A Review on Lubrication and its Importance

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Abstract— It is known since ages that oils and greases reduce the friction between sliding surfaces, by filling the surface cavities and making the surfaces smoother. Action of liquids/greases known as lubrication. In other words, lubrication is a process by which the friction and wear rates in a moving contact are reduced by using suitable lubricant. Lubricant is a substance introduced between relatively moving parts to reduce friction (μ = 0.1 to 0.0001) and wear rate. The progress in scientific research indicated that reduction in friction occurs due to decrease in adhesion component of friction compared to abrasion component of friction. Almost every relatively moving component in an assembly requires lubricant.
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I. INTRODUCTION

A. Boundary Lubrication

'Boundary Lubrication' term was coined by English Biologist "Sir Hardy" in 1922. He quoted that "Very thin adsorbed layers, about 10 A° thick, were sufficient to cause two glass surfaces to slide over each other". The layer of lubricant separates sliding surfaces, i.e. no direct contact of the sliding parts. This situation is required for many applications such as steel gears, piston-rings and metal -working tools, to prevent severe wear or high coefficients of friction and seizure.

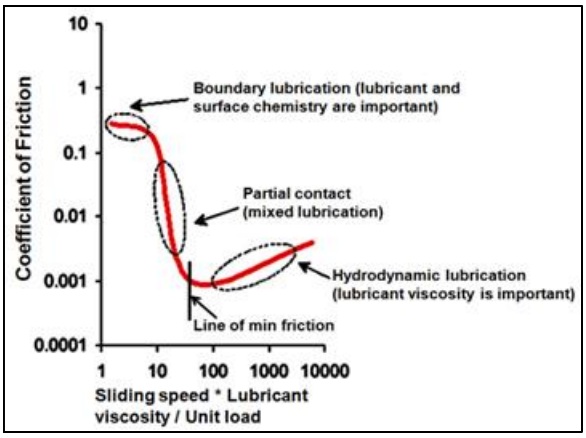
The best boundary lubricants are long chain molecules with an active end group, typically fatty acids. Representative molecules of these types are shown in Fig. 4.10. These consist of a hydrocarbon backbone of carbon atoms and an active end group. In fatty acid active group is COOH, known as the carboxyl group. Such a material, dissolved in a mineral oil, meets a metal or other solid surface with active end group attaches itself to the solid and gradually builds up a surface layer.

Characteristics required for Thin Film Lubrication:

1) Required long chain molecules, with an active end group, which by attaching itself to the solid surface builds a surface layer.
2) It should be dissolvable in mineral/lubricating oils.
3) Temperature stability: It is important because increase in operating temperature may cause reduction in molecular attraction that may lead to detachment of boundary additives from surface.

B. Mixed Lubrication

In bearings and other lubricated devices where relative motion occurs, lubrication is divided into three types: fluid film, wherein the load is supported by the film pressure of a fluid lubricant; boundary, in which the load is supported by direct surface films of the moving solid members; and mixed, where the load is carried by some mixture of the first two. All three lubrication mechanisms can be compared using stribeck curve.



C. Stribeck Curve:

This above plot for a hypothetical fluid lubricated bearing system presents friction coefficient as a function of sliding speed, fluid viscosity and unit load. Three lubrication mechanisms; boundary, mixed and hydrodynamic lubrications have been marked on this plot. This plot defines the stability of lubrication. Suppose we are operating to the right of minimum friction and something happens, say an increase in lubricant temperature. This results lower viscosity and hence a smaller value of bearing number. The coefficient of friction decreases, not as much as heat is generated in shearing the lubricant, and consequently the lubricant temperature drops. Thus, the region to the right of minimum defines stable lubrication because variations are self-correcting. To the left of line, a decrease in viscosity would increase the friction. As temperature rise would increase, the viscosity would be reduced still more. The result would be compounded. Thus, the region to the left of minimum represents unstable lubrication.

II. TYPES & PROPERTIES OF LUBRICANTS

Wear coefficients K for different lubrication mechanisms are provided in Table 4.14. Here unlubricated wear mean, no intentional lubricant at the interface. If we compare unlubricated and solid lubricated cases, we find wear rate in the presence of solid lubricants will be lesser than 1% of wear rate observed under unlubricated case.

A. Lubricant Classification

Lubricant is substance that reduces friction and wear at the interface of two materials. The lubricant at interface reduces the adhesive friction by lower the shear strength of interface. Based on the shear strength of lubricant or molecular state, lubricants are classified in four categories.

– Gaseous lubricants
– Liquid lubricants
– Semi-solid lubricants
– Solid lubricants

B. Solid Lubricants:

A solid lubricant is basically any solid material which can be placed between two bearing surfaces and which will shear more easily under a given load than the bearing materials themselves. The coefficient of friction in dry lubrication is related to the shearing force and the bearing load. Two primary property requirements are:

1) Material must be able to support applied load without significant distortion, deformation or loss in strength.
2) Coefficient of friction and the rate of wear must be acceptably low.

C. Solid lubricants as Bonded Coating:

To increase the durability of solid lubricants coated on surfaces often binders along with lubricating pigments are used. Bonded coatings provide greater film thickness and increased wear life and are more reliable and durable method for applying solid lubricants. Under carefully controlled conditions, coatings consisting of a solid lubricant and binding resin agent are applied to the material by spraying, dipping, or brushing. Dipping is less expensive method. Resins, binder agents, remain effective if operating temperature is lesser than 3000C. Inorganic binders, such as metal salts or ceramics, are used for higher temperature application (> 3000C).

Surface preparation is very important to remove contaminants and to provide good surface topography for lubricant adhesion. Air-cured coatings are temperature sensitive, therefore, heat-cured coatings, which can tolerate higher temperature are used for inorganic binders. Typical applications of bonded coating of solid lubricants are:

1) Cylindrical bushes (Plain bearings)
2) Separator (Cage of rolling bearing)
3) Electrical brushes (Additive to carbon-graphite)

Classification of Solid Lubricants:

Solid lubricants in use are self-lubricating composites. These composites are classified as polymer, metal-solid, carbon and graphite, and ceramic and cermet.

D. Polymers:

These lubricants are suitable to bear light loads. With recent advances in polymers, polymers make the largest group of solid lubricants.

There are two main limitations of solid lubricants which must be accounted before selecting polymers as solid lubricants.

- Low thermal conductivity of polymers inhibits heat dissipation, which causes premature failure due to melting.
- Two polymers in sliding contact will normally operate at significantly at reduced speeds than a polymer against a metal surface.

In polymer, sub class of solid lubricants, PTFE, Nylon and Synthetic polymers are common solid lubricants.

E. Poly Tetra Fluoro Ethylene (PTFE):

Polytetrafluoroethylene is a polymer produced from ethylene in which all the hydrogen atoms have been replaced by fluorine atoms. Teflon is trade name of PTFE given by Du Pont. Very light load applications. Poor adhesion of PTFE to other materials is responsible for very low μ (< 0.1).

F. Strengths of PTFE:

- High chemical stability, great chemical inertness, because of carbon fluorine bonds.
- Very low surface energy, low friction (0.1), high P, low V.
- Nontoxic- useful in pharmaceutical and food industries.
- Weaknesses of PTFE:
- Too soft, high wear rate.
- Poor creep resistance, Low load capacity.
- Poor thermal conductivity, high thermal expansion, temp. limit(2500C).
- Vacuum is detrimental to performance.
- Nylon: - Similar to PTFE, but slightly harder (Specific wear rate; 10-6 - 10-5 mm3/min).
- Synthetic polymers: - Most of disadvantages of PTFE can be overcome by using fillers (glass, carbon) & impregnating it with metal (bronze, lead) structures.

With a suitable rigid (metal) backing, PTFE can withstand wear under extremely high loads (100 MPa) or more, with a friction coefficient of 0.1 or less and virtual freedom from stick-slip sliding. The wear rate of polymer composites is highly dependent upon the surface roughness of the metal counter faces. In the initial operating stages, wear is significant but can be reduced by providing smooth counter faces. As the run-in period is completed, the wear rate is reduced due to polymer film transfer or by polishing action between the sliding surfaces. The low thermal conductivity of polymers inhibits heat dissipation, which causes premature failure due to melting.

1) Metal - solid lubricant:

These metal solids lubricants containing lamellar solids rely on film transfer to achieve low friction. But continuous transfer of film may reduce the life of component, therefore often "no lamellar solids" are added to lamellar solids low friction characteristics. To achieve these objectives, holes are drilled in machine parts and those holes are packed with solid lubricants. Various manufacturing techniques are used in the production of metal-solid composites. These include powder metallurgy, infiltration of porous metals, plasma spraying, and electrochemical code position.

Molybdenum disulphide starts to oxidize significantly above 3500C in oxygen and 4500C in air, but the main oxidation product is molybdic oxide, which is itself a fair high temp lubricant. In high vacuum, the disulphide is said to be stable to 10000C and it evaporates very slowly, so that it has been widely used in space.

The thickness of the film when applied is generally 15 microns, which provides the longest life. Thicker films apparently do not last as long, apparently because it becomes easier for wear particles consisting of the MoS2-resin material to come off in lose form.

a) Carbon and Graphite:

Primary limitations, low tensile strength and lack of ductility of bulk carbon make it good powder form solid lubricant. Their high thermal and oxidation stabilities at temperatures of 500 to 6000C enable use of this solid lubricant at high temperatures and high sliding speeds.

Carbon graphite seals are the most common example "Carbon and Graphite" solid lubricant group. These seals transfer layers of graphite on mating surface and provide low friction, but tight seal.

– Strengths of graphite:

1) Moderate loads (< 275 MPa).
2) Low friction.
3) High temp. stability.

– Weaknesses of graphite:

1) Corrosion.
2) Vacuum detrimental to performance.

2) Base Oil:

Many different types of base oil may be used in the manufacture of a grease, including petroleum (napthenic: more popular, parafinic) and synthetic (PAO's, esters, silicones, glycols). The viscosity of the base oil is the most significant property. A lighter, lower viscosity base oil is used to formulate low temperature greases, while heavier, higher viscosity base oil is used to formulate high temperature greases.

3) Additives:

Chemical additives are added to grease in order to enhance their performance. Performance requirements, compatibility, environmental considerations, color and cost all factor into additive selection. Solid lubricants such as graphite, MoS2, EP additives are few examples.

4) Thickener:

The two basic types of thickeners are organic thickeners and inorganic thickeners. Organic thickeners can be either soap-based or non-soap based, while inorganic thickeners are non-soap based. Simple soaps are formed with the combination of a fatty acid or ester (of either animal or vegetable origin) with an alkali earth metal, reacted with the application of heat, pressure or agitation through a process known as saponification. The fibre structure provided by the metal soap determined the mechanical stability and physical properties of the finished grease. In order to take on enhanced performance characteristics, including higher dropping points, a complex agent is added to the soap thickener to convert it to a soap salt complex thickener. The greases are then referred to as "complexes “. The most commonly economic grease is lime(calcium) base grease (max. temperature 55-800C). Soda(Sodium) base grease (max. temperature 90-1200C) is preferred over lime based grease in rolling bearings.

5) Complex Grease:

Complex grease is similar to a regular grease except that the thickener contains two dissimilar fatty acids, one of which is the complexing agent. This imparts good high temperature characteristics to the final product.

To make a lithium-based complex grease, part of the fatty acid is replaced with another acid (usually a diacid), which makes the complex soap. This type of mixed soap structure has special properties that enable the grease to be heated to a higher temperature without losing its structure or oil separating from the thickener. This maximum temperature is referred to as the dropping point. The dropping point is critical because it is the point at which the grease reverts back to a liquid (the oil separates from the thickener).

6) Advantages of Greases:

– Remains at application point & adhere to surface.
– Less-frequent application needed.
– Good for inclined/vertical shafts.
– Seal out contaminants & less expensive seals needed.
– Water resistant & reduce oil vapor problems.
– Prolong the life of worn parts by filing irregularities
– Provide better mechanical lubrication cushion for extreme conditions such as shock loading, reversing operations, low speeds & high loads.
– Reduce noise and vibration.

7) Disadvantages of Greases:

– Because of semi-solid nature of greases, it does not perform the cooling, so poor dissipation of heat.
– Once dust or dirt enters the grease, it cannot be easily removed and would act as deterrent in performance.
– No filtration. So, contaminants/wear-debris cannot be separated.

8) Grease Characteristics:

Consistency: Degree of grease hardness

1) Grease surface (maintained at 250C) is smoothed out to make it uniform.
2) Cone release mechanism is activated and cone is allowed to sink for 5 seconds.

9) Classification of Liquid Lubricants:

– Vegetable (Castor, Rapeseed) oils:
– Less stable (rapid oxidation) than mineral oils at high temp
– Contain more natural boundary lubricants than mineral oils.

10) Animal fats:

These are fatty substances extracted from animals, and fish. They are composed of fatty acids and alcohols. They are called fixed oils because they do not volatilize unless they decompose. This process is known as drying. The fixed oils which are slow to dry(slow in oxidation) are used for lubrication. Fixed oils are usually added to mineral oils to improve film formation as these lubricants have extreme pressure properties. Common examples of these lubricants are tallow, castor oil and fish oil. One of major problem of this class of lubricants in the availability.

– Mineral oils.

11) Multigrade Oils:

Most oils on shelf today are multigrade oils, such as 10W30 or 20W50. These oils are made by adding polymers in mineral oils to enhance viscosity indices. At cold temperatures, the polymers are coiled up and allow the oil to flow as their low numbers indicate. As the oil warms up the polymers begin to unwind into long chains that prevent the oil from thinning as much as it normally would. In other words, in the uncoiled form, they tend to increase the viscosity thereby compensating for the decrease in viscosity of the oil.

12) Synthetic Oils:

Synthetic oils were originally developed more than 50 years ago and became widely used in jet engines. Less than -1200F ambient temperatures, 60000 shaft rpm, and 5000+F exhaust temperatures proved too much for conventional oils. Synthetics were created specifically to withstand these harsh conditions and to date every jet engine in the world uses synthetic lubricants. Synthetic oils are engineered specifically in uniformly shaped molecules with shorter carbon chains which are much more resistant to heat and stress.

- Viscosity does not vary as much with temperature as in mineral oil.
- Rate of oxidation is much slower.
- Cost (expensive, but applied where mineral oils are inadequate).

Common synthetic oils are:

a) Polyglycols (Polyalkylene glycol):

- Originally used as brake fluids VI = 200, absorb water.
- Distinct advantages as lubricants for systems operating at high temperatures such as furnace conveyor belts, where the polyglycol burns without leaving a carbonaceous deposit. Used in textile industry.

b) Esters:

- Better (in reducing friction, resisting oxidation, prolong draining period, volatility) than mineral oils.
- Costs only a little more than mineral oils.
- Silicon: VI 300, chemically inert, poor boundary lubricant, low solubility, space application, high production cost.
- Perfluoropolyalkylether: Good oxidation & thermal stability VI= 200. In vacuum used for thin film lubrication.
- Perfluoropolyethers:
- High oxidation (3200C) & thermal (3700C) stability.
- Low surface tension & chemically inert.

Few Remarks on usage of lubricants:

c) Grease:

Provides excellent protection against environmental contamination but restricted to a speed of 2 m/s for the reason of inadequate heat dissipation.

d) Liquid:

Low viscosity oils have low fluid friction losses (provided metal to metal contact is avoided) and consequently low heat generation. Liquid can carry away heat.

Under high loads and slow rubbing speed a hydrodynamic film cannot form, hence mineral oils are combined with fatty oils to give a boundary lubrication layer.

G. *Gas Lubrication:*

Gas (i.e., Air, Nitrogen, and Helium) lubrication is used for ultra-thin film thickness(separation) between tribo-pairs.

III. Advantages

- Temperature range– (-2000C) to (20000C). No vaporization, cavitation, solidification, decomposition.
- Very low viscosity (1000 times less viscous than even the thinnest mineral oil), therefore ultra-low friction. Possible high speed.
- Cleanliness.
- No seal requirement for lubrication.

IV. Disadvantages

- Very low load capacity. Low damping. Ultra-low film thickness.
- Smooth surfaces & very low clearance (to maximize load capacity & minimize flow rate) needs a specialist designers & manufacturer (close tolerance).
- Less forgiving of errors in estimating loads or of deviations from specifications during manufacture and installation.

A. *Selection of Lubricant Type:*

Load and speed are two major factors which affect selection of lubricants environment and sealing requirements are additional factors which affect lubricant selection. Apparent area, material conductivity and friction coefficient decide the operating temperature.

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