

TRIBOLOGICAL INVESTIGATION OF BASE OIL WITH NANOPARTICLES CuO AND TiO₂ AS AN ADDITIVES

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Abstract - The importance of lubrication in machines, their life, wear, friction, and prevention from failure cannot be understated. Poor lubricant performance may lead to huge losses in terms of energy and materials. To enhance lubricating behavior of bearing oil, one can use nanoparticles in their oils. In this study, CuO and TiO₂ nanoparticles were incorporated in the base oil called SN-500 and their tribological properties were investigated. The concentrations of CuO and TiO₂ nanoparticles used in SN-500 base oil are 0.1 wt.%, 0.5 wt.%, 0.75 wt.%, and 1 wt.%. Experiments were conducted to study friction and wear using a Four Ball tribotester where different amounts of concentrations of nanoparticles along with different nano-particles, were tested. Results obtained from all tests conducted on CuO, TiO₂ nanoparticles and SN-500 base oil were compared. In case of friction reduction test, the optimum amount of nanoparticles is 0.5 wt.% of CuO is observed.

Key Words: tribotester, nanoparticles, Titanium Dioxide, bearing oils, base oil. Copper oxide

1. INTRODUCTION

Nanotechnology has been seen as the most revolutionary technique of the 21st century. It can be applied in various sectors and introduces a new age in material science. Many studies have been conducted on the tribological behavior of the lubricant with various nanoparticles added.

Tribology is said to be the 'science and technology of interacting surfaces in relative motion and related topics. The topic Tribology includes mostly technologies that relate to lubrication, wear resistance, and friction in relation to relative motion between surfaces. Tribology principles such as friction and wear are the main factors in design of machinery parts [1].

Materials are evaluated as pairs in nominally non-abrasive conditions. The pin sample is subjected to a known force in relation to the disc using an arm or lever with weights. The wear rate data are provided in cubic millimeters of volume loss and dimensional loss measured linearly on the pin and the disc.

Purva Uniyal et.al. [2] examined the integration of metal oxide nanoparticles into plant-based biolubricants. The

results demonstrate that adding optimum concentrations of nanoparticle - such as 0.1% Al₂O₃ in jojoba oil or 0.2% TiO₂ in castor oil - significantly reduces friction and wear by forming protective tribo-films and converting sliding friction into rolling friction. The authors conclude that these nanobiolubricants are effective, eco-friendly alternatives to toxic petroleum products, offering enhanced energy efficiency and industrial sustainability.

Serag salem et.al. [3] Evaluates SAE 20W-50 oil modified with ultra-low concentrations (0.02–0.12 wt%) of CuO and TiO₂ nanoparticles. Using pin-on-disc tribometry, the study reveals that TiO₂ at 0.12 wt% dramatically reduces wear volume by 90%, while CuO at 0.02 wt% lowers the coefficient of friction by 25%. These trace additions enhance performance through mechanisms like the rolling-bearing effect and tribofilm formation. Ultimately, the study concludes that these cost-effective, low-concentration additives significantly improve engine efficiency and component longevity without compromising lubricant stability or increasing costs.

Corina Birleanu et. al. [4] investigated SAE 10W40 engine oil enhanced with 0.05 wt% TiO₂ nanoparticles. The methodology involved calcining nanoparticles at various temperatures (450–750°C) and conducting four-ball tribometer tests under ASTM D4172 conditions. Results revealed that TiO₂ treated at 550°C provided the best performance, yielding the lowest coefficient of friction and wear scar area at both 23°C and 75°C. In conclusion, intermediate thermal treatment optimizes crystalline structure and dispersion stability, significantly enhancing the lubricant's anti-wear and friction-reducing capabilities under boundary lubrication.

R K Danga et. al. [5] investigates the static thermal performance of circular journal bearings using TiO₂ and CuO nano-lubricants. Researchers developed a MATLAB model using the Finite Difference Method to solve Reynolds and energy equations, incorporating the modified Krieger-Dougherty method for viscosity. Results showed that adding 2wt% TiO₂ increased load capacity by 14.23%, significantly outperforming CuO's 9.23% increase, with only a marginal rise in oil film temperature. The study concludes that these nano-lubricants substantially enhance bearing performance, offering high potential for optimizing power generation turbo-machinery.

L Pena-paras et. al. [6] employs a robust dual-methodology using T-02 four-ball (ASTM D5183) and T-11 ball-on-disk (ASTM G-99) tribo-testers to evaluate polymeric lubricants enhanced with CuO and TiO₂ nanoparticles. Results indicate that while high-load tests showed negligible improvement, the ball-on-disk tests revealed dramatic wear reductions: 33% for 0.05 wt.% CuO and 77% for 0.01 wt.% TiO₂. The study concludes that nanoparticles significantly improve anti-wear properties by acting as "valley fillers" or spacers, though it warns that higher concentrations may cause detrimental particle agglomeration.

R A Arul raja et. al. [7] provides a clear framework for evaluating nano-lubricants using the Four-ball wear test to simulate real-world tribo-systems. While it effectively details the measurement of wear scar diameter and load wear index, the paper lacks specific experimental results or data trends to validate these methods. The conclusion successfully reaffirms the importance of balancing chemico-physical properties with mechanico-dynamical testing but would be stronger if it summarized specific performance gains from nanoparticle additives.

T F Inescue et. al. [8] concludes that adding TiO₂ and ZnO nanoparticles to rapeseed oil provides marginal tribological improvements, as they fail to form a continuous protective film. While nano-additives reduced wear scar diameters during light regimes, they generally increased the friction coefficient and lubricant bath temperature due to "third-body" friction and particle agglomeration. ZnO demonstrated slightly better anti-wear performance than TiO₂, yet neat rapeseed oil often maintained superior frictional properties, suggesting that the additives' tendency to cluster limits their effectiveness in enhancing vegetable-based lubricants.

In this experimental analysis we have added CuO & TiO₂ nano-particles separately with Oleic Acid in base oil by sonication method to get uniform dispersability. Nanoparticles act as third body particles. The results of these experimental studies indicate that nano-particles improve the tribological properties of the base oil.

2. EXPERIMENTAL SETUP

2. 1. Selection of Nanoparticles

In this present research two nanoparticles were short-listed and studied viz.

1. Copper oxide (CuO)
2. Titanium Dioxide (TiO₂)

On the bases of availability, properties and cost, Copper oxide (CuO) & Titanium Dioxide (TiO₂) nanoparticles were selected and purchased from TECHINSTRO, India. The properties of CuO & TiO₂ nano-particles as per the manufactures specification are given below.

Table .1 Properties of Nanoparticles

Nanoparticles	Properties
CuO (Cupric Oxide)	Size smaller than 100 nm, Purity 99.95% with nearly spherical shape
TiO ₂ (Titanium Dioxide)	Size less than 100 nm, Purity 99.5% with nearly spherical shape

Table .2 Properties of CuO Nanoparticles

Sr. No.	Parameter	Value	Unit	Other Remarks
1	Molecular Formula	CuO		
2	Purity	99.9 %	%	
3	Color			Brownish Black
4	APS	30 -70	nm	0.5/0.1
5	SSA	60-80	m ² /g	
6	Morphology			Nearly Spherical
7	Bulk Density	0.66	g/cm ³	
8	True Density	6.4	g/cm ³	
9	Mole. Weight	79.54	g/mol	
10	Melting Point	1325	°C	

Table .3 Properties of TiO₂ Nanoparticles

Sr. No.	Parameter	Value	Unit	Other Remarks
1	Molecular Formula	TiO ₂		
2	Purity	99.9%	%	
3	Color			White
4	APS	30 -80	nm	
5	Specific Surface Area	150	m ² /g	
6	Morphology			Nearly Spherical
7	Melting Point	1843	°C	
8	True Density	3.9	g/cm ³	
9	Mole. Weight	79.8658	g/mol	
10	Bulk Density	0. 35	g/cm ³	

2. Selection of Base Oil

For this research work is SN 500 base oil manufactured by B.P.C.L. Mumbai is used. The conventional pure lubricants engine oil contains some additives for enhancement of friction reduction and anti-wear properties, but the Base oil purchased does not contain such additives. Pure lubricants are manufacturers of industrial lubricant, automobile oil and greases.

Table .4 Properties of Base Oil

Property	Range
Viscosity Kin., @40°C	101 mm ² /s
Viscosity Kin., @100°C	10.5 mm ² /s
Viscosity Index	95
Density @ 40°C	864-875 kg/m ³
Flash Point (°C)	240
Pour Point (°C)	-6

3. Nano-Oil Preparation

The nano-particles that are utilized as an additive in base oil are known as Nano Oil. Samples of Nano Oil were prepared as per the weight concentrations. A total of four samples of Nano Oil were prepared. Each sample comprises of 500 ml base oil with weight concentrations of 0.1 %, 0.5 %, 0.75 % and 1 %. Weight of 227.5 ml base oil is 200 gm. Thus, samples were prepared based on weight concentration using 200gm base oil. According to above weight concentration criteria eight samples were prepared by adding respective quantity of nanoparticles.

4. Stabilization of Nanoparticles

Stabilization of the nanoparticles plays a key role for the effective dispersion of the nanoparticles in the base lubricant. This happens because the Nano-particles possess high surface energy levels.

As a result, the particles are subjected to either aggregation or settling during usage. Stabilization helps in the maintenance of a homogenous suspension. Commonly used methods for stabilization include mechanical dispersion, ultrasonic treatment along with surfactants and/or dispersants. Ultrasonic treatment enables the breaking of nanoparticle agglomerates and dispersion throughout the lubricant. Stability of the nanoparticles enhances lubricating and wear resistance capabilities of Nano-lubricants using Cupric Oxide (CuO) and Titanium Dioxide (TiO₂) Nanoparticles [9][10].

For the stabilization and homogenous distribution of Nano-particles, ‘Surfactant’ such as oleic acid is used in order to disperse CuO and TiO₂ nanoparticles in the base oil. Based on weight concentration, the nanoparticles were poured into a glass beaker. Then, 10ml of oleic acid was mixed with the nanoparticles slowly. To properly mix the nanoparticles and oleic acid, magnetic stirring was carried out. It was performed for 15 minutes, after which sonication was carried out for 35 minutes using probe type ultrasonic sonicator [11]. After completing sonication, the mixture was poured into the base oil. Then, it was stirred again with magnetic stirring process for 15 minutes, followed by sonication using ultrasonic sonicator for 45 minutes. Due to formation of oleic acid film on the surface of Nano-particles, they can be evenly distributed in the base oil. Which is basic requirement of this tribological investigation assures consistent results throughout the experiment [12].



Fig. 1 Base Oil with Stabilized CuO Nanoparticles



Fig. 2 Base Oil with Stabilized TiO₂ Nanoparticles

5. Selection of Steel Balls

The steel balls used for tribological testing are manufactured according to the material standard AISI E-52100, which consists of a high-nickel alloy steel containing carbon and chromium. Used widely in precision rolling bearings, owing to its high hardness, fatigue strength and wear resistance. Balls have a diameter of 12.7 mm with the manufacturing accuracy of G10, which means that it has extremely small dimensions tolerance and surface quality, fit for use in

precision mechanical devices. The hardness of these balls has been tested at 62-64 HRC, which falls within the specified range of 58-67 HRC. This ensures the required hardness of the balls that would make the application possible under high loads and high-speed operations. These types of steel balls are used in rolling element bearings such as, deep groove ball bearings, thrust ball bearings, and wheel hub bearings.

3. EXPERIMENTAL PROCEDURE

3.1 Selection of Testing Parameters

In this thesis, different test parameters are chosen while conducting the tests which are compliant with the ASTM D4172 standards. According to the standard test conditions of ASTM D4172 for evaluating the Wear Preventive Properties of various Lubricating Fluids, AISI 52100 steel balls are utilized as the standard test samples in the four ball tester.

The AISI 52100 alloy steel contains high carbon, high nickel, and high chromium content and is used in the manufacturing of rolling element bearings. This alloy steel is suitable for tribology experiments due to its high strength, hardness, and wear resistance properties. According to ASTM D4172 test standards, the following parameter values need to be chosen. Load selected is 392 N or 40 kg, which is selected to create the conditions of boundary lubrication. The rotational velocity is selected as 1200 rpm to replicate the real operating conditions of machine components. This speed is chosen to create stable lubricant film formation, sufficient sliding motion between balls and repeatable results of wear. The time duration is kept as 60 min i.e. 3600 sec so that there is sufficient time for development of wear scar and there is no excessive wear.

Table .5 Steel Ball specifications

	Property	Value	Unit
Physical Properties	Hardness	62.00 - 64.00	62.00 - 64.00
	Roundness	0.25 (max)	Micron
	Surface Roughness (Ra)	0.03	Micron
	Ovality	Ovality	Micron
	Weight	8.340	Gram

3.2 Experimental Results



Fig. 3 Four Ball Tester Test Result for Base Oil

Result path of these graphs has been examined after analyzing these graphs. Now these graphs of base oil, SAE 20W40 lubricating oil, and nanoparticle additive for various concentration percentages including 0.1%, 0.5%, 0.75% and 1%, among others, are being compared with each other to find which sample has provided optimal result values.

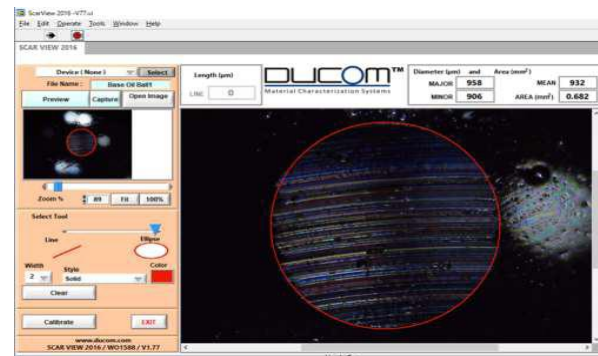


Fig. 4 Scar wear Image measurements of Base Oil from IAS

As seen above Fig., scar wear is observed on one of the three steel balls that have been lubricated by the base oil. Here, the average diameter is 932 μm while the scar wear area is 0.682 mm². The scar wear formed is nearly circular with visible concentric wear marks due to lack of additives, implying boundary or mixed lubrication using an unblended base oil.

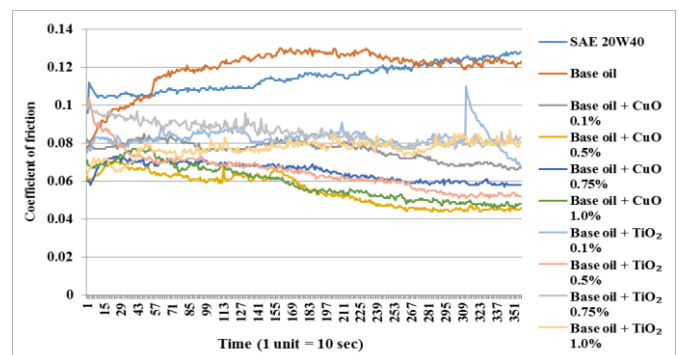


Chart. 1 Coefficient of Friction vs. Time Graph

The CuO and TiO₂ nano-particles are very efficient in reducing the COF in the base oil compared to the SAE 20W40 engine oil where the COF is high even at steady state conditions. The COF reduces with an increase in the amount of nano-particles used. This could be due to the rolling, stitching, polishing, and tribo-filming. The CuO nanoparticles have performed better than the TiO₂ nanoparticles at different concentrations of nanoparticles.

3.3 Scar Wear Diameter analysis

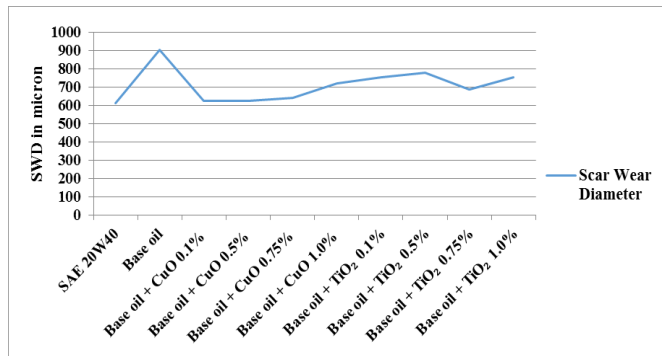


Chart. 2 SWD Vs Nano-oils

The above observations from Fig. show that for CuO dispersed oils, there are low wear scar diameters comparable to SAE 20W40 lubricating oils ranging between 625 to 721 μ m. For TiO₂ dispersed oils, the results are rather gloomy as the wear scar diameters fall between 688 to 779 μ m, except in the case of oil containing 0.75% by weight. Thus it can be concluded that if the right percentage of CuO nanoparticles is used with dispersion, then there will be remarkable results with reduced metal to metal contact.

4. CONCLUSIONS

At the same testing conditions (based on ASTM D4172 - 1200 rpm, 392 N loading, 60 minutes), the lowest average COF (0.056) and highest friction coefficient (0.071) are obtained with 0.5% weight concentration CuO in base oil. This is equivalent to a 52% reduction from commercial SAE 20W40 (about 0.115) and a 53% decrease compared with pure base oil (about 0.119).

For all the blends, the optimum concentration of 0.5 % weight concentration was observed to be best for both CuO and TiO₂, as they provided the least COF with stable curves. Although concentrations above 0.5 % weight concentration were observed to perform better than commercial oil, they showed slightly higher COF.

In general, experimental studies show that the presence of nanoparticles as additives has a significant effect on tribological properties in boundary lubrication. In particular, the application of CuO nanoparticles shows great promise for use as an additive for lubricants. It is necessary to select the proper concentration of the additive (0.5 wt.% is

optimal) and dispersion of nanoparticles to provide the greatest reduction in friction (up to 53% decrease in COF).

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