ISSN 2277 – 5528
Impact Factor- 4.015

INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES &MANAGEMENT

CFD ANALYSIS OF A NON-NEWTONIAN FLUID IN A HYDRODYNAMIC JOURNAL BEARING

Hanoca P[*1] and H V Ramakrishna[2]

[*1]Research Scholar, Department of Mechanical Engineering, Malnad College of Engineering, Hassan, India.

[2]Professor, Department of Mechanical Engineering, Malnad College of Engineering, Hassan, India.

ABSTRACT

A numerical study of non-Newtonian fluid in hydrodynamic journal bearing has been carried out. This work is conducted in commercially available ANSYS Workbench software package. The mass, momentum and energy equations are solved by SIMPLE pressure-velocity coupling scheme under pressure based solver. The effect of pressure and temperature on viscosity and density of the lubricant with cavitation effects are considered. The non-Newtonian power law model was used to study the performance characteristics of journal bearings under various flow index values such as 0.8, 0.9, 1.0, 1.1 and 1.2. The results shows that as flow index value increases, the viscosity and hydrodynamic pressure are also increase which improves the load carrying capacity of the bearings.

Keywords: *CFD, Non-Newtonian fluid, bearing etc.*

I. INTRODUCTION

Journal bearings are machine elements used to support load and encourage smooth relativemotion between solid surfaces with low friction. The lubricant is present in between the journal and bearing to avoid direct contact between them. Due to rotation of the journal, the lubricant film forms a wedge and pressure gradients are formed at the clearance between the surfaces. This generated pressure supports the bearing load. In that high pressure, the liquid lubricant losses its characteristics and behaves like non-Newtonian fluids. The generated pressures is so high at the minimal gap and next to that spot the pressure is atmospheric due to sudden change in pressure cavitation phenomenon occurs. Then also rotation of the journal, temperature of the lubricant will rises which will effects the performance of the bearings. For this reason, the effects of temperature on the viscosity, cavitation phenomenon and non-Newtonian effects are should be included in the bearing simulation.

There are several numerical works have been executed in the literature on the hydrodynamic journal bearings. The existence of pressurised lubricant film was first clarified experimentally by Britishrailroad engineer Beauchamp Tower [1]. Based on Tower'sexperiments, Osborn Reynolds originated a theory of lubrication and called as Reynolds equation [2]. K.P. Gertzos, et. al., [3] were conducted isothermal numerical analysis on journal bearings for Bingham lubricants. The analysis was carried out in FLUENT software package. Mukesh Sahu et al. [4] and Amit Chauhan et al. [5] were did numerical simulation on journal bearing by considering thermal effects. The effect of variation of pressure and temperature on the viscosity of lubricant was included during the analysis. Amit Chauhan et. al., were also did thermal analysis on non circular journal bearings [6]. Samuel Cupillard et. al., were conducted both isothermal [7] and thermal numerical [8] analysis on textured journal bearings. In both cases they considered the cavitation effects. Hanoca et. al., [9] were studied the effect of oil film thickness at the entrance of the infinitely long slider bearing using CFD analysis. Adam Czaban was simulated the conical bearing. In this analysis non-Newtonian and thermal effects are included [10]. P C Mishra studied the effect of journal misalignment, bore non circularity, and lubricant non-Newtonian behavior. He solved Reynolds equation and energy equation using finite difference approach [11].

Based on the literature survey, works on non-Newtonian behavior on journal bearings are very few. Hence in this work a non-Newtonian behavior in bearing is simulated using ANSYS Workbench software package.

II. NUMERICAL ANALYSIS

Governing Equations

To solve the all kind of fluid flow problems, conservation equation of mass and momentum are required. In this work FLUENT software is used to solve above equations to compute pressure and velocity of the fluid. In order to compute rate of heat transfer in fluid or bearing surfaces, the energy equations to be considered. The conservation of mass (Eq. (1)) and momentum (Eq. (2)) can be written as [12]:

$$\frac{\partial \rho}{\partial t} + \nabla.(\rho\vec{v}) = 0 \qquad (1)$$

$$\frac{\partial}{\partial t}(\rho\vec{v}) + \nabla.(\rho\vec{v}\vec{v}) = \nabla p + \nabla.(\bar{\bar{\tau}}) + \rho\vec{g} + \vec{F} \qquad (2)$$

Where, $\rho\vec{g}$ and $\vec{F}$ represents the gravitational and external body forces respectively.

The three dimensional energy equation for steady state and incompressible fluid is given in Eq. (3) [12].

$$\frac{\partial}{\partial t}(\rho C_P T) + \nabla.(\rho\vec{v}C_P T) = \nabla(K.\nabla T) + Q_V \qquad (3)$$

Where, Q_V is the volumetric heat source, C_P and K represents the Specific heat and thermal conductivity of the lubricant respectively.

In this analysis, the effect of variation of pressure and temperature on the viscosity of lubricant is considered. To reveal above effect the combination of Barus and Reynolds equations is used and given in Eq. (4).

$$\mu_{Barus} = \mu_0\, e^{[\alpha P - \beta(T - T_0)]} \qquad (4)$$

Similarly for density, the combination of Dowson-Higginson equation for density-pressure with temperature-density linear variation relationship is used and given in Eq. (5).

$$\rho = \rho_0 \left[1 + \frac{0.6P}{1+1.7P} + D(T - T_0)\right] \qquad (5)$$

In this study, the shear stress and strain relation of lubricant is modelled with the scheme of a non-Newtonian power-law fluid model [13].

$$\mu = \mu_{Barus}\,(1 + k\dot{\gamma})^{\frac{n-1}{2}} \qquad (6)$$

The incorporation of equations from (4) to (6) are not included in the FLUENT flow solver, so those equations are written in udf's and compiled in the flow solver. For cavitational boundary conditions Schneer and Sauer model is used.

Modeling and Meshing

The schematic representation of the journal bearing is shown in Fig.1. The journal rotates with an angular velocity ω and is in an equilibrium position under the external vertical load W as well as the pressure of the lubricant film. The geometrical specifications and properties of the oil used for the analysis are given in Table 1. The journal bearing is modeled according the specification. Then structured mesh was generated for the flow domains by using the standard mesh feature provided by ANSYS Workbench.

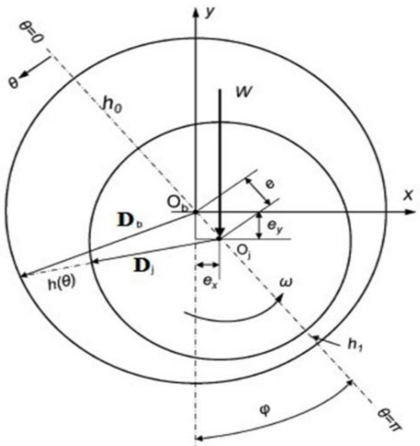

Figure 1. Schematic representation of the journal bearing

Table 1. Geometrical specification, operating conditions of journal bearing and properties of the lubricant

Parameter	Values	Parameter	Values
D_J	14.5 mm	T_0&T	20 & 27 ^{0}C
L_J	90 mm	μ_0	0.16 Pa/s
φ	60^0	ρ_0	922.5 kg/m^3
e_r	0.5	C_P	1900 J/kg.K
α	2×10^{-8} m^2/N	K	0.12W/m^0.C
β	0.03 K^{-1}	k	1
ω	200 RPM	n	0.8, 0.9, 1, 1.1, 1.2
c	0.00725 mm		

Boundary Conditions

Rigid wall with No-Slip and temperature boundary conditions are assigned for both journal and bearing surfaces. The journal surface is specified as rotating wall by imposing a rotational velocity and bearing surface as stationary wall. Pressure inlet and pressure outlet boundary conditions are specified at entrance and exit of the journal bearing respectively.

Grid Independence Test, Convergence Test and Validation of Numerical Results

Based on grid independence test it is found that 13612 cells are enough to get the desired level of accuracy for the bearing.In this analysis continuity residual criterion is maintained up to 1 x10^{-6} to reduce the errors and also get the good approximation results. Fig. 2 shows the residuals of various flow parameters. First 400 to 600 iterations run under iso-thermal condition later udf's and cavitation boundary conditions are appended to the flow solver. As a reason there is a sudden change in the residual graph. The pressure contours obtained from the present analysis are resembled with the referred journals [3], [5].

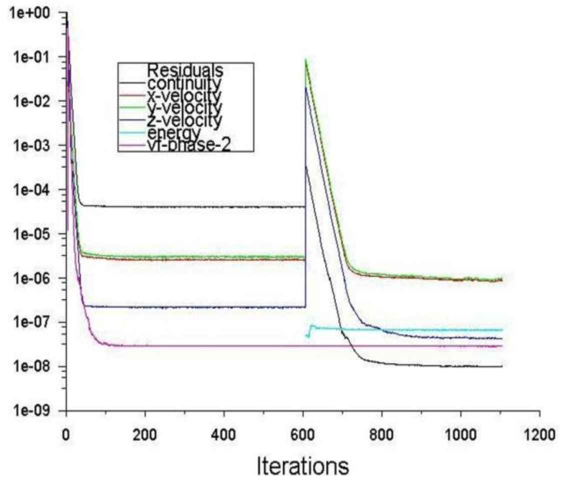

Figure 2. Residuals of various flow parameters

III. RESULTS AND DISCUSSIONS

Numerical analysis is carried out for an initial surface temperature as 293K and final surface temperature as 300K at a rotational speed of 200 RPM. Fig. 3 shows the pressure distribution on the journal surface for with and without cavitation phenomenon. The cavitation phenomenon replicates the half Sommerfeld boundary condition. In Fig. 4, the pressure distribution at mid plane across the circumference of the journal is plotted for flow index n = 0.8, 0.9, 1.0, 1.1, 1.2 and isothermal without cavitation. For flow index n = 0.8, 0.9, 1.0, 1.1 and 1.2, the maximum pressure is reached up to 1.11, 1.85, 3.08, 5.19 and 8.88 M Pa respectively. From these results it is observed that as flow index 'n' increases the maximum pressure is also increases.

If the fluid index 'n' is less than one then the fluid is shear thinning fluid, which means the viscosity reduces with an increase in rate of shear. This occurrence is shown in Fig. 5, as the flow index n decreasing from 1.0, 0.9 and 0.8 the corresponding maximum viscosity is 0.1379, 0.0801 and 0.0470 Pa-s respectively.

If the fluid index 'n' is greater than one then the fluid is shear thickening fluid, which means the viscosity increases with an increase in rate of shear. This experience is shown in Fig. 5, as the flow index n increasing

ISSN 2277 – 5528
Impact Factor- 4.015

from 1.0, 1.1 and 1.2 the corresponding maximum viscosity achieved as 0.1379, 0.2415 and 0.4363 Pa-s respectively.

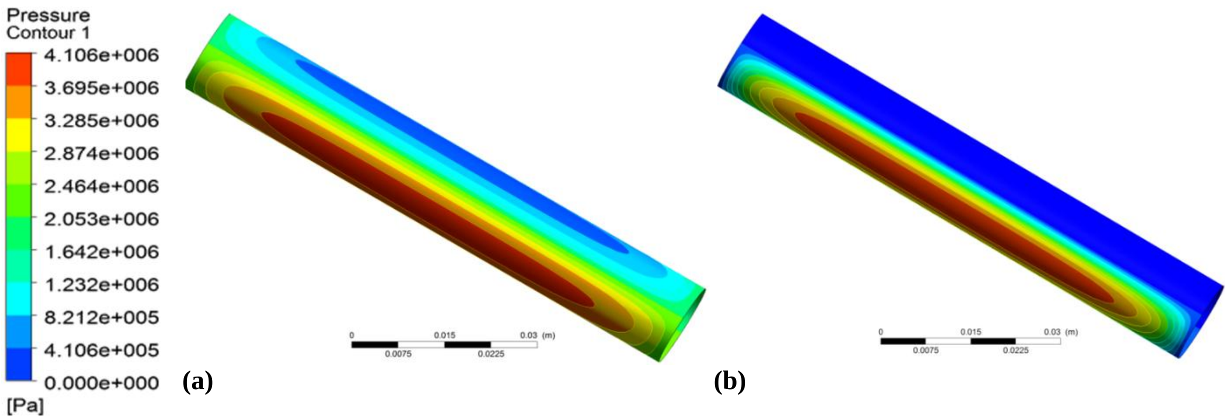

Figure 3. Pressure contours on the journal surface (a) without cavitaion (b) with cavitation

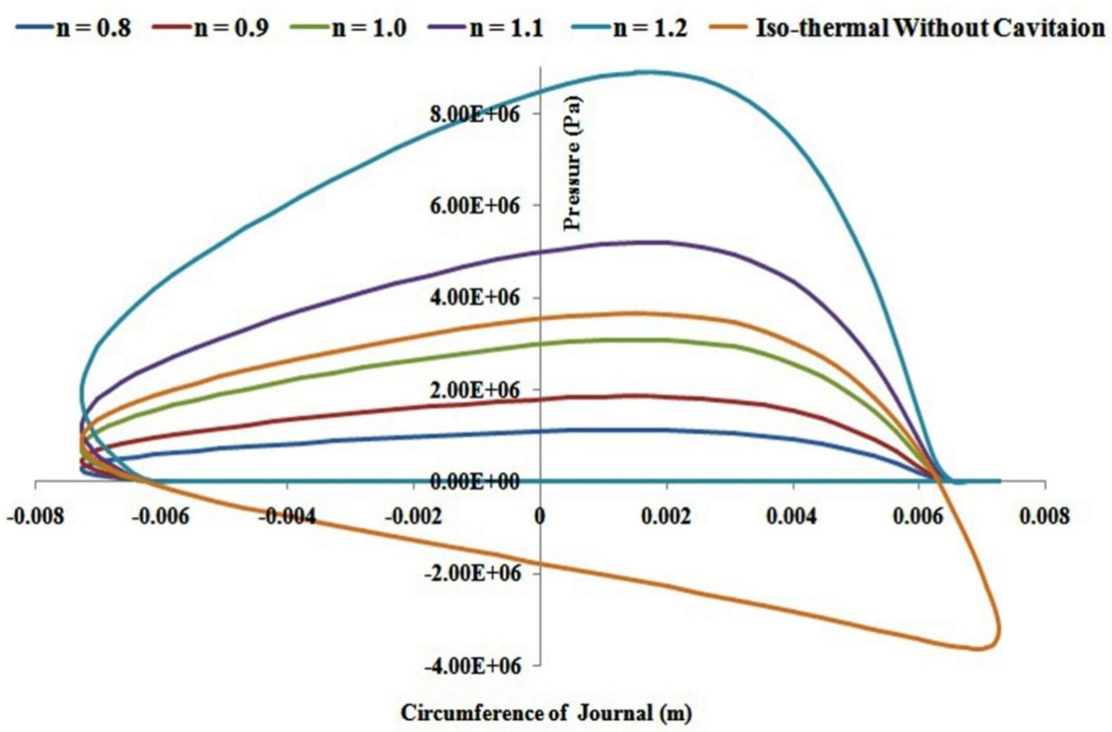

Figure 4. Pressure distribution at mid plane across the circumference of the journal for various flow index

ISSN 2277 – 5528
Impact Factor- 4.015

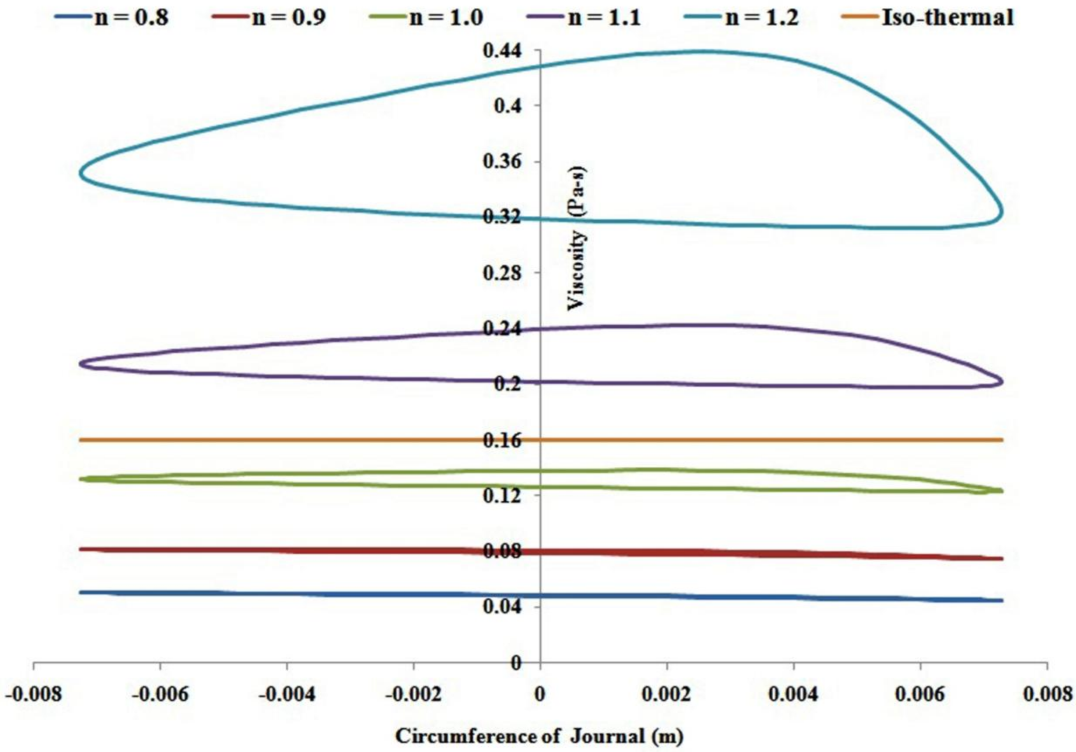

Figure 5. Viscosity distribution at mid plane across the circumference of the journal for various flow index

If flow index n is 1, then the power law model signifies a Newtonian fluid where the viscosity is constant. But in this case the viscosity is varied along the circumference of the journal because of considering the effect of pressure and temperature on the viscosity i.e. combination of Barus and Reynolds equation. In isothermal case (n=1), one can find constant viscosity along the circumference of the journal i.e. 0.16 Pa-s.

In Fig. 5 it is also observed that, if flow index 'n' is greater than one, difference between the maximum and minimum viscosity is more. The curve/profile of variation of viscosity along the circumference of the journal looks like an elliptical shape. This bulge/elliptical shape of viscosity profile is goes on amalgamates as flow index value decreases from 1.2 to 0.8.

IV. CONCLUSION

The performance characteristics of hydrodynamic journal bearing lubricated with a non-Newtonian power law lubricant were examined. The Navier–Stokes and energy equations were solved using the FLUENT package. The conclusions are summarized as follows:

1. Conducting the numerical analysis by considering the effect of pressure and temperature on viscosity and density of lubricant is more realistic simulation work as compared to the isothermal without cavitation conditions.
2. If n < 1, the viscosity of the lubricant will reduces and the generated maximum pressure is also less as compared to n = 1.
3. If n >1, the fluid becomes shear thickening fluid and viscosity will increases finally generated maximum pressure is also high as compared to n = 1.

Nomenclature

D_J	Diameter of the journal
L_J	length of the journal
O_b	Centre of bearing
O_J	Centre of journal
c	Radial clearance
e_r	Eccentricity ratio
φ	Attitude angle and
h	Oil film thickness
T_0	Initial temperature
T	Temperature of the surfaces
ρ	Density of lubricant
K	Thermal conductivity of lubricant
C_P	Specific heat of lubricant
α	Viscosity-pressure coefficient
β	Viscosity–temperature coefficient
n	Power law flow index
k	Consistency index
e	Eccentricity
μ	viscosity of lubricant

REFERENCES

1. *B. Tower, "First report on friction experiments," Proc. Inst. Mech. Eng., vol. 34, no. 1, pp. 632–659, 1883.*
2. *O. Reynolds, "On the Theory of Lubrication and Its Application to Mr. Beauchamp Tower's Experiments, Including an Experimental Determination of the Viscosity of Olive Oil.," Proc. R. Soc. Lond., vol. 40, no. 242–245, pp. 191–203, 1886.*
3. *K. P. Gertzos, P. G. Nikolakopoulos, and C. A. Papadopoulos, "CFD analysis of journal bearing hydrodynamic lubrication by Bingham lubricant,"* Tribol. Int., *vol. 41, no. 12, pp. 1190–1204, 2008.*
4. *M. Sahu, A. K. Giri, and A. Das, "Thermohydrodynamic Analysis of a Journal Bearing Using CFD as a Tool," Int. J. Sci. Res. Publ., vol. 2, no. 9, pp. 1–5, 2012.*
5. *A. Chauhan, A. Singla, N. Panwar, and P. Jindal, "CFD Based Thermo Hydrodynamic Analysis of Circular Journal Bearing," J. Adv. Mech. Eng., vol. 4, no. 5, pp. 475–482, 2014.*
6. *A. Chauhan, R. Sehgal, and R. K. Sharma, "Investigations on the thermal effects in non-circular journal bearings," Tribol. Int., vol. 44, no. 12, pp. 1765–1773, 2011.*
7. *S. Cupillard, M. J. Cervantes, and S. Glavatskih, "A CFD study of a finite textured journal bearing," in Proc. of 24th Symposium on Hydraulic Machines and Systems (IAHR), Foz do Iguassu, 2008.*
8. *S. Cupillard, M. J. Cervantes, and S. Glavatskih, "Thermohydrodynamic analysis of a journal bearing with a microgroove on the shaft," Comput. Therm. Sci. Int. J., vol. 6, no. 1, 2014.*

9. *P. Hanoca and H. V. Ramakrishna, "To Investigate the Effect of Oil Film Thickness at the Entrance of the Infinitely Long Slider Bearing Using CFD Analysis," Procedia Eng., vol. 127, pp. 447–454, 2015.*
10. *A. Czaban, "CFD analysis of non-Newtonian and non-isothermal lubrication of hydrodynamic conical bearing," J. KONES, vol. 21, 2014.*
11. *P. C. Mishra, "Mathematical modeling of stability in rough elliptic bore misaligned journal bearing considering thermal and non-Newtonian effects," Appl. Math. Model., vol. 37, no. 8, pp. 5896–5912, Apr. 2013.*
12. *I. N. C. Fluent, "Fluent 6.3 users guide," Fluent Doc., 2006.*
13. *K. Kanakamedala, "Numerical Simulation of the Flow of a Power Law Fluid in an Elbow Bend," Texas A&M University, 2009.*