocking, preignition and surface ignition. These call higher octane fuels which are more expensive and do not eliminate the need for ultimate decarbonizing.

**Carbon residue test methods.**

Provide with some indication about the relative coke forming tendency of the oil in some application and quality-controlled lubricants. So, the test can be helpful in selecting oils for certain industrial applications such as heat treating, lubrication of bearing subjected to high temperature and air compressors. It is claimed that the presence of viscous oil (bright stock) in the base oils plays an important role in the formation of carbon deposits.

**c. High Oxidation Stability.**

One of the most important requirement of the lubricant is that its properties are not changed during use [5-10]. The lubricant is often subjected to several oxidizing conditions which are primarily due to the oxidative changes of the oil. While the temperature of the oil, engine parts presence of oxygen, nature by products of fuel composition contribute to the oxidative change the properties of the lubricant during use. Therefore, It's essential that the lubricating oil; when exposed to high temperature; doesn't contribute to the forming of deposits even after a long period of continuous engine running. So, the lubricant resistance to the oxidative depends mainly on the nature of the lubricant and the presence of anti-oxidant additives.

**d. Wear Reduction.**

Wear occurs in lubricated systems by three mechanisms (abrasion, corrosion and metal-to-metal contact. i.e adhesion). The lubricant play an important role in combating each type of wear.

**i. Abrasive wear**

It is caused by solid particles entering into the area between the lubricated surfaces and physically eroding these surfaces and may contaminate wear fragments. To cause wear, the solid particles must be larger than the oil-film thickness and harder than the lubricated surfaces. The flushing action of the lubricant, especially in forced feed or once through systems, severs to remove potentially harmful solid particles from the area of lubricated surfaces.

**ii. Corrosive wear**

Corrosive wear is generally caused by the products of oxidation of lubricants. The high sulfur content of the fuel helps the corrosive attack. In other words, corrosion is the principal cause of wear in the internal combustion engines because the products of combustion are highly acidic and contaminate the lubrication oil, lubricants function to minimize corrosive wear is

in two ways: proper refinement plus the use of oxidation inhibitors which reduces lubricant deterioration and keeps the level of corrosive oxidation products low.

### **iii. Adhesive wear**

This type of wear can significantly affect certain parts of the engine where metal-to-metal contact takes place. Adhesive wear takes place also if power was increased without corresponding modification in design, finishing and composition of the metal parts. Wear of this type also results from breakdown of lubricant film. It can also be the result of excessive surface roughness or interruption of the lubricant supply. A plentiful supply of the proper viscosity of oil is often the best way to avoid these conditions. The composition of the base oil and addition of certain chemical additives are also the important factors in protection of engine parts components against adhesive wear.

### **e. Detergency and Dispersancy.**

With the exception of detergency and dispersancy in the combustion chamber, deposits in the oil are controlled by its detergent power. The source of the deposits found in engines are many and their volume depends mainly on the used, the quality of combustion, the temperature of lubricating oil and coolant, and on the gas sealing of the ring in the cylinder. If these deposits are not removed with the oil when it is drained, their accumulation in the engine would drastically shorten the engine life. The role of the detergent additives is to reduce the amount of deposits formed and their removal easy. The detergent property imparted to oils by additives seems to perform differently depending upon whether deposits result from high or low temperature, low temperature deposits are mainly yielded from the fuel combustion and the detergency function is to keep them in suspension or solution in the lubricating oil. However, high temperature deposits are mainly related to the oxidized fraction of the oil.

The role of detergency here is not only to maintain these products in suspension, but also to stop the development of those chain reactions which promote the formation of varnishes and lacquers. The physical and functional properties of the lube oil will depend on the properties of carbon atoms in the various ring structures and aliphatic side chain.

### **f. Seal compatibility**

Lubricants are often used in machines where they come into contact with rubber or plastic seal. The strength and degree of swell of these seals may be affected by interaction with the oil. Various tests have been devised to measure the effect of base oils on different seals and under different test conditions [13]. The strength and degree of swell of these seals may be affected by interaction with the oil. Various tests measure the effects of base oils on different seals and under different test conditions.

#### *1.3.3. Required performance characteristics for lubricating oils*

Selection and application of lubricating oil are determined by the functions which are expected for performance. In one application, such as delicate instrument bearing, the reduction of friction

is paramount and in another, such as metal cutting, the temperature control may be most important. A lubricating oil performance or requirement for a modern high speed engine should fulfill the following five important functions:

**1. Reduction of the frictional resistance:**

The reduction of engine resistance to minimum is necessary to ensure maximum mechanical efficiency (running costs of a vehicle or engines are influenced by the lubricant viscosity)

**2. Protection of the engine against all types of wear:**

All users want minimum maintenance costs, longer engine life and increased usefulness. Modern oil has allowed longer intervals between engine overhauls.

**3. Reduction of gas and oil leakages:**

The reduction of gas and oil leakages in an efficient and lasting manner is necessary to maintain engine performance and to prevent the combustion products from adulterating the oil.

**4. Contributing to the thermal equilibrium of the engine:**

In modern engines, the oil functions and more as a heat exchange medium, dissipating the heat is not converted into work. This is often associated with the first function in this list where the viscous oil gives greater frictional resistance and its slow internal circulation leads to a rapid temperature rise of some vital part of the engine. To cool efficiently, the oil must be able to circulate quickly.

**5. Removal of all injurious impurities:**

The lubricant gives the function of protecting the engine against corrosive and mechanical wear which is caused by all injurious impurities. So, the removal of these impurities by lubricants is very important for the engine. The function and the corresponding qualities required for engine lubricating oils are summarized in Table (1).

*1.3.4. Types of lubricants*

*1.3.4.1. Gaseous lubricants*

Gaseous lubricants belong to the simplest, lowest viscosity lubricants known and include air, nitrogen, oxygen, and helium. They are applied in aerodynamic and aerostatic bearings. Since the chemical properties and the aggregate state of most gases remain unchanged over a wide temperature range, gaseous lubricants offer several advantages over liquid lubricants. First, they can be applied at both very high and very low temperatures. Their chemical stability eliminates any risk of contamination of the bearing by the lubricant, important for the machinery used in many branches of industry, primarily in the food, pharmaceutical and electronic industries.

A useful property of gases is that their viscosities increase with temperature, whereas the opposite is true of liquids, resulting in load – carrying capacity of gas – lubricated bearings

Main functions required	Qualities required
Reduce frictional resistance	<ul style="list-style-type: none"> <li>• Viscosity not too high to provide good pumpability or to cause undue cracking resistance.</li> <li>• Minimum viscosity without risk of metal to metal contact under the varying condition of temperatures, speed and load.</li> <li>• Sufficiently high viscosity a high temperature; good lubrication property outside the hydrodynamic condition.</li> <li>• Anti-seizure properties, especially during the run-in period.</li> </ul>
Protect against corrosion and wear	<ul style="list-style-type: none"> <li>• Must protect metallic surface against corrosive action of fuel decomposition product (wear, SO<sub>2</sub>, HBr, HCl, etc.)</li> <li>• Must resist degradation (resist oxidation and have a good thermal stability).</li> <li>• Must counteract action of fuel and lubricant decomposition product at high temperatures, especially on non-ferrous metals.</li> <li>• By intervention in the friction mechanism, must reduce the consequences of unavoidable metal-to-metal contact.</li> <li>• Must resist deposit formations which would affect lubrication (detergency or dispersancy action).</li> <li>• Must contribute to the elimination of dust and other pollutants (dispersancy action).</li> </ul>
Assist sealing	<ul style="list-style-type: none"> <li>• Must have sufficient viscosity at high temperature and low volatility.</li> <li>• Must limit wear.</li> <li>• Must not contribute to formation of deposits and fight against such formation.</li> </ul>
Contribute to cooling	<ul style="list-style-type: none"> <li>• Must good and thermal stability and oxidation resistance.</li> <li>• Must have low volatility.</li> <li>• Viscosity must not be too high.</li> </ul>
Facilitate the suspension and eliminate undesirable products	<ul style="list-style-type: none"> <li>• Must be able to maintain in fine solid material whatever the temperature and physical and chemical condition.</li> </ul>

**Table 1.** Function and qualities required for engine oils.

increasing with temperature. However, the relatively low viscosity of gases generally limits the load-carrying capacity of self-acting, aerodynamic bearings to 15-20kPa. It is possible to achieve better bearing performance with gaseous lubricants than with liquid lubricants due to the very low viscosity of the gases which results in smaller heat generation by internal friction. In some cases, such as in foil air bearings, sliding contact occurs during stops and starts [14], therefore solid lubricants such as PTFE are used to reduce friction.

#### 1.3.4.2. Liquid lubricants

**Mineral oils:** As the hydrodynamic behaviour of plain bearings of plain bearings is totally dependent on the viscosity characteristics of the lubricant, typical liquid bearing lubricants are



straight mineral oil raffinates of various viscosity grades. The viscosity grade required is dependent upon bearing speed, oil temperature and load. table (2) provides a general guideline to selecting the correct ISO viscosity grade. The ISO grade number indicated is the preferred grade for the speed and temperature range. ISO 68- and 100- Grade oils are commonly used in indoor, heated applications, with 32- grade oils being used for high-speed, 10,000 rpm, units and some outdoor low temperature applications. The higher the bearing speed, the lower the oil viscosity required and also that the higher the unit operating temperature, the higher the oil viscosity required. If vibration or minor shock loading is possible, a higher grade of oil than the one indicated in table (2) should be considered.

Bearing Speed (rpm)	Bearing / Oil Temperature (°C)			
	60	75	90	
0-50	60	75	90	
300-1,500	-	68	100-150	-
1,800	32	32 - 46	68 - 100	100
3,600	32	32	46 - 68	68 - 100
10,000	32	32	32	32-46

**Table 2.** Plain Bearing ISO viscosity grade selection

Other methods for determining the viscosity grade required in an application are to apply minimum and optimum viscosity criteria to a viscosity – temperature plot. A third and more complex method is to calculate the oil viscosity needed to obtain a satisfactory oil film thickness.

The lubrication of bearings for machine tools usually requires mineral oils of ISO VG 46 or 68. for fast – running grinding spindles with plain bearings, mineral oils of ISO VG 5 or 7 are required, dependent on bearing clearance and speed. Bearings operating under high loads need lubricants of ISO VG 68 or 100. the service life of the bearing can be increased if the viscosity of the selected liquid lubricant at operating temperature exceeds the calculated optimum viscosity.

On the other hand, increased viscosity also increases operating temperature. In practice, therefore, the extent to which lubrication can be improved in this way is often limited. The chemical compositions of these oils differ from typical base oils in that they contain somewhat more aromatic hydrocarbons and heterocyclic compounds, which act as natural oxidation inhibitors. An increased viscosity for oils derived from the same crude oil does not significantly change their chemical composition; the difference generally lies with the increasing chain length of the paraffinic hydrocarbons, mostly isoparaffins, and in the aliphatic substituents of naphthenic and aromatic rings, together with a slight increase in the number of naphthenic and aromatic rings. More highly refined mineral oils and oxidation inhibitors are used for

applications where higher temperatures or longer service periods require better ageing stabilities.

**Synthetic lubricants:** in practice, every synthetic oil of adequate viscosity and good viscosity-temperature behavior can be used as a bearing lubricant, e.g. polyglycols are very good bearing lubricants for mills and calenders in the rubber, plastics, textile and paper industries. However, in most cases the synthetic oils specifically developed for lubricating particular equipment are also used to lubricate its bearings. Although synthetic oils do not form a lubricant film under pressure as well as mineral oils and may not be effective bearing lubricants despite their higher temperature viscosity.

**Biodegradable products:** Biodegradable products of vegetable or animal origin are also considered for liquid lubrication, e.g. the effects of sunflower oil added to base oil on the performance of journal bearings. The use of vegetable oils as lubricants is likely to increase due to environmental and government requirements and is becoming increasingly important.

#### 1.3.4.3. *Solid lubricants*

General description: bearings used under vacuum, at very high temperatures or under very high radiation cannot be lubricated by liquid lubricants or greases. For these and many other cases, solid lubricants are used, deemed to be any solid material used to reduce friction and wear between two moving surfaces.

In general, the solid material is interposed as a film between sliding and /or rolling surfaces. Simply stated, an adequate solid material is required for the special lubrication requirements of extreme operating conditions, such as very high or very low temperatures over a wide range, e.g. -200 to 850°C, and corrosive atmospheres. Such materials normally have a layered crystalline structure which ensures low shear strength, thereby minimizing friction. The shear strength between the crystalline layers is weak and sets up a low and sets up a low friction mechanism by slippage of the crystalline layers under low shearing forces. Examples of layer-lattice solids are molybdenum disulphide, graphite, boron nitride, cadmium iodide and borax. Solid lubricants are used mainly in the form of powders or as bonded solid films.

A good solid film lubricant has strong adhesion to the bearing substrate material, full surface coverage and good malleability. It should also be chemically stable and prevent corrosion, taking into account operational and environmental conditions. Many solid film lubricants have poor wear resistance, since any breaks in the film are not self-healing, in contrast to the surface coating formed by a liquid lubricant. Advanced solid film lubricants perform reliably in many specific applications and much experience has been gained to better understand their limitations. The most commonly used disulphide, graphite, polytetrafluoroethylene propylene.

Another group of materials, the self-lubricated materials, are related to solid lubricants and are particularly important for bearings. Their self-lubricating characteristics eliminate the need of grease or other lubrication and gave improved performance under high temperature conditions. Graphalloy (Graphite/metal) alloys make use of special properties of graphite, the structure of which can be compared to a deck of cards with individual layers able to easily slide off. This phenomenon gives the material a self lubricating ability matched by few other

materials and allows for the elimination of grease or oil that would evaporate, congeal or solidify, causing premature failure. The graphite matrix can be filled with a variety of embedded lubricants to enhance chemical, mechanical and tribological properties to give a constant, low friction coefficient rather than just a surface layer, helping to protect against catastrophic failure. Lubrication is maintained during linear motion where lubricant is not drawn out and dust is not pulled in.

A recent development in solid bearing lubricants is micro-porous polymeric lubricants, MPL, where a polymer containing a continuous microporous network has oil contained within the pores, which may include appropriate additives [14]. The oil content in the polymer can be more than 50% by weight and the microporous polymer acts as a sponge, releasing and absorbing oil when necessary.

### 1.3.5. Lubricant impurities and contaminants

#### • Water Content

Water content (ASTM D95, D1744, D1533, and D96) is the amount of water present in the lubricant. It can be expressed as parts per million, percent by volume or percent by weight. It can be measured by centrifuging, distillation and voltametry. The most popular, although least accurate, method of water content assessment is the centrifuge test. In this method a 50% mixture of oil and solvent is centrifuged at a specified speed until the volumes of water and sediment observed are stable. Apart from water, solids and other solubles are also separated and the results obtained do not correlate well with those obtained by the other two methods. The distillation method is a little more accurate and involves distillation of oil mixed with xylene. Any water present in the sample condenses in a graduated receiver. Voltametry method is the most accurate. It employs electrometric titration, giving the water concentration in parts per million.

Corrosion and oxidation behaviour of lubricants is critically related to water content. An oil mixed with water gives an emulsion. An emulsion has a much lower load carrying capacity than pure oil and lubricant failure followed by damage to the operating surfaces can result. In general, in applications such as turbine oil systems, the limit on water content is 0.2% and for hydraulic systems 0.1%. In dielectric systems excessive water content has a significant effect on dielectric breakdown. Usually the water content in such systems should be kept below 35 [ppm].

#### • Sulphur Content

Sulphur content (ASTM D1266, D129, D1662) is the amount of sulphur present in an oil. It can have some beneficial, as well as some detrimental, effects on operating machinery. Sulphur is a very good boundary agent, which can effectively operate under extreme conditions of pressure and temperature. On the other hand, it is very corrosive. A commonly used technique for the determination of sulphur content is the bomb oxidation technique. It involves the ignition and combustion of a small oil sample under pressurised oxygen. The sulphur from the products of combustion is extracted and weighed.

- **Ash Content**

There is some quantity of noncombustible material present in a lubricant which can be determined by measuring the amount of ash remaining after combustion of the oil (ASTM D482, D874). The contaminants may be wear products, solid decomposition products from a fuel or lubricant, atmospheric dust entering through a filter, etc. Some of these contaminants are removed by an oil filter but some settle into the oil. To determine the amount of contaminant, the oil sample is burned in a specially designed vessel. The residue that remains is then ashed in a high temperature muffle furnace and the result displayed as a percentage of the original sample. The ash content is used as a means of monitoring oils for undesirable impurities and sometimes additives. In used oils it can also indicate contaminants such as dirt, wear products, etc.

- **Chlorine Content**

The amount of chlorine in a lubricant should be at an optimum level. Excess chlorine causes corrosion whereas an insufficient amount of chlorine may cause wear and frictional losses to increase. Chlorine content (ASTM D808, D1317) can be determined either by a bomb test which provides the gravimetric evaluation or by a volumetric test which gives chlorine content, after reacting with sodium metal to produce sodium chloride, then titrating with silver nitride [14].

## 2. Conclusion

1. The technology of lubrication has been used from the ancient times, from the pyramid building where massive rock slabs are moved, up to present modern times.
2. The main purpose of lubrication is to reduce friction and wear in bearings or sliding components to prevent premature failure.
3. Adequate lubrication also helps to prevent foreign material from entering the bearings and guards against corrosion and rusting. Satisfactory bearing performance can be achieved by adopting the lubricating method that is most suitable for the particular application and operating conditions
4. A lubricant prevents the direct contact of rubbing surfaces and thus reduces wear. It keeps the surface of metals clean. Lubricants can also act as coolants by removing heat effects and also prevent rusting and deposition of solids on close fitting parts.
5. lubricant is consisting of either oil or grease. Most grease is from animal fats or vegetable lard.
6. Lubricating oils are made from the more viscous portion of the crude oil which remains after removal by distillation of the gas oil and lighter fraction
7. There are three major types of lubricants: Gaseous lubricants e.g. air, helium, Liquid lubricants e.g. oils, water and Solid lubricants e.g. graphite, grease, teflon, molybdenum disulphide etc. Liquid lubricant is the most commonly used lubricant because of its wide

range of possible applications while gaseous and solid lubricants are recommended in special applications.

8. Lubricants do not persist working without additives.
9. Additives are chemical compounds added to lubricating oils to impart specific properties to the finished oils. Some additives impart new and useful properties to the lubricant; some enhance properties already present, while some act to reduce the rate at which undesirable changes take place in product during its service.

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