

*"Development of high precision and high speed machineries is due to the advancement in lubricant technology".*

## 18.1 FRICTION AND WEAR

All material surfaces, no matter how smooth they are, show many irregularities in the form of peaks (or **asperities**) and valleys, which are large when considered on a molecular scale (see Fig. 1). When two solid surfaces are pressed over each other, a real contact between these surfaces occurs only at a **limited number of asperities**, i.e., peaks of the upper surface are in contact with peaks of the lower surface. Even under small loads, the local pressure at the asperities may be

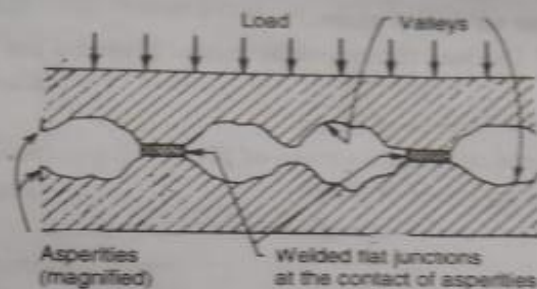


Fig. 1. Contact between asperities get flattened under high local load.

sufficiently great to cause appreciable *deformation* in ductile metals. This causes the formation of *weld junctions*, between the asperities. It is these junction areas that carry all the load between the two surface. Thus, the *real or true area of contact* is only a **small fraction** of the *apparent contact area* between the two surfaces.

**Sliding friction** : If two materials of *different hardness* slide over one another, the peaks of the softer metal *get broken more easily* than the peaks of the

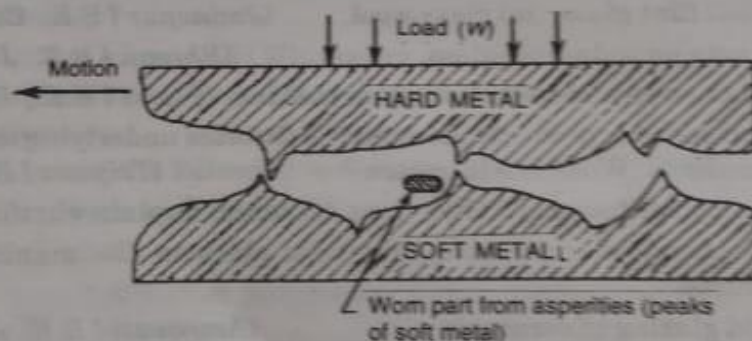


Fig. 2. Surface wear during sliding is due to shearing of asperities.

harder metals (see Fig. 2). The sliding friction may involve additional effects, such as : (a) **ploughing** (or cutting) out the softer material by the asperities of the **harder material**, and (b) the **interlocking** of the surface irregularities.

**Rolling friction** occurs when a loaded sphere or cylinder rolls over a flat surface of the other body. Generally, the 'coefficient of the rolling friction' is *very low as compared to the sliding friction*. On the other hand, the coefficient of sliding friction is *much larger for the static condition than for the kinetic condition*. Rolling friction is believed to be caused by *elastic deformation of the two surfaces as a result of the development of a contact area between a loaded sphere and a flat surface*. The rolling friction is, therefore, *not detectably affected by the presence of lubricants*. However, in practical ball bearings, there is always a certain amount of sliding occurring between the balls and the cages, which makes lubrication necessary.

**Frictional heats effects** : During a motion of the sliding surface, a considerable amount to **frictional heat is evolved at the rubbing surfaces**. This results in **high local temperature**, even under relatively light loads and speeds. This is because the liberated frictional heat is not uniformly distributed over the apparent contact area between the rubbing material, but it is *highly localized*, particularly at the surface asperities. This may even raise their temperature to melting point of the material, thereby accounting for the formation of **welded junctions**. The generation of the frictional heat is a self-accelerating process, since increased friction and adhesion at the localized hot spots increases the rate of heat evolution on continuous sliding, thereby leading to a large scale seizure or welding of the two surfaces.

## 18.2 LUBRICANTS

In all types of machines, the surfaces of moving or sliding or rolling parts rub against each other. Due to mutual rubbing of one part against another, a **resistance is offered to their movement**. This resistance, is known as **friction**. Friction causes a lot of wear and tear of surfaces of moving parts ; and a large amounts of energy are dissipated in the form of heat, thereby causing loss in the efficiency of machine. Moreover, the moving parts get heated up, damaged and even sometimes results in **seizure** (i.e., welding of two surfaces due to heat). The ill-effects of frictional resistance can be minimized by using a suitable substance, which forms a thin layer in-between the moving parts. Any substance introduced between two moving / sliding surfaces with a view to reduce the frictional resistance between them, is known as a **lubricant**. The main purpose of a lubricant is to keep the sliding / moving surfaces apart, so that frictional resistance and consequent destruction of material is minimized. The process of reducing frictional resistance between moving / sliding surfaces, by the introduction of lubricants in-between them, is called **lubrication**.

**Functions of a lubricant** : (1) It reduces surface deformation, wear and tear, because the direct contact between the rubbing surfaces is avoided. (2) It reduces loss of energy in the form heat. In other words, it acts as a coolant. (3) It reduces waste of energy, so that efficiency of machine is enhanced. (4) It reduces expansion of metal by local frictional heat. (5) It avoids seizure of moving surfaces, since the use of lubricant minimizes the liberation of frictional heat. (6) It avoids or reduces unsmooth relative motion of the moving / sliding parts. (7) It reduces the maintenance and running cost of the machine. (8) It also, sometimes, act as a seal. For example, lubricant used between piston and the cylinder wall of an internal combustion engine acts as a seal, thereby preventing also the leakage of gases under high pressure from the cylinder.

## 18.3 MECHANISM OF LUBRICATION

There are mainly *three* types of mechanism by which lubrication is done :

(1) **Fluid-film or thick-film or hydrodynamic lubrication** : In this, the moving/sliding surfaces are separated from each other by a thick-film of fluid (at least  $1,000 \text{ \AA}$  thick ), so that direct surface-to surface contact and welding of junctions

rarely occurs. The lubricant film covers / fills the irregularities of the sliding / moving surfaces and forms a thick layer in-between them, so that there no direct contact between the material surfaces [see Fig. 3 (a)]. This consequently reduces wear. The resistance to movement of sliding / moving parts is only due to the internal resistance between the particles of the lubricant moving over each other. Therefore, the

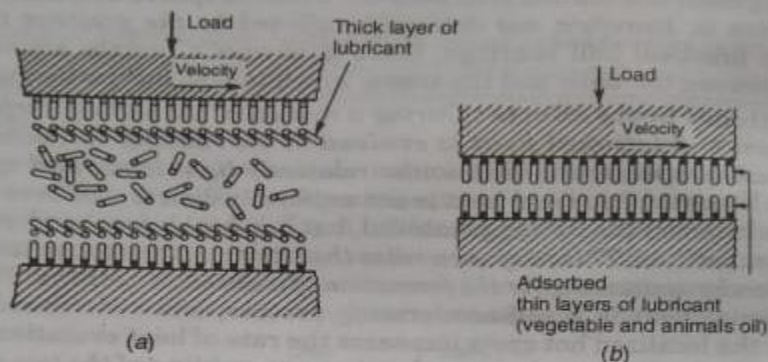


Fig. 3. (a) Fluid-film lubrication ; (b) boundary lubrication.

lubricant chosen should have the **minimum viscosity** under working conditions and at the same time, it should **remain in place and separate the surfaces**. In such a system, friction depends on the **viscosity, thickness of the lubricant, the relative velocity and area of the moving / sliding surfaces**. The coefficient of friction in such cases is as low as 0.001 to 0.03. Hydrodynamic friction occurs in the case of a shaft running at a fair speed as well as in well-lubricated bearing with not too high load. In a *journal bearing* (see Fig. 4), a film of the lubricating oil covers the irregularities of shaft as well as the bearing surfaces ; and the **metal surfaces do not come into direct contact with each other**. Thus, the resistance to movement is only due to the **internal resistance of the lubricant**. Delicate instruments, light machines like watches, clocks, guns, sewing machines, scientific instruments, etc. are provided with this type of lubrication.

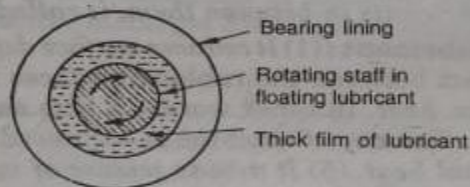


Fig. 4. Hydrodynamic lubrications.

**Hydrocarbon oils** are considered to be satisfactory lubricants for fluid-film lubrication. In order to maintain viscosity of the oil in all seasons of year, ordinary hydrocarbon lubricants are **blended** with selected long chain polymers. Moreover, hydrocarbon petroleum fractions, generally, contain **small quantities of unsaturated hydrocarbons**, which get oxidised under operating conditions, forming **gummy products**. So **antioxidant** (like amino-phenols) are used in journal bearing.

(2) **Boundary lubrication or thin-film lubrication** is done, when a **continuous film of lubricant cannot persist** and **direct metal-to-metal** is possible due to certain reasons. This happens when : (i) a shaft starts moving from rest, or (ii) the

speed is very low, or (iii) the load is very high, and (iv) viscosity of the oil is too low. Under such conditions, the clearance space between the moving/sliding surfaces is lubricated with an oil lubricant, a thin layer of which is adsorbed, (i.e., surface attached) by physical or chemical forces or both on both the metallic surfaces. These adsorbed layers avoids direct metal-to metal contact. The load is carried by the layers of the adsorbed lubricant on the both metal surfaces [see Fig. 3 (b)]. The coefficient of friction in such is, usually, 0.05 to 0.15. The oil-film keeps the distance apart between of the meeting surfaces of the order of the height of the asperities.

**Vegetable and animal oils** (glycerides of higher fatty acids) and their soaps possess property of adsorption (or surface attachment), either physically adsorbed to metal surfaces or react chemically at the metal surfaces, forming a thin film of metallic soap, which acts as lubricant. The load is carried by the two layers of adsorbed lubricant. Although the fatty oils possess a greater adhesion property (called oiliness) than mineral oil, yet they tend to break down at high temperatures. In order to improve the oiliness of mineral oils (which are thermally stable), small amounts of fatty oils or fatty acids are added. Graphite and molybdenum disulphide either alone or as stable suspension in oil are also used for boundary lubrication. These materials form films on the metal surfaces, which possess low internal friction and can bear compression as well as high temperatures.

For boundary lubrication, the lubricant molecules should have : (i) long hydrocarbon chains ; (ii) polar groups to promote spreading and orientation over the metallic surfaces at high pressure ; (iii) lateral attraction between the chains ; (iv) active groups or atoms, which can form chemical linkages with the metals or other surfaces. High viscosity-index, resistance to heat and oxidation, good oiliness, and low pour-point are some of the good qualities of boundary lubricants.

(3) **Extreme-pressure lubrications** : When the moving/sliding surfaces are under very high pressure and speed, a high local temperature is attained and under such conditions, liquid lubricants fail to stick and may decompose and even vaporize. To meet these extreme-pressure conditions, special additives are added to mineral oils. These are called "extreme-pressure additives". These additives form on metal surfaces more durable films, capable of withstanding very high loads and high temperatures. Important additives are organic compounds having active radicals or groups such as chlorine (as in chlorinated esters), sulphur (as in sulphurized oils) or phosphorus (as in tricresyl phosphate). These compounds react with metallic surfaces, at prevailing high temperatures, to form metallic chlorides, sulphide or phosphides. These metallic compounds possess high melting points (e.g., iron chloride and iron sulphide melts respectively at 650°C and 1,100°C) and serve as good lubricant under extreme-pressure and extreme-temperature conditions. If by chance, the low shear strength films are broken by the rubbing action of moving parts, they are immediately replenished.

#### 18.4 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.

#### 18.5 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. A 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 possess 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 hydrolyse*, 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** are obtained by distillation of petroleum. The length of the hydrocarbon chain in petroleum oils varies between about 12 to 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. The oiliness of petroleum oils can be increased by the addition of high molecular weight compounds like oleic acid, stearic acid, etc.

The 'oil layer' is distilled (to recover the solvent), when the *refined oil* is left behind. Similarly, solvent layer is distilled (to recover the solvent), when the residue (containing asphaltic, naphthenic and resinous substances) is left behind and is used as a source of these or as a fuel oil.

**Merits and demerits :** Solvent refining method (i) is cheaper, (ii) removes asphaltic materials quite satisfactorily, thereby reducing any chance of formation of carbon deposits, during the use of refined oil, (iii) gives higher yield of refined oil, and (iv) gives a refined product, which shows less change in viscosity with temperature. But solvent refined oil is less resistant to oxidation, due to the removal of natural oxidation inhibitors present in it. Also, such oils possess lower oiliness. Hence, it becomes necessary to add some *additives* to solvent refined oils to improve these drawbacks.

(3) **Blended oils :** No single oil serves 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 a 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 adsorbed 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 ; (b) *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 prevents the separation of wax from the oil.

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

(v) **Thickeners** such as *polystyrene, polyesters, etc.*, 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 themselves *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 preventors** 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*.

### 18.6 GREASES OR SEMI-SOLID LUBRICANTS

**Lubricating grease** is a *semi-solid*, consisting of a soap dispersed throughout a liquid lubricating oil. The liquid lubricant may be a petroleum oil or even a 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 ceases 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 can not remain in place, due to high load, low speed, intermittent operation, sudden jerks, etc. For example 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 upto 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 a 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 80°C, 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 upto 175°C. 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* [upto 15°C] 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. Fillers (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.

### 18.7 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, e.g., in commutator bushes of electric generators and motors ; (iii) the operating temperatures or load is too high, even for a semi-solid lubricant to remain in position ; and (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 [see Fig. 5 (a)] 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 [see Fig. 5 (b)] in which a layer of a Mo atoms lies between two layers of S atoms. Poor interlamellar attraction is responsible for low shear strength in a direction parallel to the layers.

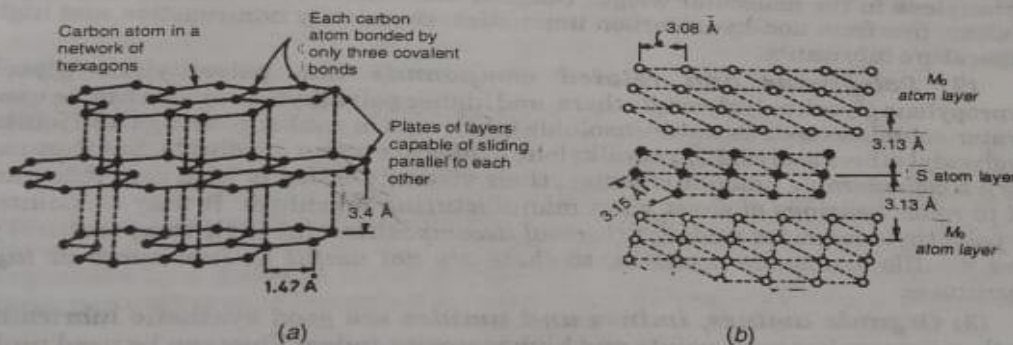


Fig. 5 (a) Layered structure of graphite ; (b) Sandwich-like structure of molybdenum disulphide.

Solids lubricants are used either in the *dry power form* 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 375°C. 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, oil 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 upto  $400^{\circ}\text{C}$ . 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 alongwith 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.

### 18.8 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 sever conditions such as those existing in aircraft engines, in which the same lubricant may have to used in the temperature range of  $-50^{\circ}\text{C}$  and  $250^{\circ}\text{C}$ . 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 : (i) 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 – 50,000 are residue-free, light in colour, 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  $-50^{\circ}\text{C}$  to  $250^{\circ}\text{C}$ .

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

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

### 18.9 LUBRICATING EMULSIONS

An **emulsion** is two-phase system, consisting of a fairly coarse dispersion of two immiscible liquids, the one being dispersed as fine droplets in the other. The **disperse** (or the internal) **phase** is the liquid that is broken into droplets. The

surrounding liquid, is known as the *continuous or external or dispersing phase*. Usually, the size of dispersed droplets varies from 1 to 6 micron. A dispersion system consisting of two immiscible liquids is *inherently unstable*, and to increase its stability, a *third agent, called emulsifier or emulsifying agent, is added*. Emulsifiers are compounds exhibiting both and non-polar character. The emulsifier molecule contains a *hydrophobic-end and a hydrophilic-end. The hydrophobic-end of the molecule is preferably wetted by oil; whereas the hydrophilic-end is wetted by water*. Thus, emulsifier molecule is adsorbed at the interface of the two phases (oil and water), resulting in the formation of a *protective film* around the dispersed droplets. A Sodium Soap molecule illustrates well the functioning of an emulsifier. The sodium soap is the sodium salt of a long chain fatty acids like  $C_{15}H_{31}COONa$ , possessing a hydrophilic group  $-COONa$  and hydrophobic-end,  $C_{15}H_{31}$ .

Geometric calculations have shown that the maximum amount of dispersed in the other liquid can be 74.02% of the total volume. Thus, a water-oil emulsion mixture with less than 26% oil would tend to form an *O/W emulsion*; whereas a mixture with more than 74% oil would result in a *W/O emulsion*. Composition between 26 and 74% can result in both types of emulsion.

(a) **Oil in-water emulsions** are obtained by adding an oil containing about 3-20% water-soluble emulsifying agent to a suitable quantity of water. The most usual emulsifying agents are sodium soaps and sodium and potassium salts of sulphonic acids. The main use of such an emulsion is as *cooling and lubricating liquid for cutting tools*. Another use is lubrication for certain rather heavy sliding components such as pistons in marine diesel engines and large internal combustion engines. Such emulsions also give rust protection.

(b) **Water-in-oil emulsions** are prepared by mixing together water containing about 1 to 10% water-soluble emulsifier (like alkaline-earth soap, e.g., calcium stearate) with oil. These emulsions possess much higher viscosity than that of the oil from which they are prepared. An emulsion which uses about 40% water by volume is widely used to lubricate compressors and pneumatic tools. They provide cooling effect (due to the evaporation of water), besides lubrication action.

## 18.10 PROPERTIES OF LUBRICATING OILS

1. **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 moves faster than the next lower layer, due to *viscous drag* (i.e., internal friction). Consider two layers of a liquid separated by a distance,  $d$  and moving with a relative velocity difference,  $v$ . Then, force per unit area ( $F$ ) required to maintain this velocity difference is given by:

$$F = \eta v / d$$

where  $\eta$  (pronounced *eta*) is a constant of the liquid, called *coefficient of viscosity*. If  $v = 1$  unit (e.g., cm/s),  $d = 1$  unit (e.g., cm.) then,  $F = \eta$ . Hence, **coefficient of viscosity** ( $\eta$ ) may be defined as "the force per unit area required to maintain a unit velocity gradient (i.e., velocity difference of one unit in the fluid or liquid layers, which are unit distance apart) between two parallel layers". The unit of viscosity is *poise*. If a force of 1 dyne is required to maintain a relative velocity difference of  $1 \text{ cm s}^{-1}$  between two parallel layers 1 cm apart, its coefficient of viscosity is 1 poise. A smaller corresponding unit is *centipoise*, which is equal to 1/100 of poise.

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 moving/sliding surfaces, and consequently, excessive wear will take place. On the other hand, (ii) if the viscosity is **too high**, excessive friction will result.

**Effect of temperature on viscosity :** *Viscosity of liquids decreases with increasing temperature and, consequently, the lubricating oil becomes thinner as the operating temperature increases. Hence, viscosity of a good lubricating oil should not change much with change in temperature, so that it can be used continuously, under varying conditions of temperature. The rate at which the viscosity of an oil changes with temperature is measured by an arbitrary scale, known as the "viscosity-index" (V.I.). If the viscosity of an oil falls rapidly as the temperature is raised, it has a low viscosity-index. On the other hand, if viscosity of an oil is only slightly affected on raising the temperature, its viscosity-index is high.*

**Determination of viscosity-index :** For this purpose, we use a series of two types of standard oils. *paraffinic-base Pennsylvanian oils* (V.I. = 100) and *naphthanic-base Gulf oils* (V.I. = 0). Against each of these is marked their viscosities at 100°F and 210°F. The former are known as 'H'-oils and the latter as 'L'-oils.

**Step I :** The viscosities of the oil under-test at 100°F and also at 210°F are first found out. Let these values be 'U' and 'V' respectively. *The difference between the two values should be low, if the oil is good; and high, if the oil is poor.*

**Step II :** Now from the list of H-oils (with V.I. = 100), the oil which has the same viscosity at 210°F as the oil under-test is selected, and its corresponding viscosity at 100°F is read off. Let it be H.

**Step III :** Then, from the list of L-oils (i.e., with V.I. = 0), the oil which has same viscosity at 210°F as the oil under-test is selected, and its corresponding viscosity at 100°F is read off. Let it be L. Then :

$$\text{V.I.} = \frac{L - U}{L - H} \times 100$$

where U = Viscosity at 100°F of the oil under-test.

L = Viscosity at 100°F of the low-viscosity standard oil (i.e., Gulf, oil) having a V.I. of 0 and also having the same viscosity at 210°F as the oil under-test.

and H = Viscosity at 100°F of the high-viscosity standard oil (i.e., Pennsylvanian oil) having a V.I. of 100 and also having the same viscosity at 210°F as the oil under-test.

**Viscosity-index and molecular structure of oil :** *The molecular structure of lubricating oils has a direct bearing on their viscosity and viscosity-index. (i) Molecules of a linear or rod-like structure, possessing flexibility, through free rotation about the chemical bonds, exhibit high V.I. (ii) A low freezing point or high viscosity of an oil can be secured by attaching short side-chains to the chain of the linear molecule. This is due to the fact that side-chains tend to prevent alignment of the neighboring molecules. In general, an oil of high molecular weight possesses a high boiling point and high viscosity.*

**How to increase V.I. of an oil ?** V.I. of lubricating oils can be increased by adding certain polymers, which are only partially soluble in the oil. (i) At low temperature, when the solubility of the added polymer in oil is slight, so the effect of the polymer on the viscosity of the oil is also slight. (ii) At high temperature, when the solubility of the polymer in oils is considerable, its effect will be to increase viscosity of the oil. Thus, by the correct addition of organic polymers, it is possible to produce oil-polymer blends, which have a very slight temperature coefficient of viscosity or even none at all, i.e., *viscous-static*.

**Measurement of viscosity of a 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. *Redwood viscometers* and *Saybolt viscometer* are used, respectively in Commonwealth countries and U.S.A., 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 an oil through Redwood viscometer at 20°C is 100 seconds, then its viscosity is "100 Redwood seconds" at 20°C. A brief description of Redwood viscometer, used in this country, is given below :

**Redwood viscometer** is of two types : "*Redwood viscometer No. 1*" is commonly used for determining viscosities of thin lubricating oils and is shown in Fig. 6 and it has a "jet" of bore diameter 1.62 mm and length 10 mm. On the other hand, "*Redwood viscometer No. 2*." is used for measuring viscosities of highly viscous oils like fuel oil. It has a jet of diameter 3.8 mm and length 15 mm. *Redwood viscometer No. 1* consists of the following essential parts :

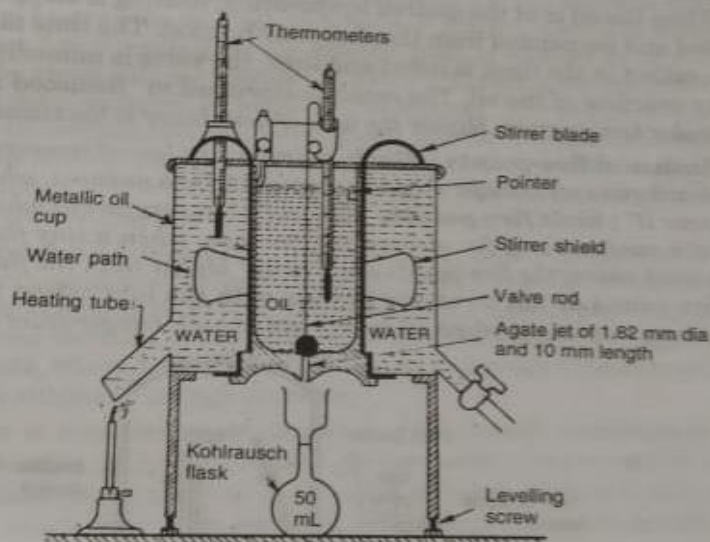


Fig. 6. Redwood viscometer No. 1.

(i) **Oil cup** is a silver-plated brass cylinder (90 mm in height and 46.5 mm in diameter). The upper end of the cup is open. The bottom of the cylinder is fitted with an *agate jet* (with bore of diameter 1.62 mm and length 10 mm). The jet is opened or closed by a "*valve rod*", which is a small silver-plated brass ball fixed to a *stout wire*. The level to which the cylinder is to be filled with oil is indicated by a "*pointer*", which is a stout, tapered, upwards-pointing wire fixed on the inner side of the cylinder. The lid of the cup is fitted with a thermometer, which indicates the oil temperature.

(ii) **Heating bath** : Oil cup is surrounded by a *cylindrical copper bath*, containing water. It is provided with a *tap* (for emptying water from it) and a *long side-tube projecting outwards* (for heating the bath water by means of a gas burner or a spirit lamp). A *thermometer* indicates the temperature of the water.

(iii) **Stirrer** : Outside the oil cylinder is stirrer, carrying four blades, for stirring the water in the bath for maintaining uniform desired temperature. The stirrer is provided with a circular shield at the top, to prevent any water splashing into the oil cylinder.

(iv) **Spirit level** : The lid of the cup is provided with a spirit level for vertical levelling of the jet.

(v) **Levelling screws** : The entire apparatus rests on three legs, provided at their bottom with levelling screws.

(vi) **Kohlrausch flask** is a specially-shaped flask for receiving the oil from the jet outlet. Its capacity is 50 mL up to the mark in its neck.

**Working** : The levelled oil cup is cleaned and ball of valve rod is placed on the agate jet to close it. Oil under-test, free from any suspension, etc., is filled in the cup upto the pointer level. An empty Kohlrausch flask is kept just below the jet. Water is filled in the bath and side-tube is heated slowly with constant stirring of the bath. When the oil is at the desired temperature, heating is stopped and the ball valve is lifted and suspended from thermometer bracket. The time taken for 50 mL of the oil to collect in the flask is noted and then, the valve is immediately closed, to prevent any overflow of the oil. The result is expressed in "Redwood No. 1 seconds" at the particular temperature. Higher the time of flow, lesser is the viscosity of the oil.

**2. 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 40° 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

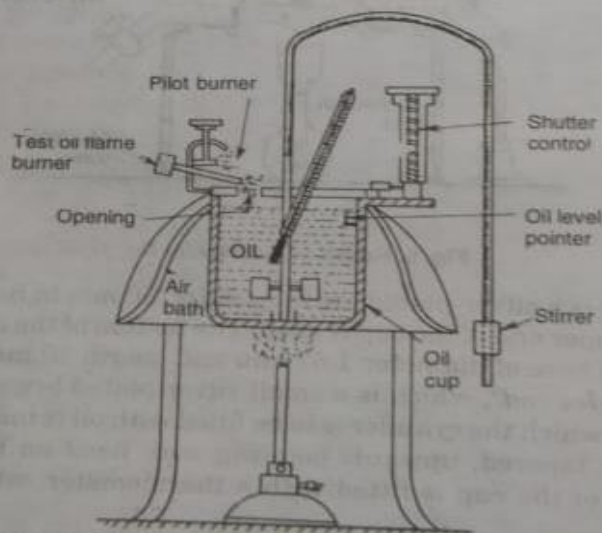


Fig. 7. Pensky-Marten's flash-point apparatus.

lubricant should have flash-point at least above the temperature at which it is to be used. This safeguards against risks of fire, during the use of lubricant. The flash and fire-points are, usually, determined by using **Pensky-Marten's apparatus** (see Fig. 7.), which essentially consist of :

(i) **An oil cup** is about 5 cm in diameter and 5.5 cm deep. The level to which oil is to be filled is marked inside the cup. The cup lid is provided with four openings of standard sizes. Through one of these passes a thermometer; while the second opening is used for introducing test flame. Through third opening passes stirrer carrying two brass blades; while the fourth is meant for admission of air.

(ii) **Shutter** is a lever mechanism, provided at the top of the cup. By moving the shutter, opening in the lid opens and flame (carried by a flame exposure device) is dipped into this opening, thereby bringing the flame over the oil surface.

(iii) **Flame exposure device** is a tiny flame, connected to the shutter by a lever mechanism.

(iv) **Air bath**: Oil cup is supported by its flange over an air-bath, which is heated by a gas burner.

(v) **Pilot burner**: As the test-flame is introduced in the opening, it gets extinguished, but when the test flame is returned to its original position, it is automatically lighted by the pilot burner.

**Working**: Oil under-examination is filled upto the mark in the oil cup and then heated by heating the air-bath by a burner. Stirrer is worked between tests at a rate of about 1 to 2 revolutions per second. Heat is applied so as to raise the oil temperature by about 5°C per minute. At every 1°C rise of temperature, test-flame is introduced for a moment, by working the shutter. The temperature at which a distinct flash (a combination of a weak sound and light) appears inside the cup, is recorded as the flash-point. The heating is continued thereafter and the test-flame is applied as before. When the oil ignites and continues to burn for at least 5 seconds, the temperature reading is recorded as the fire-point of the oil.

**3. Oiliness of a lubricant** is a measure of its capacity to stick on to the surfaces of machine parts, under conditions of heavy pressure or load. When a lubricating oil of poor oiliness is subjected to high pressure, it has a tendency to be squeezed out of the lubricated machine parts, thereby its lubrication action stops. On the other hand, lubricants, which have good oiliness stay in-between the lubricated surfaces, when they are subjected to high pressure.

Oiliness is very important property of lubricants, particularly for extreme-pressure lubrication. Mineral oils have got very poor oiliness; while vegetable oils have good oiliness. So, in order to improve the oiliness of mineral oils, additives like vegetable oils and higher fatty acids (such as oleic and stearic acids) are added to them. No direct test is available for measuring oiliness.