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RESEARCH

Effect of Using Zinc Oxide Nano-particles as Anti-wear and Anti-friction Additive in Mineral Oil for a Tribo-pair operating in Mixed Lubrication Regime

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A B S T R A C T

Experimental investigations have been conducted in the present research work to determine the effectiveness of Zinc oxide nano-particles as anti-wear and anti-friction additive in a mineral oil. The nano lubricants containing 0.5%, 1.0% and 1.5% quantity of zinc oxide nano-particles (% by weight) were prepared in two different base oils using the same surfactant to study these effects. The effectiveness of Zinc oxide nano-particles as anti-wear and anti-friction additive is shown to be dependent on the properties of the base oil. The wear tests were conducted on block on disk test setup to determine the anti-wear performance of the nano lubricants. The wear of the block is measured in terms of its weight loss. The results of the experimental investigations are reported. The addition of Zinc oxide nano-particles in low viscosity lubricant reduces the wear by about 94% and coefficient of friction by 59%. However, addition of Zinc oxide nano-particles in high viscosity lubricant reduces the wear by about 92% but increases the coefficient of friction by up to 71%.

1. INTRODUCTION

The contact between the two surfaces during relative motion is generally avoided so as to eliminate friction and wear, however in several applications the load and speed conditions are not favorable and the tribo pair operates in mixed lubrication regime [1]. Many studies in the past have focused on the optimum design of the tribo-pairs in order to ensure the creation of sufficient lubricant film thickness responsible for the separation of the contacting surfaces [2], such as encountered in engine journal bearings [3]. Many alternative technologies have been employed to separate the contacting surfaces, like passive magnetic bearings [4,5] but the use of Multi-Walled Carbon Nano-tubes (MWCNT) [6], zinc oxide nano-particles [7], molybdenum disulphide nano-particles, tungsten disulphide etc. are considered as cost effective solutions for minimizing wear when used as lubricant additives. Extensive studies on lubricating oils have established that additives play a dominant role in mixed lubrication.

The addition of zinc oxide nano particles (ZnO) in base oil enhance anti-wear properties [8]. At ambient pressure and temperature, ZnO crystallizes in the form of a hexagonal lattice as shown in figure 1, and is characterized by two interconnecting sub-lattices of Zn^{2+} and O^{2-}, such that each Zn ion is surrounded by tetrahedra of O-ions, and vice-versa. This tetrahedral coordination gives rise to polar symmetry along the hexagonal axis. This polarity is responsible for a number of the properties of ZnO, including its piezoelectricity and spontaneous polarization, and is also a key factor in crystal growth, etching and defect generation [9].

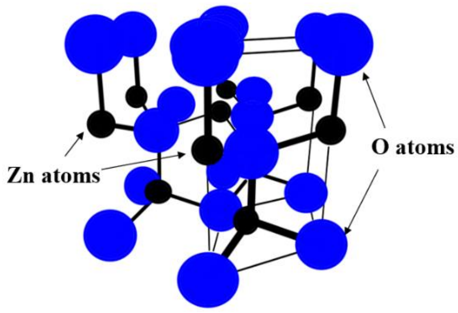


Fig. 1. Hexagonal structure of ZnO, adapted from [9].

It is known that zinc oxide nano particles added to a lubricant can become a catalyst of the oxidation of hydrocarbon mixtures. This affects the process of wear of materials under friction by promoting the formation of relatively “thick” surface layers with a high content of oxygen. These regions reduce considerably the tangential stresses and the temperature in contact spots. The zinc oxide nano particles cover significant portion of the friction surface. On the contrary, in the case of conventional lubricant the formation of a “thin” oxidized layer (about 20 nm thick) seems to be connected with deep oxidation of the industrial oil. For conventional mineral oil lubricant intense oxidation processes begin to act and the deficit of molecular oxygen limits the formation of oxide films on the mating surfaces, which causes adhesion wear of the specimens [10].

In a tribo-pair that operates under heavy load and slow relative speed, the conditions for the formation of thick film separating the two sliding surfaces are not conducive and interacting surfaces contact each other at several locations and tribo-pairs are said to operate in mixed lubrication regime. The Figure 2 depicts a schematic representation of mixed lubrication regime, in which applied load is shared by fluid film and asperity contacts. Two distinct regions: first, where fluid film separates the tribo-pairs and second where the asperities are in contact are shown in the Figure 2.

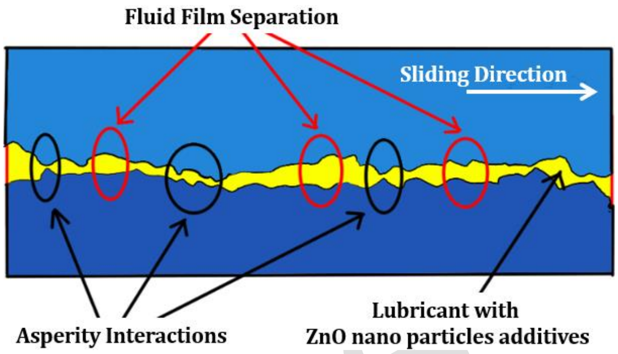


Fig. 2. Mixed lubrication conditions.

The asperity contacts under relative sliding results in wear. Due to the presence of asperity contacts and very thin lubricant film, the lubricant viscosity, anti-wear and anti-friction or extreme pressure additives assumes significance in determination of the tribological performance in mixed lubrication. The operating life under mixed lubrication regime is finite/limited due to the damages caused by wear.

The phase composition of the zinc-bearing surface structure, which is responsible for decrease in the wear is quite complex [10]. One mechanism of action, as proposed, stated that the nanoparticles get entrained into rolling and sliding contacts at slow speeds when the film thickness is smaller than the particle size contributing to film thickness. It is also been reported that the transition to mild wear occurs due to the formation of wear protective tribo-films on the rubbing surfaces by tribo-sintering of the oxide particles [11,12]. The schematic representation is shown in Figure 3 (View A). Another mechanism of action, proposed as mechanical entrapment theory [13], states that the nanoparticles penetrate in the contact area and then deposit on it. The schematic representation is depicted in Figure 3 (View B). Another experimental study suggested that ZnO nano particles, when used as oil additives, deposit on the rubbing surface and improve the tribological properties of the base oil [14]. The schematic representation is shown in Figure 3 (View A). It was also experimentally established that increase of nano particle concentration in the base oil increases their deposition on wear surfaces [15]. However, in another study [16] it was shown that ZnO nano particles have better extreme pressure properties as compared to anti-wear properties.

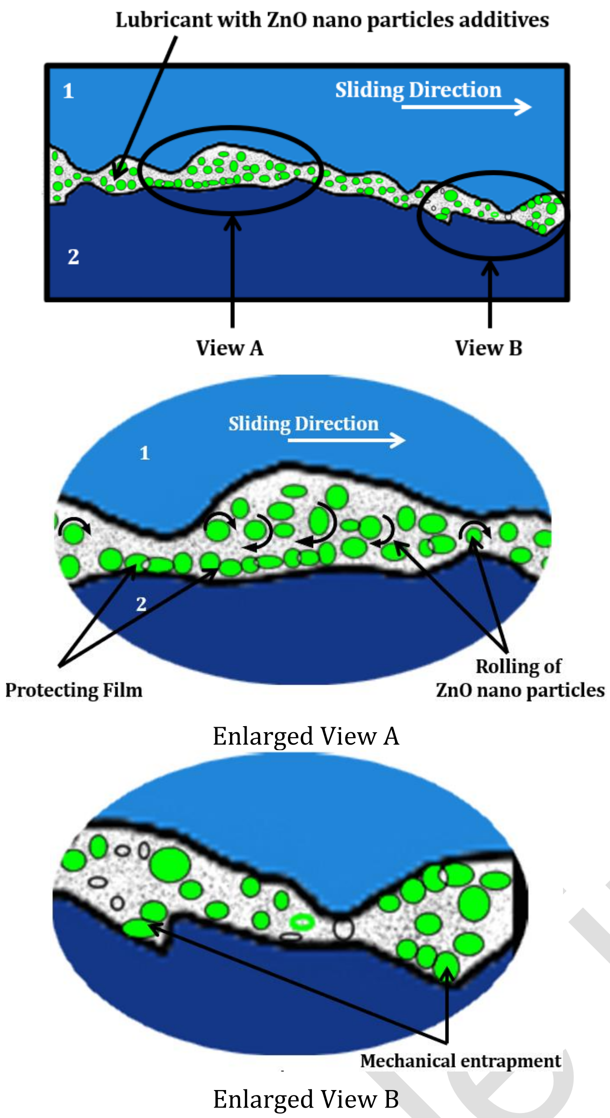


Fig. 3. Types of mechanisms: protective film, rolling & entrapment.

The review of the existing literature reveals that there is a need to explore the effectiveness of adding zinc oxide nano particles as additive in oil in minimizing friction and wear of a tribo-pair subjected to sliding under extreme operating conditions of heavy load and slow speed.

In the present work nano lubricants containing varying quantities 0.5%, 1.0% and 1.5% of zinc oxide nano-particles (% by weight) were prepared in two different base oils using the same surfactant to study these effects. The wear tests were conducted on block on disk test setup to determine the anti-wear and anti-friction performance of these nano lubricants. The block and disc test setup is used in conducting wear tests. The load and speed conditions are selected so as to cause the operation in mixed lubrication regime. The experimental results are reported.

2. EXPERIMENTAL DETAILS

The wear tests have been conducted on block and disk test setup as shown in Figure 4. This test set up is manufactured by M/s Ducom Instruments,

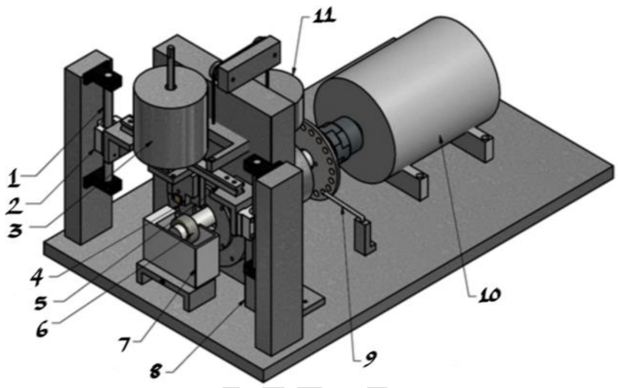
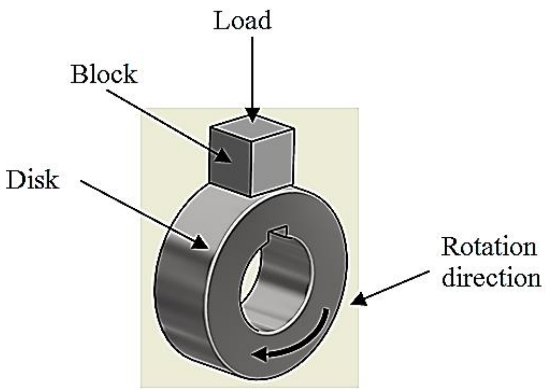


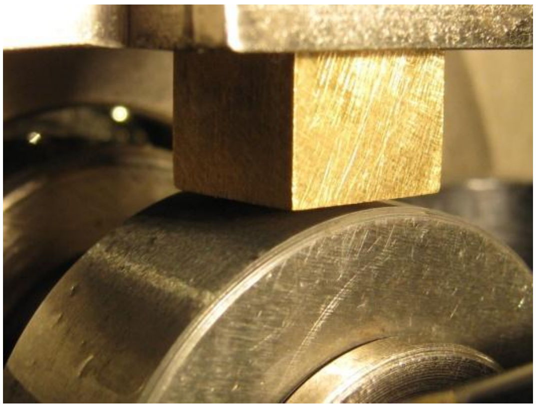
Fig. 4. Block and disk test setup

India, where: 1-Slide way; 2-Linear Bearing, 3-Load, 4-Block, 5-Loading Platform, 6-Disk, 7-Lubricant Tank, 8-Load Cell, 9-Proximity Sensor, 10-Motor, 11-conter weight. The disk is connected via a spindle to a 1.5 kW AC induction motor controlled by a variable frequency drive. The block is fixed to a holder which in turn is connected to the loading arm which rests on linear motion (LM) guide way. The LM guide way is fixed to the support having linear sliding bearing guided by vertical slide ways of circular cross-section. The vertical slide ways are rigidly fixed to the base plate. The load is applied on the top of the holder that presses the conformal block against the disk as shown in figure 4.

The lubrication system consists of an oil sump placed on a stand which partially submerges the rotating disk. Two cartridge heaters are fixed below the oil sump for heating the lubricant. The temperature is measured by RTD sensor (least count 0.1°C) fixed below the oil sump. A PID module is used to maintain the lubricant temperature at a desired value. A cantilevered beam type load cell is mounted on the side frame and the loading arm is in contact with it. The tangential force between the block and disk is transmitted to the load cell and data is acquired using LabView interface. The disk speed is measured by an inductive type proximity sensor (fixed on the base plate) and a sensor disc (with 24 holes on its periphery) fixed to the motor shaft. The test setup consists of a stationary block resting on a disk as shown in figure 5.



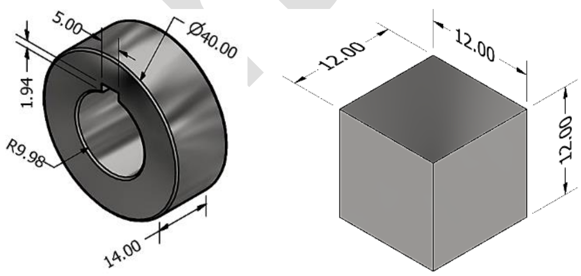
(a)



(b)

Fig. 5. Block resting on disk (a) Schematic (b) Photograph [17].

The disk used in the experimental setup is of 40 mm diameter and 14 mm width. The disk is fabricated of EN-31 steel hardened to 50 HRC. Its composition is: Carbon 0.90-1.20%, Silicon 0.10-0.35%, Manganese 0.35-0.75%, Chromium 1.00-1.60%, Phosphorus 0.05% and Sulphur 0.05%. The grinding of the disk surface was carried out to obtain a surface finish of about 0.20μm corresponding to N 4 grade as shown in figure 6(a).



(a) (b)

Fig. 6. Details of (a) disk and (b) block (all dimensions in mm)

The blocks were fabricated of phosphorus bronze material with a hardness of 70 BHN (The grade of phosphorus bronze material is BS 1400: LG2. Its composition is: Cu: 85%, Sn: 5%, Pb 5%, Zn 5%, and P 0.05%). The grinding of the block surface was carried out along the direction of sliding to obtain a surface finish of about 0.47μm corresponding to N 5 grade as shown in figure 6(b).

The Zinc Oxide nano particles were purchased from PlasmaChem GmbH, Germany. The average particle size mentioned by the manufacturer is 14 nm, the specific surface area is 30±5 m^2/g and the purity is > 99%. Three lubricants samples were prepared by adding varying quantities (0.5, 1.0 and 1.5% by weight) of Zinc oxide nano-particles in two commercial lubricants, namely Mobil DTE Light (Grade: ISO VG 32, Kinematic viscosity at 100°C: 5.5cSt) and Mobil DTE Medium (Grade: ISO VG 46, Kinematic viscosity at 100°C: 6.9 cSt, Viscosity Index: 98). These lubricants are premium performance circulating lubricants designed for applications including steam and hydro turbine sets and other systems where long lubricant service life is required. They are manufactured by Mobil India. The lubricant samples were prepared by dispersing 0.5, 1.0 and 1.5% quantity of Zinc oxide nano particles with Ammonium Citrate which is added as dispersant to enhance the stability of the suspension by ultrasonic homogenization. The ultrasonic homogenization, with a power of 250W, was carried out for one hour to de-agglomerate and disperse the surfactant and Zinc oxide nano-particles in the base oil.

The stability of lubricants with nano particles additives is still a challenge faced by the Lubrication Engineers. The problem of stability, manifested as settling and agglomeration of the nano particles over a period of time and in the absence of suitable dispersant is still unresolved. There is a need to continuously maintain a dispersed suspension at all times while the system is under operation.

However, in the present experimental work, the Ammonium Citrate was used as a dispersant to ensure the stability of the suspension. The tests were carried out immediately after the samples were prepared and thus the chances of settling and agglomeration of the Zinc oxide nano particles were minimized.

The wear tests were conducted for one hour duration at a load of 70 N and speed of 25 rpm (corresponding sliding speed is 0.005 m/s). The lubricant temperature was maintained at 70°C. Since the role of an additive in a lubricant assumes significance under mixed lubrication regime, therefore, these operating parameters are chosen so as to ensure that the operative regime is mixed lubrication. The friction and wear of the block using these lubricant samples was recorded. Three trials of each test were conducted to account for the experimental errors. The wear of the blocks was quantified in terms of its weight loss.

3. EXPERIMENTAL RESULTS AND DISCUSSION

The Figure 7 shows the coefficient of friction results of the wear tests conducted on block and disk test setup at the operating conditions mentioned in the previous section.

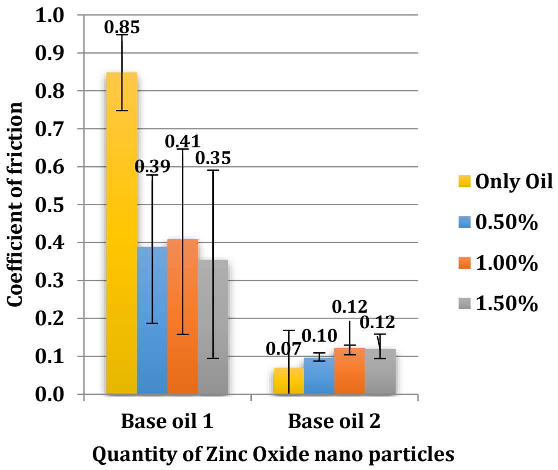


Fig. 7. Experimental results of Coefficient of friction for two base oils

It is observed that addition of 0.5% of Zinc Oxide nano particles in the base oil 1 (Mobil DTE Light lubricant) is able to reduce the friction by about 54%. With a further addition of 0.5% Zinc Oxide nano particles (total 1% ZnO nanoparticles) the reduction in friction was about 52%. The reduction in the friction reduced to 59% with a further addition of 0.5% Zinc Oxide nano particles (total 1.5% ZnO nanoparticles). This indicates that the addition of 1.5% of Zinc Oxide nano particles in the base oil 1 (Mobil DTE Light lubricant) gives the maximum reduction in friction.

However, it is observed that addition of Zinc Oxide nano particles (0.5%, 1.0% and 1.5%) in the base oil 2 (Mobil DTE Medium) increases the friction in the range of 43% to 71%.

The Figure 8 shows the result of the wear tests conducted on block and disk test setup at the operating conditions mentioned in the previous section. The wear quantified as weight loss was measured using a precision weighing balance HR-250 AZ manufactured by A&D Company, Ltd., Japan having a readability of 0.1 mg.

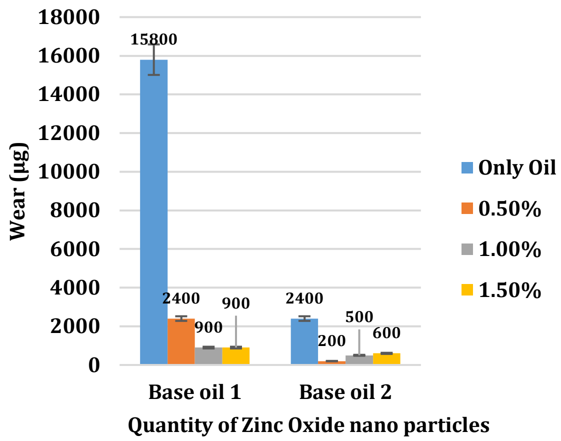


Fig. 8. Effect of base oil on Wear of blocks with Zn Oxide nano particles additive

It is observed that addition of 0.5% of Zinc Oxide nano particles in the base oil 1 (Mobil DTE Light lubricant) is able to reduce the wear significantly by about 85%. With a further addition of 0.5% Zinc Oxide nano particles (total 1% ZnO nanoparticles) the reduction in wear was about 94%. However, the reduction in the wear remained at 94% with a further addition of 0.5% Zinc Oxide nano particles (total 1.5% ZnO nanoparticles). This indicates that the addition of 1.0% of Zinc Oxide nano particles in the base oil 1 (Mobil DTE Light lubricant) gives the maximum reduction in wear and further increase in the quantity of Zinc Oxide nano particles is not beneficial.

It is observed that addition of 0.5% of Zinc Oxide nano particles in the base oil 2 (Mobil DTE Medium) is able to reduce the wear significantly by about 92%. With a further addition of 0.5% Zinc Oxide nano particles (total 1% ZnO nanoparticles) the reduction in wear reduced to about 79%. A reduction of 75% in the wear was observed with a further addition of 0.5% Zinc Oxide nano particles (total 1.5% ZnO nanoparticles). This indicates that the addition of 0.5% of Zinc Oxide nano particles in the base oil 2 (Mobil DTE Medium) gives the maximum reduction in wear and further increase in the quantity of Zinc Oxide nano particles is rather detrimental.

4. CONCLUSIONS

Based on the experimental investigations it is concluded that:

- The use of zinc oxide nano particles as additives in low viscosity mineral oil is effective in reducing both the wear and coefficient of friction under mixed lubrication conditions.
- The use of zinc oxide nano particles as additives in high viscosity mineral oil is effective in reducing only the wear under mixed lubrication conditions. The coefficient of friction, however, actually increased.
- The effectiveness of zinc oxide nano particles in minimizing the wear is comparatively better when used with low viscosity mineral oil as compared to high viscosity mineral oil.
- A reduction in coefficient of friction is observed with the use of zinc oxide nano particles as additive only in low viscosity mineral oil.
- However, an increase in the coefficient of friction is observed with the use of zinc oxide nano particles as additive in high viscosity mineral oil.
- The high viscosity mineral oil is relatively better than low viscosity mineral oil both in terms of resulting wear as well as coefficient of friction.
- Further theoretical and experimental studies are required to establish the reasons for the increase in the wear and friction with the increase in zinc oxide nano particles quantity when used with high viscosity mineral oil.

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