CHAPTER - I

INTRODUCTION

Tribology is the art of applying operational analysis to problems of great economic significance namely - reliability, maintenance and wear of technical equipment ranging from spacecraft to household appliances. To have a thorough understanding of the subject and its application to machine to machine elements it becomes necessary to know many areas such as chemistry of lubricant, physics of fluid flow, surface topography, contact mechanics, material science, mathematics, mechanical engineering. The subject Tribology generally deals with the technology of lubrication, friction control and wear prevention of surfaces having relative motion under load. Tribology is defined as the science and technology of interacting surfaces in relative motion and of related subjects and practices.

The movement of one solid surface over another is fundamentally important to the functioning of many kinds of mechanism, both artificial and natural. In many instances low friction is desirable. The satisfactory operation of joints, whether hinges or doors or human hip joints, demands a low friction force. Work done in overcoming friction in bearings and other mechanical components is dissipated as heat and its reduction will lead to an overall increase in efficiency. Friction is essential in brakes and clutches; high friction is desirable between a vehicle tyre and the road surface.

Whenever surfaces move over one another, wear will occur. Generally, wear involves progressive loss of material. In most cases, wear is
detrimental, leading to increased clearances between the moving components, unwanted freedom of movement and loss of precision, often vibration, increased mechanical loading and yet more rapid wear and sometimes fatigue failure. The loss by wear of relatively small amounts of material can be enough to cause complete failure to large and complex machines. High wear rates are sometimes desirable. (grinding and polishing). One method of reducing friction and wear is to lubricate the surfaces in some way. Indeed, the study of lubrication is very closely related to that of friction and wear. According to I.V. Kragelsky, V. Valisin (1990), the definition, the types and effects of Friction and Wear are discussed below.

1.1 Friction

Friction may be defined as the resistance to motion which exists when a solid object is moved, tangentially or otherwise against the surface of another object with which it touches. The friction is a property of interaction of surfaces of solids whenever two solids touch against each other so that the forces of actions and reactions come into play and the solids undergo a surface interaction.

1.1.2 Laws of Friction

Friction is quantitatively expressed as a force and frictional force is the force exerted by either of the two contacting bodies tending to oppose relative tangential displacement of the other. Two different situations are encountered here one in which applied force is insufficient to cause any motion and, the other, in which sliding occurs because of applied force.

1. In situations where the resultant of the tangential force is smaller than other forced loads specific to that particular situation, the
friction force (F) will be equal and opposite to the resultant of applied forces and no tangential motion will occur.

2. When applied force is enough and tangential motion occurs, the friction force always acts in a direction opposite to that of the relative velocity of the surfaces.

3. The friction force F is proportional to the normal force / load.

4. The friction force is independent of the apparent area of contact but is dependent on real area of contact.

5. The friction force has weak dependence on the sliding velocity

**Slip – Stick Theory**

This theory assumes that one surface is resting over another on junctions. When one surface starts sliding over another a rise in temperature occurs at these junctions and causes local welding at points of contact. This causes resistance to motion i.e., friction. Sliding occurs on account of applied force, by tearing apart these welds. Immediately after this sliding, local welding takes place on another set of junctions which are again torn to enable sliding and such sticking and slipping continues.

**1.1.3 Types of Friction**

Normally, friction is of two types

- Sliding friction
- Rolling friction

Sliding friction occurs when one object slides against the surface of another object. Rolling friction is the resistance to motion which occurs when an object is rolled over an abutting surface. The rolling object may be of irregular shape, like a boulder or pebble, or of sound spherical or cylindrical shape having a smooth surface of geometric perfection.
1.1.4 Effects of Friction

Friction is somewhat essential and desirable for our day to day living. Some of the processes which are dependent on friction for their effectiveness, of required magnitude, are mentioned below.

1. Force transmitting components which are expected to operate without interface displacement and where static friction is often higher than dynamic friction such as
   a) Walking or running on floors, with or without shoes,
   b) Driving automobiles on roads, or rolling stocks on rails,
   c) Drive surfaces or traction surfaces, such as power belts,
   d) Gripping objects by hand or by mechanical devices like jaws and tongs etc.,
   e) Clamped surfaces like press-fitted or keyed or wedge – damped pulleys, couplings or gears etc. on shafts,
   f) Bolted joints or other joints / fasteners

2. Energy absorption and controlling components; such as brakes, clutches and some resilient couplings. In these cases brake or clutch materials of higher co-efficient of friction are used and generally the difference between static and dynamic coefficient are reduced. Too high a friction may cause squeal or vibration or jumping.

3. Metal working operations like rolling or sheet metal working etc.

4. Quality control components that require constant friction such as in knitting or weaving of products or in glass fibre industries etc., where the tightness of weave or yarn must be controlled or reproduced with the help of some friction and this produces uniform fabric.

5. Friction welding or friction cutting.
6. Use of friction causes oscillations in musical instruments of violin family.

7. Driving nails, screws and other such fasteners which are held by friction. However, friction is mostly undesirable and a very substantial part of the total energy consumption. Reduction of friction, either through design improvement, better material selection, surface modification or through better lubrication etc., is an extremely important problem or job of the modern technology.

The effect of friction on components may be broadly grouped into following categories.

- Temperature rise of components
- Frictional Vibration
- Energy / Power loss
- Wear of components
- Stick-slip oscillations
- Frictional elasticity

1.2 Wear

Generally objects or products lose their usefulness on account of three main reasons: obsolescence, breakage and wear. From tribological considerations, wear is the most important reason amongst the three. Various authors have defined wear in different words. To consider few definitions,

- "Damage or loss of quality by usage"
- "The destruction of material produced as a result of repeated disturbances of frictional bond"
- "The progressive loss of the substance from the operating surface of a body, occurring as a result of relative motion of the surfaces"
“The removal of material from solid surface as a result of mechanical action”

“Removal of material from surface in relative motion by mechanical or chemical processes”

1.2.1 Types of Wear

The wear, encountered in industrial situations, can broadly be classified into following types

1. Adhesive wear
2. Abrasive wear
3. Erosive wear
4. Fretting wear
5. Corrosive wear (Chemical)
6. Others

1.3 Lubrication

Lubrication is the most important component of tribology as it takes care of friction and wear. The primary objective of lubrication is to reduce the severity of friction and wear and shear stresses in solid surface contacts.

1.3.1 Purpose of Lubrication

Though lubrication was basically conceived with the idea of reducing friction, today, lubrication performs multiple functions, some of which are given below.

1. Reduce sliding and rolling friction (primary function) for prolonging the life of parts and components and to prevent wear.
2. Reduce electrical and mechanical power consumption (by reducing friction).
3. Protect bearings and other components from corrosion and rust etc.,
4. Take away heat from components, work as coolant.
5. Clean the parts, to some extent, by carrying away some of the impurities or wear products to sump.
6. Protect bearings from dust and other foreign matters and also work as seal for escape of gases etc. (esp. for greases).
7. Reduces noise, vibration and shock between gear teeth and other components.

1.3.2 Lubrication Principles (Types)

For performing the above mentioned functions, different principles of lubrication are in vogue; some of them are
- Boundary Lubrication
- Hydrostatic Lubrication
- Hydro-dynamic lubrication
- Elasto-hydrodynamic lubrication (EIID)
- Plasto-hydrodynamic (PHD) lubrication

1.3.3. Boundary Lubrication

This is thin film lubrication where organic film is physically adsorbed or chemisorbed, but the film occasionally breaks by asperities of the two surfaces and often metal to metal contact takes place. This often exists at starting and stopping or when heavy load rotates at low speed or high temperature when oil tends to be squeezed out. As such, boundary lubricants are added with some boundary agents like fatty acids etc. In boundary lubrication the solids are not separated by the lubricant, fluid film effects are negligible and there is considerable asperity contact. The frictional characteristics are determined by the properties of the solids and the lubricant film at the common interfaces. The surface films vary in thickness from 1 to
10nm, depending on the molecular size. Co-efficient of friction in boundary lubrication may vary from 0.08 to 0.2. Boundary lubrication often refers to the chemical effects in lubrication.

1.3.4 Hydrostatic Lubrication

In hydrostatic lubrication, high pressure oil is supplied over the whole range of load and speed from external pump source to separate the two surfaces by thick oil film. In this type of lubrication, the friction is nearly zero (co-efficient of friction is only about 0.0001µm) as the load fully floats and the friction depends only on the viscosity of oil. However, this principle is not used extensively in industries, as it involves complicated oil pumping system and leak prevention and collection devices.

1.3.5 Hydrodynamic Lubrication

Hydrodynamic lubrication is generally characterized by conformal surfaces. A positive pressure develops in a hydrodynamically lubricated bearing because the bearing surfaces converge and the relative motion and the viscosity of the fluid separate the surfaces. The existence of this positive pressure implies that a normal applied load may be supported. The magnitude of the pressure developed is not generally large enough to cause significant elastic deformation of the surfaces. It is shown that the minimum film thickness in a hydrodynamically lubricated bearing is a function of normal applied load velocity of the lower surface, lubricant viscosity. In hydrodynamic lubrication, the films are generally thick so that opposing solid surfaces are not prevented from coming into contact. This condition is often referred to as “the ideal form of lubrication”, since it provides low friction and high resistance to wear.
1.3.6 EHD and PHD Lubrication

These can be considered as extension of hydrodynamic lubrication. In elastohydrodynamic lubrication (EHD), because of heavily loaded components, the generated pressure of the oil is so much that is causes small elastic deformations of components. There are two distinct forms of EHL; Hard EHL and soft EHL. Hard EHL relates to materials of high elastic modules such as metals. In this form of lubrication the elastic deformation and the pressure viscosity efforts are equally important. Many machine components carry heavy loads with low geometrical conformity such as gears, cams, rolling element bearings. The surfaces which carry this load are likely to deform. A very thin lubricant film actually supports the load. The EHD lubrication deals with the lubrication of elastic contacts. All the assumptions used in the classical theory of hydrodynamic lubrication cannot be used especially because the variation of viscosity with pressure must be considered here. In addition to this, a heavy load which causes elastic deformation of solids, changes the geometry of the lubricant film. Hence as the shape of the lubricant film determines the pressure distribution the classical elasticity equation and the hydrodynamic equation are solved simultaneously.

Hard EHL is characterized by metallic surfaces and soft EHL by surfaces made of elastomeric materials. The pressures developed in hard EHL are high so that elastic deformation of the solid surfaces becomes important. The minimum film thickness for hard EHL is relatively insensitive to load because the contact area increases with increasing load and thereby providing a larger lubrication area to support the load.

For soft EHL, the elastic distortions are large even for light loads and the viscosity within the conjunction varies a little with pressure because pressures are relatively low and the elastic effect predominates.
PHD (Plasto-hydrodynamic) lubrication is applicable more in metal working processes and attempts to maintain a fluid film between die or roll and the work material during plastic deformation process. During rolling or drawing, the entrained (converging) lubricant film cannot escape from the deformation zone and, because of pressure, aids to some plastic deformation of work-metal. The lubricant thus thins out and spreads to the proportion of surface extension during deformation. This leads to better lubrication and often complete separation between the die and the work – metal and thus reduce friction and die / roll wear considerably.

1.3.7 Types of Lubricants

Lubricants can be classified into three categories

- Lubricating oils
- Greases
- Solid Lubricants

1.4 Theory of Non – Newtonian Fluids

Many of the fluids encountered in day today life (such as water, air, gasoline and honey) are adequately described as being Newtonian, but there are even more that are not common examples include mayonnaise, peanut butter, toothpaste, egg whites, liquid soaps and multigrade engine oils. Other examples such as molten polymers and slurries are of considerable technological importance. A distinguishing feature of many non-Newtonian fluids is that they have microscopic or molecular-level structures that can be rearranged substantially in flow.
For crystalline solids, a definite amount of stress produces a corresponding strain but the rate of strain is zero. That is \( \frac{\partial u}{\partial y} = 0 \) for any value of stress.

In between the two extremities (inviscid fluid at one end and crystalline solid at the other end) we have a host of fluids exhibiting various types of stress versus rate of strain. One such behaviour (linear and passing through the origin) is expressed in terms of Newton’s law of viscosity. All fluids which follow this law are called Newtonian fluids and the others Non-Newtonian fluids.

The flow curve for Non-Newtonian fluids \( \tau \) versus \( -\frac{\partial u}{\partial y} \) is non-linear. Quite a few fluids of industrial importance like Sherries, colloidal suspensions, plastic solutions, lubricating oils greases etc fall under this head.

Non-Newtonian fluids can be classified under three main divisions.

### 1.4.1 Time Independent Fluids

For these fluids there is only one value of \( \tau \) for a particular value of \( -\frac{\partial u}{\partial y} \). In other words, flow curve is not a function of the time during which the stress is applied. The slope of the flow curve varies with \( -\left( \frac{\partial u}{\partial y} \right) \) at different points. So we can write \( \mu = f\left( -\frac{\partial u}{\partial y} \right) \).
1.4.2 Time Dependent Fluids

Depending upon the time for which the stress has been applied, different values of \( -\frac{\partial u}{\partial y} \) can be obtained, when a definite amount of stress is applied to these fluids.

That is, \( \mu = f\left(-\frac{\partial u}{\partial y}, t\right) \)

1.4.3 Visco – Elastic Fluids

These fluids behave both as liquids and as solids, because on the application of stress, they flow like liquids and also experience shear, like solids. On removal of the stress, these fluids exhibit a partial elastic recovery towards their original conditions.

To satisfy the needs for modern machines, the use of complex fluids as lubricants is getting more and more important. For example, high polymer additives are often included in lubricating oils as a kind of viscosity index improver that the variation of viscosity with the temperature decreases. On the other hand the oil containing the polymer additives exhibits certain non-Newtonian behaviour thus leading to classical continuum theory becoming inapplicable.

1.5 Hydrodynamic Lubrication

The modern period of lubrication began with the work of Osborne Reynolds (1842-1912). Reynold’s research was concerned with rotating shafts rotating in bearings and cases. When a lubricant was applied to the shaft, Reynolds found that a rotating shaft pulled a converging wedge of lubricant between the shaft and the bearing. He also noted that as the shaft gained velocity, when the liquid flew between the two surfaces at a greater rate.
Because the lubricant is viscous, this produces a liquid pressure in the lubricant wedge that is sufficient to keep the two surfaces separated. Under ideal conditions, Reynolds showed that this liquid pressure was great enough to keep the two bodies from having any contact and that the only friction in the system was the viscous resistance of the lubricant.

There are four essential elements in hydrodynamic lubrication. The first two are obvious, a liquid (hydro-) and relative motion (-dynamic). The other two are the viscous properties of the liquid, and the geometry of the surfaces between which the convergent wedge of fluid is produced. When considering hydrodynamic lubrication we must be very careful about how we treat the viscous properties of our lubricant. Since the only friction present in a hydrodynamic lubrication system is the friction of the lubricant itself, it would make sense to have a less viscous fluid in order to minimize friction: the less viscous a liquid the lower the friction. Too low of a viscosity jeopardizes our system though. We have to be very careful that the distance between the two surfaces is greater than the largest surface defect. The distance between the two surfaces decreases with higher loads on the bearing, less viscous fluids and lower speeds.

The surface geometry is also very important. The surfaces have to be such that a converging wedge of fluid can develop between the surfaces, allowing the hydrodynamic pressure of the lubricant to support the load of the shaft or moving surface. This is obtained in a number of ways, a common design other than the shaft and bearing configuration is the titled pad bearing, where a titled pad skims over a sheet of fluid.

Hydrodynamic lubrication is an excellent method of lubrication since it is possible to achieve coefficients of friction as low as 0.001 ($\mu=0.001$), and there is no wear between the moving parts. Special attention
must be paid to the heating of the lubricant by the frictional force since viscosity is temperature dependent. One method of accomplishing this is to cycle the lubricant through a cooling reservoir in order to maintain the desired viscosity of the fluid. Another way of handling the heat dissipation is to use commercially available additives to decrease the viscosity’s temperature dependence.

We also have to pay special attention to the extremes of motion, when using hydrodynamic lubrication: starting and stopping. When the surfaces are at rest with respect to each other, or at very low speeds, the distance of separation is theoretically zero.

Hydrodynamic lubrication is, sometimes referred to as fluid film lubrication, where the bearing surfaces are completely separated by a film of oil. This type of lubricating action is similar to a speedboat operating on water. When the boat is not moving, it rests on the supporting water surface. As the boat begins to move, it meets a certain amount of resistance or opposing force due to viscosity of the water. This causes the leading edge of the boat to lift slightly and allows a small amount of water to come between it and the supporting water surface. As the boat’s velocity increases, the wedge-shaped water film increases in thickness until a constant velocity is attained. When the velocity is constant, water entering under the leading edge equals the amount passing outward from the trailing edge. For the boat to remain above the supporting surface there must be an upward pressure that equals the load.

The same principle can be applied to a sliding surface. Fluid film lubrication reduces friction between moving surfaces by substituting fluid friction for mechanical friction. To visualize the shearing effect taking place in the fluid film, imagine the film is composed of many layers similar to a
deck of cards. The fluid layer in contact with the moving surface clings to that surface and both move at the same velocity. Similarly, the fluid layer in contact with the other surface is stationary. The layers in between move at velocities directly proportional to their distances from the moving surface. For example, at a distance of $\frac{1}{2} \text{h}$ from surface 1, the velocity would be $\frac{1}{2} \text{V}$. The force $F$ required to move surface 1 across surface 2 is simply the force required to overcome the friction between the layers of fluid. This internal friction, or resistance to flow, is defined as the viscosity of the fluid.

The principle of hydrodynamic lubrication can also be applied to a more practical example related to thrust bearings used in the hydropower industry. Thrust bearing assembly is also known as tilting pad bearings. These bearings are designed to allow the pads to lift and tilt properly and provide sufficient area to lift the load of the generator. As the thrust runner moves over the thrust shoe, fluid adhering to the runner is drawn between the runner and the shoe causing the shoe to pivot, and forming a wedge of oil. As the speed of the runner increases, the pressure of the oil wedge increases and the runner is lifted as full fluid film lubrication takes place. In applications where the loads are very high, some thrust bearings have high pressure-pumps to provide the initial oil film. Once the unit reaches 100 percent speed, the pump is switched off.

In heavily loaded bearings such as thrust bearings and horizontal journal bearings, the fluid’s viscosity alone is not sufficient to maintain a film between the moving surfaces. In these bearings higher fluid pressures are required to support the load until the fluid film is established. If this pressure is supplied by an outside source, it is called hydrostatic lubrication. If the pressure is generated internally, that is within the bearing by dynamic action, it is referred to as hydrodynamic lubrication. In hydrodynamic lubrication, a fluid wedge is formed by the relative surface motion of the journals or the
thrust runners over their respective bearing surfaces. The guide bearings of a vertical hydroelectric generator, if properly aligned, have little or no loading and will tend to operate in the center of the bearing because of the viscosity of the oil.

1.6 Fluid Film Lubrication

In fluid film lubrication, the moving surfaces are completely separated by a distance. This distance is filled with a film of liquid or gaseous lubricant type. Then, the applied load is carried by the pressure generated within the fluid and frictional resistance to motion arises entirely from the shearing of the viscous fluid.

The hydrodynamic film is formed when the geometry, surface motion and fluid viscosity combine to increase the fluid pressure enough to support the load. The increased pressure, forces the surfaces apart and prevents surface contact. Therefore, in hydrodynamic lubrication one surface floats over the other surface. The increase in fluid pressure that forces the surfaces apart is hydrodynamic lift.

Fluid film lubrication involves a thin film of lubricant which increases the separation of the bearing surfaces. Load on the bearing surfaces is supported by the pressure in the fluid film.

Fluid film lubrication occurs when opposing bearing surfaces are completely separated by a lubricant film and frictional resistance to motion arises entirely from the shearing of the viscous fluid. A finite time is required to squeeze the fluid out of the gap and this action provides a useful cushioning effect in bearings.
As the load is time dependent it is necessary to know the condition at which the lubricant film is likely to break down when time $t$ becomes large enough. There are two principal ways of getting the fluid into the bearing.

i) In hydrostatic and gas or air bearings the fluid is pumped into the inner surfaces of the bearing through an orifice or through a porous material.

ii) In fluid dynamic bearings the bearing rotation sucks the fluid on to the inner surface of the bearing forming a lubricating wedge under or around the shaft.

A pressure is built up during the interval due to the resistance of the viscous lubricant to extrusion and the load is then supported by the lubricant film.

A short notes on Bearings and Squeeze film Lubrication according to Majumdar.B.C.,(1999) are discussed below.

1.7 **Bearings**

A bearing is a system of machine elements whose function is to support an applied load by reducing friction between the relatively moving surfaces. The load may be radial, axial or combination of these. Bearings are classified according to the direction of applied load. If the bearing supports a radial load, it is called radial or journal bearing. On the other hand, a thrust bearing supports an axial load. Some bearings can support both radial and axial load and they are known as conical bearings.

Figure 1.1 depicts a bearing configuration. There are two main types of bearings commonly used in practice. They are rolling element and fluid film bearings. Rolling element bearings have much wider use in industries
since rolling friction is lower than the sliding friction. Lubricant used in rolling-element bearings is usually grease.

If two mating surfaces, during operating conditions are completely separated by lubricant film, such a type of lubrication is called fluid film lubrication. Bearings operating under this kind of lubrication are fluid film bearings. As metal-to metal contact is completely avoided by this system of lubrication, it is sometimes known as perfect-lubrication. Fluid film bearings are lubricated by the hydrodynamic flow which is generated by relative surface motion and / or external pressurization. A fluid film bearing operating on the principle of hydrodynamic lubrication is also called “Self-acting” bearing, in which the load is supported due to wedging effect of the fluid caused by the relative tangential motion between two surfaces.

![Diagram](image)

Figure 1.1 Bearing Configuration

In an externally pressurized (sometimes-called hydro-static) bearing, the load is supported due to pressure in the fluid which is supplied from an external source. In addition to these two types, there is another class of fluid film bearing known as “Squeeze – Film” bearing, which supports a load because of oscillating relative normal motion. In externally pressurized
and squeeze-film bearings, the pressure within the clearance space can be generated without the wedging effect (or converging film)

1.7.1 Applications of Bearing

The range of application and the performance of bearings are literally amazing in steel industry, for example, a roll neck bearing may carry more than 2 million kg. In the instrument industry and elsewhere on the other hand, bearings may carry essentially no load and are often used only for alignment purposes.

1.8. Squeeze Film Lubrication

The squeeze film behaviour arises from the phenomenon of two lubricated surfaces approaching each other with a normal velocity. Because the viscous lubricant contained between these two surfaces cannot be instantaneously squeezed out, it takes a certain time for these surfaces to come into contact. Hence the viscous lubricant has a resistance to extrusion, a pressure is built up during that interval and the lubricant film then supports the load.

The squeeze technology is mainly seen in the following machine components:

1. The time of approach of faces of disc clutch under lubricated conditions.
2. The mechanism of walking with rubber soles on wet or dry pavements.
3. The absorption of vibrations in jet engines using annular squeeze films between the engine bearings and their support, and
4. The rolling characteristics of an automobile tyre on a wet road.

The performance of a parallel disc clutch is seriously affected if the faces of the clutch are expressed to the action of lubricant. Due to the existence of lubricant on these faces squeeze film lubrication takes place, thereby, delays the physical contact between the active surfaces. When
elimination of lubricant is not possible, one can design these bearing surfaces by taking minimum time of approach into consideration.

The mechanics of walking also poses more or less similar problem when water, ice or slush is present on pavement. The time of approach in this case is hindered by the increased viscosity of melting ice or water.

A typical application of squeeze film technology is a squeeze film vibration absorber in an aircraft jet engine. Here the engine shaft rotates at high speed in ball bearing races. However the bearing supports are isolated from the engine support structure by a squeeze film annulus, which absorbs unwanted vibration to some extent. This device has been found to have better performance characteristics when compared to an annular rubber strip used as damper.

1.9 Non-Newtonian Fluid versus Couple stress fluid

Due to Prawal Sinha and Chandan Singh(1981) non-Newtonian behavior is observed in various lubrication processes as a consequence of severe operational requirements, use of additives, use of lubricants with long chain modules or even use of a lubricant contaminated with dust or metal particles.

Non-Newtonian fluids such as molten plastics, pulps and emulsion in chemical engineering practice has motivated many investigators to analyze the behavior of these fluids in motion. Such fluids violate the Newtonian postulate that the stress tensor is directly proportional to deformation tensor. In contrast with the Newtonian regime where a linear relationship exists between the shear stress and shear rate, non-Newtonian fluids may generally be characterized by the constitutive relation
Shear stress = Consistency \times \text{rate of shear}
The non-dimensional parameter $\bar{\ell} = \sqrt{\frac{\eta}{\mu}}$ is the couple stress parameter. The dimension of $\sqrt{\frac{\eta}{\mu}}$ is of length and may be regarded as the chain length of the polar additives in the lubricant. Hence the parameter $\bar{\ell}$ provides microstructure size effect on the mechanism of interaction of the lubricant with the bearing geometry.

According to Bujurke, Naduvinamani, Jayaraman (1991) in the case of incompressible fluids when the body forces and body moments are absent the equation of motion derived by Stoke's with usual notations is

$$\rho \frac{DV}{Dt} = -\nabla p + \mu \nabla^2 V - \eta \nabla^4 V$$

where $\rho$ is the density, $V$ is a velocity vector, $D/Dt$ is a substantive derivative and $p$ is the pressure, $\mu$ and $\eta$ are material constants. The flow problems discussed by Stoke's indicate the significant effect of couple stresses as well as show the experiments measuring the various material constants. It is found that there is an influence of size effects in couple stress fluids that are not preset in the non-polar cases.