Summary

In Modern or machine civilization, lubrication is vitally important. Lubrication concerns itself with the reduction of frictional resistance between two contacting surfaces forced to slide over one another. As secondary objectives, lubrication tends to minimize wear and prevent corrosion. Lubrication is accomplished by inserting a thin film of lubrication between the sliding surfaces, thus lower fluid friction substituted for the higher dry metal friction. The phenomenon of lubrication was well known before its theoretical mechanism was developed. However, only in the 20th century man had begun in understanding the mechanism of friction and lubrication.

In modern civilization, numerous theoretical and experimental works have been done on the subject of Fluid Film Lubrication. Various Mathematical models involving a number of bearing and slider shapes and lubricants as Newtonian fluids, non-Newtonian fluids or even air have been considered and the results have been verified experimentally in a good cases.

With the development of instrumental design, porous metal bearings are widely used because of their simple structure, low-cost and self-lubrication characteristics. In order to prevent viscosity variation with temperature change, in recent years, lubricating oils with sufficient additives of high-molecular-weight polymers as a viscosity index improver are often used. These even contain magnetic suspensions in high energy efficiency systems. But with the introduction of polymers or suspensions, the lubricants behave as non-Newtonian
fluids. These non-Newtonian lubricants can be theoretically analyzed based especially on (i) Power-law fluid model, (ii) micro-polar fluid model (iii) magnetic fluid model, etc which are briefly outlined below. We have used micro-polar fluid as a very special case in major portion of our thesis:

(i) Power law fluid model:

In power law fluid model, a constitutive equation in modified form is

\[ T_{ij} = 2\mu \left( \frac{2e_{ik}e_{ki}}{k} \right)^{n-1} \varepsilon_{ij}, \quad (1) \]

where \( n \) is power law index, \( \mu \) the viscosity coefficient, \( T_{ij} \) the stress tensor and \( \varepsilon_{ij} \) the strain tensor.

(ii) Micro-polar fluid model:

Couple stress fluid theory was one of the specialized micro-polar fluids theory, proposed by Stokes (1966), whose constitutive equations are given by

\[ T_{ij} = (-p + \lambda \nabla_k v_k) \delta_{ij} + \mu (v_{ij} + v_{ji}) - \frac{1}{2} (\rho \varepsilon_{ijk} \gamma_{jk} + T_{lj} \varepsilon_{lj}) - \frac{1}{2} (\rho \varepsilon_{ijk} \gamma_{jk} + T_{lj} \varepsilon_{lj}) + \eta \nabla^2 (v_{ij} - v_{ji}), \quad (2) \]

\[ M_{ij} = 9 \eta e_{i\alpha \beta} v_{\beta, \alpha} + 2 \eta e_{i\alpha \beta} v_{\beta, \alpha} + \rho g_i + e_{ijk} T_{jk} + M_{ji} = 0, \quad (3) \]

where \( v_i \) the velocity components, \( p \) the pressure, \( \rho \) the density, \( T_{ij} \) and \( M_{ij} \) are respectively stress and couple stress tensor, \( g_i \) the body couple per unit mass, \( \mu \) and \( \lambda \) the classical viscosity coefficients and \( \eta \) and \( \eta \),
the new material constants of the couple stress fluid, $\delta_{ij}$ the Kroneker delta and $\epsilon_{ijk}$ the Levi-civita’s symbol (permutation tensor.)

(iii) **Magnetic fluid model:**

As a special case, the couple stress fluid model can be applied to analyze the properties of polar magnetic fluid, where the body forces $b_i$ in the equation of motion,

$$\rho v_i = \rho b_i + T_{jkl} ,$$

is $\sigma(E + \nabla \times B) \times B$ due to the electric and magnetic fields $E$ and $B$ respectively.

It is important to note that different prominent fluid parameters such as viscosity, couple stress parameter etc and different factors of lubrication such as load bearing capacity; frictional loss, minimum clearance etc. are significantly affected by temperature produced by the flow of lubricants as well as bearing motion. The basic energy equation for couple stress fluid model in tensor notation is given by:

$$\rho c_p \left( \frac{\partial T}{\partial t} + \nabla \cdot (\mu \mathbf{u}) \right) = \mu \mathbf{u} \cdot \mathbf{u} + \eta \mathbf{u} \cdot \nabla (\nabla \cdot \nabla \mathbf{u}) ,$$

where $T$ and $k$ are the temperature and thermal conductivity, $\mu$ and $\eta$ are the viscosity-coefficient and couple stress parameter, $u_i$ the fluid velocity components, $c_p$ the specific heat of constant pressure, $\rho$ the fluid density.

The motivation of the present work is to study a few aspects of fluid film lubrication with various types of journals and bearings and, associated with a number of non-Newtonian fluids as lubricants for studying and comparing load bearing capacities, inverse solution, and thermal effects of the bearings. We have also studied the effects of
temperature in couple stress fluid film and effects of non-Newtonian rheology and viscosity-pressure dependence in sphere-plate squeeze-film system as well. Keeping all the above aspects in mind, five problems have been discussed theoretically, using constitutive equations (1) - (6). Wherever possible, we have compared our theoretical results with available existing theoretical and experimental results.

In the first chapter, we have given an introduction on the subject and on the relevant areas. The mathematical models of slider bearings and various fluid models, and, the scope of the thesis have been outlined.

The second chapter deals with "An inverse solution for journal bearings lubricated with temperature dependent couple stress fluids". An analysis to study an inverse solution for infinitely long journal bearings lubricated with incompressible thermal couple stress fluids, is presented. For a given experimentally measured pressure distribution, the eccentricity ratio of journal bearing and the couple stress parameter of polymeric fluid used as lubricant have been estimated. In order to solve the inverse problem, the least-squares optimization technique has been used. An efficient numerical scheme consisting of a modified Reynolds equation for pressure gradient, the film thickness equation, given pressure distribution and the boundary condition for the pressure field, is developed to solve the inverse lubrication problem. Assuming the variation of lubricant viscosity, analytical expressions for temperature and mean temperature, have been presented. The variation of lubrication viscosity has been estimated by using an iterative technique in finite difference method. The proposed inverse algorithm has been tested using some pressure distribution available in existing works. A comparative study of eccentricity ratio in Newtonian and non-
Newtonian behavior of lubricants has been made. The results show that there is a good agreement between the present inverse solution and existing direct solution under identical circumstances. However, as the percentage of random error is increased, the number of iterations required for convergence increases slightly, and the accuracy of the iteration process slightly increases as the fluids thermal parameter increases.

In the third chapter, “A study of anisotropic porous finite squeeze fluid film bearing lubricated with couple stress fluids is dealt with”. A theoretical study of a lubricating squeeze film of fluids with polymeric additives between two rectangular parallel plates, one non-porous and the other anisotropic porous, has been presented. The lubricants having polymeric additives have been modeled as couple stress fluid. In order to present the effects of anisotropic nature of porous plate and to derive a general form of Reynolds equation for pressure gradient, slip boundary conditions at the porous surface and a modified form of Darcy's Law have been considered. Solving Reynolds equation in two different methods, the expressions for film pressure have been derived and their comparative study has been considered. Expressions for load carrying capacity and time height relation have also been derived in terms of Fourier series. Using these expressions, results have been evaluated numerically for some assumed parametric values. It is observed that, under identical lubricant properties, the length-breath ratio of a rectangular plate for maximum load capacity depends on the anisotropic nature of porosity of the porous plate. The time height relation corresponding to maximum load capacity also depends on anisotropic nature of porosity.
In the fourth chapter, we have considered “Thermal effects in couple stress fluid film lubrication of Journal bearings”. A theoretical study of the effects of temperature in journal bearings lubricated with couple stress fluid has been considered. The couple stress fluid, model was proposed by V.K.Stokes. The variation of viscosity of lubricants, having polymer additives, with temperature developed by the frictional heat due to the flow of fluid, is assumed. Analytical expressions for fluid pressure gradient, temperature, mean temperature, lubricant parameter like viscosity coefficient, and bearing factors like load capacity, attitude angle, friction etc., are derived. Variation of lubricant viscosity, mean temperature over film thickness and zero pressure-gradient angles are analyzed by using an iterative procedure. The influence of thermal effects on maximum pressure and point of cavitation has been studied and presented graphically. The load bearing capacity has also been analyzed in both isothermal and non-isothermal condition and comparative study of load bearing capacities has been made for both Newtonian and non-Newtonian fluids. The analysis indicates that the couple stress parameter increases the load bearing capacity of journal bearing and thermal effects on lubricants reduce this increment. The reduction of the increment enhances wear and tear of bearings materials.

In the fifth chapter, “An analysis for optimum Shape of slider bearings using inverse solution method is taken up”. Our aim is to development of an algorithm for predicting the optimum shape of slider bearing and pressure distribution using an inverse solution method. The proposed algorithm needs only to obtain the load and moment conditions in order to simultaneously estimate the slider bearing shape and the pressure distribution. The algorithm is developed from the
Reynolds integral, and, from force and moment balance equations. The least-squares error method, variation method, Gauss-Seidel method and Newton-Raphson method are employed to calculate the optimum shape of slider bearing. Primary results reveal that as the degree of the shape polynomial function increases, there are corresponding gains in the maximum pressure, load and torque are and a corresponding decline in the minimum film thickness. On the other hand, the lower the degree of the objective shape polynomial function is, the more accurate the estimated slider bearing shape and pressure distribution are. With increases in degree of polynomial and number of grid point, the errors in the estimated slider bearing shape and pressure distribution can be reduced. The initial guessed values of the coefficients for the estimated slider bearing shape ($S_j$), the position of the maximum pressure ($X_m$) and the outlet film thickness ($H_0$) have been notable effects upon the estimated results for the present algorithm. Moreover, the greatest error of initial guessed value is that of $S_j$, followed by $X_m$ and then $H_0$. The estimated pressure distributions are more accurate than the estimated values for film thickness. Consequently, the present algorithm is capable of providing accurate results for slider bearing shape and pressure distribution.

In the sixth chapter, we have considered 'A theoretical study of combined effects of couple stresses in lubrications and viscosity-pressure dependence in the sphere-plate squeeze–film system'. A theoretical analysis of the combined effect of non-Newtonian couple-stress lubricants and variation of viscosity with pressure in the squeeze film motion between a sphere and a flat plate is presented. To account for the couple stress effect, arising from a lubricant blended with various additives and to consider the viscosity-pressure dependence, the
nonlinear non-Newtonian Reynolds-type equation is derived, in accordance with the Stokes micro-continuum constitutive equation cooperated with the Barus formula. Through a small perturbation technique, the analytical approximate solution for the film pressure is obtained. According to the result, the combined effects of couple stresses produced by the spin of microelements and viscosity-pressure dependence provide an enhancement in the load-carrying capacity and lengthen the response time as compared to the classical iso-viscosity Newtonian-lubricant case. On the whole, the sphere-plate squeeze film characteristics are improved, especially for higher values of couple stress parameter and viscosity parameter.

In the seventh and last chapter, we have put over all concluding remarks on works done in this research project including a hopeful remark on social and economical benefits, those may have as an outcome from the research work undertaken in the project. We have also narrated prospect of future works in this field on the basis or as an extension of the present work.

The thesis is appended with a wide range of references on the subjects and topics considering the thesis.