Lubricant

A **lubricant** is a substance, usually organic, introduced to reduce friction between surfaces in mutual contact, which ultimately reduces the heat generated when the surfaces move. It may also have the function of transmitting forces, transporting foreign particles, or heating or cooling the surfaces. The property of reducing friction is known as lubricity.

Selecting the proper lubricant, along with careful maintenance of that lubricant, is essential to ensure adequate protection to any machine.
Oil will reduce the friction between two sliding surfaces by creating a protective film. It also assists with heat dissipation by spreading out the heat in the system.

Functions of a Lubricant

1. Reduced friction

Lubricant forms an oil film on the surface of metals, converting solid friction into liquid friction to reduce friction, which is the most common and essential function of lubricants. Reduced friction prevents heating and abrasion on the friction surface.

2. Cooling

Friction certainly causes heating on the area and more heat is produced if metals rub against each other. Therefore the heat needs to be absorbed or released; otherwise the system is destroyed or deformed. To prevent it, lubricants are applied. Especially cooling is critical to rolling oils, cutting oils, and lubricating oils used in an internal combustion engine.

3. Load balancing

Components like gear or bearing are limitedly contacted on a certain line or surface, so load can be increased in a moment, making systems at risk for being destroyed and attached to each other. Therefore the application of lubricant protects systems against increased load by forming an oil film to disperse load in the film.

4. Cleaning

Long-term use of systems may lead to corrosion or aging, producing foreign substances. In case of using hydraulic oil and gear oil, sediments accumulate such as sludge from deterioration. Especially an internal combustion engine generates too much soot, so that it is likely to shorten the life of systems and make them fail to work properly. Therefore lubricant itself cleans out foreign substances like soap.

5. Sealing

Sealing is to close the macro-gap between systems. Sealing the space between pistons and cylinders in the internal combustion engines or air compressors blocks the leakage of combustion gas and the inflow of external foreign substances to maintain the defined internal pressure and protect the system. Especially in the hydraulic system, lubricants itself serve to prevent the leakage by creating a hydraulic film.

6. Rust prevention

Metals produce rust when contacting water and oxygen. However, rust formation can be controlled and the system lifetime is extended if the surface of metals is coated with lubricating film.

CLASSIFICATION OF LUBRICANTS

Lubricants can be broadly classified, on the basis of their physical state, as follows: (1) Liquid lubricants or lubricating oils; (2) Semi-solid lubricants or greases, and (3) Solid lubricants.

1 Lubricating oils

Lubricating oils reduce friction and wear between two moving/sliding metallic surfaces by

providing a continuous fluid film in-between them. They also act as:
(a) cooling medium; (b) sealing agent, and (c) corrosion preventer. Good lubricating oil must possess: (a) low pressure (or high boiling point), (b) adequate viscosity for particular service conditions, (c) low freezing point, (d) high oxidation resistance. (e) Heat stability, (f) non-corrosive properties, (g) stability to decomposition at the operating temperatures. Lubricating oils are further classified as:

1. **Animal and vegetable oils:** Before the advent of the petroleum industry, oils of the vegetable and animal origins were the most commonly used lubricants. They posses good oiliness (a property by virtue of which the oil sticks to the surface of machine parts, even under high temperatures and heavy loads).
   However, they: (i) are costly, (ii) undergo oxidation easily forming gummy and acidic products and get thickened on coming in contact with air, (iii) have some tendency to hydrolyze, when allowed to remain in contact with moist-air or aqueous medium. So at present, they are rarely used as such. Actually, they are used as "blending agent" with other ' lubricating oils (like mineral oils) to produce desired effects in the latter.

2. **Mineral or petroleum oils**: Mineral or petroleum oils are obtained by distillation of petroleum. The length of the hydrocarbon chain in petroleum oils varies between about 12to 50 carbon atoms. The shorter-chain oils have lower viscosity than the longer-chain hydrocarbons. These are the most widely used lubricants, because they are; (i) cheap, (ii) available in abundance, and (iii) quite stable under service conditions. However, they possess poor oiliness as compared to that of animal and vegetable oils. Tile oiliness of petroleum oils can be increased by the addition of high molecular weight compounds like oleic acid, stearic acid, etc.

   Purification : Crude liquid petroleum oils contain lot of impurities (like wax, asphalt,etc.) and consequently, they have to be thoroughly purified before being put to use.(i) The wax, if not removed, raises the pour-point and renders the lubricating oil unfit for use at low temperatures. (ii) Certain constituents get easily oxidized under working conditions and cause sludge formation. (iii) Some constituents mainly asphalt, undergo decomposition at higher temperatures, causing carbon deposition and sludge formation. A number of processes are used for removing these unwanted impurities by using Dewaxing or acid refining or by solvent refining.

3. **Blended oils**: No single oil saves as the most satisfactory lubricant for many of the modern machineries. Typical properties of petroleum oils are improved by incorporating specific additives. These so-called 'blended oils' give desired lubricating properties, required for particular machinery. The following additives are employed

(i) Oiliness-carriers: Oiliness of a lubricant can be increased by addition of an oiliness-carrier like vegetable oils (e.g., coconut oil, castor oil) and fatty acids (like palmitic acid, stearic acid, oleic acid. etc.).

(ii) Extreme-pressure additives: Under extreme-pressure, a thick film of oil is difficult to maintain, and the oil need to have a high oiliness. Besides improving oiliness directly, high-pressure additives are used. .these additives contain certain materials which are absorbed on the metal surface or react chemically with metal, producing a surface a layer of low shear-strength on the metal surface, thereby preventing the tearing up of the metal. Another property of high-pressure additives is that they react, at high temperature on metal surfaces, forming surface alloys so as to prevent the welding together of the rubbing parts under severe operating conditions.

The main substances added for high-pressure lubrication are :(a) fatty ester, acids, etc., which form oxide film with the metal surface ; (i) organic materials, which contain sulphur ; (c) organic chlorine compounds ; (d) organic phosphorus compounds. High-pressure lubricants also contain some lead in order to produce thin film of lead sulphide and other lead compounds on the surfaces of machines like gear teeth.

(iii) Pour-point depressing additives used are phenol and certain condensation products of chlorinated wax with naphthalene. These prevent the separation of wax from the oil.

(iv) Viscosity-index improvers are certain high molecular weight compounds like hexanol.

(v) Thickeners such as polystyrene are materials usually of molecular weight between 300 and 3,000. They are added in order to give the lubricating oil a higher viscosity.

(vi) Antioxidants or inhibitors, when added to oil, retard oxidation of oil by getting them-selves preferentially oxidized. They are particularly added in lubricants used in internal combustion engines, turbines, etc., where oxidation of oil is a serious problem. The antioxidants are aromatic, phenolic or amino compounds.

(vii) Corrosion preventers are organic compounds of phosphorus or antimony. They protect the metal from corrosion by preventing contact between the metal surfaces and the corrosive substances.

(viii) Abrasion inhibitors like tricresyl phosphate.

(ix) Antifoaming agents (like glycols and glycerol) help in decreasing foam formation.

(x) Emulsifiers such as sodium salts of sulphonic acid.

(xi) Deposit inhibitors are detergents such as the salts of phenol and carboxylic acids. Deposits are formed in internal combustion engine, due to imperfect combustion. Such additive disperses and cleans the deposits.

2 GREASES OR SEMI-SOLID LUBRICANTS

Lubricating grease is a semi - solid, consisting of a soap dispersed throughout liquid lubricating oil. The liquid lubricant may be petroleum oil or even synthetic oil and it may contain any of the additives for specific requirements. Greases are prepared by saponification of fat (such as tallow or fatty acid) with alkali (like lime, caustic soda, etc.), followed by adding hot lubricating oil while under agitation. The total amount of

Mineral oil added determines the consistency of the finished grease. The structure of lubricating greases is that of a gel. Soaps are gelling agents, which give an interconnected structure (held together by intermolecular forces) containing the added oil. At high temperatures, the soap dissolves in the oil, whereupon the interconnected structures cease to exist and the grease liquefies. Consistency of greases may vary from a heavy viscous liquid to the of a stiff solid mass. To improve the heat-resistance of grease, inorganic solid thickening agents (like finely divided clay, bentonite, colloidal silica, carbon black, etc.) are added.

Greases have higher shear or frictional resistance than oils and, therefore, can support much heavier loads at lower speeds. They also do not require as much attention unlike the lubricating liquids. But greases have a tendency to separate into oils and soaps. Grease are used : (i) in situations where oil cannot remain in place, due to high load, low speed, intermittent operation, sudden jerks, etc. e.g. rail axle boxes, (ii) in bearing and gears that work at high temperatures ; (iii) in situations where bearing needs to be sealed against entry of dust, dirt, grit or moisture, because greases are less liable to contamination by these ; (iv) in situations where dripping or spurting of oil is undesirable, because unlike oils, greases if used do not splash or drip over articles being prepared by the machine. For example, in machines preparing paper, textiles, edible articles, etc.

The main function of soap is thickening agent so that grease sticks firmly to the metal surfaces. However, the nature of the soap decides: (a) the temperature up to which the grease can be used; (b) its consistency; (c) Its water and oxidation resistance.

So, greases are classified after the soap used in their manufacture. Important greases are:

(i) Calcium-based greases or cup-greases are emulsions of petroleum oils with calcium soaps. They are, generally, prepared by adding requisite amount of calcium hydroxide to hot oil (like tallow) while under agitation. These greases are the cheapest and most commonly used. They are insoluble in water, so water resistant. However, they are satisfactory for use at low temperatures, because above 80oC, oil and soap begins to separate out.

(ii) Soda-base greases are petroleum oils, thickened by mixing sodium soaps. They are not water resistant, because the sodium soap content is soluble in water. However, they can be used up to 175oC. They are suitable for use in ball bearings, where the lubricant gets heated due to friction.

(iii) Lithium-based greases are petroleum oils, thickened by mixing lithium soaps. They are water-resistant and suitable for use at low temperatures [up to 15oC] only.

(iv) Axle greases are very cheap resin greases, prepared by adding lime (or any heavy metal hydroxide) to resin and fatty oils. The mixture is thoroughly mixed and allowed to stand, when grease floats as stiff mass. Filters (like talc and mica) are also added to them. They are water-resistant and suitable for less delicate equipments working under high loads and at low speeds. Besides the above, there are greases prepared by dispersing solids (like graphite, soapstone) in mineral oil. These are mostly used in rail axle boxes, machine bearings, tractors rollers, wires ropes etc.

3 SOLID LUBRICANTS

Solid lubricants are used where:

(i) operating conditions are such that a lubricating film cannot be secured by use of lubricating oils or greases;

(ii) contamination (by the entry of dust or grit particles) of lubricating oil or grease is unacceptable,

(iii) the operating temperatures or load is too high even for a semi-solid lubricant to remain in position;

(iv) Combustible lubricants must be avoided.

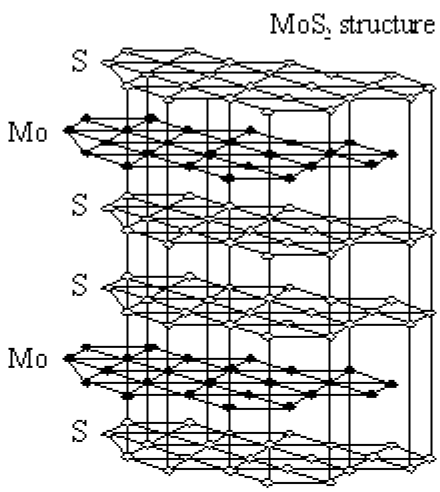
The two most usual solid lubricants employed are graphite and molybdenum disulphide. Graphite consists of a multitude of flat plates, one atom thick, which are held together by only weak bonds, so that the force to shear the crystals parallel to the layers is low. Consequently, the parallel layers slide over one another easily. Usually, some organic substances are mixed solid lubricants so that they may stick firmly to the metal surface.

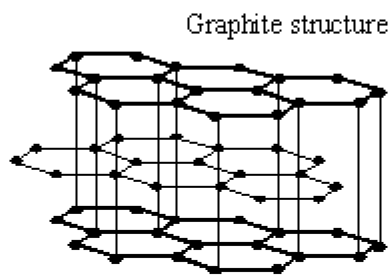
On the other hand, molybdenum disulphide has a sandwich like structure in which a layer of Mo atoms lies between two layers of S atoms. Poor interlaminar attraction is responsible for low shear strength in a direction parallel to the layers. Solids lubricants are used either in the dry powder or mixed with water or oil. The solids fill up the low spots in the surfaces of moving parts and form solid films, which have low frictional resistance. The usual coefficient of friction between solid lubricants is between 0.005 and 0.01.

(a) Graphite is the most widely used of all solid lubricants. It is very soapy to touch, non-inflammable and not oxidized in air below 375oC. In the absence of air, it can be used upto very much higher temperatures. Graphite is used either in powdered form or as suspension. Suspension of graphite in oil or water is brought about with the help of an emulsifying agent like tannin. When graphite is dispersed in oil, it is called 'oildag' and when it is dispersed in water; it is called 'aquadag'. Oildag is found particularly useful in internal combustion engines, because it forms a film between the piston rings and the cylinder and gives a tight-fit contact, thereby increasing compression. On the other hand, oildag is useful where a lubricant free from oil is needed. e.g., foodstuffs industry. Graphite is also mixed with greases to form graphite-greases, which are used at still higher temperatures.

Uses: As lubricant in air-compressors, lathes, general machine-shop works, foodstuffs industry, railway track-joints, open gears, chains, cast iron bearings, internal combustion engine, etc.

(b) Molybdenum disulphide possesses very low coefficient of friction and is stable in air up to 400oC. Its fine powder may be sprinkled on surfaces sliding at high velocities, when it fills low spots in metal surfaces, forming its film. It is also used along with solvents and in greases. Besides the more important graphite and molybdenum disulphide, other substances like soapstone, talc, mica, etc., are also used as solid lubricants.





3 SYNTHETIC LUBRICANTS

Petroleum-based lubricants can be used under abnormal conditions like extremely high

temperature, chemically reactive atmosphere, etc. By employing certain specific additives. However, synthetic lubricants have been developed which alone can meet the most drastic and severe conditions such as those existing in aircraft engines, in which the same lubricant may have to use in the temperature range of -50oC and 250oC. Such a lubricant should possess low freezing point, high viscosity-index and also should be non-inflammable.

Modern synthetic lubricants possess, in general, the following distinguishing characteristics: (1) non-inflammable, (ii) high flash points, (iii) high thermal stability at high operating temperatures, (iv) high viscosity-index, (v) chemical stability, etc. Important synthetic lubricants are given below.

(1) Polymerized hydrocarbons like polyethylene, polypropylene, polybutylene in the molecular weight range of 500 to 50,000 are residue-free, light in color, free from non-hydrocarbon impurities, chemically non-reactive and high temperature lubricants.

(2) Polyglycols and related compounds like polyethylene glycol, polypropylene glycol, polyglycidyl ethers, and higher polyalkylene oxides can be used as water-soluble as well as water-insoluble lubricants in rubber bearings and joints. Polyglycidyl ethers and higher polyalkylene oxides are water-insoluble, but they can absorb a considerable amount of water. Their viscosity-index is high and these are used in roller bearings of sheet glass manufacturing machines. It may be pointed that polyethylene oxides undergo thermal decomposition (at high temperature) to evolve volatile oxidisable products, so these are not useful as lubricants at high temperatures.

(3) Organic amines, imines and amides are good synthetic lubricants, since they possess low pour-points and high viscosity-index. They can be used under temperature conditions of -50oC to 250oC

(4) Silicones are very good synthetic lubricants, because are not oxidized below 200oC and possess high viscosity-index. These are frequently used for low temperature lubrication purposes. It may be pointed have that silicones are oxidized quickly above 200oC and undergo cracking process at about 230oC, so they are not employed for high temperature applications.

(5) Fluorocarbons are not decomposed by heat, not easily oxidizable and chemically inert and resistant to chemicals, except molten sodium.

PROPERTIES OF LUBRICATING OILS

Viscosity: - Viscosity is the property of a liquid or fluid by virtue of which it offers resistance to its own flow. A liquid in a state of steady flow on a surface may be supposed to consist of a series of parallel layers moving one above the other. Any two layers will move with different velocities; top layer move faster than the next lower layer, due to viscous drag (i.e., internal friction).

Viscosity is the most important single property of any lubricating oil, because it is the main determinant of the operating characteristics of the lubricant: (i) if the viscosity of the oil is too low. a liquid oil film cannot be maintained between two mooing/sliding surfaces, and consequently, excessive wear will take place. On the other hand, (ii) If the viscosity is too high, excessive friction will result. The viscosity is temperature depending property.

Measurement of viscosity of lubricating oil is made with the help of an apparatus called

the viscometer. In a viscometer, a fixed volume of the liquid is allowed to flow, from a given height, through a standard capillary tube under its own weight and the time of flow in seconds is noted. The time in seconds is proportional to true viscosity. Oswald viscometer, Redwood viscometers, Saybolt viscometer are used, for measuring viscosities of lubricating oils. The results are expressed in terms of time taken by oil to flow through particular instrument. For example, if time of flow of oil through Redwood viscometer at 20oC is 100 seconds, then its viscosity is 100 Redwood seconds at 20oC. Now a day Brookfield viscometer is commonly used for determining the viscosity of lubricating oils.

Viscosity index: - The viscosity index (VI) is an arbitrary, unitless measure of the change of viscosity with temperature, mostly used to characterize the viscosity-temperature behavior of lubricating oils. The lower the VI, the more the viscosity is affected by changes in temperature. The VI was originally measured on a scale from 0 to 100; however, advancements in lubrication science have led to the development of oils with much higher VIs.

The viscosity of a lubricant is closely related to its ability to reduce friction in solid body contacts. Generally, the least viscous lubricant which still forces the two moving surfaces apart to achieve "fluid bearing" conditions is desired. If the lubricant is too viscous, it will require a large amount of energy to move (as in honey); if it is too thin, the surfaces will come in contact and friction will increase.

The viscosity index can be calculated using the following formula;

$$\mathrm{VI} = 100\frac{L-U}{L-H}$$

$$VI = (L - U)/(L - H) * 100$$

Flash and fire-points: Flash point is the lowest temperature at which the oil lubricant gives off enough vapours that ignite for a moment, when a tiny flame is brought near it; while fire-point is ' the lowest temperature at which the vapours of the oil burn continuously for at least five seconds, when a tiny flame is brought near it. In most cases, the fire-points are 5 to 40o higher than the flash-points. The flash and fire-points do not have any bearing with the lubricating property of the oil, but these are important when oil is exposed to high temperature service. A good lubricant should have flash point at least above the temperature at which it is to be used. These safeguards against risks of fire, during the use of lubricant. The flash and fire-points are, usually, determined by using Pensky-Marten's apparatus.

Cloud and pour-points: When oil is cooled slowly, the temperature at which it becomes cloudy or hazy in appearance, is called its cloud-point while the temperature at which the oil ceases to flow or pour, is called its pour-point. Cloud and pour-points indicate the suitability of lubricants in cold conditions. Lubricant used in a machine working at low temperatures should possess low pour-point; otherwise solidification of lubricant will cause jamming of the machine. It has been found that presence of waxes in the lubricating oil raise the pout-point. Determination of pour-point is carried out with help of pour-point apparatus.

Steam emulsion number (S.E.N.)

Emulsification: It is the property of oils to get intimately mixed with water, forming a mixture, called emulsion. Certain oils form emulsions with water easily. Emulsions have a tendency to collect dirt, grit,. Foreign matter etc., thereby causing abrasion and wearing out of the lubricated parts of the machinery. So, good lubricating oil should form an emulsion with water, which breaks off quickly. The tendency of lubricant-water emulsion to break is determined by A.S.T.M. test. In this, 20 ml of oil is taken in a test-tube and steam at 100oC is bubbled through it, till the temperature is raised to 90oC. The tube is then placed in a bath maintained at 90oC and the time in seconds is noted, when the oil and water separate out in distinct layers.

(S.E.N.): The time in second in which oil and water emulsion separates out in distinct layers, is called steam emulsion number (S.E.N.). A goad lubricant should possess a low steam emulsion number.

Carbon residue: Lubricating oils contain high percentage of carbon in combined form. On heating, they decompose depositing a certain amount of carbon. The deposition of such carbon in machine is intolerable, particularly in inert combustion engines and air-compressors. A good lubricant should deposit least amount of the carbon in use. The estimation of carbon residue is, generally, carried out by Conradson method.

Aniline point: Aniline point of oil is defined as the minimum equilibrium solution temperature. For equal volume of aniline and oil sample. Aniline point gives an indication of the possible deterioration of oil in contact with rubber sealing’s, pickings, etc. Aromatic hydrocarbons have a tendency to dissolve natural rubber and certain types of synthetic rubbers. Consequently, low aromatic content in the lubricants is desirable. A higher aniline-point means a higher percentage of paraffinic hydrocarbons and hence, a lower percentage of aromatic hydrocarbons.

Aniline point is determined by mixing mechanically equal volumes of the oil sample and aniline in a test-tube. The mixture is heated, till homogeneous solution is obtained. Then, the tube is allowed to cool at a controlled rate. The temperature at which the two phases (oil and aniline) separate out is recorded at the aniline point.

Neutralization number: Neutralization number refers to the determination of acidic or basic constituents of an oil. Determination of acidic constituents is more common and it is referred to as Acid number or value, which is defined as the number of milligrams of KOH required to neutralize the free acids in 1 g of the oil.
Generally, free acids are not present in the lubricants, unless refined in faulty manner. Lubricating oil should possess acid value less than 0.1. Value greater than 0.1 indicates that oil has been oxidized. This will, consequently, lead to corrosion, besides gum and sludge formation.

Types of Lubrication Mechanism/ Mechanism of Lubrication

Considering the nature of motion between moving or sliding surfaces, there are different types of mechanisms by which the lubrication is done. They are:

- Hydrodynamic lubrication or thick film lubrication
- Boundary lubrication or thin film lubrication
- Extreme pressure lubrication

Hydrodynamic Lubrication or Thick Film Lubrication

Hydrodynamic lubrication is said to exist when the moving surfaces are separated by the pressure of a continuous unbroken film or layer of lubrication. In this type of lubrication, the load is taken completely by the oil film.

The basis of hydrodynamic lubrication is the formation of an oil wedge. When the journal rotates, it creates an oil taper or wedge between the two surfaces, and the pressure build up with the oil film supports the load.

Hydrodynamic lubrication depends on the relative speed between the surfaces, oil viscosity, load, and clearance between the moving or sliding surfaces.

In hydrodynamic lubrication the lube oil film thickness is greater than outlet, pressure at the inlet increases quickly, remains fairly steady having a maximum value a little to the outside of the bearing center line, and then decreases quickly to zero at the outlet.

<u>Application of hydrodynamic lubrication</u>

- Delicate instruments.
- Light machines like watches, clocks, guns, sewing machines.
- Scientific instruments.
- Large plain bearings like pedestal bearings, main bearing of diesel engines.

Hydrocarbon oils are considered to be satisfactory lubrication for fluid film lubrication. In order to maintain the viscosity of the oil in all seasons of the year, ordinary hydrocarbon lubricants are blended with selected long chain polymers.

Boundary Lubrication or Thin Film Lubrication

Boundary lubrication exists when the operating condition are such that it is not possible to establish a full fluid condition, particularly at low relative speeds between the moving or sliding surfaces.

The oil film thickness may be reduced to such a degree that metal to metal contact occurs between the moving surfaces. The oil film thickness is so small that oiliness becomes predominant for boundary lubrication.

Boundary lubrication happens when

- A shaft starts moving from rest.
- The speed is very low.
- The load is very high.
- Viscosity of the lubricant is too low.

Examples for boundary lubrication:

- Guide and guide shoe in two stroke engine.
- Lubrication of the journal bearing in diesel engines (mainly during starting and stopping of engine).
- Piston rings and when cylinder liner is at TDC and BDC position when the piston direction changes and if the relative speed is very slow.

Extreme pressure lubrication

When the moving or sliding surfaces are under very high pressure and speed, a high local temperature is attained. Under such condition, liquid lubricant fails to stick to the moving parts and may decompose and even vaporize. To meet this extreme pressure condition, special additives are added to the minerals oils. These are called “extreme pressure lubrication." These additives form on the metal surfaces more durable films capable of withstanding high loads and high temperature. Additives are organic compounds like chlorine (as in chlorinated esters), sulphur (as in sulphurized oils), and phosphorus (as in tricresyl phosphate).