Effect of TiO2 additive volume fraction in lubricant oil on the performance of hydrodynamic journal bearing

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Abstract
Hydrodynamic journal bearings are widely used in rotating machines where high loading condition prevails. In this work, effect of different volume fractions of TiO2 (Titanium dioxide) additive in commercially available SAE30 lubricant oil on the performance of hydrodynamic journal bearing is analysed experimentally. Hydrodynamic journal bearing test rig is used to perform the experiment. The experiment is carried out by taking different volume fractions of TiO2 additive (0.075%, 0.1% and 0.15%) in SAE30 lubricant base oil and their effect on journal bearing characteristics like coefficient of friction, pressure distribution, temperature rise, eccentricity ratio, attitude angle, minimum film thickness and displacement is analysed. Paraffin oil is used to uniformly distribute the TiO2 in the base oil and to resist sedimentation.

The study shows that the addition of TiO2 additive in the base SAE30 lubricant oil is capable of significantly reducing the values of friction coefficient and maximum temperature rise. It has been found that the addition of TiO2 additive improves the performance of the hydrodynamic journal bearing. Results reveals that the additive performs better at higher loading conditions.

Key words: Hydrodynamic journal bearing, Coefficient of friction, Pressure, Load, Temperature

1. Introduction
Hydrodynamic journal bearings are used in compressors, pumps, turbines, internal combustion engines, motors, generators etc. due to their high load carrying capacity and good damping properties [1-3]. The main function of journal bearing is to support radial load and facilitate motion as well as transfer of power [4][5]. Additives are introduced in the base stock to improve their tribological performance, thermal properties and anti-oxidation capability [6][7]. Like other additives TiO2 additives are also used to improve the performance of base oil or lubricant. It is capable of enhancing the load carrying capacity [8] and reducing the friction and wear [9-11]. Tribofilm formation on the sliding surface and ball bearing effect of the TiO2 particles are primary reason behind it [12]. Surfactants and dispersants are generally used to disperse additives in the base oil uniformly and to avoid their sedimentation [13]. Thus, in this study paraffin oil is used along with the pure oil to uniformly distribute the TiO2 additive.

2. Experimental study
2.1 Sample preparation
TiO2 (Titanium Dioxide) additives used in this study is purchased from Qualikems Fine Chem Pvt. Ltd. (Nandesari, Vadodara, India). SAE30 oil as exhibited in figure 1(a) is used as a base oil in the experiment and TiO2 additive is blended in it. Figure 1(b) shows the SAE30 oil mixed with TiO2 additive.

![Fig. 1 (a) Pure SAE30 lubricant oil, (b) SAE30 oil mixed with TiO2 additive and (c) Paraffin oil](image-url)
To hinder the sedimentation and aggregation of the TiO$_2$ particles and for its homogenous mixing in the base oil, Paraffin oil as shown in figure 1(c) is used as dispersant [14]. Table 1 shows the properties of SAE30 lubricant oil.

| Property                          | Value in metric unit |
|-----------------------------------|-----------------------|
| Density at 20°C                   | 0.885*10$^3$ Kg/m$^3$ |
| Kinematic Viscosity at 40°C       | 85.76 cSt             |
| Kinematic Viscosity at 90°C       | 11.42 cSt             |
| Viscosity Index                   | 100                   |
| Flash Point                       | 210 °C                |
| Pour Point                        | -23 °C                |
| Sulfated Ash                      | 1.67 %                |

The experiment is performed by taking pure SAE30 oil and then subsequently adding different volume fractions (0.075%, 0.1% and 0.15%) of the TiO$_2$ additive in the base oil. The calculation for the mass of TiO$_2$ has been carried out by using equation 1 [15].

$$m_{TiO_2} = \rho_{TiO_2} \times \phi \times V_l$$  \hspace{1cm} (1)

Where, $m_{TiO_2}$ is the mass of TiO$_2$ additive (g)

$\rho_{TiO_2}$ is density of additive TiO$_2$ (kg/m$^3$)

$\phi$ is volume fraction

$V_l$ is Volume of lubricant in litre

The calculated amount of TiO$_2$ is weighed on weighing machine and is then mixed with paraffin oil dispersant. Paraffin oil is 15% by volume of base lubricant oil. The mixture is allowed to mix using magnetic stirrer for 30 minutes. Then it is dispersed in the SAE30 base lubricant oil and is mixed for two hours.

2.2 Hydrodynamic journal bearing test rig

Journal bearing test rig shown in figure 2 consists of a journal having diameter 100 mm, mounted horizontally on a housing supported on self-aligned bearing. The one side of journal is connected to 3 phase induction motor with toothed belt drive, on the other side the test bearing is fitted. The other end of journal/shaft is mounted above the frame to rotate in the horizontal axis.

![Fig. 2 Hydrodynamic Journal Bearing Test Rig (HJBTR)](image-url)
A pneumatic cylinder is fitted above the frame to apply load on the bearing. Air pressure is generated by air compressor. A reciprocating double acting piston is fitted in the cylinder and connected to the bearing with load cell and chain. Difference of air pressure in upper and lower part of piston created pressure difference across the piston. This pressure difference causes load on the piston which is transformed to the bearing via connected load cell and chain fitted to the bracket on the bearing. Load cell calculate the load, displays on software screen. Pneumatic cylinder is capable to sustain maximum load of 10kN when pressure in the pneumatic pressure gauge shows 6 bar.

An oil tank of capacity 20 litres is used to store the lubricant. A 3-phase induction motor is used to pump the lubricant. Pumped lubricant is cooled by a cooling fan arrangement placed over oil tank. Pressure of pumped lubricant can be regulated by pressure regulator valve. Pumped lubricant reach to journal bearing arrangement via inlet pipe, circulate within it. Side flow of lubricant come back to the oil tank via drain pipe, filtered at inlet of oil tank. The lubricant stored in oil tank can be circulate again and again (figure 3).

6 pressure sensors and 6 temperature sensors mounted on the bearing as illustrated in figure 4 are used to measure pressure and temperature. Lubricant reach between journal-bearing arrangements via entry hole. Also, entry holes are made on bearing to reach the lubricant at various sensors. Variable frequency drive is used to control the speed of 3-phase induction motor. WINDUCOM 2010 software is used to control the journal bearing test rig. An NI cable and a MODBUS cable is used to interface between computer and journal bearing test rig. MODBUS cable send command from computer to different components of machine and the components responds accordingly. NI cable send the response of different sensors of machine to the computer software. Table 2 shows the specifications and geometric properties of HJBTR.

| Table 2 Specifications and geometric properties of HJBTR |
|-----------------|-----------------|
| **Speed Range** | 150 to 1500 RPM |
| **Normal test load Range** | Upto 10 kN |
| **Maximum Pressure Range** | 68.9 bar |
| **Temperature Range** | Room Temperature to 200°C |
| **Maximum Film Thickness** | 100 μm |
| **Bearing Material** | Brass |
| **Shaft Diameter (d_s)** | 100.0 mm |
| **Bearing Inner Diameter (d)** | 100.2 mm |
| **Bearing Length (L)** | 100.0 mm |
| **Radial Clearance (c)** | 0.100 mm |
3. Result and discussion

The experiment is performed at a speed of 1400 rpm and the load varies from 600 N to 1000 N. The operating temperature inside the bearing is below 100°C and the pressure range inside the bearing is 0 to 7 bars.

3.1 Variation of coefficient of friction

Friction coefficient value is decreasing with increase in the volume fraction of the additives as exhibited in the figure 5. The coefficient of friction is minimum for 0.15% volume of TiO$_2$ added in the SAE30 oil at all loading conditions. However, 0.1% volume fraction of the TiO$_2$ is not following the trend.

![Figure 5](image)

**Fig. 5** Variation of coefficient of friction with volume fraction for different loads.

![Figure 6](image)

**Fig. 6** Variation of coefficient of friction with load for different volume fractions of the TiO$_2$ additive.

Figure 6 shows the variation of the friction coefficient with load. It can be seen from the graph that the friction coefficient is increasing with increase in load.

It’s evident from the both figures (Figure 7 and Figure 8) that the COF value is decreased by 66.89%, 61.69% and 73.54% for 0.075%, 0.1% and 0.15% volume fraction of the TiO$_2$ dissolved in the base SAE30 oil respectively at 600 N as compared to the pure base oil. The COF value is decreased by 37.25%, 32.05% and 41.234% for 0.075%, 0.1% and 0.15% volume fraction of the TiO$_2$ dissolved in the base SAE30 oil respectively at 1000 N compared to the base oil. TiO$_2$ particles form a tribofilm between the journal bearing surface, this tribofilm formation [29][30] prevents the direct metal to metal contact and thus reduces the friction values drastically.

3.2 Pressure distribution at different load for various volume fractions

Figure 7 (a-e) shows the variation of the Pressure with circumferential angle at different loads. Readings of pressure are taken from the six pressure sensors installed at a gap of 36° each. Each graph is plotted at constant load and for different volume fractions (0.075%, 0.1% and 0.15%) of TiO$_2$ additive.

Maximum pressure or peak pressure is obtained at a circumferential angle of 108° for all loading conditions and each composition of the TiO$_2$ additives added. The peak pressure is maximum for SAE30 base lubricant oil than the peak pressure of SAE30 oil dissolved with different volume fractions of the TiO$_2$ additives at 600N. However, with increase in the load the value of peak pressure for the SAE30 lubricant oil dissolved with TiO$_2$ additives comes closer to the pure SAE30 oil. At initial loading condition, the value of peak pressure is decreasing with an increase in the TiO$_2$ concentration in the base oil (figure 7(a)). Whereas, the gap in peak pressure is decreasing with increase in load. The difference in peak pressure between pure oil and base oil with 0.15% volume fraction of TiO$_2$ is 0.004581 (N/m$^2$) at 600N. However, at 1000N the difference reduces to 0.002083 (N/m$^2$). Apparently, the TiO$_2$ additives in base SAE30 oil show better results at higher loads.

The value of the peak pressure developed is improving as the load is increased for all compositions of the TiO$_2$ additives in base oil and is also improving for the pure SAE30 oil. The development of pressure is conducive in keeping the journal bearing away from the contact of surface asperities.
Fig. 7 Variation of Pressure with Circumference Angle for different volume fractions of the TiO2 added at (a) 600 N, (b) 700 N, (c) 800 N, (d) 900 N, and (e) 1000 N.

3.3 Temperature distribution at different volume fraction.
Figure 8 is a bar graph showing temperature on the y-axis and the numbers on the x-axis from 1 to 5 are the temperature sensors installed at a gap of 36° each. Temperature sensor 3 installed at an angle of 108° is showing the maximum temperature than all other sensors. Indicating that the temperature is maximum at a circumferential angle of 108°. Addition of the TiO2 particles in pure SAE30 oil reduces the maximum temperature value and its lowest for 0.1% volume fraction of TiO2 (Figure 9). The result indicates that addition of the TiO2 additive improves the heat dissipation rate.
3.4 Variation of other characteristics with volume fraction

Eccentricity ratio is initially increasing with increase in the volume fraction of the TiO2 additive and then further decreasing. It is minimum for pure base oil and maximum for 0.1% TiO2 added (Figure 10). Similar behavior is followed by the attitude angle vs volume fraction graph as depicted in figure 11 where attitude angle is initially increasing with addition of the additive and is then decreasing. For 0.15% volume fraction, the value of attitude angle is more compared to that of the 0.1% volume fraction.

Minimum film thickness decreases with increase in the volume fraction of the additive up to 0.1% TiO2 and is then increasing (Figure 12). In a journal bearing operation, minimum fluid film thickness plays a crucial role to deter the direct metal to metal contact [16]. In this case, film thickness is maximum for pure SAE30 base
lubricant oil and minimum for 0.1% TiO2 additive. X and Y displacement of journal bearing is illustrated in figure 13. Both X and Y displacement are maximum for 0.1% volume fraction of TiO2 additive and is minimum for pure SAE30 lubricant oil.

4. Conclusion
Addition of the TiO2 additive in the SAE30 base oil can significantly reduce the value of the friction coefficient. The value of the peak pressure developed is improved as the load is increased for all compositions of the TiO2 additives in base SAE30 oil. The result shows that TiO2 additives perform better at higher load. Addition of the TiO2 particles in pure SAE30 oil reduces the maximum temperature raised in the journal bearing. However, value of minimum thickness is maximum for pure oil. Eccentricity ratio, attitude angle and displacement values are minimum for SAE30 base oil and is maximum for 0.1% volume fraction of TiO2 additive. The characteristics displayed by 0.1% TiO2 additive volume fraction highly discourages its use in journal bearing. Whereas, 0.15% TiO2 is displaying more amicable results compared to others.

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References
1. Kalani, A., Soni, S., & Jani, R. (2015). Expert Knowledgebase System for Computer Aided Design of Full Hydrodynamic Journal Bearing. International Journal of Mechanical Engineering and Technology, 6(8), 46-58.
2. Kerlekar, R. S., Dhande, D. Y., Nigade, M. B., & Kondhalkar, G. E. (2015). Performance Analysis of 3 Lobe Hydrodynamic Journal Bearing. International Journal of Engineering Research and General Science, 3(4).
3. Sharma, S., & Awasthi, R. K. (2017). Effect of aspect ratio on the performance of hydrodynamic journal bearing operating under wear. International Journal of Theoretical and Applied Mechanics, 12(3), 497-522.
4. Kasolang, S., Ahmad, M. A., Joyce, R. D., & Tai, C. F. M. (2012). Preliminary study of pressure profile in hydrodynamic lubrication journal bearing. Procedia Engineering, 41, 1743-1749.
5. Shahnaz, S., Bagheri, S., & Hamid, S. B. A. (2016). Enhancing lubricant properties by nanoparticle additives. International journal of hydrogen energy, 41(4), 3153-3170.
6. Krishna, P. V., Srikant, R. R., Padmini, R., & Viswaditya, J. L. P. P. (2013, July). Application of nanomaterials as coolants/lubricants in machining. In International Conference on Advanced Nanomaterials & Emerging Engineering Technologies (pp. 674-682). IEEE.
7. Singh, A., Chauhan, P., & Mamatha, T. G. (2019). A review on tribological performance of lubricants with nanoparticle additives. Materials Today: Proceedings.
8. Binu, K. G., Shenoy, B. S., Rao, D. S., & Pai, R. (2014). A variable viscosity approach for the evaluation of load carrying capacity of oil lubricated journal bearing with TiO2 nanoparticles as lubricant additives. Procedia materials science, 6, 1051-1067.
9. Ilie, F., & Covalu, C. (2016). Tribological properties of the lubricant containing titanium dioxide nanoparticles as an additive. Lubricants, 4(2), 12.
10. Ingole, S., Charanpahari, A., Kakade, A., Umare, S. S., Bhatt, D. V., & Menghani, J. (2013). Tribological behavior of nano TiO2 as an additive in base oil. Wear, 301(1-2), 776-785.
11. Xia, W., Zhao, J., Wu, H., Jiao, S., Zhao, X., Zhang, X., ... & Jiang, Z. (2018). Analysis of oil-in-water based nanolubricants with varying mass fractions of oil and TiO2 nanoparticles. Wear, 396, 162-171.
12. Wu, H., Zhao, J., Cheng, X., Xia, W., He, A., Yun, J. H., ... & Jiang, Z. (2018). Friction and wear characteristics of TiO2 nano-additive water-based lubricant on ferritic stainless steel. Tribology International, 117, 24-38.
13. Padgurskas, J., Rukuiza, R., Prosyčevas, L., & Kreivaitis, R. (2013). Tribological properties of lubricant additives of Fe, Cu and Co nanoparticles. Tribology International, 60, 224-232.
14. Wu, Y. Y., & Kao, M. J. (2011). Using TiO2 nanofluid additive for engine lubrication oil. Industrial Lubrication and Tribology, 63(6), 440-445.
15. Sepyani, K., Afrand, M., & Esfe, M. H. (2017). An experimental evaluation of the effect of ZnO nanoparticles on the rheological behavior of engine oil. Journal of Molecular Liquids, 236, 198-204.
16. Verma, S., Kumar, V., & Gupta, K. D. (2016). Effect of elasticity on capillary compensated flexible multi-recess hydrostatic journal bearing operating with micropolar lubricant. Journal of The Institution of Engineers (India): Series C, 97(1), 11-23.