Lubricants

In all types of machines, the surfaces of moving or sliding or rolling parts rub against each other. This mutual rubbing of one part over the other leads to resistance of movement which is called as friction.

Friction causes a lot of wear and tear of surfaces of moving parts and since heat generated in this process, it reduces the efficiency of the machinery. The problems of frictional resistance can be minimized by using lubricants which forms a thin layer between the moving parts.

Definition of lubricant: *A lubricant is defined as a substance introduced between two moving or sliding surfaces to reduces the frictional resistance between them.* The main purpose of a lubricant is to keep the moving surfaces apart so that frictional resistance and destruction of materials can be minimized.

Definition of lubrication: *The process of reducing frictional resistance between the two surfaces by the introduction of lubricants in between them is known as lubrication.*

Function of a lubricant:

(i) Lubricant reduces frictional resistance by keeping the moving surfaces of a system apart and prevent their direct contact.

(ii) It reduces surface deformation, wear and tear by keeping moving surface apart.

(iii) It reduces waste of energy. Hence the efficiency of the machine is enhanced.

(iv) It reduces frictional heat which prevents expansion of metal.

(v) It avoids seizure of moving surfaces as the lubricant minimizes the liberation of frictional heat. Due to the usage of lubricant, heat generation will be minimized. Evan if some amount of heat is liberated it will be absorbed by the lubricant. Hence, lubricants can also function as coolants.

(vi) It avoids unsmooth relative motion of moving parts.

(vii) It reduces the maintenance and running cost of machine, by preventing rust and corrosion.

(viii) In the internal combustion engines lubricant can acts as a seal between the piston and the cylinder. As a result the leakage of gases can be avoided.

Mechanism of lubricants:

There are mainly three types of mechanisms by which lubrication takes place. They are:

(i) Fluid film or thick film or hydrodynamic lubrication

(ii) Boundary lubrication or thin film lubrication

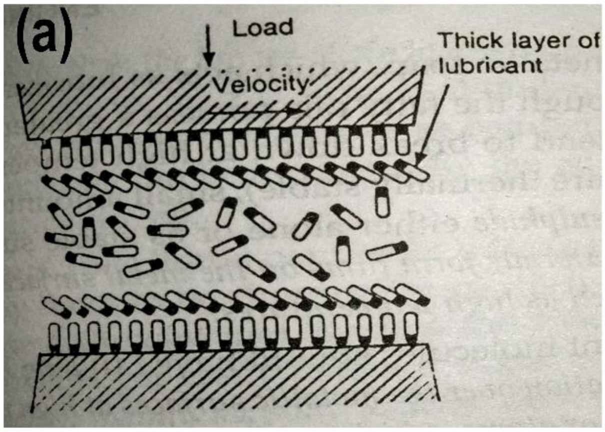
(iii) Extreme pressure lubrication

(i) Fluid film or thick film or hydrodynamic lubrication:

In this type of lubrication, the moving surfaces are separated from each other by a thick continuous unbroken film of fluid having thickness at least 1000Å, so that there is no direct contact between them. The lubricant film covers the irregularities of the surfaces so that two moving surfaces do not come in contact with each other and the load is taken completely by oil film. Since the metal surfaces are not contact with each other, the friction is reduces. The resistance to movement of sliding or moving parts is due to internal resistance between the particles of the lubricant moving over each other. For this, the lubricant should have minimum viscosity under working conditions in the same time it should remain in place and separate the surfaces. In such system friction depends on viscosity, thickness of lubricant, the relative velocity and area of the moving surfaces. The coefficient of friction will be less (0.001 to 0.003) in this type of lubrication. *Thick film lubrication can be used when load is low and the speed is high.*

The hydrodynamic friction occurs in case of a shaft running at a fair speed as well as in well lubricated bearing with not too high load. A film of the lubricant oil covers the irregularities of shaft as well as the bearing surfaces so that metal surface do not come in to contact with each other. Thus resistance of movement due to internal resistance of the lubricant.

The fluid film lubrication is done by hydrocarbon oils. These are blended with selected long chain polymers to maintain the viscosity of oil as constant in all seasons. The viscosity of hydrocarbon oils increases with increasing molecular weight. The hydrocarbon petroleum fraction generally fractions contain small quantities of unsaturated hydrocarbons which get oxidised under operating conditions and form gummy products. So *antioxidants like amino phenols are used in hydrocarbon oils.*



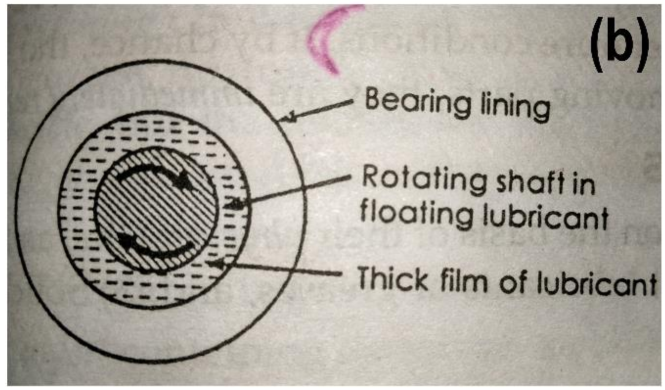


Figure: (a) Fluid film lubrication (b) Hydrodynamic lubrication

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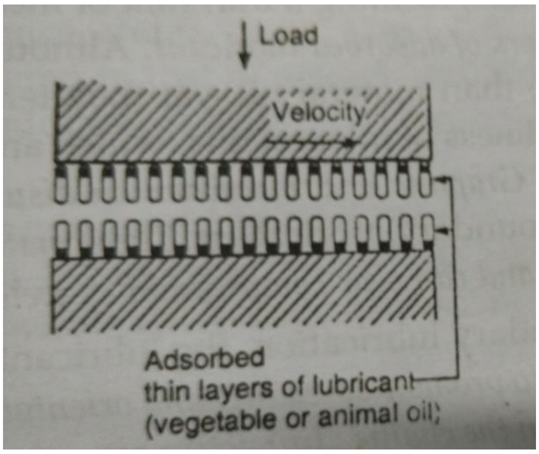
Examples: Delicate instruments, light machines like watches, clocks, guns, sewing machines etc are provided with fluid film lubrication.

(ii)Boundary lubrication or thin-film lubrication:

Boundary lubrication can be used in the system under high load and slow speed. In this kind of lubrication, the lubricating film is thin. It has about the same thickness as the surface roughness such that the asperities on the solid surface are in contact as a result load is carried by the surface asperities rather than by the lubricants. The oil film thickness is so small that the effectiveness of the lubricant depends on its oiliness, which has the ability of the lubricant to stick on the surface.

This type of lubrication occurs when a continuous film of lubricant cannot persist and direct metal to metal contact occurs between the moving surfaces. In these conditions, the space between the moving or sliding surfaces is lubricated such a way that a thin layer of lubricant is adsorbed on the metallic surfaces due to physical or chemical forces. This adsorbed layer helps to avoid the direct metal to metal contact between the rubbings surfaces. This load is carried by the layers of adsorbed lubricant on both the metal surfaces. The thickness of boundary film may be one or two molecular thickness 20-30 Å unit and coefficient of friction varies from 0.05 to 0.15.

Boundary lubrication happens when (i) a shaft starts moving from rest (ii) the speed is very slow and the load is very high (iv) viscosity of the lubricant is very less.



For boundary lubrication, the lubricant molecules should have

(i) Long hydrocarbon chains which increases the lateral attraction between the chains (larger the hydrocarbon chain greater the van der Waals forces of attraction). (ii) Polar groups to promote wetting or spreading over the surface, lateral attraction between the chains (iii) Active functional groups which can form chemical bonds with metals or other surfaces, (v) High viscosity index (vi) Good oiliness or the capacity to stick to metal surface should be good (vii) resistance to heat and oxidation and (viii) low pour point.

Solid lubricants, greases and oils with proper additives function as lubricants in this type of lubrication.Graphite and MoS_2, vegetable and animal oils and their soaps are used for boundary lubrication. These materials form films on the metal surfaces having internal friction. So they can bear compression and high temperatures.

(iii) Extreme pressure lubrication:- When the moving or sliding surfaces are subjected to very high pressure and speed, heat is generated causing the following harmful effect

(i) Local high temperature develops resulting in the formation of a welded junction and metal tearing

(ii) The lubricants fail to stick to the metal surface as result there is vaporization or decomposition of lubricating oil may occurs

(iii) Surface deformation and seizure takes place.

These problems are minimized by adding special additives to mineral oils. These additives form durable films on metal surfaces which can withstand high loads and high temperatures. *Important additives are organic esters as chlorinated esters, sulphur as in sulphurised oils or phosphorous as in tricresyl phosphate*. These compounds react with metallic surfaces at high temperatures and form metallic chlorides, sulphides or phosphides. These metallic compounds possess high melting points and serve as good lubricants at high temperatures and high pressures.

It is important that under extreme pressure condition the lubricant is not just a film or coating over the metal surface, it is a permanent modification of the metal surface. The surface compound is a few molecular layers thick. The coefficient of friction is 0.1 to 0.4 cm/s. The film is remain intact under high pressure and temperature and lubricate the surface. If by chance the film breaks due to the rubbing action of the moving parts, it is immediately replenished. Extreme pressure lubricants find in use in aircrafts and spacecrafts.

Classification of lubricant:

Lubricants are classified on the basis of their physical state as follows

1. Liquid Lubricants or Lubricating Oils
2. Semi-Solid Lubricants or greases
3. Solid Lubricants.

1. Liquid Lubricants or Lubricating Oils: Lubricating oils reduce friction and wear between two moving metallic surfaces by providing a continuous fluid film in between the surfaces. They can acts as (a) cooling medium (ii) sealing agent and (iii) corrosion preventer.

A good lubricant must have the following characteristics.

a. It must have high boiling point or low vapour pressure.

b. Thermal stability and oxidation resistance must be high.

c. It must also have adequate viscosity for particular operating conditions.

d. The freezing point must be low.

e. It must also have non-corrosive property.

f. Stability to decomposition at the operating temperature.

Lubricating oils are further sub-classified as

(i) Animal and Vegetable oils: *Animal and vegetable oils are glycosides of higher fatty acids.* They have very good oiliness. However, they are costly, undergo oxidation very easily, and have a tendency to hydrolyse when it contact with moist air or water. These oils undergo decomposition on heating without distilling, and hence they are "fixed oils". They are used as additives to improve the oiliness of petroleum oils. Actually they are used as "blending agent" with other lubricating oil.

(ii) Petroleum oils or Mineral oils: *They are obtained by fractional distillation of crude petroleum oils. The length of the hydrocarbon chain varies between C_{12} to C_{50}. They are cheap abundant and quite stable under operating conditions. They possess poor oiliness, the oiliness of which can be improved by the addition of higher molecular weight compounds like oleic acid, stearic acid.*

(iii) Blended oils or Additives for lubricating oils: No single oil serves as the most suitable lubricant for many of the modern machineries. Specific additives are incorporated into petroleum oils to improve their characteristics. These oils are to improve their characteristics. These oils are called “blended oils” and give desired lubricating properties, required for particular machinery. The oiliness of a lubricant can be increased by addition of oiliness carrier like vegetable oil and fatty acid like palmitic acid or stearic acid.

(iv) Synthetic lubricants: Mineral oils cannot be used effectively as they tend to get oxidized at very higher temperatures while wax separation will occur at very low temperatures. So, synthetic lubricants have been developed, which can meet the severe operating conditions such as in aircraft engines. The same lubricants may have to be in the temperature range of -50^0 C to 250^0C. Polyglycol ethers, fluoro and chloro hydrocarbons, organophosphates and silicones are currently used as synthetic lubricants.

Semi-solid lubricants or greases: - Greases are semi-solid lubricants which consist of a soap dispersed in lubricating oil. They are made by Saponification of fat with alkali followed by addition of hot lubricating oil with constant stirring. Consistency of grease is governed by amount of oil added.

Conditions for using semi-solid lubricants:

(i) When it is necessary to seal the bearing or joint against the dirty & dust particles.

(ii) When the machine is worked at low speed under high load.

(iii) When the contamination of lubricating oil is unacceptable and harmful for products.

(iv) When the lubricating oil is not suitable for machines.

On the basis of soap used in manufacture of semi-solid are classified as:-

Calcium based grease: - These greases are prepared by mixing of calcium hydroxide with hot petroleum oil. They are insoluble in water. These can be used upto 80^0C. These are also called ‘*Cup grease’.*

Soda-based grease: - These grease are prepared by mixing of sodium soap with petroleum oil. They are soluble in water. These can be used upto 175^0C. These greases are used in ball bearings.

Lithium-based grease: - These greases are prepared by mixing of lithium soap with petroleum oil. They are water resistant. They are suitable to use at low temperature.

Axle grease:-These are prepared by adding lime or any metal hydroxide to resin and fatty acids. They are water resisting and suitable for high temp and low speed. These are used in tractor rollers and machines bearings.

SOLID LUBRICANTS:-"The lubricants that exist in solid form are called solid lubricants". e*.g.: - graphite, molybdenum disulphide etc. They are used in heavy machines under high load and low speed.*

Conditions for using Solid Lubricants:-

(i) Machines that are under high load and low speed.

(ii) When liquid and semi-solid lubricants are highly combustible.

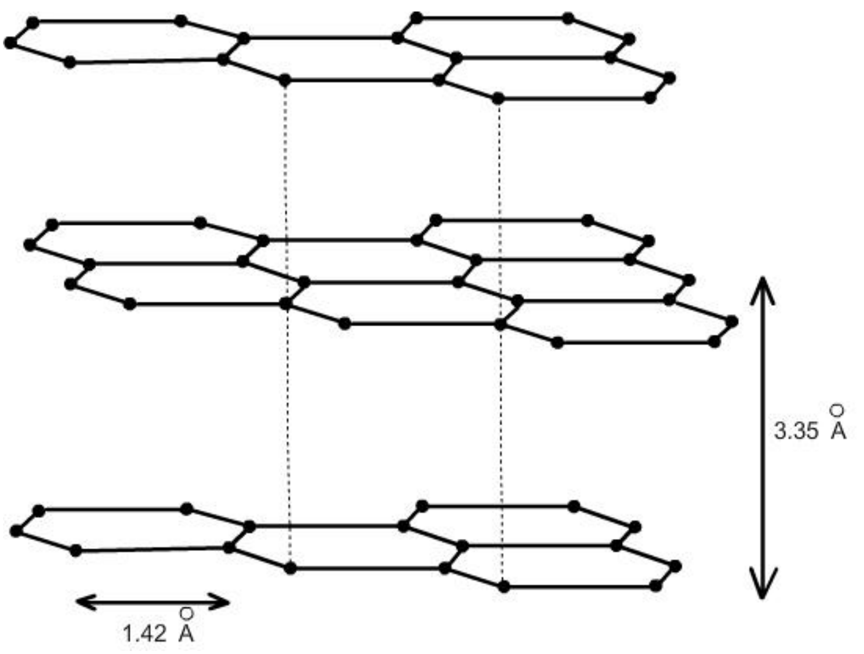
(iii) In machines where liquid and semi-solid lubricants can't work.

(iv) When contamination of oil and grease with dust particles is noticed.

Graphite and Molybdenum disulphide are the widely used solid lubricants.

Properties and uses of graphite and MoS_2 solid lubricant.

Graphite: In graphite carbon is sp^2 hybridised. Each carbon thus linked to three other carbon atoms forming hexagonal rings. Thus graphite has two dimensional sheet-like layered structure. The various layers are held together by weak van der Walls forces of attractions so the force to shear the crystals parallel to the layers is low in graphite. Consequently, the parallel layers slide over one another easily which make graphite soft and good lubricating agent. The distance between any two successive layers of graphite is 3.35Å while C-C bond length is 1.42 Å.



Graphite as solid lubricant:

(i) It is soapy in touch.

(ii) It is non inflammable.

(iii) It is not oxidized in air up to 375^0C

(iv) It is used either in powdered form or in suspension form. Suspension of graphite in oil or water is brought about with the help of *emulsifying agent like tannin.*

(v) When graphite is dispersed in oil, it is called *'oil dag'* and when it is dispersed in water; it is called '*aquadag'. Oil dag is useful in internal combustion engine and aquadag is useful in food stuffs industry*.

(vi) Graphite also mixed with greases to form graphite- greases which can used at higher temperature.

Uses of graphite lubricant: *Graphite can be used as lubricant in air- compressor, lathes, general machine shop works, food stuffs industry, in internal combustion engine and railway track joints etc.*

Molybdenum disulphide: (i) It has sand-witch like structure. The layer of molybdenum atoms lie between two layers of sulphur atom. These layers are held together by very weak Vander Waals forces. Due to these forces, it is soft & smooth in nature.

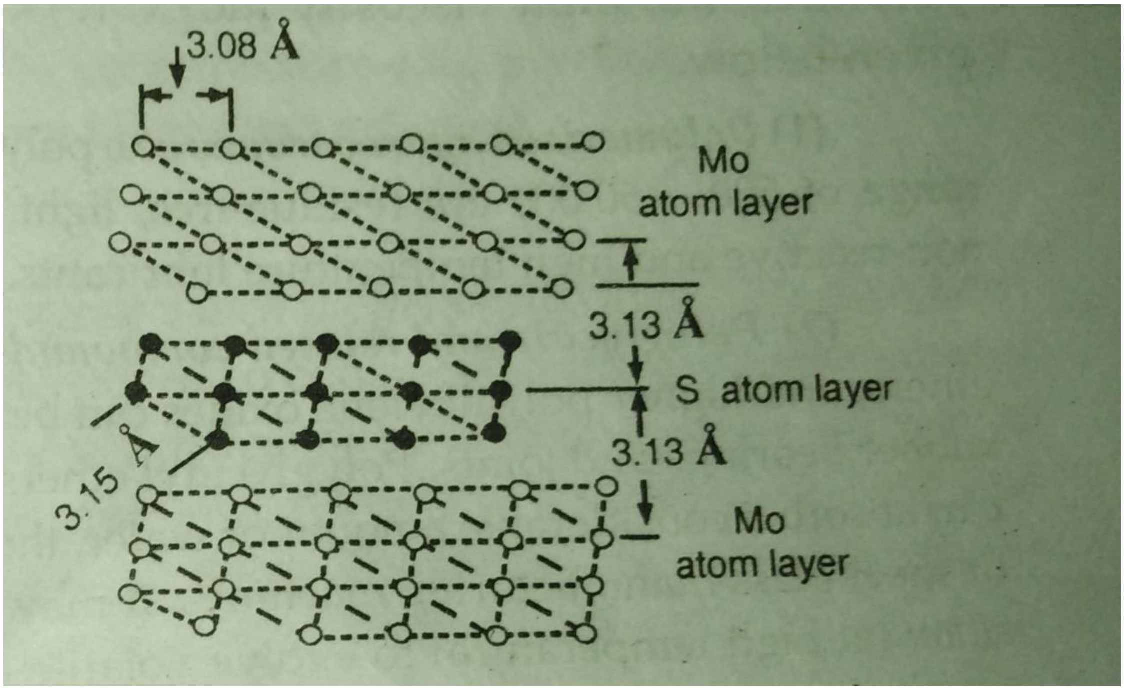
(ii) It possesses very low coefficient of friction

(iii) It is stable in air up to 400^0C.

(iv) It has high specific gravity than graphite.

(V) It is used as either in powdered form or in additive. When it fills low spot of metal surfaces it forming film.

(vi) MoS_2 widely used as a solid lubricant because of its low friction and robustness.



Sandwitch like structure of MoS_2.

Properties of lubricating oil:

(i) Viscosity: It is the resistance offered by liquid or fluid towards its own flow. It is determined by Red Wood Viscometer. A liquid in a state of steady flow on a surface may be supposed to consist of a series of parallel layer moving one above the other. Any two layers will move with a different velocities, top layer moves faster than the next lower layer due to internal friction. It is the indicator of flow ability of a lubricating oil.

If two layers of a liquid separated by a distance d and moving with a velocity difference ν then the force per unit area (F) required to maintain the velocity difference is given by

$$F = \eta \nu / d$$

Where η is called coefficient of viscosity.

If v = 1cm/s, d = 1 cm then $F = \eta$

So coefficient of viscosity (η) may be defined as the force per unit area required to maintain a unit velocity gradient between two parallel layers. The cgs unit for measuring the coefficient of viscosity is the 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.

(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.

Viscosity Index: The rate at which the viscosity of an oil changes with temperature is measured by an arbitrary

scale known as Viscosity Index. If the viscosity of an oil falls rapidly as the temperature is raised, it has low viscosity index. If the viscosity of an oil slightly affected on rising the temperature, it has high viscosity index

For a good lubricating oil viscosity-index should be high.

Determination of Viscosity Index: To determine viscosity index Two types of standard oils, Paraffinic-base Pennsylvanian oils (V.I =100) and Naphthanic- base Gulf oils (VI =0) are used. Against each of these is marked their viscosities at 100°F and 210°F. Former are known as H-oils and latter as L-oils.

Following steps involved to determine viscosity index:

Step 1: 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 2: Now from the list of H-oils (VI =100), the oil which as the same viscosity at 210°F as the oil under-test is selected, and its corresponding viscosity at 100°F is determine: say H.

Step 3: Then, from the list of L-oils (VI = 0), the oil which as same viscosity at 100°F is determine: say L.

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

Where U: viscosity at 100°F of the test oil (sample)

L: viscosity at 100°F of the low-viscosity standard oil

H: viscosity at 100°F of the high-viscosity standard oil

(ii) Flash and Fire Point: The minimum temperature at which the oil gives off sufficient vapours to ignite for a moment (flash), when a flame is brought near the surface of the oil, called its *Flash point.*

The lowest temperature at which the vapours of the oil burn continuously for at least 5 seconds, called its *Fire point.*

Good lubricant should have higher flash point w.r.t working temperature.

In most cases, the fire-points are 5 to 40° C 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 safe guards

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 point: When an 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. 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. Cloud and pour point indicate the suitability of lubricants in cold condition. Pour point determiners the suitability of a lubricant oil for low temperature. *The presence of waxes in the lubricating oil increases the pour point.*

(iii) Aniline point: Aniline point is defined as "the minimum equilibrium solution temperature for equal volume of aniline and oil sample". It gives an indication of the possible tendency of deterioration of an oil when it comes into contact with packing, rubber sealing etc. A lower aniline point of an oil means a higher percentage of aromatic hydrocarbons in it. Aromatic hydrocarbons have a tendency to –dissolve natural rubber and certain types of synthetic rubbers. Thus good lubricating oil should have higher aniline point.

Determination of aniline Point: Aniline point is determine by mixing equal volumes of aniline and the oil_sample in a tube. Then the mixture is heating until a homogeneous solution is obtained. _Then the tube is allowed to cool at a specific rate, until the two phases (oil & aniline) separate out is recorded at the aniline point.

Cutting fluid: Any liquid (such as oil, water or oil emulsion) or a gas used to cool as well as to lubricate is called a cutting fluid. Emulsions of oil-in-water are mostly used as cutting fluids. Cutting fluids are required for tools used in the machine shop for cutting, threading, sawing, planning, turning, drilling, etc. ; and the cutting fluid performs either of the fractions ; (i) to cool the tools, or (ii) to lubricate the tools, or (iii) to cool as well as to lubricate the tools.

In such machining operations, the friction is very high, due to close contact between the work-piece and the tool; and this generates large amounts of local heat, thereby the tool gets overheated and it may even lose its temper and hardness. Consequently, in such a case, the cutting fluid provides cooling, besides lubrication. In order to provide satisfactory service, the cutting fluid should possess:

1. good lubricating property
2. Low viscosity, so that the lubricant can easily fill in the cracks formed on the work-piece
3. Chemical Stability
4. Non-corrosive nature towards the metals of the work-piece as well as tool
5. High thermal conductivity.