Squeeze Film Characteristics of Porous Conical Bearings with Combined Effects of Piezo-Viscous Dependency and non-Newtonian Couple Stresses

Kashinath Biradar, Neminath Naduvinmani and Adinatha Upadhya

June 19, 2022

Squeeze Film Characteristics of Porous Conical Bearings with Combined Effects of Piezo-Viscous Dependency and non-Newtonian couple stresses

Biradar Kashinath[1] , Neminath B. Naduvinmani[2] and Adinatha C. Upadhya[3]

[1]Department of Mathematics, Government First Grade College, Kalaburagi, Karnataka, India.
[2]Department of Mathematics, Gulbarga University, Kalaburagi, Karnataka, India.
[3]Department of Mathematics, Sangolli Rayanna First Grade Constituent College, Belagavi, Karnataka, India.

Abstract

The present article analyzes the combined effect of piezo-viscous dependency and non-Newtonian couple stresses on the squeeze film performance of porous Conical bearing. A most general modified Reynolds equation is derived for porous conical bearing using the stokes micro continuum theory of couple stress fluid and Barus experimental research. The standard perturbation method is used to solve Reynolds equation and approximate analytical solution is obtained for the squeeze film pressure, load carrying capacity and squeeze film time as compared to Newtonian lubricants. It was observed that the non-Newtonian properties dilatants fluids increases pressure, load capacity and squeeze film time as compare to Newtonian lubricants.

Keywords: Squeezing Film, Pressure Dependent viscosity, Non-Newtonian Couple stress Fluid, Porous Conical bearings.

1. Introduction

Pressure arises in a fluid film between two mutually approaching surfaces. This is called the squeeze effect and the fluid film is called the squeeze film. Squeeze film technology is ubiquitous in many areas of modern engineering systems such as automotive engines, approaching gears, machine tools, bearings, skeletal joints, etc. The squeeze film lubrication between two infinitely long parallel plates is studied by Cameron[1]. The unsteady flow between two parallel discs with arbitrary varying gap width was studied by Ishizawa [2]The flow of an incompressible fluid between two parallel plates due to normal motion of the plates is investigated by Bujurke et al[3]. Many authors have investigated theoretically and experimentally the squeeze film phenomenon with a Newtonian fluid such as Pinkus and Sternlicht [4], Jackson [5], Hamrock [6], Naduvinamani and Siddanagouda [7], Biradar Kashinath [8] etc. With the development of modern machine elements, the increasing use of Newtonian lubricants blended with various types of additives cannot be accurately described by the classical continuum theory. Therefore, many micro-continuum theories have been proposed. Among these, the stokes [9] micro-continuum theory is much used. Squeeze film lubrication in thrust bearings was investigated by Ramanasih and Sarkar [10], Ramanasih [11] investigated squeeze films between finite plates lubricated by fluids with couple stress. Lin[12-14] studied squeeze film of long partial journal bearings, as well a hemispherical bearing and a sphere on a plate. Naduvinmani et al.[15] studied the squeeze film bearings in circular stepped plates. Biradar et.al [16] studied squeeze film lubrication between parallel stepped plates with couple stress fluids. The effects of couple stresses on the static and dynamic behaviour of the squeeze film lubrication of narrow porous journal bearings are analysed by Naduvinmani et.al.[17] . Fathima et al.[18] analysed the performance of hydrodynamic squeeze film between anisotropic porous rectangular plates with couple stress fluids. It is observed that these increased the load carrying capacity and delayed time approach in squeeze film bearings and also found that the pressure decreases when increasing the permeability . In all the analysis referred above the lubricant viscosity μ is assumed to be the constant value. According Barus [19] and Bartz and Ether [20], the dependency of viscosity pressure has taken a form

$$\mu = \mu_0 e^{\alpha p} \tag{1}$$

where viscosity is taken as ‘ μ ’ pressure as ‘p’ pressure dependent viscosity (PDV) as ‘α’ , the viscosity at ambient pressure as μ_0 is and taking temperature to be constant. The relation (1) indicates the lubricant viscosity is increasing exponentially and it could alter the predicted performance of squeeze film bearings. According to the earlier research study, the viscosity pressure dependence is more significant in analysing the phenomenon of high pressure in lubrication. In modern years, researchers are more interest to describe the dependency of viscosity pressure through which phenomenon of lubrication could be studied. Lu.FR. et al. [21] predicted the combined effects of non-Newtonian rheology and viscosity pressure dependency in the sphere plate squeeze film of circular plates. Lin JR.et.al. [22] investigated the combined effects of piezo-viscous dependency and non-Newtonian couple stresses in wide parallel plate squeeze film characteristics. N. B. Naduvinmani et.al. [23] studied the effect of piezo-viscous Dependency and couple stress on squeeze film lubrication between parallel stepped plates. It is observed that piezo-viscous and couple stresses effects can improve the squeeze film performance characteristics because of the greater carrying capacity obtained for a lower film thickness. Recently, B Vijayakumar and Sundarammal Kesavan [24] investigated Effects of pressure distribution on parallel circular porous plates with effect of piezo-viscous dependency and non-Newtonian couple stress fluid. Hanumgouda et al.[25] the combined effect of magnetic field and surface roughness on the squeeze film lubrication between porous conical bearing lubricated with couple stress fluid. Vasanth Kumar et.al [26] investigated the combined effect of piezo-viscous dependency and non-Newtonian couple stress fluid on the squeeze film characteristics of porous circular plates. Biradar et.al [27] studied the combined effect of piezo-viscous dependency and non-Newtonian couple stresses on the squeeze film performance of porous triangular Plates. In this paper , an attempt has been made to study the Squeeze Film Characteristics of Porous Conical Bearings with Combined Effects of Piezo-Viscous Dependency and non-Newtonian couple stresses.

2. Mathematical formulation and Solution of the problem

A schematic diagram of the squeeze film of porous conical bearings lubricated with non-Newtonian couple stress piezo-viscous fluid in Figure 1. Where the film height in the direction of the cone axis is 'h', the cone has an angle of 2θ and a radius of 'a'. It is assumed that the fluid inertia, body forces and body couples are negligible and the viscosity μ varies with pressure in the following analysis. The basic equations of the motion under these assumptions for the couple stress fluid flow in the film region are given by

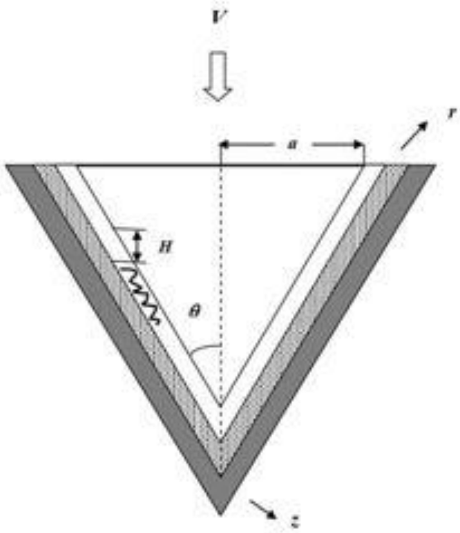

Figure1. Geometrical representation of the Squeeze film of Porous Conical bearings.

$$\frac{1}{r}\frac{\partial(ru)}{\partial r}+\frac{\partial w}{\partial z}=0, \qquad (2)$$

$$\mu\frac{\partial^2 u}{\partial z^2}-\eta\frac{\partial^4 u}{\partial z^4}=\frac{\partial p}{\partial r}, \qquad (3)$$

$$\frac{\partial p}{\partial z}=0. \qquad (4)$$

where u and w are the velocity components in the x and z directions respectively, p is the pressure, μ is the dynamic viscosity and η represents a new material constant responsible for the couple stress fluids.

The relevant boundary conditions are

At Lower surface: z = 0

$$u=0\,,\ \frac{\partial^2 u}{\partial z^2}=0 \qquad (5a)$$

$$w=-w^* \qquad (5b)$$

At Upper surface: $z=h\sin\theta$

$$u = 0 \, , \; \frac{\partial^2 u}{\partial z^2} = 0 \qquad (6a)$$

$$w = \sin\theta \left(-\frac{dh}{dt} \right) \qquad (6b)$$

The modified form of Darcy's explains the flow inside the porous region for couple stress fluid, the velocity components are as follows equation:

$$u^* = \frac{-k}{\mu(1-\beta)} \frac{\partial p^*}{\partial r} \qquad (7)$$

$$w^* = \frac{-k}{\mu(1-\beta)} \frac{\partial p^*}{\partial z} \qquad (8)$$

where u^* and w^* are the Darcy velocity components in x and z directions respectively, $\beta = \frac{\eta}{\mu\kappa}$ represents ratio of microstructure size to pore size, k represents permeability of the porous material, p* is the pressure field in the porous layer. The pressure in the porous region is defined as p* and in consideration of steady state condition given by Laplace's equation:

$$\frac{1}{r}\frac{\partial}{\partial r}\left(r \frac{\partial p^*}{\partial r} \right) + \frac{\partial^2 p^*}{\partial z^2} = 0 \qquad (9)$$

To find the total pressure in a porous region, Morgan and Cameron's [28] approximations are applied. The surface z = - δ is taken as non-porous and at z = 0 as porous and pressure within porous region is taken as p = p*. Integration with respect to z to both sides of equation (9) up to the thickness of porous region gives;

$$\left(\frac{\partial p^*}{\partial z} \right)_{z=0} = -\delta \left(\frac{1}{r}\frac{\partial}{\partial r}\left(r \frac{\partial p^*}{\partial r} \right) \right) = -\delta \left(\frac{1}{r}\frac{\partial}{\partial r}\left(r \frac{\partial p}{\partial r} \right) \right) \qquad (10)$$

Solving equations (2) and (3) with boundary conditions (5a) and (6a) the velocity component *u* can be obtained as follows.

$$u(r,z) = \frac{e^{-2\alpha p}}{2\mu_0} \frac{\partial p}{\partial x} \left\{ \frac{z(z - h\sin\theta)}{e^{-\alpha p}} + 2l^2 - 2l^2 \frac{\cosh\left[\dfrac{(2z - h\sin\theta)}{e^{-0.5\alpha p} 2l} \right]}{\cosh\left[\dfrac{h\sin\theta}{e^{-0.5\alpha p} 2l} \right]} \right\} \qquad (11)$$

where

$l = \sqrt{\frac{\eta}{\mu_0}}$ is the couple stress parameter.

Substituting the expression for *u* from equation (11) in the continuity equation (2) and integrating across the film thickness and using the boundary conditions (5b) and (6b) gives the nonlinear modified Reynolds equation for conical plates lubricated with couple stress fluids in the form

$$\frac{1}{r}\frac{\partial}{\partial r}\left\{ \left[f(h,l,\alpha,p) r + \frac{12k\delta e^{-\alpha p}}{(1-\beta)} \right] \frac{\partial p}{\partial r} \right\} = -12\mu_0 \sin\theta \frac{\partial h}{\partial t}, \qquad (12)$$

where

$$f(h,l,\alpha,p) = e^{-\alpha p} h^3 \sin^3\theta - 12l^2 e^{-2\alpha p} h \sin\theta + 24 l^3 e^{-2.5\alpha p} \tanh\left[\frac{e^{0.5\alpha p} h \sin\theta}{2l} \right].$$

Introducing the non-dimensional variables and parameters

$$r^* = \frac{r}{a\cos ec\theta},\ l^* = \frac{l}{h_0},\ h^* = \frac{h}{h_0},\ \upsilon = \frac{\alpha\mu_0 a^2\left(-\frac{dh}{dt}\right)\cos ec\theta}{h_0^3},\ p^* = \frac{ph_0^3}{\mu_0 a^2\left(-\frac{dh}{dt}\right)\cos ec\theta},\psi = \frac{k\delta\sin\theta}{h_0^3}$$

into equation (12), the non-dimensional modified Reynolds equation is obtained in the form

$$\frac{\partial}{\partial r^*}\left\{ f^*\left(h^*,l^*,\upsilon,p^*,\psi\right) r^* \frac{\partial p^*}{\partial r^*}\right\} = 12r^*, \tag{13}$$

where

$$f^*(h^*,l^*,\upsilon,p^*) = e^{-\upsilon p^*} h^{*3}\sin^3\theta - 12l^{*2}e^{-2\upsilon p^*}h^*\sin\theta + 24l^{*3}e^{-2.5\upsilon p^*}\tanh\left[\frac{e^{0.5\upsilon p^*}h^*}{2l^*}\right] + \frac{12e^{\upsilon p^*}}{1-\beta}$$

The non-dimensional Reynolds equation (13) is observed to be highly non-linear. To obtain the first order analytical solution for small values of viscosity parameter $0 \le \upsilon << 1$, a small perturbation method for the film pressure adopted by putting

$$p^* = p_0^* + \upsilon p_1^* \tag{14}$$

into the Reynolds equation (7.2.8) and neglecting second and higher order terms of υ, we obtain the following two equations responsible for pressure p_0^* and p_1^* respectively

$$\frac{\partial}{\partial r^*}\left\{ r^* \frac{\partial p_0^*}{\partial r^*}\right\} = -\frac{12r^*}{f_0^*(h^*,l^*,\psi)}, \tag{15}$$

$$\frac{\partial}{\partial r^*}\left\{ r^* \frac{\partial p_1^*}{\partial x^*}\right\} = -\frac{f_1^*\left(h^*,l^*,\psi\right)}{f_0^*\left(h^*,l^*,\psi\right)}\frac{\partial}{\partial r^*}\left\{ r^* p_0^* \frac{\partial p_0^*}{\partial r^*}\right\}, \tag{16}$$

where

$$f_0^*\left(h^*,l^*\right) = h^{*3}\sin^3\theta - 12l^{*2}h^*\sin\theta + 24l^{*3}\tanh\left[\frac{h^*\sin\theta}{2l^*}\right] + \frac{12\psi}{1-\beta} \quad \text{and} \tag{17}$$

$$f_1^*\left(h^*,l^*\right) = -h^{*3}\sin^3\theta + 6l^{*2}h^*\sin\theta\left[4 + \sec h^2\left(\frac{h^*\sin\theta}{2l^*}\right)\right] - 60l^{*3}\tanh\left[\frac{h^*\sin\theta}{2l^*}\right] - \frac{12\psi}{(1-\beta)^2} \tag{18}$$

Solving the equations (14) and (15) under the pressure boundary conditions

$$\begin{aligned} &\frac{dp^*}{dr^*} = 0 \quad \text{at } r^*=0, \\ &p^*=0 \quad \text{at } r^*=1. \end{aligned} \tag{19}$$

The expression for dimensionless pressure developed in the film region is obtained in the form

$$p^* = \frac{3\left(1-r^{*2}\right)}{f_0^*\left(h^*,l^*,\psi\right)} - \frac{9}{2}\upsilon\left[\frac{f_1^*\left(h^*,l^*,\psi\right)}{f_0^{*3}\left(h^*,l^*,\psi\right)}\left(r^{*2}-1\right)^2\right].$$

The load carrying capacity w^* can be obtained by integrating the film pressure over the squeeze film area as follows

$$w = \int_{0}^{a\cos ec\theta} 2\pi prdr \tag{20}$$

This in the non-dimensional form is given by

$$w^* = \frac{wh_0^3}{\pi\mu_0 a^4\left(-\frac{dh}{dt}\right)\cos ec^3\theta} = 2\int_0^1 p^* r^* dr^* \tag{21}$$

using expression (21) the above equation becomes

$$w^* = \frac{3}{2}\left\{\frac{f_0^{*2}(h^*,l^*,\psi) - \upsilon f_1^*(h^*,l^*,\psi)}{f_0^{*3}(h^*,l^*,\psi)}\right\}. \tag{22}$$

The non dimensional squeezing time t^*can be calculated by integrating relation (22) with respect h^* with the initial condition of $h^* = 1$ at $t^* = 0$

$$t^* = \frac{3}{2}\int_{h^*}^{1}\left[\frac{f_0^{*2}(h^*,l^*,\psi) - \upsilon f_1^*(h^*,l^*,\psi)}{f_0^{*3}(h^*,l^*,\psi)}\right]dh^*, \tag{23}$$

where

$$t^* = \frac{-wh_0^2}{\pi\mu_0 a^3 \cos ec^3\theta}t.$$

It is to be noted that the dimensionless film pressure, the dimensionless load carrying capacity and the dimensionless squeeze film time cannot be obtained by direct integration. However, they could be numerically evaluated by Gaussian quadrature method.

3. Results and discussion:

The present paper predicts the, Squeeze film characteristics of porous conical bearings with combined effects of Piezo-Viscous Dependency and non-Newtonian couple stress with respect to the different non-dimensional parameters like, parameter l^* for couple stresses, parameter h^* for film thickness and parameter ψ for permeability . Hence geometry study of the mechanism of fluid interaction provided with the bearing is analysed. To calculate the non-dimensional quantities such as p^*, w^* and t^* where, h^*= 0.7, l^* = 0 to 0.2, υ = 0.0 to 0.03, ψ = 0.0 to 0.001.

3.1 Squeeze film pressure

Figure 2 predicts the variation of dimensionless pressure p^* with the dimensionless radial coordinate x^* for different values of υ and l^* with h=0.7 and $\theta=\pi/3$. The results of iso-viscous non-Newtonian case (υ =0.0, l^* = 0.1) are found to be dispense higher squeeze film pressure in comparison to the iso-viscous Newtonian (υ =0.0, l^* = 0.0) lubrication situation, further the dimensionless pressure p^* increases for increasing values of couple stress parameter l^* (0.1) and pressure dependent viscosity υ (0.03). It seen that the squeeze film pressure increase with increasing values of couple stress l^* (0.15,0.2) and pressure dependent viscosity υ. Figure 4 describes the variation of dimensionless maximum pressure p^*_{max} with h^* for different values of υ and l^* with $\theta=\pi/3$. It is found that the dimensionless maximum pressure p^*_{max} decreases for increasing values of h^*. Figure 5 shows the variation of non-dimensional pressure with the non-dimensional radial coordinate x^* for different values of the permeability factor ψ with h=0.7 and $\theta=\pi/3$. It is found that non-dimensional pressure decreases with increasing the values of permeability parameter ψ. As the porous layer thickness increases, more fluid flow into the porous region and which reduces the pressure.

3.2 Load carrying capacity

Figure 6 predicts the variation of dimensionless load carrying capacity w^* with half cone angle θ for different values of υ and l^* with h=0.7. It is found that the dimensionless load carrying capacity w^* decreases for increasing values of θ and also found that the non-Newtonian effects (l^* = 0.1) are yield higher load carrying capacity as compared with Newtonian (l^* = 0.0) case. It is observed that dimensionless load carrying capacity increases for increasing values of couple stress parameter l^* (=0.1) and pressure dependent viscosity υ (=0.03). Increasing the values of non-Newtonian couple stress parameter (l^* = 0.15, 0.2) results in higher values of w^*. Figure 7 describes the variation of dimensionless load carrying capacity w^* with h^* for different values of υ and l^*

with $\theta = \pi/3$. It is found that the dimensionless load carrying capacity w^* decreases for increasing values of h^*. Further, the w^* increases for increasing values of υ and l^*. Figure 8 shows the variation of dimensionless load carrying capacity w^* for different values of the permeability factor ψ with h=0.7 and $\theta=\pi/3$. It is found that dimensionless load carrying capacity w^* decreases with increasing the values of permeability parameter ψ and also found that dimensionless load carrying capacity w^* decreases with increase in film thickness.

3.3 Squeeze film time

Figures 9 and 10 shows the variation of dimensionless squeeze film time t^* with non-dimensional film thickness h^* for different values of υ and l^* with $\theta = \pi/3$ and $\theta = \pi/4$ respectively . It is observed that dimensionless squeeze film time t^*, decreases for increasing the values of h^* with higher squeeze film time for lower film thickness. It is also observed that under iso-viscous case, the non-Newtonian (υ =0.0, l^* = 0.1) effects are observed to yield higher dimensionless load carrying as compared with Newtonian (υ =0.0, l^* = 0.0) case. the presence non-Newtonian couple stress (υ =0.0, l^* = 0.1) result is an increase in dimensionless squeeze film time t^*. A longer dimensionless squeeze film time t^* is also obtained when the combined effects of pressure-dependent viscosity and non-Newtonian couple stress (υ =0.03, l^* = 0.1,0.15,0.2) are included. It is evident that decreasing the angle θ increases the non-Newtonian effects on the t^*. Figure 11 shows the variation of dimensionless squeeze film time t^* for different values of the permeability factor ψ with h=0.7 and $\theta=\pi/3$. It is found that dimensionless squeeze film time t^* decreases with increasing the values of permeability parameter ψ.

4. Conclusions

On the basis Baru's experimental formula , Stokes theory of couple stress lubricants and Darcy's equation the impact of PDV on squeeze film lubrication amid a porous conical bearings lubricated with couple stress fluids are analysed. Based on this, we draw the following conclusions.

1. The effect of pressure-dependent viscosity provides an increase in the squeeze film pressure, load carrying capacity and elapsed response time for the porous conical plates as compared with iso-viscous lubricants.
2. The maximum pressure, load carrying capacity and squeeze film time decreases for increasing values of film thickness.
3. The effect of couple stress is to enhance the squeeze film pressure and load carrying capacity of the porous conical plates as compared with Newtonian case.
4. The presence of non-Newtonian fluid is responsible to strengthen the squeeze film time as compared with Newtonian fluid.
5. The squeeze film Pressure, Load carrying capacity and squeeze film time decreases with increase of porous parameter ψ.

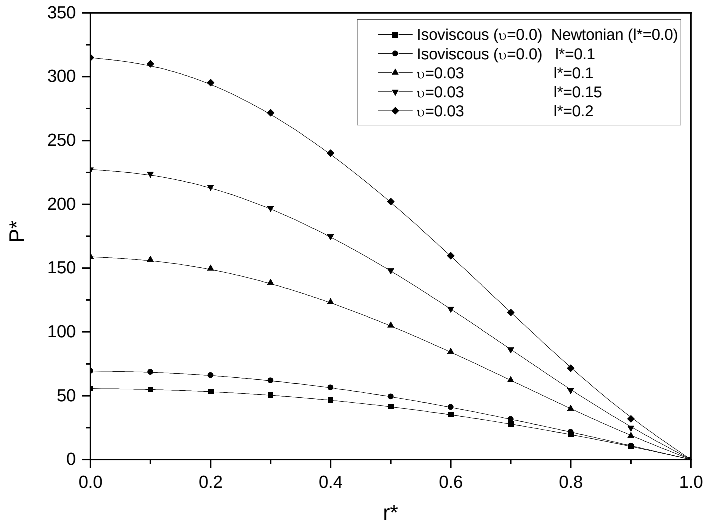

Figure 2. Variation in the film pressure P^* with radial axis r^* for different values of υ and l^* with h^*=0.7 and $\theta = \pi/3$.

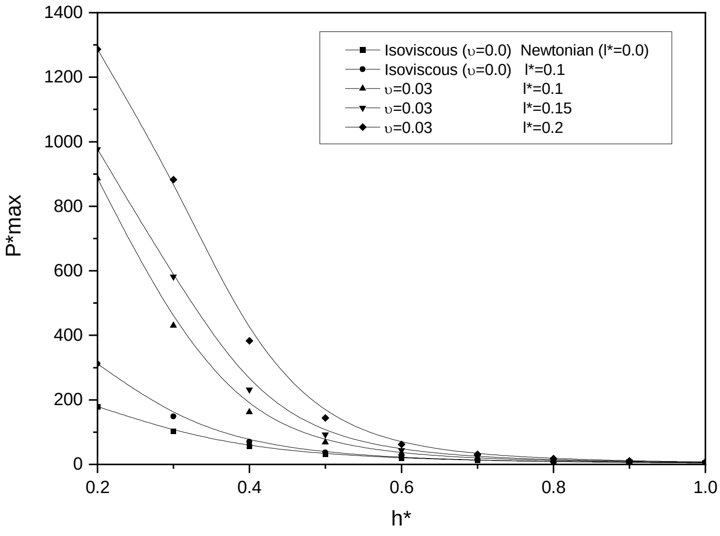

Figure 3. Variation in the film maximum pressure P^*_{max} with h^* for different values of υ and l^* with $\theta = \pi/3$.

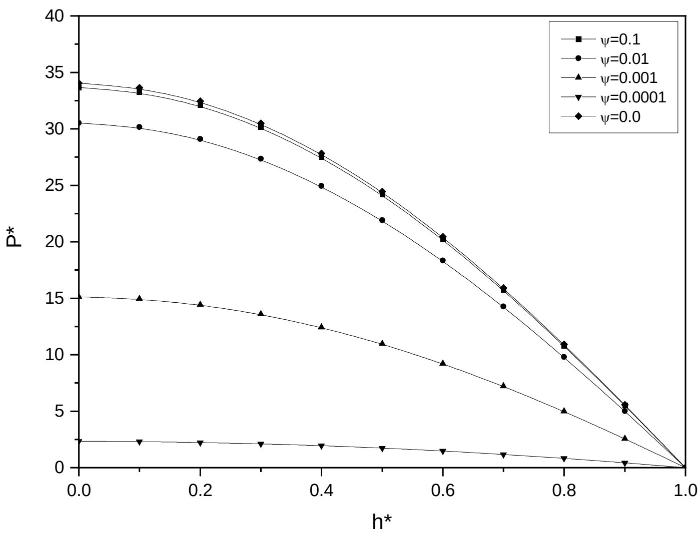

Figure 4. Variation in the film pressure P^* with h^* for different values of ψ with $\theta = \pi/3$, h^* =0.7.

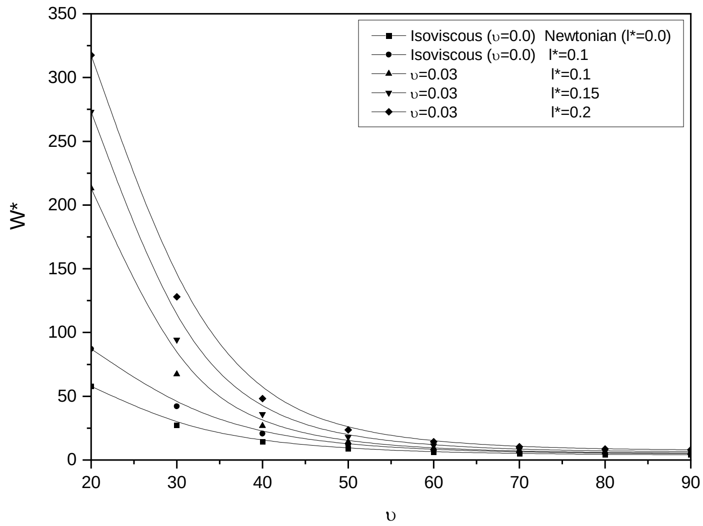

Figure 5. Variation in non-dimensional load carrying capacity w^* with θ for different values of υ and l^* with h^*=0.7 .

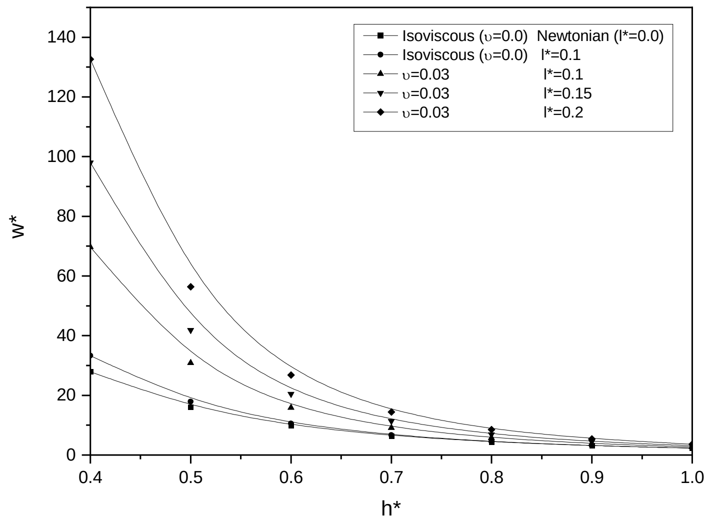

Figure 6. Variation in non-dimensional load carrying capacity w^* with h^* for different values of υ and l^* with $\theta = \pi/3$.

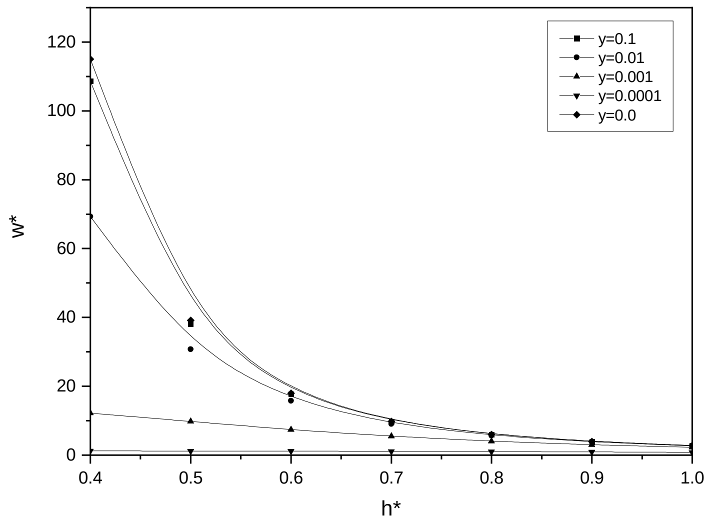

Figure 7. Variation in non-dimensional load carrying capacity w^* with h^* for different values of ψ with $\theta = \pi/3$

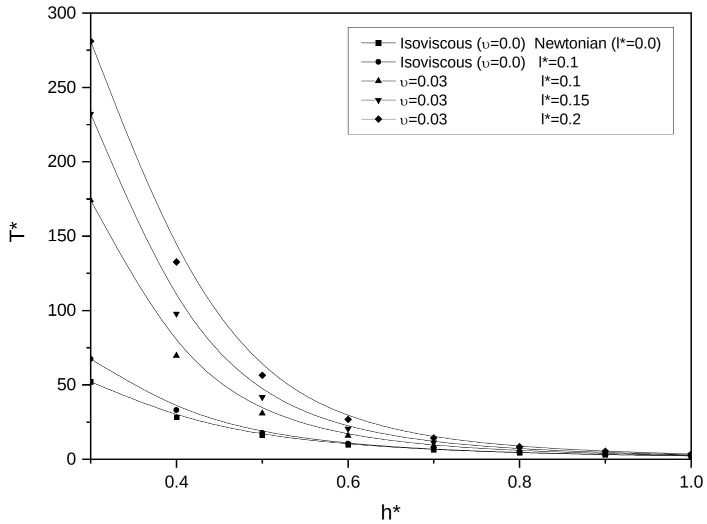

Figure 8. Variation in non-dimensional squeeze film time T^* with h^* for different values of υ and l^* with $\theta = \pi/3$.

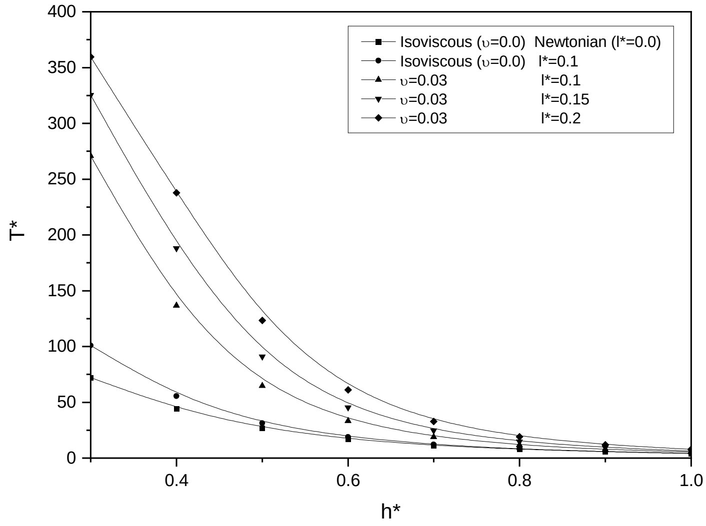

Figure 9. Variation in non-dimensional squeeze film time T^* with h^* for different values of υ and l^* with $\theta = \pi/4$.

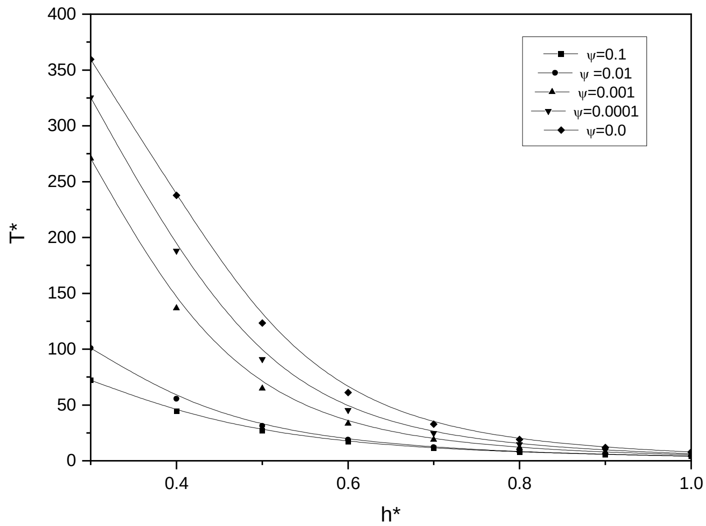

Figure 10. Variation in non-dimensional squeeze film time T^* with h^* for different values of ψ with $\theta = \pi/3$

5. References

[1] *A Cameron, The principles of Lubrication, Longmans, Green and Company, London, UK,1966.*

[2] *S. IshizawaThe unsteady laminar flow between two parallel disks with arbitrary varying gap width. Bull. JSME 9 (1966), pp. 533-550.*

[3] *Bujurke N M Achar P K and Pai N P 1995 Computer Extended Series for Squeezing Flow between Plates Fluid Dynamics Research 16 173-187.*

[4] *O Pinkus and B Strenlicht, Theory of Hydrodynamic Lubrication, McGraw-Hill, New York,NY USA,1961.*

[5] *Jackson J..D., A study of squeeze flow, Applied science research section A,11, 148-152, 1963.*

[6] *Harmrock, Fundamentals of Fluid Film Lubrication, McGraw-Hill, New York, NY, USA, 1994.*

[7] *Naduvinamani N B and Sddanagouda A 2009 Squeeze film lubrication on circular stepped plates with couple stress fluids J. Braz. Soc. Mech. Sci & Eng 31(1) 21-26.*

[8] K. Biradar, Magneto hydrodynamic couple stress squeeze film lubrication of triangular plates, Int. J. Eng Inventions, Vol. 3, 2013, 66-73.,

[9] *V. K. Stokes, Couple Stresses in fluids, Phy. Fluids, 1966, 9, 1709-1715.*

[10] *Ramanaish G and Sarkar P. Squeeze films and thrustbearings lubricated by fluids with couple stress. Wear 1 978; 48: 309–316.*

[11] *G. Ramanaiah, Squeeze films between finite plates lubricated by fluids with couple stress,Wear, 1979, 54, 315-320.*

[12] *Lin JR. Couple-stress effects on the squeeze film characteristics of hemispherical bearings with reference to*

synovial joints. Appl Mech Eng1996; 1: 317–332.
[13] *Lin JR. Squeeze film characteristics of long partial journal bearings lubricated with couple stress fluids.TriboInt1997; 30: 53–58.*
[14] *Lin JR. Squeeze film characteristics between a sphere and a flat plate: couple stress fluid model. Comput stuct 2000: 75; 73-80.*
[15] *N.B. Naduvinmani and Siddanagouda: A squeeze film lubrication between circular stepped plates of couple stress fluids, JBSME, 2009, 31, 21-26.*
[16] *K. Biradar: Squeeze film lubrication between parallel stepped plates with couple stress fluids, Int. J. Stat. Math., 2012, 3,(2), 65-69.*
[17] *Naduvinamani N B and Siddanagoda, Static and dynamic behaviour of the squeeze film lubrication of narrow porous journal bearings with couple stress fluids, proc. Inst. Mech Eng Part-J J Eng Tribology 2001;205: 45-62.*
[18] *S.T. Fathima, N.B. Naduvinmani, H. M. Shivkumar and B. N.Hanumangouda, A study on the performance of hydromagnetic squeeze film between anisotropic porous rectangular plates with couple stress fluids, Tribol. Online, 2014, 9(1), 1-9.*
[19] *C. Barus, Isothermal isopiestics and isometrics relative to viscosity, Am. J. Sci., 1893, vol. 45. pp 87-96.*
[20] *W.J.Bartz and J. Ether, Influence of pressure viscosity oils on pressure tempreture and film thickness in elatohyrodynamical lubricated rolling contacts, ASME J Lubricat Technol 1976; 98, 500-508.*
[21] *Lu RF and Lin JR, A theoretical study of combined effects of non-Newtonian rheology and viscosity-pressure dependence in the sphere-plate squeeze-film system. Tribol Int 2007,40,125-131.*
[22] *Lin JR, Chu LM and Liang LJ, Combined Effects of piezo-viscous dependency and non-Newtonian couple stress in wide parallel- plate squeeze film characteristics, Tribol Int 2011, 25, 1-9.*
[23] *N.B.Naduvinmani, Siddangoda A., and Hiremath A.G. Efeects of piezo-viscous dependency and coupled stress on squeeze film lubricantion between parallel stepped plates, Tribology Tranactions 2016, vol. 59, No.2, 237-243*
[24] *B Vijayakumar and Sundarammal Kesavan; Effects of pressure distribution on parallel circular porous plates with effect of piezo-viscous dependency and non-Newtonian couple stress fluid, Journal of physics conference series 1000(2018)012021.*
[25] *Hanumagowda B.N.,Swapna S, Nair and Salma A.; the combined effect of magnetic field and surface roughness on the squeeze film lubrication between porous conical bearing lubricated with couple stress fluid. IJMPERD,Vol. 10, Issue 3, Jun 2020, 8665-8676.*
[26] *Vasanth Kumar, Hanumagowda B.N.,Jogyalla S., Raju B.T.,1 Combined effect of piezo-viscous dependency and non- Newtonian couple stress fluid on the squeeze film characteristics of porous circular plates, Journal of Advanced Research in Fluid Mechanics and Thermal Sciences 51, Issue 2 (2018) 158-168.*
[27] *Biradar K. N.B. Naduvinmani and A.C. Upadhya; the combined effect of piezo-viscous dependency and non-Newtonian couple stresses on the squeeze film performance of porous triangular Plates, Stochastic Modeling & Applications, vol 26, No.3, spl. Issue 2022 part-2.*
[28] *Morgan V.T. and Cameron A, Mechanism of lubrication in porous metal bearings, proceedings of the conference on lubrication and wear, Institution of mechanical engineers, London, pp. 151-157.*

Appendix

Notation

a radius of conical plate.
υ viscosity-pressure parameter
h film thickness
h^* non-dimensional film thickness
l couple stress parameter.
l^* non-dimensional couple stress parameter
p squeeze film pressure
p^* non-dimensional pressure in the porous region
u,w velocity component in the r and z directions, resply.
W load carrying capacity
W^* non–dimensional load carrying capacity
t response time
t^* dimensionless response time
μ lubricant viscosity
μ_0 viscosity at ambient pressure and a constant temperature

α pressure-viscosity coefficient,

β ratio of microstructure size of polar additives to the pore size

η material constant responsible for couple stress fluids

κ permeability parameter

ψ non dimensional permeability parameter

V squeezing velocity, $\left(-\dfrac{dh}{dt}\right)$

θ half angle of conical plate.

*****