MultiCraft

International Journal of Engineering, Science and Technology
Vol. 6, No. 1, 2014, pp. 34-42

INTERNATIONAL JOURNAL OF ENGINEERING, SCIENCE AND TECHNOLOGY

www.ijest-ng.com
www.ajol.info/index.php/ijest

Computational analysis of journal bearing operating under lubricant containing Al_2O_3 and ZnO nanoparticles

Kalakada Sreedhar Babu [1*], K. Prabhakaran Nair [1], P.K. Rajendrakumar[1]

[1]*Department of Mechanical Engineering, National Institute of Technology Calicut, Kerala-673601, INDIA*
[*]*Corresponding Author: e-mail: sbkalakada@yahoo.com, Tel +91-9037689649*

Abstract

In this paper, the mathematical model developed for relationship between viscosity and temperature for the lubricant SAE 15W40 multi grade engine oil with Al_2O_3 and ZnO nanoparticles is presented. The developed mathematical model for viscosity and temperature of lubricant containing nanoparticles is used for the computation of static performance characteristics of the bearing. These performance characteristics mainly depend on the viscosity of the lubricant. The addition of nanoparticles on commercially available lubricant considerably enhances the viscosity of lubricant and in turn changes the performance characteristics. To obtain pressure and temperature distribution, modified Reynolds and energy equations are used, and these equations are solved by using Finite Element Method. An iterative procedure is used to establish the film extent. The performance characteristics are calculated from the obtained pressure field. The computed results show that addition of nanoparticles increase the viscosity of lubricant and in turn change the performance characteristics of journal bearing.

Keywords: Journal Bearing; Lubricant additives; Nanoparticles; Static performance Characteristics

DOI: http://dx.doi.org/10.4314/ijest.v6i1.4

1. Introduction

Hydrodynamic journal bearings are extensively used in high speed rotating machinery. When a bearing rotates at high speed and heavy load, the heat generated due to large shear rates in the lubricant film raises its temperature which lowers the viscosity of the lubricant and in turn affects the performance of journal bearing. A thermohydrodynamic analysis is therefore necessary to predict the performance characteristics of the bearing. Many investigations (Ferron *et al*., 1983; Gethin, 1996; Sehgal *et al*., 2000; Chun, 2004; Agostino and Senatore, 2006; McCarthy *et al*., 2009) have been carried out on thermohydrodynamic analysis of journal bearings.

Addition of nanoparticles increases the viscosity of lubricant (Prasher *et al*., 2006; Praveen *et al*., 2007; Lee *et al*., 2008; Weerapun and Somchai, 2009; Kole and Dey, 2010; Madhusree and Dey, 2010; Margareth *et al*. 2010) and hence it varies load capacity of the bearing (Vijayaraghavan and Brewe, 1998). These suspended solid particles produce thickness of lubricants, which in turn affects the various performance characteristics of journal bearing. A limited study has been carried out for bearing operating under lubricant with nanoparticles (Nair *et al*., 2009). The present work aims to study the performance characteristics of circular journal bearing operating under lubricants with nanoparticles and effect of variation of viscosity of nanolubricants with temperature on the performance characteristics. In the present study oil used is SAE 15W40 multigrade engine oil with Al_2O_3 and ZnO nanoparticles.

2. Analysis

Modified Reynolds and energy equations are used to obtain pressure and temperature distributions in the fluid film of journal bearing.

2.1. Reynolds Equation.

The following modified non-dimensional Reynolds equation (Nair *et al*., 2009) is used to obtain pressure distribution in the clearance space of journal bearing. The boundary conditions used are Reynolds boundary conditions.

$$\frac{\partial}{\partial\theta}\left[\frac{\bar{h}^3}{12\bar{\mu}}\left[\frac{\partial\bar{p}}{\partial\theta}\right]\right]+\frac{\partial}{\partial z}\left[\frac{\bar{h}^3}{12\bar{\mu}}\left[\frac{\partial\bar{p}}{\partial z}\right]\right]=\frac{1}{2}\frac{\partial\bar{h}}{\partial\theta} \quad (1)$$

$$\bar{p}=0 @ \theta=0, \theta=\theta_2 \ and \ z=\pm L/2$$

$$\frac{d\bar{p}}{d\theta}=0 @ \theta=\theta_2$$

2.2. Energy Equation

To obtain temperature distribution the following modified energy equation (Ferron *et al*., 1983; Banwait and Chandrawat, 1998) is used

$$\left[\frac{\bar{h}}{2}-\frac{\bar{h}^3}{12\bar{\mu}}\frac{\partial\bar{p}}{\partial\theta}\right]\frac{\partial\bar{T}}{\partial\theta}-\frac{\bar{h}^3}{12\bar{\mu}}\frac{\partial\bar{p}}{\partial\bar{z}}\frac{\partial\bar{T}}{\partial\bar{z}}=\frac{\bar{\mu}}{\bar{h}}+\frac{\bar{h}^3}{12\bar{\mu}}\left[\left(\frac{\partial\bar{p}}{\partial\theta}\right)^2+\left(\frac{\partial\bar{p}}{\partial\bar{z}}\right)^2\right] \quad (2)$$

$$T=T_a @ \theta=0$$

$$T=Constant \ @ z=-\frac{L}{2} \ to \ +\frac{L}{2}$$

3. Models of viscosity

The standard experimental procedure for measuring the variation of viscosity of commercial lubricant containing nanoparticles with temperature is as follows. Al_2O_3 and ZnO nanoparticles were suspended in commercially available SAE15W40 multi-grade engine oil at different concentrations to formulate the nanolubricant. 500 ml of engine oil was used for making the nanolubricant. Density of the oil was measured on weight to volume basis using a 25 ml flask and a precision balance. Commercially available nanoparticles in the range of 20-150 nm supplied by M/s Sigma Aldrich Ltd., Bangalore, were used in the experimental study. The size and true density of the nanoparticles have been provided by the suppliers. The size distribution of the particles was verified using Scanning Electron Microscopy (SEM). The nanoparticles were added to the oil on weight percentage basis, such as 0.1%, 0.25%, 0.5% etc. and the mixture was then agitated using an ultrasonic shaker for 40 minutes to ensure uniform dispersion and good suspension stability. Temperature was maintained at 30ºC. The viscosity of the nanolubricant was measured using a Redwood Viscometer. 125 ml of oil was used for each trial. Time required for emptying 50 ml of oil was measured and viscosity was calculated using Redwood formula.

Variations of dynamic and kinematic viscosities were obtained at a temperature range of 30-90ºC. From the viscosity data obtained, the relative viscosity (relative viscosity is defined as the ratio of viscosity of nanolubricant at any temperature to viscosity of base lubricant at the same temperature) values have been calculated and expressed as a function of the temperature and particle concentration in the commercial lubricant SAE15W40. The variation of relative viscosity of commercial lubricant with Al_2O_3 and ZnO nanoparticles and its effect due to temperature are plotted in Figures 1-3. These Results have shown that for the increase in particle concentration, the relative viscosity increases with the increase in temperature. Viscosity models are developed to obtain the relationship between viscosity and temperature of commercial lubricant with Al_2O_3 and ZnO nanoparticles at temperatures varying from 30^0-90^0C. The non-dimensional regression models developed are given as follows.

$$\frac{\mu}{\mu_0}=e^{(K_1-K_2\bar{T})} \quad (3)$$

Nanoparticles	K_1	K_2
Al_2O_3	$1.016-0.804\alpha+3.974\alpha^2-5.691\alpha^3$	$1.163-0.661\alpha+3.046\alpha^2-4.360\alpha^3$
ZnO	$1.016-0.281\alpha+1.086\alpha^2-1.499\alpha^3$	$1.163-0.350\alpha+1.023\alpha^2-1.247\alpha^3$

The values of developed mathematical models are compared with experimental results, and the percentage error was calculated for each of the viscosity models with experimental values. The results obtained are shown in the Figures 1-2. These results clearly show that the values obtained from the developed viscosity models are very close to the experimental values and in any case the maximum error obtained is 2. 3%. These results show that the developed viscosity models can predict viscosity of lubricant containing different concentrations of nanoparticles at any temperature, as good as experimental results.

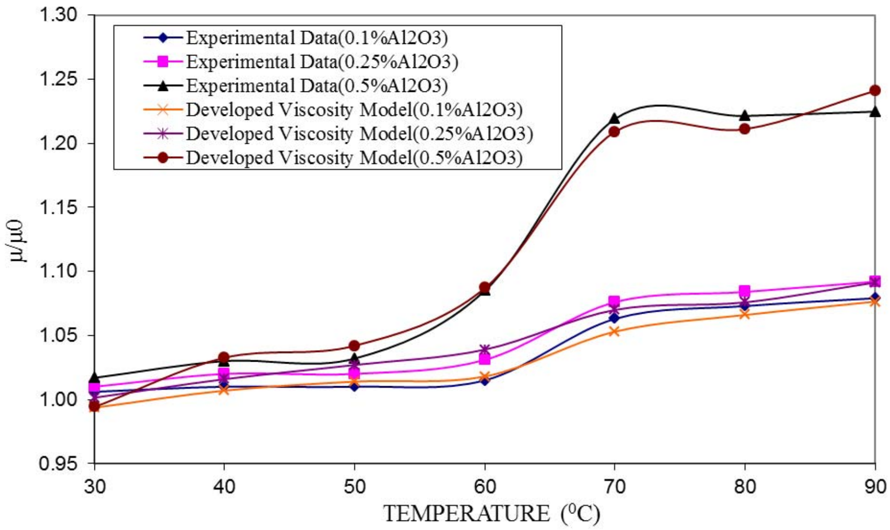

Fig.1 Variation of absolute viscosity of lubricant SAE 15W40 with % weight concentration of Al_2O_3 nanoparticles at temperature range 30^0-90^0C

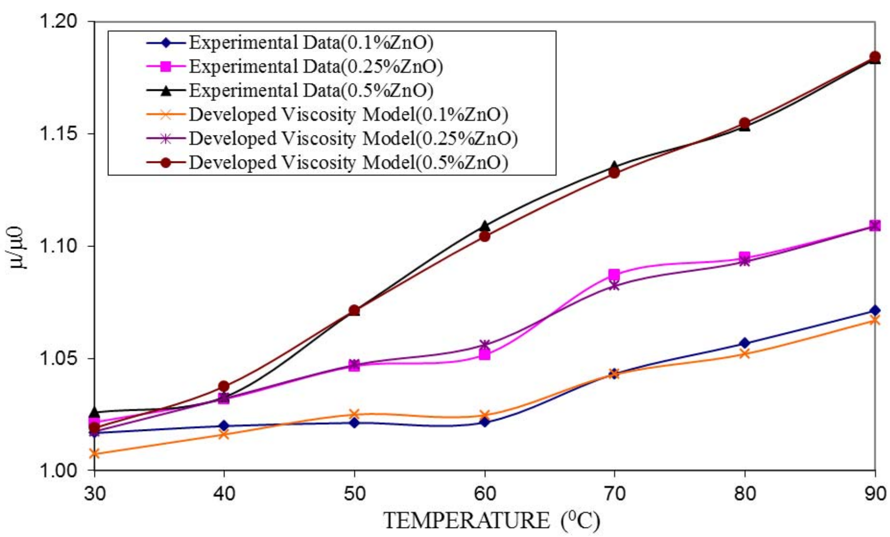

Fig.2 Variation of absolute viscosity of lubricant SAE 15W40 with % weight concentration of ZnO nanoparticles at temperature range 30^0-90^0C

4. Performance Characteristics

The performance characteristics are evaluated using the following equations

4.1. Load carrying capacity

$$\begin{bmatrix} \overline{W}_\zeta \\ \overline{W}_\eta \end{bmatrix} = \begin{bmatrix} \overline{W}Cos\phi \\ \overline{W}Sin\phi \end{bmatrix} = \int_{\theta 1}^{\theta 2} \int_{-1}^{+1} \overline{p} \begin{bmatrix} Cos\theta \\ Sin\theta \end{bmatrix} d\theta d\overline{z} \quad (4)$$

$$\overline{W} = \left[\overline{W}_\zeta{}^2 + \overline{W}_\eta{}^2 \right]^{1/2} \quad (5)$$

4.2. Attitude Angle

$$\Phi = \mathrm{Tan}^{-1}\,(W_\zeta / W_\eta) \tag{6}$$

4.3. Frictional Force

$$F = \int_{\theta 1}^{\theta 2}\int_{-1}^{+1} \bar{h}\,\frac{\partial \bar{p}}{\partial \theta}\, d\theta\, d\bar{z} + \int_{\theta 1}^{\theta 2}\int_{-1}^{+1} \frac{\bar{\mu}}{\bar{h}}\,\bar{U}\, d\theta\, d\bar{z} \tag{7}$$

4.4. End Leakage

$$Q_z = \int_{\theta 1}^{\theta 2} \frac{\bar{h}^3}{12\bar{\mu}}\frac{\partial \bar{p}}{\partial \bar{z}}\bigg|_{-1}^{+1} d\theta \tag{8}$$

5. Solution Procedure

In order to obtain the non-thermoviscous and thermovicsous static performance characteristics of journal bearing operating under lubricant containing Al_2O_3 and ZnO nanoparticles both modified Reynolds equation and energy equations are solved with appropriate boundary conditions. Both equations are solved by using the powerful technique finite element method and MATLAB code is developed for complete analysis. The modified Reynolds equation is solved to obtain the non-dimensional pressure distribution and the film is extended with suitable boundary conditions by iterative scheme. Non-thermoviscous static performance characteristics are obtained by assuming the viscosity field remains constant. But in thermoviscous case the viscosity field varies with temperature distribution. To obtain the temperature distribution in the lubricant film, the modified energy equation is used and the temperature distribution obtained by solving the energy equation is used to update the viscosity field. The viscosity model developed above is used to modify the viscosity field. The modified viscosity field is substituted in the Reynolds equation to obtain the modified pressure field. The iterative process is continued till a convergence is achieved. The final pressure obtained is used to calculate performance characteristics of the journal bearing. The various static characteristics defined by load carrying capacity, friction force, end leakage and attitude angle are computed using the relevant formulae.

6. Results and Discussion

The static performance characteristics in terms of load capacity, friction force, end leakage and attitude angle are computed for different values of eccentricity ratios and lubricants containing 0-0.5% weight concentration of nanoparticles (Al_2O_3 and ZnO) for the non-thermoviscous and thermoviscous cases. The computed results are shown in Figures 3-9. Figure 3 shows that the effect of 0-0.5% weight concentration of Al_2O_3 nanoparticles in the lubricant on load capacity of journal bearing in both non-thermoviscous and thermoviscous cases, and it is seen that in non-thermoviscous case, increase of weight concentration of Al_2O_3 nanoparticles produce the slight effect on load capacity of the bearing, but in thermoviscous case increase of weight concentration of Al_2O_3 nanoparticles produce the significant effect on load capacity of the bearing especially at high values of an eccentricity ratio.

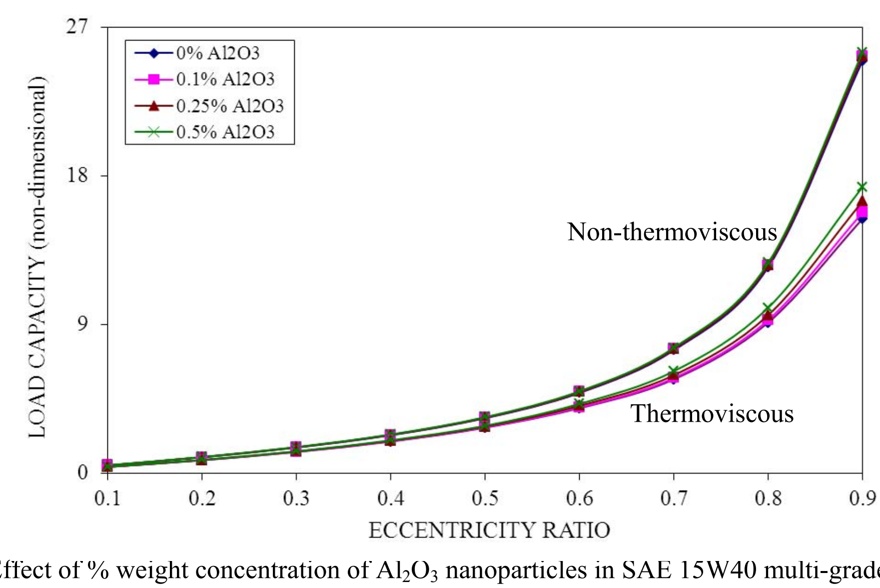

Fig.3 Effect of % weight concentration of Al_2O_3 nanoparticles in SAE 15W40 multi-grade engine oil on Load carrying capacity of journal bearing

Figures 4-5 show the percentage variation of load capacity with the increase of weight concentration of nanoparticles Al_2O_3 and ZnO at any eccentricity ratio. These figures clearly show that in thermoviscous case, the percent increase of load capacity of journal bearing operating under lubricant containing nanoparticles are more significant at high eccentricity ratios. For example, at high eccentricity ε=0.9 it is seen that the addition of 0.5% weight concentration of nanoparticles in the lubricant increases the load capacity approximately 12.53% (Al_2O_3) and 11.16% (ZnO) than those obtained without addition of nanoparticles in thermoviscous case. This shows that addition of nanoparticles enhances viscosity considerably and increases the load capacity of the bearing.

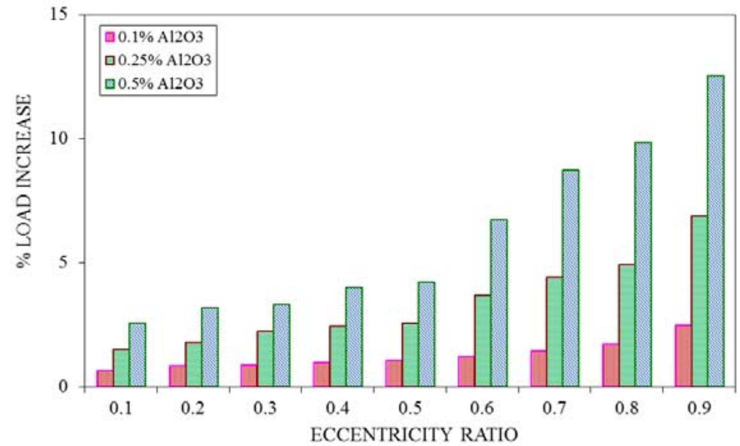

Fig.4 Effect of % weight concentration of Al_2O_3 nanoparticles in SAE 15W40 multi-grade engine oil on % Load increase of journal bearing

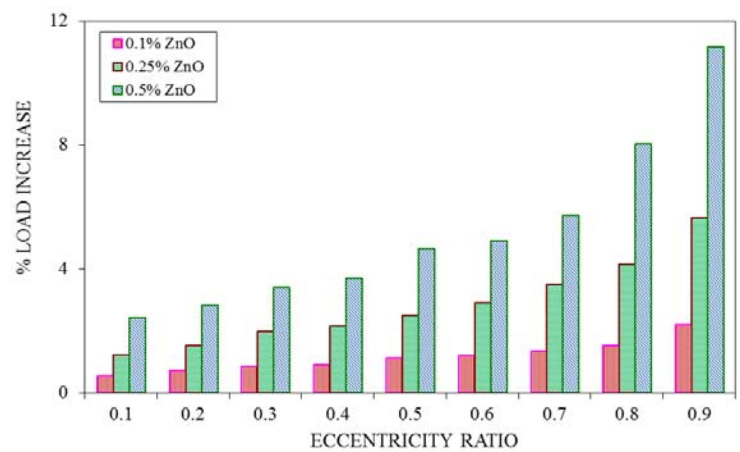

Fig.5 Effect of % weight concentration of ZnO nanoparticles in SAE 15W40 multi-grade engine oil on %Load increase of journal bearing

Figure 6 shows the variation of friction force with 0-0.5% weight concentration of ZnO nanoparticles for both non-thermoviscous and thermoviscous cases at eccentricity ratio 0.9 and it show that addition of nanoparticles increases friction force in both non-thermoviscous and thermoviscous cases. In thermoviscous case at eccentricity 0.9 the value of friction force obtained is 6.6% (Al_2O_3) higher than those obtained without addition of nanoparticles.

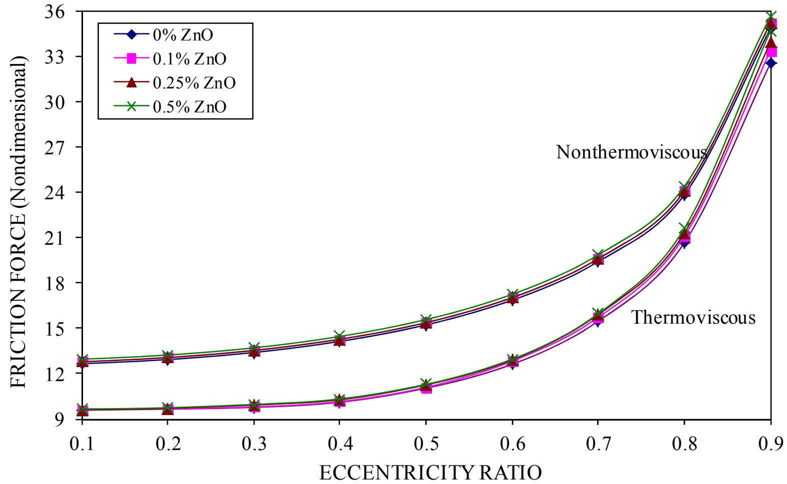

Fig.6 Effect of % weight concentration of ZnO nanoparticles in SAE 15W40multi-grade engine oil on frictional force of Journal bearing

Figures 7-8 show the variation of end leakage with concentration of nanoparticles for both non-thermoviscous and thermoviscous cases. For any eccentricity ratio addition of nanoparticles decreases end leakage in both non-thermoviscous and thermoviscous cases.

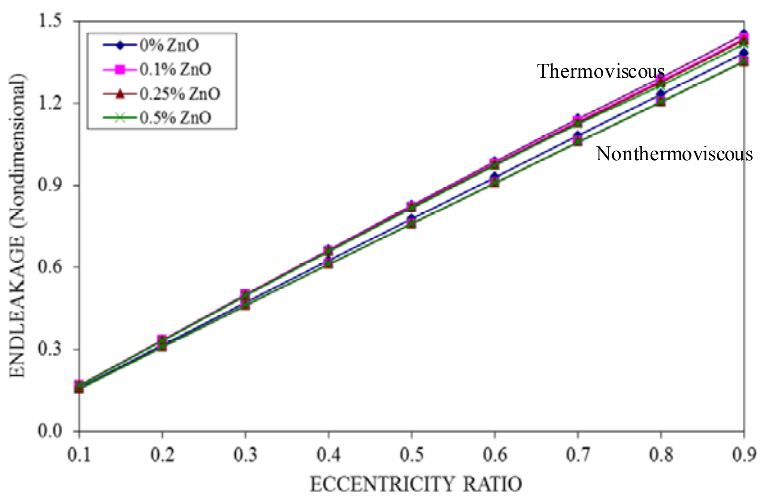

Fig.7 Effect of % weight concentration of ZnO nanoparticles in SAE 15W40 multi-grade engine oil on end leakage of journal bearing

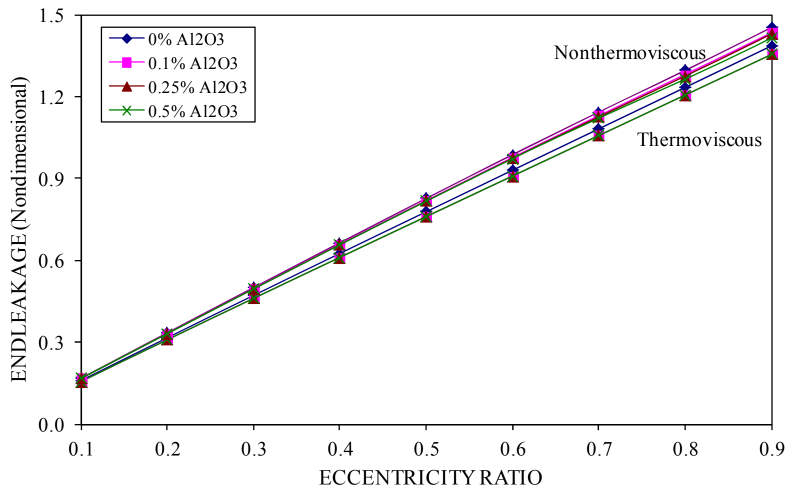

Fig.8 Effect of % weight concentration of Al_2O_3 nanoparticles in SAE 15W40 multi-grade engine oil on end leakage of journal bearing

The effect of weight concentration of ZnO nanoparticles in the lubricant on the attitude angle of journal bearing for thermoviscous case is shown in Figure 9, and it is observed that the addition of nanoparticles decrease the attitude angle of the journal bearing. Therefore addition of nanoparticles in lubricant influences characteristics considerably in thermoviscous case.

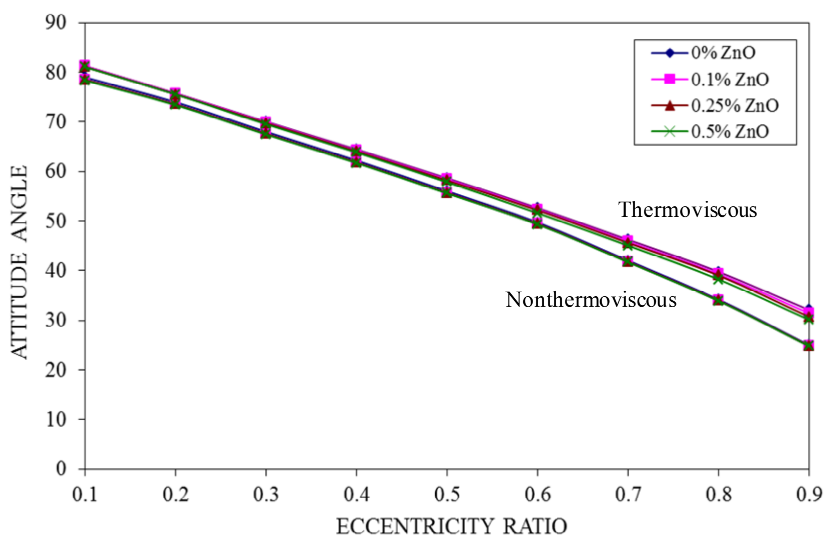

Fig.9 Effect of % weight concentration of ZnO nanoparticles in SAE 15W40 multi-grade engine oil on attitude angle of journal bearing

7. Conclusions

In non-thermoviscous case increase of weight concentration of nanoparticles change the performance characteristics of bearing slightly. But in thermoviscous case addition of nanoparticles increase the load capacity of journal bearing at any eccentricity ratio, and this increase is significant at high values of the eccentricity ratio. 0.5% weight concentration of nanoparticles increases the load capacity by 12.53% (Al_2O_3) and 11.16% (ZnO) in thermoviscous case when bearing operates at ε=0.9. The friction force of bearing increases with the increase in concentration of nanoparticles for both non-thermoviscous and thermoviscous cases. At any eccentricity ratio, both end leakage and attitude angle decrease with the increase in concentration of nanoparticles in both non-thermoviscous and thermoviscous cases, and these decreases are considerable in thermoviscous case and at higher eccentricity ratios.

Nomenclature

h	Film Thickness
p	Pressure
Q_z	End leakage of the bearing
T	Temperature
U	Speed of the bearing
W	Load Capacity
Z	Axial coordinate
ε	Bearing eccentricity ratio
η	coordinate along perpendicular to line of centers
μ	Viscosity of lubricant
Ø	Percent volume concentration of nanoparticles
Φ	Attitude angle
θ	Angular coordinate
ζ	coordinate along line of centers

References

Agostino, V. D. and Senatore, A. 2006. Analytical solution for two-dimensional Reynolds equation for porous journal bearings, *Industrial Lubrication and Tribology*, Vol. 58, No. 2, pp. 110-117.

Banwait S. S., Chandrawat H. N., 1998. Study of thermal boundary conditions for a plain journal bearing, *Tribology International*, Vol. 31, No. 6, pp. 289-296.

Chandrasekar, M., Suresh S., Chandra. B.A, 2010. Experimental investigations and theoretical determination of thermal conductivity and viscosity of Al_2O_3/water nanofluid, *Experimental Thermal and Fluid Science*, Vol. 34, pp.210–216.

Chun S.M., 2004. "Thermohydrodynamic lubrication analysis of high-speed journal bearing considering variable density and variable specific heat", *Tribology International*, Vol. 37, pp. 405-413.

Ferron J, Frene J and Boncompain R, 1983. A study of thermohydrodynamic performance of a plain journal bearing comparison between theory and experiments, *Transactions of ASME, Journal of Lubrication Technology*, Vol. 105, pp. 422-428.

Gethin D.T, 1996. Modeling the thermohydrodynamic behavior of high speed journal bearings, *Tribology International*, Vol. 29, No. 7, pp. 579-596.

Kole M., Dey T.K., 2010. Viscosity of alumina nanoparticles dispersed in car engine coolant, *Experimental Thermal and Fluid Science*, Vol. 34, pp. 677–683.

Lee J H, Hwang K S, Jang S P, Lee B H, Kim J H, Choi S U S, Choi C J, 2008. Effective viscosities and thermal conductivities of aqueous nanofluids containing low volume concentrations of Al_2O_3 nanoparticles, *International Journal of Heat and Mass Transfer*, Vol. 51, pp. 2651-2656.

Madhusree, K., Dey, T.K, 2010, Viscosity of alumina nanoparticles dispersed in car engine coolant, *Experimental Thermal and Fluid Science*, Vol. 34, pp.677–683.

Margareth, PeterRudolfSeidl , Carlos Rodrigues Pereira Belchior, 2010. Lubricant viscosity and viscosity improver additive effects on diesel fuel economy, *Tribology International*, Vol. 43, pp. 2298-2302.

McCarthy, D.M.C., Glavatskih, S.B. and Byheden, A, 2009. Influence of oil type on the performance characteristics of a two-axial groove journal bearing, *Lubrication Science*, Vol. 21, pp. 366-377.

Prabhakaran N. K., Ahmed M.S. and Al-qahtani S.T., 2009. Static and dynamic analysis of hydrodynamic journal bearing operating under nano lubricants, Int. J. Nanoparticles, Vol. 2, No. (1/2/3/4/5/6), pp.251-262.

Prasher R, Song D, Wang J, Phelan P, 2006. Measurements of nanofluid viscosity and its implications for thermal applications, *Applied Physics Letters*, Vol. 89, pp. 133108-1-133108-3.

Praveen, K.N., Devdatta, P.K., Debasmita, M., Debendra, K.D, 2007. Viscosity of copper oxide nanoparticles dispersed in ethylene glycol and water mixture, *Experimental Thermal and Fluid Science*, Vol. 32, pp. 397-402.

Sehgal, R., Swamy, K. N. S., Athre, K. and Biswas, S, 2000. A comparative study of the thermal behaviour of circular and non-circular journal bearings, *Lubrication Science*, Vol. 12, No. 4, pp. 329-334.

Vijayaraghavan D., Brewe D. E., 1998. Effect of rate of viscosity variation on the performance of journal bearings, *Journal of Triboiogy*, Vol. 120 ,pp. 1-7.

Weerapun, D., Somchai, W, 2009. Measurement of temperature-dependent thermal conductivity and viscosity of TiO2-water nanofluids, *Experimental Thermal and Fluid Science*, Vol. 33, pp. 706–714.

Biographical notes

Kalakada Sreedhar Babu received BTech degree in Mechanical Engineering from the Nagarjuna University (India) in 1992 and MTech degree in Maintenance Engineering from the Mysore University (India) in 1995. He worked two years in the industry and eleven years in the engineering college as Assistant Professor and Associate Professor. Currently he is pursuing PhD at the Faculty of Mechanical Engineering, National Institute of Technology Calicut (India). His research interests are in nanotribology, applications, simulations, Lubrication. His publications include lubricants containing nanoparticles and its applications in journal bearings.

K. Prabhakaran Nair is a Professor of Mechanical Engineering and Dean in National Institute of Technology Calicut (India). He received B.Sc. Engg in Mechanical Engineering from the University of Kerala (India) in 1975 and MScEngg in Machine Design from the same university in 1978. He received his Ph.D. from Indian Institute of Technology Roorkee (India) in 1998. He has teaching experience for 33 years and research experience for 23 years. He served as a Lecturer, Assistant Professor, Professor, Head and Dean. He has published 35 papers in international journals and 20 papers in international conferences. His current research interests are tribology and nanotribology. His publications include lubricants containing nanoparticles and its applications in journal bearings.

P.K. Rajendrakumar received B. Tech degree in Mechanical Engineering from the Calicut University (India) in 1982, M. Tech. degree in machine design from the Indian Institute of Technology Madras (India) in 1989 and PhD from Indian Institute of Science, Bangalore in 1998. He is working as Professor of Mechanical Engineering in National Institute of Technology Calicut (India). He has published 13 papers in international journals and 12 papers in international conferences. His research interests are in Contact Mechanics, Friction & Wear, Lubrication, Bio-mechanics. His publications include lubricants containing nanoparticles and its applications in journal bearings.

Received February 2013
Accepted April 2013
Final acceptance in revised form September 2013