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RESEARCH

Experimental Analysis on Tribological Behavior of Nano Based Bio-Lubricants using Four Ball Tribometer

S. Baskar[a], G. Sriram[a], S. Arumugam[a]

[a]*Sri Chandrasekharendra Saraswathi Viswa Mahavidyalaya, Enathur – 631561, Kanchipuram, India*.

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Corresponding author:

S. Baskar
Sri Chandrasekharendra Saraswathi Viswa Mahavidyalaya, Enathur – 631561, Kanchipuram, India,
E-mail: baskar.s@kanchiuniv.ac.in

A B S T R A C T

The present work describes the tribological behavior of CuO, WS_2 and TiO_2 nano particles as an antiwear additive to a chemically modified rapeseed oil (CMRO). The tribological tests were run on a four ball tribometer. The variation of viscosity of various nano based biolubricants with respect to temperature is also estimated in accordance with ASTM D 445. The test results were compared with petroleum based synthetic lubricant (SAE20W40). The test results exhibited that CMRO with nano CuO has better tribological characteristics, smoother wear scar and higher viscosity compared to synthetic lubricant and other nano based biolubricants.

1. INTRODUCTION

The development of lubricant depends not only the lubricant properties perse, but also on other factors such as speed, load and temperature. Lubricant plays a significant role in the reduction of friction and wear in a mechanical system so that the system can drive for the prolonged period. The vegetable oil based lubricant is the best replacement for petroleum based synthetic lubricant [1,2]. The major deficiency of vegetable oil as biolubricant is caused by poor oxidation stability and cold flow behaviour due to the presence of unsaturated carbon bond in its atomic structure. A chemical modification is the best way to improve the thermo-oxidative stability of vegetable oil based lubricating oils [3-6]. Liu et.al, have found that the additives in lubricating oil play an important role in the reduction of the friction and wear behaviour of two mating surfaces [7]. In the recent past, there are few interesting reports confirming that the effect of nanoparticle dispersed in lubricating oil showed a better friction reduction and wear resistance between two mating surfaces [8-15]. It is evident from the existing literatures that the tribological characteristics of various nanoparticles dispersed in base oil showed reduced friction and wear reduction between the rubbing surfaces [16-18]. Furthermore, the addition of nanoparticles increases the viscosity of base oil [19-23]. Many of the researchers have studied the effect of adding nano particles to the mineral and synthetic lubricants, but very limited literatures reported the use of nano particles in the vegetable oil based biolubricants. The present study is focused on the evaluation of the tribological behaviour and viscosity of nano based bio-lubricant using a four-ball tribometer and Viscometer respectively.

2. EXPERIMENTAL PROCEDURE

2.1 Lubricant preparations

In the present investigation, high grade rapeseed oil is used as base oil. The base oil was chemically modified via epoxidation, hydroxylation and esterification processes in order to improve its thermo oxidative stability and cold flow behaviour of base oil. The detailed procedure for chemical modification process is adapted from the earlier study of Arumugam and Sriram [5]. The various nano particles (CuO, WS_2 and TiO_2 of 0.5 wt%) are dispersed in CMRO with sizes of approximately 40-70 nm, 40-80 nm and 30-50nm respectively using an ultrasonic sonicator [10]. The nanoparticles used in this study were obtained from US Research Nanomaterials Inc. (USA). The properties of nanoparticles are listed in Table 1 and the measured properties of nano based bio-lubricants are listed in Table 2.

Table 1. Properties of nano particles.

Properties	Values of CuO	Values of WS_2	Values of TiO_2
Purity (%)	99	99.9	99.5
Size range (nm)	40 -70	40-80	30 -50
Color	Black	Gray	White
Morphology	Nearly spherical	Nearly spherical	Nearly spherical
Bulk density (kg/m^3)	0.76x10^3	0.25x10^3	0.42x10^3

Table 2. Measured properties of lubricating oil samples.

Properties	SAE20W40	CMRO + nano CuO	CMRO + nano WS_2	CMRO + nano TiO_2
Viscosity @100°C (cSt) [ASTM D445]	15.2	15.6	15.3	15.0
Pour point (°C) [ASTM D97]	-21	-16	-15	-15
Flash point (°C) [ASTM D92]	250	242	220	239
Viscosity index [ASTM D2270]	133	185	179	170
Specific gravity @ 15°C [ASTM D287]	0.87	0.89	0.88	0.88
Wear scar diameter (mm) [ASTMD4172]	0.5849	0.3546	0.3749	0.3847

2.2 Experimental apparatus

A four ball tribometer TR-30L-IAS, a versatile equipment supplied by Ducom Instruments Bengaluru, used to conduct the experiments as shown in Fig. 1. Fig. 2 shows the schematic diagram of a four ball tribometer. The machine consists of four balls, one ball at the top and three on the bottom side. The three balls at bottom are fixed in a ball pot which is filled with the lubricant sample to be tested.

Fig. 1. Four ball tribometer.

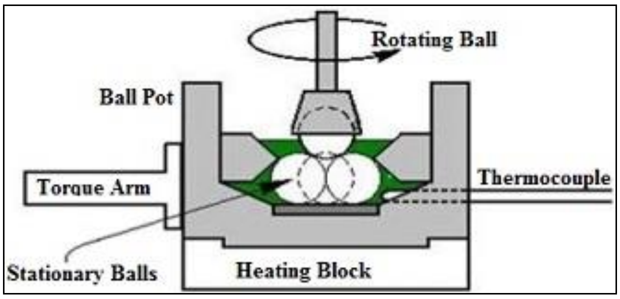

Fig. 2. Schematic diagram of Four ball tribometer.

The one ball on top, fixed on a collet, is used to press against the bottom balls. Acetone is used to clean the surface of each ball before and after the test. The balls are made up of AISI E-52100 chrome alloy steel with a diameter of 12.7 mm, extra polished to grade 25 and hardness of 64 HRC. In each test the new balls are used. The ball pot is supported above the loading lever on a thrust bearing and plunger with a load cell which is fixed to a loading lever to measure the normal load. The frictional torque exerted on the three balls is measured by a frictional load cell. A RTD type temperature sensor is mounted at the bottom part of ball pot between the two heaters. The test lubricant is heated to 75 °C by a heater fixed in a four ball tribometer with a speed of about 1200 rpm and normal load of 148 N. The specific CCD microscope is used for capturing the images the wear scar of three fixed balls in the ball pot. The specific image capture software is used for measuring the wear scar diameter and wear scar image on the ball surface. The test was conducted in accordance with ASTM D 4172. Further the viscosity of various lube oil samples was measured using a Redwood Viscometer.

3. RESULTS AND DISCUSSION

3.1 Frictional behaviour

The friction torque of various nano based bio-lubricants and synthetic lubricant are shown in Fig. 3. From the Fig. 3 friction torque of CMRO containing nano CuO, nano WS_2 and nano TiO_2 are 0.055, 0.06 and 0.06 nm respectively, whereas for the synthetic lubricant SAE20w40 the value is 0.07 nm. The friction torque is reduced by about 21 %, 14 % and 14.5 % for CMRO containing nano CuO, nano WS_2 and nano TiO_2 respectively as compared with the synthetic lubricant (SAE20w40). Similarly the coefficient of friction of various nano based biolubriacnts is shown in Fig. 4. The coefficient of friction of three lubricating oils such as CMRO containing nano CuO, nano WS_2 and nano TiO_2 are 0.0814, 0.0841 and 0.0825 respectively, whereas for the synthetic lubricant (SAE20w40) is 0.1009. The coefficient of friction is lowered by about 19 %, 16 % and 18 % for CMRO containing nano CuO, nano WS_2 and nano TiO_2 respectively as compared with synthetic lubricant (SAE20w40).

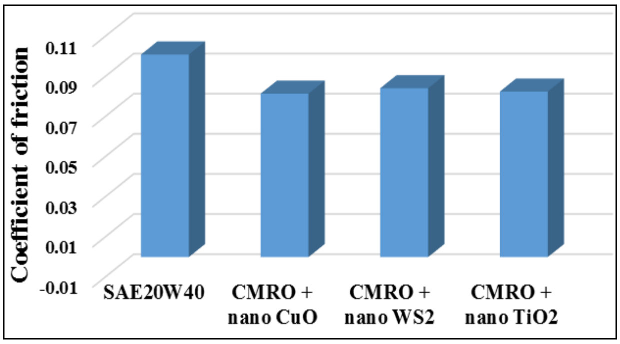

Fig. 4. Coefficient of friction for various lubricating oils.

It is observed from the analysis that CMRO containing nano CuO exhibits minimum friction torque and coefficient of friction [8,10] as compared with lubricating oils. The nano particles which are added to the CMRO increases the viscosity thereby increases the oil film thickness that reduces the contact between the ball surfaces. Although all the nano particles (CuO, WS_2 and TiO_2) used in this study are of spherical morphology that are responsible for reduced coefficient of friction, however the nano particles start to diffuse and shrink in volume when the lubricant temperature increases from room temperature to operating temperature. When the oil temperature increases, the nano particles is assemble further and diffuse to be comparatively tight clusters. Since the density and melting point of bulk nano CuO is higher than other two nano particles considered in this investigation as reported in Table 1, the CuO nano particles can maintain their spherical profile even after diffusion and particles were considered assembled is the other important reason for lower frictional coefficient.

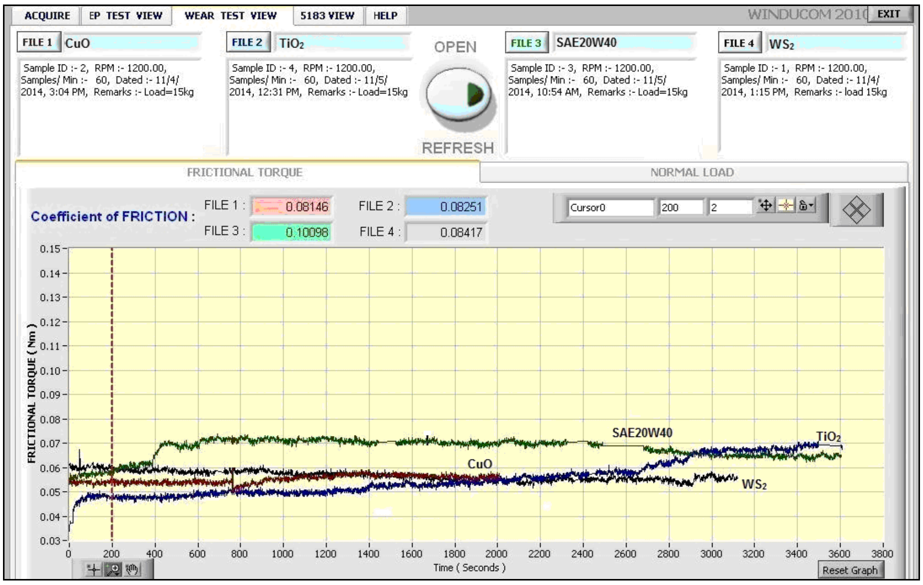

Fig. 3. Friction torque for various lubricating oils.

Table 3. Viscosity variation of lubricating oils.

Temperature in °C	Kinematic viscosity in cSt			
	SAE20W40	CMRO + Nano CuO	CMRO + Nano WS_2	CMRO + Nano TiO_2
40	123.4	128.7	128.3	127.9
50	100.1	102.3	101.9	101.2
60	80.7	83.1	82.9	82.4
70	62.2	63.9	63.3	62.9
80	43.8	45.4	45.1	44.9
90	30.1	31	30.9	30.6
100	15.2	15.6	15.3	15.0

The above findings are also consistent with the previous study by Wu et al. (8). They reported that the addition of nano CuO improves the tribological behavior of API-SF engine oil and base oil than with lubricant containing nano TiO_2 and nano diamond particles.

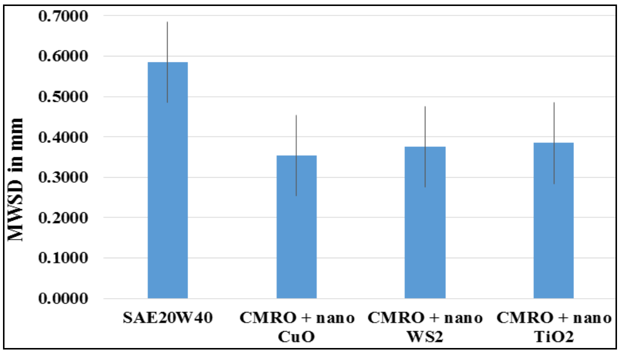

Fig. 5. Mean wear scar diameter of lubricating oils.

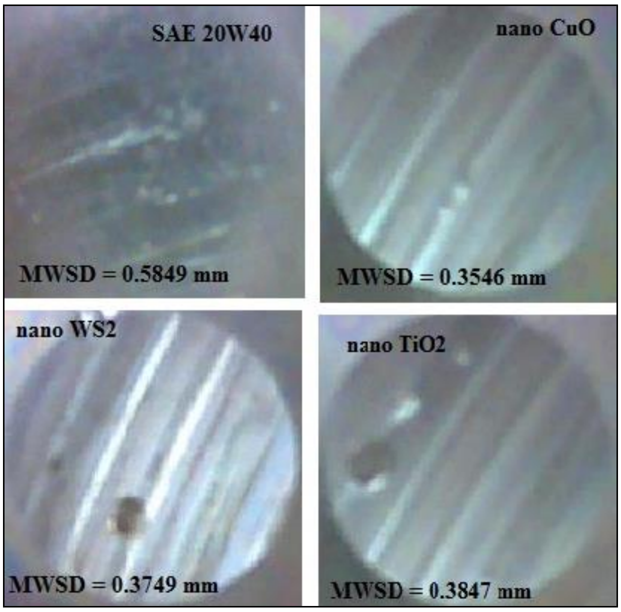

Fig. 6. Wear scar image of lubricating oils (Magnification 50X).

Figures 5 and 6 shows the mean wear scar diameter and scar images of tested lubricant samples respectively. The mean wear scar diameter is lowered by about 39%, 36% and 34% for CMRO containing nano CuO, nano WS2 and nano TiO2 respectively as compared to that of synthetic lubricant (SAE20W40). The CMRO containing nano CuO exhibits minimum wear scar diameter compared with other lubricating oils. It is evident from the Fig. 6 that wear scar image of CMRO containing nano CuO is smoother, clearer and circular in shape, whereas for the synthetic lubricant wear scar image is unclear, rough and oval in shape.

3.2 Viscosity of various lubricating oils

The viscosity variation with respect to various lubricating oils are shown in Fig. 7 and Table 3. Fig. 7 indicates that the viscosity of CMRO containing nano CuO is higher than the other lubricating oils. It is evident that the nanoparticles are added to the base oil, they are placed between the oil layers and lead to ease of fluid layer movement to each other and viscosity decrease slightly.

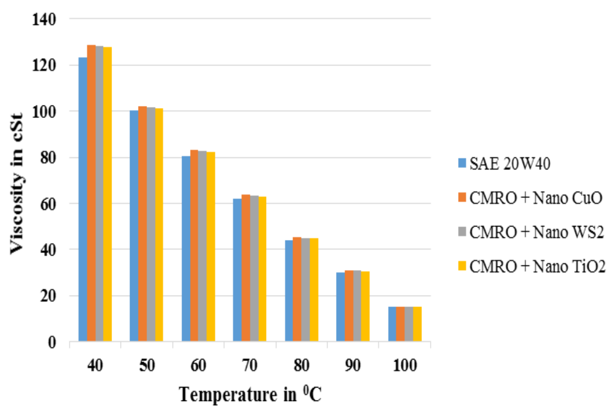

Fig. 7 Viscosity (cSt) of Lubricating oils.

The CMRO containing nano CuO agglomerate, enhance larger and asymmetric particles, which prevent the movement of oil layers on each other, so the viscosity is increased than the other lubricating oils.

4. CONCLUSION

For the tests performed on a four-ball tribometer and Viscometer with synthetic lubricant and CMRO containing various nano particles, the conclusions drawn are as follows:

1. The frictional coefficient of CMRO containing nano CuO is lesser than synthetic lubricant and CMRO containing nano WS_2 and nano TiO_2 respectively.
2. The worn wear scar value of CMRO containing nano CuO is reduced than synthetic lubricant and CMRO containing nano WS_2 and nano TiO_2 respectively.
3. The viscosity of CMRO containing nano CuO is higher than synthetic lubricant and CMRO containing nano WS_2 and nano TiO_2 respectively.

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