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CFD Analysis of Circular Hydrodynamic Journal Bearing Using Nano lubricant

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Abstract **- The goal of this work is to examine the exhibition attributes of HP FILM oil utilized in a journal bearing. Zinc oxide nanoparticles (ZnO, 0.5 Wt. %) of size 40nm are utilized as an added substance to inspect the exhibition of oil. The viscosity of the oil is processed utilizing a changed Krieger–Dougherty viscosity model. The morphology of nanoparticles is concentrated with the scanning electron microscopy and X-ray beam diffraction. The investigation of pressure distribution, temperature distribution, von-mises stress, strain, and deformation for the two oils is done on Ansys fluent for working conditions determined by ASTM principles. The outcomes got in this examination are relied upon to be useful to bearing originators, scientists, and academicians worried about the applicable investigation.**

Index Terms **- Ansys Fluent, Nano lubricant, ZnO, FEA, CFD.**

I.INTRODUCTION

The hydrodynamic journal bearing may be a bearing operating with hydrodynamic lubrication, during which the bearing surface is separated from the journal surface by the lubricant film generated by the journal rotation. Hydrodynamic journal bearings are considered to be an important component of all the rotating machinery. These are wont to support radial loads under high speed operating conditions. Nano lubricants typically contain base oils or fully formulated lubricants with colloidal solid particles suspended within them. There are usually three components during a nano lubricant; the lubricant/ base oil solvent, the nanoparticles that act as antiwear (AW)/extreme pressure (EP) additive or friction modifier (FM), and therefore the reform the surfactant that inhabits the interface area between the oil and the particles. There are many reasons to be used of nanoparticles as a lubricant additive. The foremost important feature is their tiny size that permits the nanoparticles to enter the contact area, leading to a positive lubrication effect Nanoparticles also are versatile. The effectiveness of nanoparticles depends on various factors, including their compatibility with base oil/lubricant, their sizes, and morphologies, also as their concentrations.

II. LITERATURE REVIEW

After studying we conclude that Coefficients of contraction of a cast 4.4% bronze were found to be 16.3 x 10-6, 17.3 x 10-6, and 17.9 x 10-6 for the ranges 1000C to 20° C, 200° to 20° C, and 300° to 20° C, respectively [1]. After studying copper colloidal dispersions are successfully prepared by the utilization of a reducer under refluxing conditions. The UV-vis spectra of copper colloids in 2-ethoxyethanol and water showed distinct absorption peaks at 572 and 582 nm, respectively [2]. The experimental results show that the thermal conductivities of nanoparticle fluid mixtures increase relative to those of the bottom fluids [3]. From the results, thermal conductivity enhancement of nanofluid depends on the thermal conductivity which of the suspended particles. MWCNT nanofluids have poor stability due to its fibrous morphology and entanglement. However, additionally of surfactant, stability is often improved in aqueous suspension [4]. Last, it had been found that the optical properties of the copper nanoparticle arrays are significantly suffering from the presence of copper oxides. Removal of the copper oxides with glacial ethanoic acid yields a dramatic difference within the observed LSPR [5]. Nanoparticles should be added to the lubricant of R-134a cooling system without dispersant. Al2O3 nanofluid has better growth rates of thermal conductivity at higher temperature, so nanofluid has better effects within the cases of upper temperature [6]. The precise heat values of an EG/W mixture 60:40 by mass with none nanoparticle suspension obtained from the experiments. Show good agreement with those of the ASHRAE 3 data, validating the accuracy of experimental setup and procedure [7]. The thermal conductivity of thin film is far smaller than that of single crystal, decreasing with the decrease in grain size. Reduction of the intrinsic thermal conductivity ZnO by lattice imperfection is that the main reason of the low thermal conductivity of thin film [8]. Variation in load, oil film thickness, pad tilting and temperature of the individual bearing pads was highly hooked into the alignment and individual pad pre-load from assembly [9]. When nanoparticles are added to the lubricant (nanofluid), the resultant coefficient of viscosity increases, therefore improving the bearing load capacity [10]. The influence of nanoparticle concentration and temperature on thermal conductivity and viscosity of ZnO–EG and ZnO–EG–water nanofluids revealed increased thermal conductivity and reduced viscosity [11]. The dendritic structure of the external layer played a key role within the tribological characteristics of the fabric. [12]. The foremost important challenge and a prerequisite is to take care of dispersion stability of such nano lubricants for long duration [13]. The TiO2 nanoparticles possess good stability and solubility within the lubricant [14]. Chemical composition of nanoparticles played a crucial role on anti-wear performance. The dimensions of nanoparticles showed visible effects on both friction and wear [15]. The observed clear increasing of the exciton thermal conductivity and reduction of the contact thermal resistance [16]. The friction coefficient of ta-C/steel contact reaches lowest among all three cases and ta-C coating shows highest specific wear rate. Additionally, when lubricated by CeO2 additivities oil, ta-C coating exhibits lowest specific wear rate but highest friction coefficient [17]. The anti-friction and anti-wear properties are improved for the lubricants operating with TiO2 nanoparticles [18]. After addition of TiO2 nanoparticles within the lubricant, the viscosity of the lubricant is increased. It tends to extend the pressure distribution, frictional force, attitude angle [19]. As results, it had been found that the warmth quantity caused by shear friction was small within the case of the transition condition, whereas the temperature inside the bearing was approximately an equivalent as that of the availability oil, from both experimental and analytical perspectives [20]. The lubrication oil used is usually a well experimented and it meets the need of the engine but still nanoparticle addition, increase the warmth transfer properties and also increase the operating lifetime of engine parts by mitigating the frictional power loss percentage in engines through the utilization of nanoparticle additives with engine oils [21]. Density of nano lubricant is varied with the addition of nanoparticles. Smaller size and better volume fraction of nanoparticles results in increment in density [22]. An elliptical bearing operating with TiO2 nano lubricant shows effective performance over other combinations [23]. Thermal conductivity of the nanofluid was significantly increased thanks to the effect of added mass fraction. Thermal conductivity increased with temperature increasing [24]. By adding ZnO and MoS_2 nanoparticles to the pure fluid, the viscosity index increased and in higher concentrations, this increase was higher. Adding nanoparticles to the pure fluid decreased the pour point. Adding ZnO and MoS2 nanoparticles to pure oils at different concentrations increased the flash point of the nano lubricants relative to the pure diesel fuel [25].

III. THEORETICAL SURVEY

A. Theoretical assumptions

Hydrodynamic bearings are important parts of rotating machinery. Journal bearings are similar with a cylindrical bearing face on which the shaft running through the bearing. There are many researchers had carries out a research on the performance characteristics analysis of the journal bearing system, as it is the very critical area of the tribology. This type of bearing is used for the steam turbine in thermal power plant situated at Eklahre, Nashik, India. The pressure and temperature characteristics are mostly influenced by some chemical components known as additives that are additionally included in the base oil. These additives in base oil tend to improve the characteristics of oils such as increase in viscosity, dispersion in oil and decrease in specific heat capacity, increase in thermal conductivity of oil. For this theory various books and research paper are studied from that we had found that the lubrication theory is initially described by Navier, Strokes and they have given a solution to the basic equations. After that study we also had also found that Reynold extend that work and derived an equation which is known as Reynold's equation, which is mostly applicable and accepted by most of hydrodynamic theories and hydrodynamic rules. The following assumptions are considered during the study [26, 19]

1. The flow is laminar.
2. The shaft and bearing are rigid and smooth.
3. The lubricant is incompressible.
4. There is continuous supply of lubricant.
5. The viscosity of lubricant is constant.
6. The effect of curvature of the film with respect to film thickness is neglected.
7. There is no slip at the boundaries.
8. The inertia forces in the oil film are negligible.
9. Load applied on bearing is constant.
10. There is no misalignment in bearing structure.

B. Pressure Distribution

The schematic view for a plain bearing is presented as shown in Figure.1. Reynolds's equation in two-dimensional form for hydrodynamic journal bearing is expressed as in equation 1 [23]

$$\frac{u}{2}\frac{\partial h}{\partial x} - \frac{1}{12\mu}\frac{\partial}{\partial x}\left(h^3\frac{\partial p}{\partial x}\right) - \frac{1}{12\mu}\frac{\partial}{\partial z}\left(h^3\frac{\partial p}{\partial z}\right) = 0 \qquad (1)$$

By expanding the above equation, we found new equation as in equation 2 [23]

$$\frac{\partial}{\partial \theta}\left(\frac{h}{12\mu}^3\frac{\partial p}{\partial \theta}\right) + R^2\frac{\partial}{\partial z}\left(\frac{h}{12\mu}^3\frac{\partial p}{\partial z}\right) = \frac{UR}{2}\frac{\partial h}{\partial \theta} + \frac{V}{R^2} + \frac{h}{2R^2}\frac{\partial U}{\partial \theta}\frac{\partial h}{\partial t} \qquad (2)$$

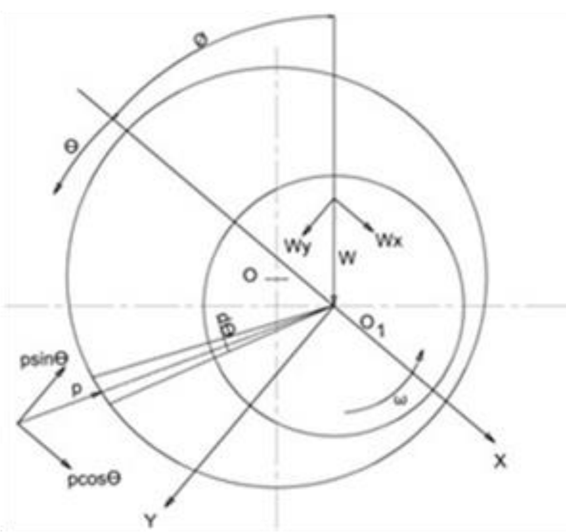

Figure 1 Schematic of hydrodynamic Journal Bearing component [23]

C. Temperature Distribution.

From various studies it was found that for proper design of bearing it is very important to calculate temperature riseΔT. This calculation is simply possible by assuming that, it is possible to neglect the heat conducted through the bearing material in comparison to the heat removed from the continuous replacement of fluid. The below equation 3 is used to calculate the temperature rise of oil in a journal bearing. [19, 23]

$$\Delta T = \frac{8.3P\left(\frac{fR}{C}\right)}{10^6\left(\frac{Q}{nRCL}\right)\left(1 - 0.5\frac{Q_s}{Q}\right)} \qquad (3)$$

The dimensionless parameter like$\frac{fR}{C}$, $\frac{Q}{nRCL}$ and $\frac{Q_s}{Q}$ are referred from Raimondi Boyd chart. The values of these dimensionless parameters for the various intermediate eccentricity ratios are computed using a linear interpolation technique.

Bearing type Circular Bearing

- Dia of Bearing (d) = 50mm
- Dia of Shaft/Journal (D) = 50mm
- Length of Bearing (l) = 50mm
- Clearance (C) = 0.05mm
- Thickness of Bearing (t) = 5mm
- Clearance Ratio (C/R) = 0.002
- Material of bearing = phosphorous Bronze
- Load on Journal/Shaft = 1000N
- Speed (rpm) = 500 to 1000 rpm

D. Nano lubricant

Nano lubricant is a combination of base oil, additives, nanoparticle additives and surfactant. Some of the following researchers have provided the study on the viscosity, specific heat capacity and thermal conductivity of lubricant Nano additives on the performance of the system. Nanoparticles are material particles of size 10 to 120 nm that are added to fluid to improve their physical properties. Now a days in are of tribology such types of nanoparticles are added to in lubricant to reduce wear and friction between contacting surfaces. ZnO nanoparticles are synthesized using chemical precipitation method using Zinc nitrate hexahydrate as precursor at 313.15K. Ammonium carbonate has been used as reducing agent in the process. Morphology and crystallographic patterns of the synthesized ZnO nanoparticles were examined using scanning electron microscopy shown in figure 2, XRD analysis is shown in figure 3. [27]

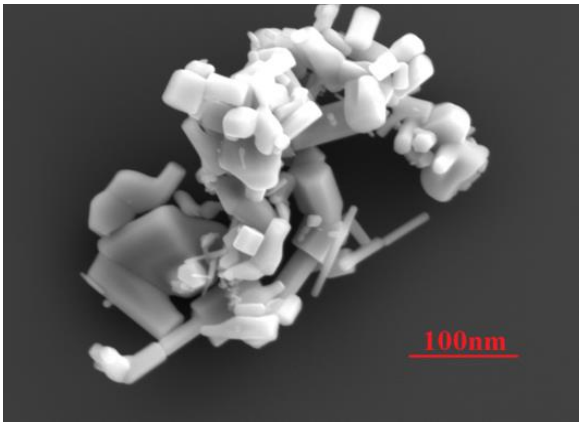

Figure 2 SEM image of ZnO [27]

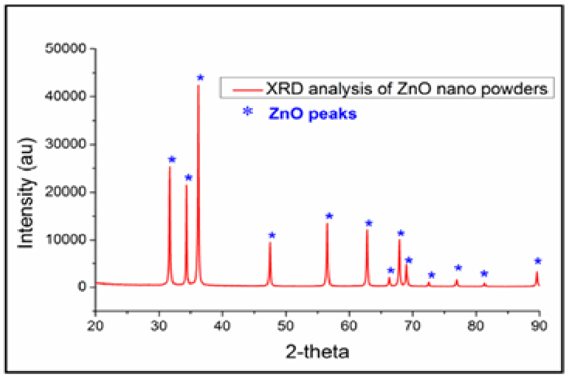

Figure 3 XRD Analysis of ZnO [27]

The ZnO Nanoparticles [Tech4Nano] are added to to lubricant at 0.5% [SR surywanshi 2019] weight concentration converted in volume concentration of nanoparticles are given as in equation 11. [18]

$$W_{ZnO} = \left(\frac{\emptyset}{100-\emptyset}\right)\left(\frac{\rho_{ZnO}}{\rho_{bf}}\right)(W_{bf}) \qquad (11)$$

$$\emptyset = \frac{\left(\frac{W_{ZnO}}{\rho_{ZnO}}\right)}{\left(\frac{W_{ZnO}}{\rho_{ZnO}}+\frac{W_{bf}}{\rho_{bf}}\right)} X100 \qquad (12)$$

The Krieger-Dougherty viscosity model is given as in equation 13. [26]

$$\frac{\mu_{nf}}{\mu_{bf}} = \left(1-\frac{\emptyset_a}{\emptyset_m}\right)^{-2.5\emptyset_m} \qquad (13)$$

$$\emptyset_a = \emptyset\left(\frac{a_a}{a}\right)^{3-D} \qquad (14)$$

Furthermore, by considering D = 1.8, a_a = 7.77, $\emptyset_m$ = 0.5; equation (13) is expressed as:

$$\frac{\mu_{nf}}{\mu_{bf}} = \left(1-\frac{\emptyset}{0.5}\left(\frac{a_a}{a}\right)^{1.3}\right)^{-1.25} \qquad (15)$$

The HP FILM series oils (FILM oil 46) offer superior oxidation resistance. This property is important in the intervals for the replacement of oil and filter. Now a days, the manufacturers are prefers to these oils as they provide more characteristics within a single product. These oils are used in the applications where hydraulic system plays an important role. These oils are also used where load carrying capacity is high, anti-wear protection and thin oil film protection is required. Based on these properties FILM oil 46 grade is considered in this study to investigate the pressure and temperature distribution of journal bearing system. The viscosity of nano lubricant is computed by using modified Krieger-Dougherty viscosity model as per Eq. (15) [26]. The weight concentration of the nanoparticle is converted into the volume concentration by using an Eq. (12) [18]. When nanoparticles are added to lubricant, the physical properties of the resultant nano lubricant (base lubricant + nanoparticles) changes. Specific heat capacity of nano lubricant is functional parameter for analyzing the heat transfer performance of nano lubricant. Density of nano lubricant is given by equation (16) [10, 8]

$$\rho_{nf} = (1-\emptyset)\rho_{bf} + \emptyset\rho_{Zno} \qquad (16)$$

When solid particles dispersed in a liquid, the equation of the specific heat for the two-phase mixture will be a function of the particle concentration. Such a correlation for nano lubricant was presented by Pak and Cho [7, 18, 10], taking the idea from the liquid-particle mixture theory. It is expressed as in equation 17. [17]

$$C_{pnf} = \emptyset C_{pZnO} + (1-\emptyset)C_{pbf} \qquad (17)$$

Thermal conductivity of lubricant plays an important role in determining its cooling behavior, moreover, the low thermal conductivity of conventional lubricants limit their performance. Thermal conductivity is also mainly contributed to heat transfer behavior. The thermal conductivity of the nano lubricant is calculated in this work by the equation presented in Ref. [10, 22], based on the works of Maxwell for liquid and solid suspensions as in equation 18 [18]

$$\frac{K_{nf}}{K_f} = \frac{K_{ZnO}+2K_f+2\emptyset(K_{ZnO}-K_f)}{K_{ZnO}+2K_f-\emptyset(K_{ZnO}-K_f)} \qquad (18)$$

Properties of nanoparticles for this study are given below [27]

- Molecular weight = 81.39 gm/mol

- Density = 5.61 gm/cm3
- CAS No = 1314-13-2
- Zinc Content ≈ 75%
- Purity = 99.5%
- Average particle Size = <100nm

Properties of lubricant for this study are given in table 1 [28]

Viscosity at 40^0C (without nanoparticles)	43.60X10^9 MPa-S
Viscosity at 40^0C (with nanoparticles)	45.143X10^9 MPa-S
Pour Point ^{0}C	-60
Flash Point ^{0}C	1900
Relative Density / Sp.Gravity	0.863
Density kg/m^3	863
Specific heat capacity KJ/KgK at 40^0C without nanoparticle	1.95

Table 1 Properties of lubricant

IV. COMPUTATIONAL FLUID DYNAMICS (CFD)

Finite Element Analysis or FEA is the simulation of a physical phenomenon using a numerical mathematic technique referred to as the Finite Element Method, or FEM. This process is at the core of mechanical engineering, as well as a variety of other disciplines. It also is one of the key principles used in the development of simulation software. Computational fluid dynamics (CFD) is a branch of fluid mechanics that uses numerical analysis and data structures to analyze and solve problems that involve fluid flows. Computers are used to perform the calculations required to simulate the free-stream flow of the fluid, and the interaction of the fluid (liquids and gases) with surfaces defined by boundary conditions. CFD is applied to a wide range of research and engineering problems in many fields of study and industries, including aerodynamics and aerospace analysis, weather simulation, natural science and environmental engineering, industrial system design and analysis, biological engineering, fluid flows and heat transfer, and engine and combustion analysis. Phase of simulations are shown in figure 4.

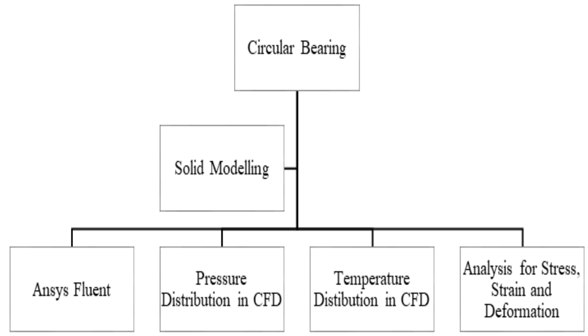

Figure 4 Phases of Simulation

A. Creo Modelling

Creo is a family or suite of Computer-aided design (CAD) apps supporting product design for discrete manufacturers and is developed by PTC. The suite consists of apps, each delivering a distinct set of capabilities for a user role within product development. Creo modelling is shown in figure 5.

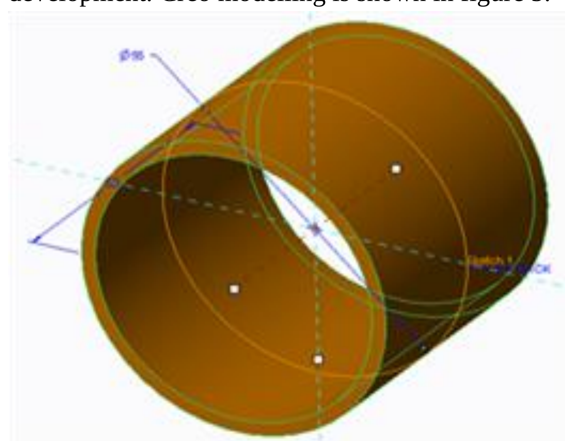

Figure 5 Modelling of Circular Bearing

B. Introduction to Ansys Fluent.

Ansys FLUENT software contains the expansive physical displaying abilities expected to show stream, tempestuous, heat move, and responses for modern applications going from wind current over an airplane wing to burning during a furnace, from bubble columns to grease platforms, from blood flow to semiconductor manufacturing. Ansys Fluent can solve your most sophisticated models for multiphase flows, reactions, and combustion. Even complicated viscous and turbulent, internal and external flows, flow-induced noise predictions, heat transfer with and without radiation are often modeled with ease. Modelling in ansys is shown in figure 6.

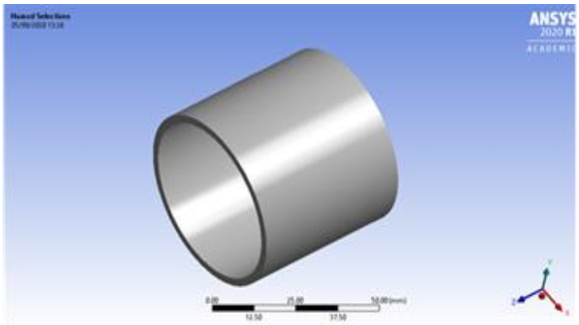

Figure 6 Modelling in analysis

Meshing has applications in fields of Geography, designing, CFD (Computational Fluid Dynamics). Using CFD, you are ready to analyze complex problems involving fluid-fluid, fluid-solid, or fluid-gas interaction. Meshing of element is shown in figure 7.

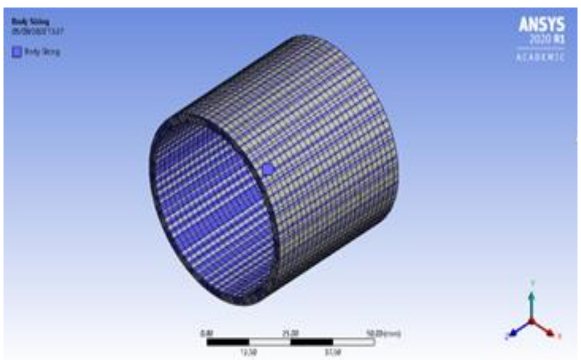

Figure 7 Finite Element Meshing

C. CFD Analysis for Pressure and Temperature Distribution

ANSYS FLUENT always uses gauge pressure; you will simply set the operating pressure to zero, making gauge and absolute pressures equivalent. If the density is assumed constant or if it is derived from a profile function of temperature, the operating pressure isn't utilized in the density calculation. The utmost Pressure distributed is 6.83 MPa.

1. Pressure distribution for 500 RPM without Nano lubricant is shown in figure 8 and 9

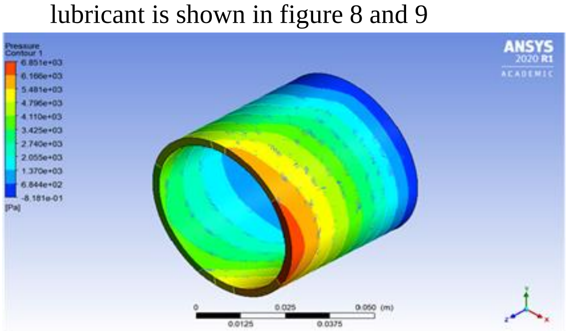

Figure 8 pressure distribution for circular bearing at 500 RPM without Nano lubricant

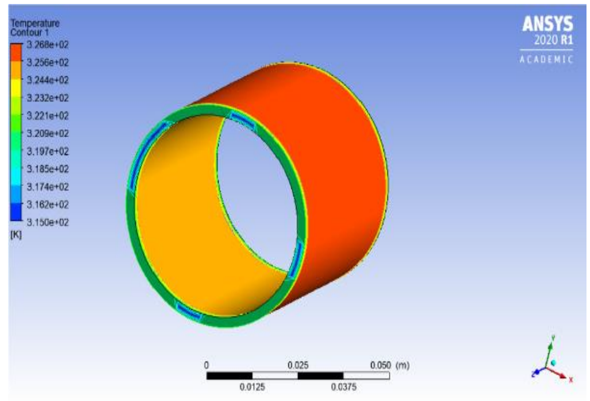

Figure 9 temperature distribution for circular bearing at 500 RPM without Nano lubricant

1. Pressure distribution for 750 RPM without Nano lubricant is shown in figure 10 and 11

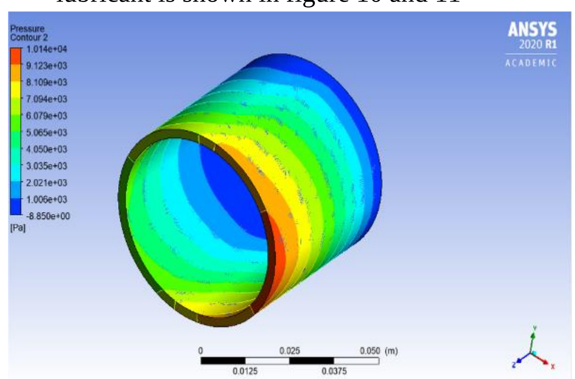

Figure 10 pressure distribution for circular bearing at 750 RPM without Nano lubricant

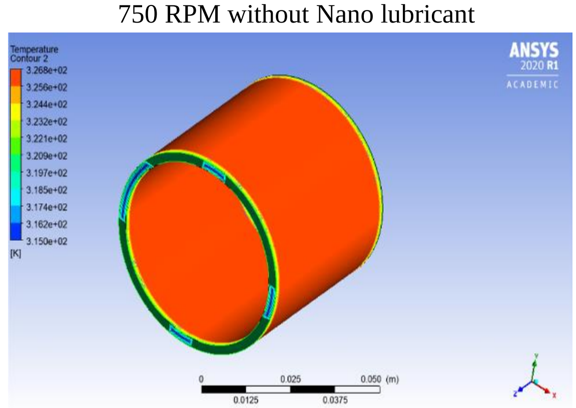

Figure 11 temperature distribution for circular bearing at 750 RPM without Nano lubricant

2. Pressure distribution for 1000 RPM without Nano lubricant is shown in figure 12 and 13

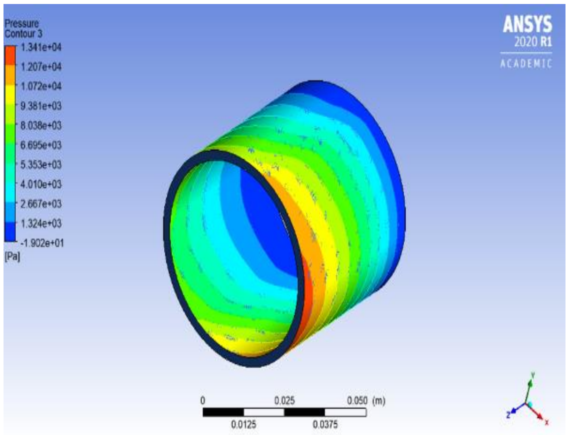

Figure 12 pressure distribution for circular bearing at 1000 RPM without Nano lubricant

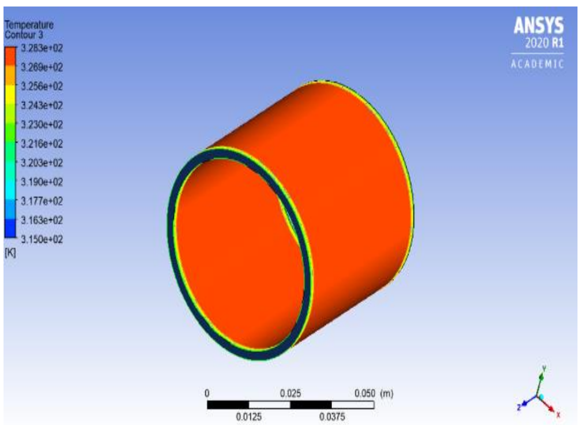

Figure 13 temperature distribution for circular bearing at 1000 RPM without Nano lubricant

3. Pressure distribution for 500 RPM with Nano lubricant is shown in figure 14 and 15

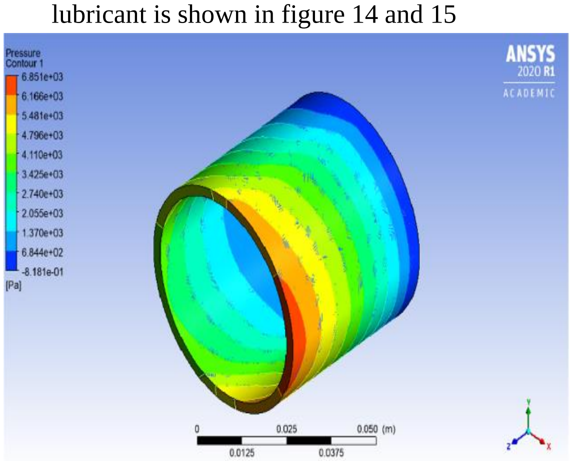

Figure 14 pressure distribution for circular bearing at 500 RPM with Nano lubricant

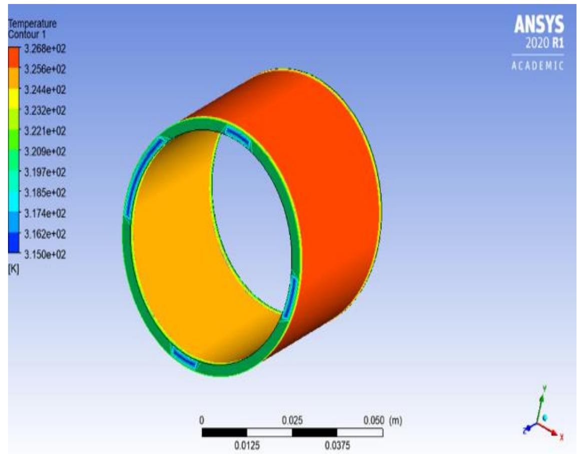

Figure 15 temperature distribution for circular bearing at 500 RPM with Nano lubricant

4. Pressure distribution for 750 RPM with Nano lubricant is shown in figure 16 and 17

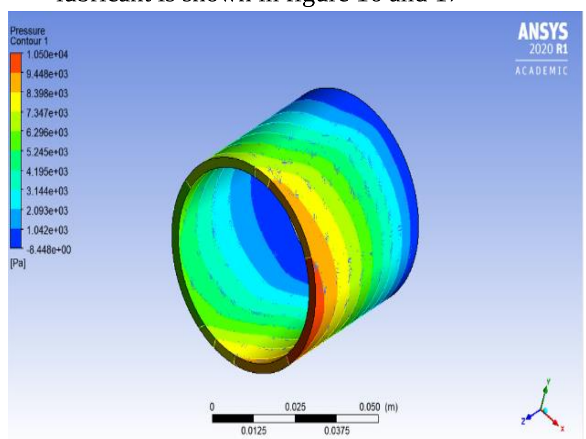

Figure 16 pressure distribution for circular bearing at 750 RPM with Nano lubricant

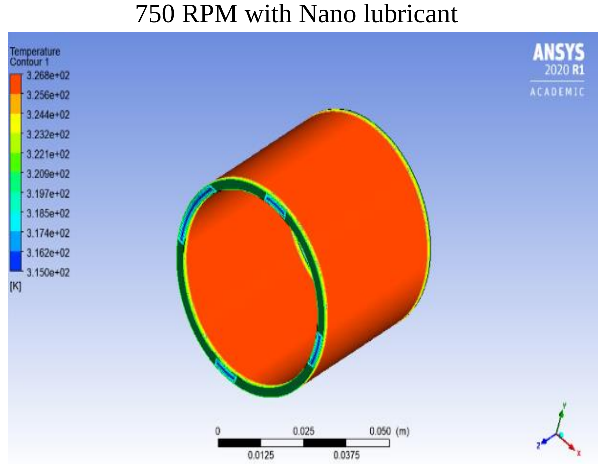

Figure 17 temperature distribution for circular bearing at 750 RPM with Nano lubricant

5. Pressure distribution for 1000 RPM with nano lubricant is shown in figure 18 and 19

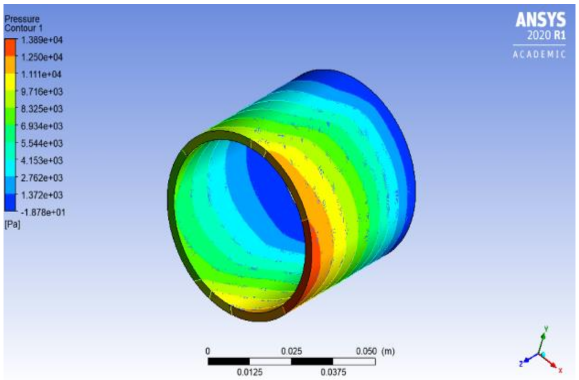

Figure 18 pressure distribution for circular bearing at 1000 RPM with Nano lubricant

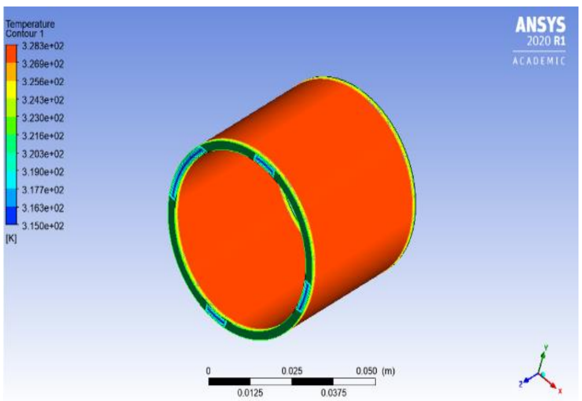

Figure 19 temperature distribution for circular bearing at 1000 RPM with nano lubricant

IV. RESULT AND DISCUSSION

From CFD analysis of circular hydrodynamic journal bearing with Nano lubricant and without Nano lubricant we below results such as pressure distribution in circular bearing, temperature distribution in circular bearing.

A. Pressure Distribution

Pressure distribution in hydrodynamic journal bearing is obtained from CFD analysis and values of pressure distribution are as per table 2

Pressure Distribution		
Speed	Circular Bearing	Circular Bearing with Nano Particles
500	6.85	7.09
750	10.14	10.5
1000	13.42	13.89

Table 2 Pressure Distribution in MPa

From table 2 it is seen that pressure distribution in circular bearing with nanoparticle is maximum compared to only circular bearing with lubricant. Graphical representation of circular bearing pressure distribution is given in figure 20

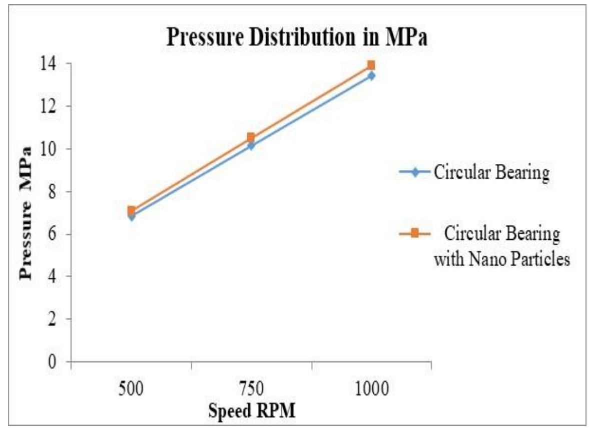

Figure 20 Pressure Distribution in MPa

B. Temperature Distribution

Temperature distribution in hydrodynamic journal bearing is obtained from CFD analysis and values of temperature distribution are as per table 3

Temperature Distribution		
Speed	Circular Bearing	Circular Bearing with Nano Particles
500	326.8	325.41
750	327.7	327.4
1000	328.3	328.2

Table 3 Temperature Distribution in ^{0}K

From table 4 it is seen that temperature distribution in circular bearing with nanoparticle is maximum compared to only circular bearing with lubricant. Graphical representation of circular bearing temperature distribution is given in figure 21.

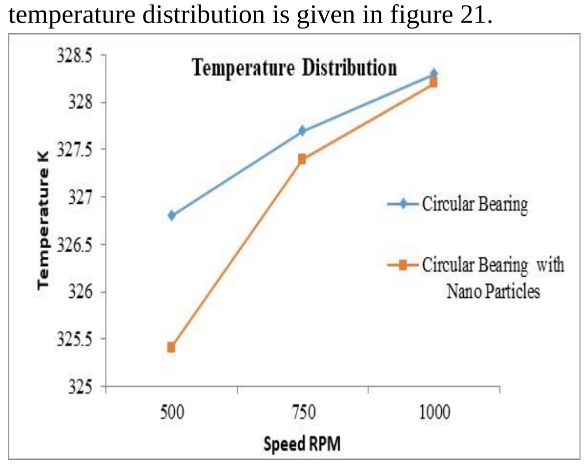

Figure 21 Temperature Distribution ^{0}K

V. COMPARATIVE ANALYSIS

The set of reading are taken for 3 types of speed from CFD analysis and theoretical reading are taken some from compared research study, some readings from calculation of equation 3 [19, 23].

Type of bearing	Speed in Rpm	P/Pmax		
		Theo	Analysis	% error
Circular bearing without ZnO	500	0.463	0.766	1.656
	750	0.494	0.897	1.816
	1000	0.51	0.892	1.748
circular bearing with ZnO	500	0.464	0.882	1.898
	750	0.496	0.948	1.912
	1000	0.511	0.943	1.846
		ΔT		
Circular bearing without ZnO	500	5.61	13.3	2.371
	750	8.09	14.2	1.754
	1000	10.7	14.8	1.383
circular bearing with ZnO	500	5.66	13.91	2.458
	750	8.27	15.9	1.923
	1000	10.81	16.7	1.544

Table 4. Comparative analysis

The value of $\frac{P}{P_{max}}$ ratio is taken from Raimondi-Boyd chart for comparative analysis. All values are displayed in table 4.

VI. CONCLUSION

The circular bearing working with ZnO nanoparticle is considered in this project. An analytical approach has presented to evaluate the pressure distribution, & temperature distribution at different operating speed with ZnO nanoparticle and without ZnO nanoparticle. From results and comparative study, we conclude that:

1. Circular bearing with Nano lubricant is more effective than without nano lubricant for pressure distribution.
2. As we add ZnO Nano lubricant temperature rise in bearing increases compare to simple lubricant.
3. From comparative study we concluded that minimum % error is 1.656 and maximum % error 1.912% is in pressure distribution and minimum % error is 1.383% and maximum % error 2.458 % is in temperature distribution.

VII. ACKNOWLEDGMENT

The report is result of direction, moral help and commitment gave on me all through my work. For this I recognize and express my significant feeling of appreciation and due to everyone who have been a source of inspiration during the experimentation. First and foremost I offer my sincere phrases of thanks with innate humility to Dr.V.C.Shewale (H.O.D) Mechanical Engineering Department, for providing help whenever needed. The consistent guidance and support provided by Prof.D.V.Kushare is very thankfully acknowledged and appreciated for the key role played by him in providing me with his precious ideas, suggestions, help and moral support that enabled me in shaping the experimental work.

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