Experimental Investigation of Influence of SiO_2 Nanoparticles on the Tribological and Rheological properties of SAE 40 Lubricating Oil

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Abstract: The SiO_2 nanoparticles have been used in the SAE 40 Lubricating oil upto 1% by weight considered as nano lubricant for testing of the rheological stability and tribological properties. The rheological properties of the nano lubricant were tested according to ASTM D 7552-09 for the various concentrations. The nano lubricant was found stable rheologicaly. The tribological analysis conducted on Pin on Disc test rig (ASTM G99) for fully flooded and starved conditions of lubrication. The nano lubricant showed the reduced coefficient of friction and negligible specific wear rate as compared to the plain SAE 40 lubricating oil. In the SEM images the thin layer of SiO_2 nanoparticles was observed on the surface of the pin. The SiO_2 nanoparticles present on the surface may enhance tribological properties of the material.

Keywords: Nanoparticles, Nano lubricant, Rheology, SEM, Tribology Coefficient of Friction, Specific Wear Rate.

1.0 INTRODUCTION

The recent study shows that almost 30-35% of the power produced by the internal combustion engine of the vehicle wasted in the form of tribological losses [1], [2]. These losses increase the fuel consumption in the engine [3], [4]. The burning of more fuel would raise the engine emission and harmful green house gasses [5], [6].

Various attempts have been made by the researches to overcome the tribological losses or to minimize the friction and wear between the matting surfaces by modifying the surfaces [7]–[10]. The lubricant plays a vital role for improving the tribological properties of the matting surface [11], [12]. Friction modifiers such as organomolybdenum compounds [13], [14], organic friction modifiers [15]–[17], used as lubricant additive has improved the tribological properties [18]. The friction modifiers are generally more effective in the boundary or mixed lubrication regime [18]. There is scope for improvement which the lubricant alone can’t achieve. The lubricant enriched with nanoparticles may have the better tribological properties then the virgin lubricant or lubricant having other friction modifiers [19]–[22]. The nanoparticles as lubricant additive heals the cracks if the tribopairs hence improving the service life of the tribopairs [20].

SiO_2 nanoparticles had size 40-50 nm hardness 12 GPa [23], elastic modulus 150 GPa [24]. SiO_2 nanoparticle reduces the friction and wear at the matting surface by preventing the direct contact between the matting parts and enhance the rolling effect hence boost the tribological properties [25], [26].

2.0 EXPERIMENTAL SETUP

The experiment was performed on the Pin on Disc wear and friction test rig (ASTM G99). The mild steel disc diameter 165 mm and thickness 10 mm was casted. The disc was superfinished by surface grinding and lapping, the surface rms value roughness checked by the surface roughness tester in the circumferential direction at an angle of 30^0 radial outward directions around 2 μm.

The solid cylindrical pin of 10 mm diameter and length 32 mm made up of cast iron was casted. The face of the pin was made flat circular. The composition of the pin measured by spectroscopy came out to be C-3.51%, Cr-1.06%, Mn-0.56%, Si-2.97% Fe-91.9%. The length of the pin was kept such that the bending of pin would not occur.

The lubricant used at the interface of materials during experiment was 15W40 (SAE 40) which is the standard lubricant for the Diesel engine. The kinematic viscosity of the lubricant measured by (ASTMD-445) came out to be 98.922 mPa·s and the density measured by (ASTMD-4052) came out to be 871.82 kg/m^3 at 40^0 C.

2.1 Test Rig: The pin on disc wear and friction testing test rig (ASTM G-99) as shown in Figure 1 was used for the tribotesting, the specification is given in table 1. The test rig is automatic computer controlled system having the speed range of 200 rpm to 2000 rpm. The counter disc was attached over a rotating plate with the help of bolts. The pin was kept in the plunger which is directly attached to the gravity assisted force. The force is transferred to the pin in vertically downward direction with the help of single lever mechanism with leverage 1:1.

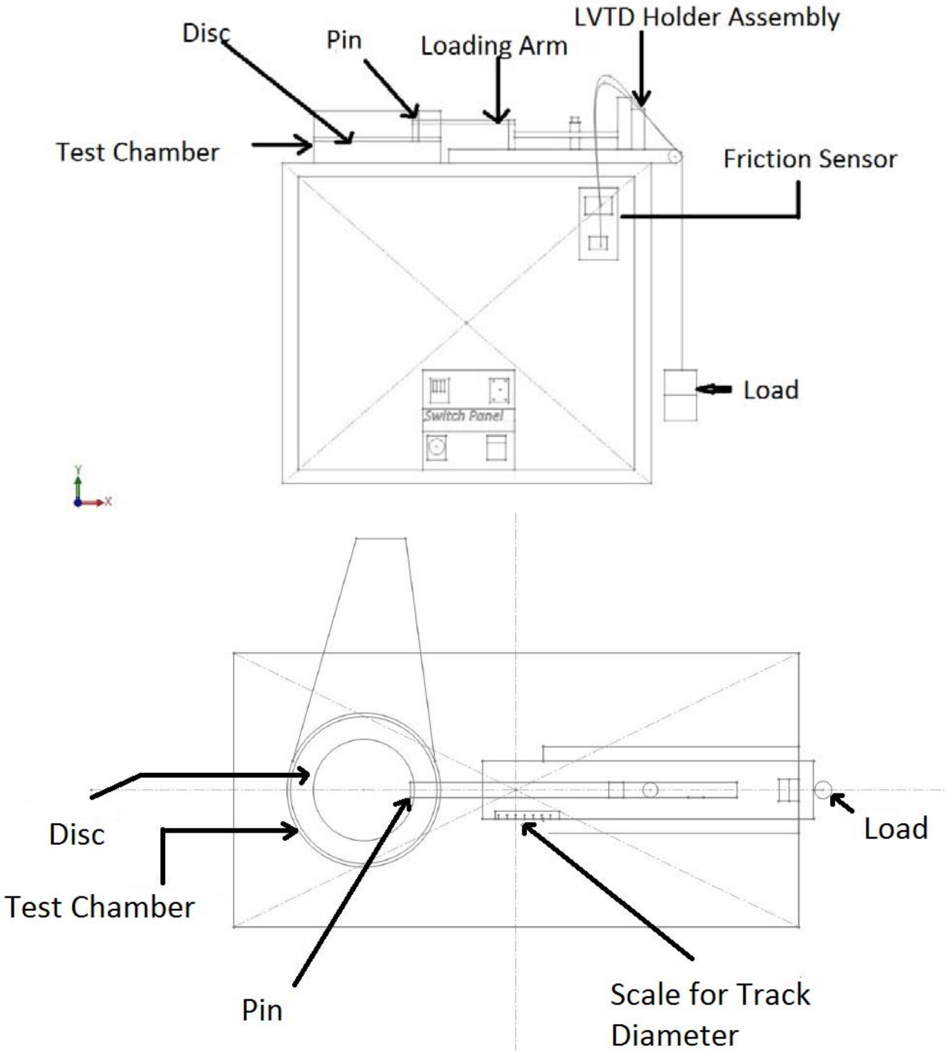

Figure 1: Pin on Disc Test Rig (a) Front View (b) Top View

Table 1: Specification of Pin on Disc Test Rig

S.No	Parameter	Unit	Minimum value	Maximum Value
1	Pin Diameter	mm	3	12
2	Track diameter	mm	0	165
3	Disk rotating speed	rpm	200	2000
4	Friction Force	N	0	200
5	Normal Force	N	1	200

2.2 Nano Lubricant: The nanoparticles of SiO_2 having the average particle size 50-60 nm were mixed in the lubricant SAE 40. The mixing of nanoparticles was done on weight ratio basis. The amount of nanoparticles to be mixed in the lubricant starts from 0.2% by weight upto 1% by weight in the successive increment of 0.2%. The nanofluid was not stable beyond 1% nanoparticles as the nanoparticles got sedimented.

2.3 Preparation of Nano Lubricant: The nano lubricant prepared by mixing the nanoparticles in the lubricant. The mixing carried out by continuous stirring by using the magnetic stirrer at 2000 rpm and 60^0 C for

2 hours. The nanofluid was sonicated by ultrasonicator for 60 minutes. The nano lubricant was observed stable even after two months of preparation.

3.0 RESULT AND DISCUSSIONS

3.1 Rheological Analysis of Nano Lubricant: The Rheological study was carried as per (ASTM D 7552-09) at shear rate 20 s^{-1}, in the temperature range 0^0C to 100^0C.

There was no significant change in the Rheological properties of the nano lubricant as it compared to the standard lubricant (15W40). The nano lubricant was stable on the basis of rheology as the change in the viscosity with respect to amount of nanoparticles is less than 5%. The rheological investigation shows that as the amount of nanoparticles in the lubricant increased the viscosity of the lubricant decreased.

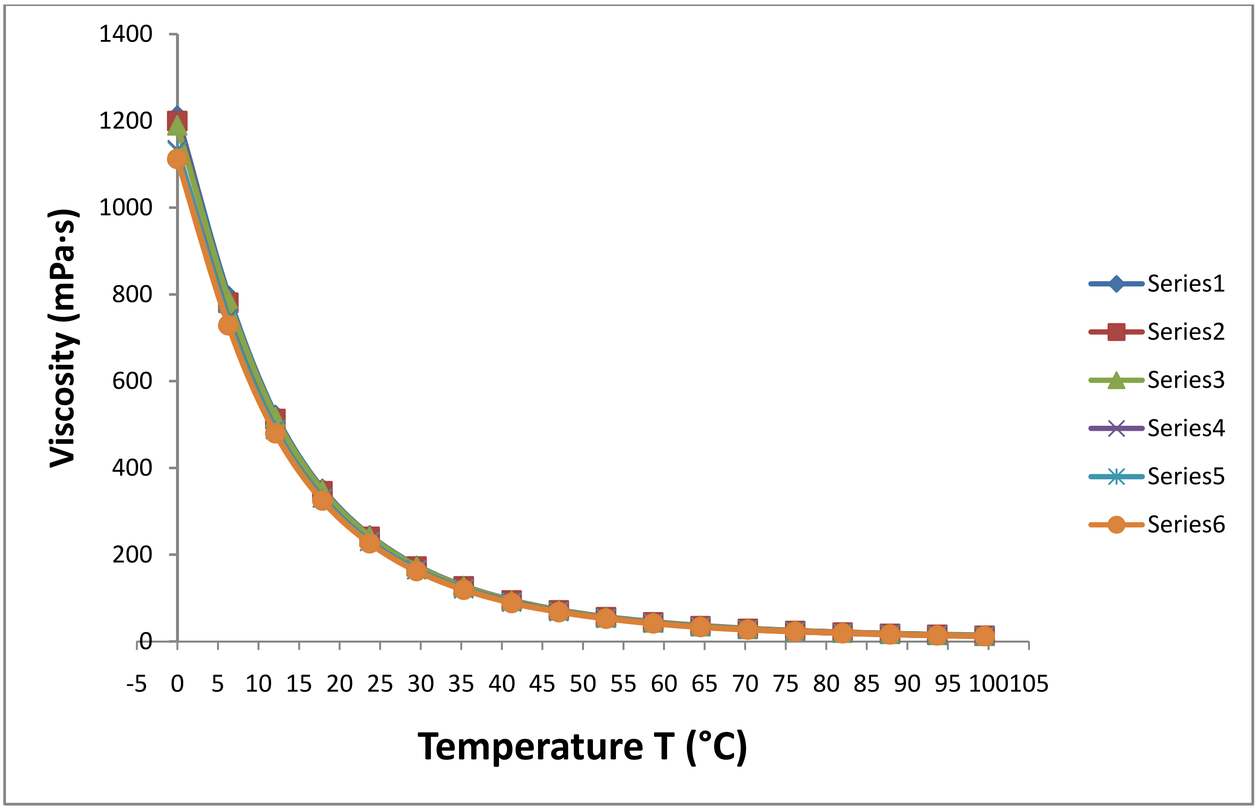

Figure 2: Rheological behavior of Lubricant

Relation between temperature and viscosity:

$$y = -8E\text{-}07T^5 + 0.000T^4 - 0.034T^3 + 2.215T^2 - 73.84T + 1110.$$

Where y: viscosity in mPa·s T: Temperature (^{0}C)

3.2 Tribological Study: The experiment was conducted at a load of 40 N with variable sliding speed, the sliding speed 3.663m/s, 5.2631m/s 7.3260 m/s, 10.4712 m/s, 13.6054m/s ranging from low speed range to medium and the high speed range. The atmospheric temperature at the time of testing was 28^0 C. The experiment was carried in fully flooded as well as starved lubrication condition.

In the tribological study coefficient of friction was derived from the friction force given by the software by dividing it with the applied load.

The specific wear rate was derived from the wear by the following relations:

$$Sw = \frac{Vw}{P \times D}$$

Where, S_w = specific wear rate, mm^3 / N-m

V_w = Volume of wear loss, in mm^3

P = Applied load in Newton, N

D = Sliding Distance in meters, m

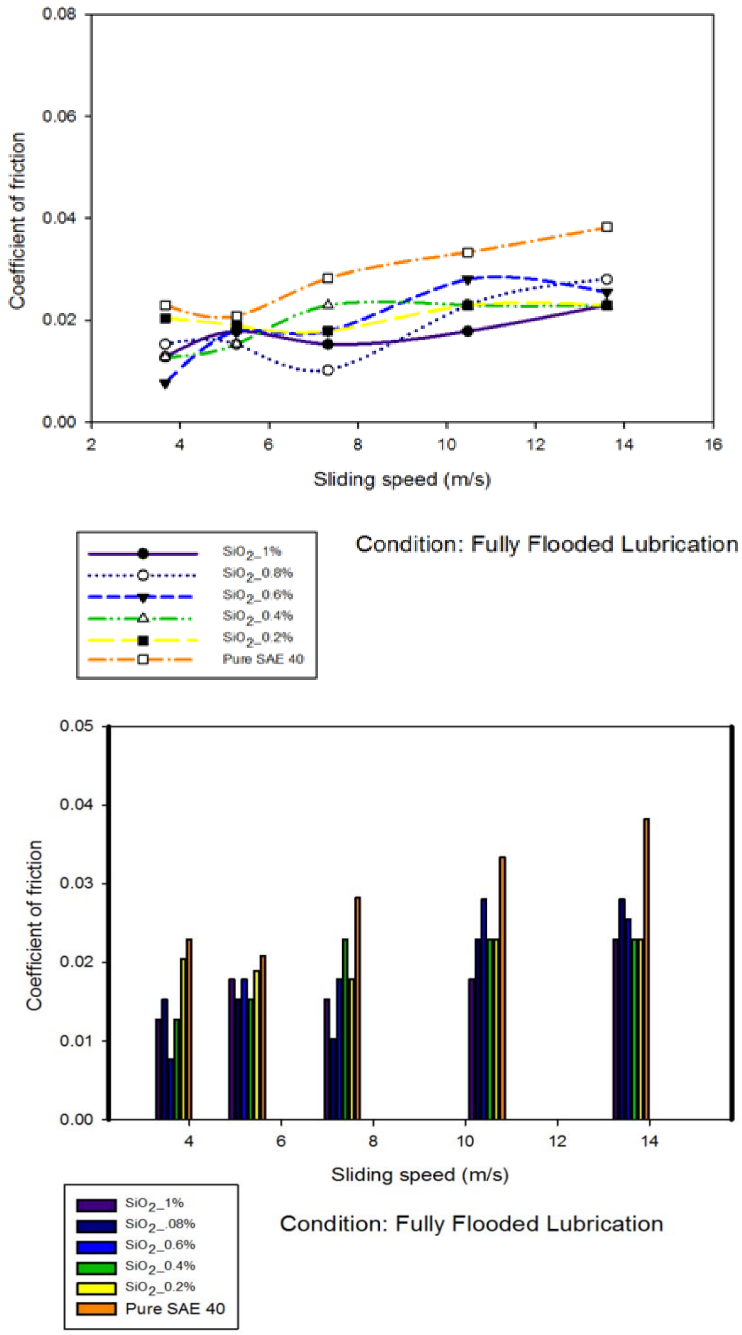

Figure 3: Variation of coefficient of friction with sliding speed for various compositions of Nanofluid in fully flooded Lubrication.

3.2.1 Study of Coefficient of friction for fully flooded condition: Figure 3 shows the variation of coefficient of friction with respect to speed at a constant load of 40 N for the different compositions of nanoparticles in the lubricant starting from 1%, 0.8%, 0.6%, 0.4%, 0.2% and Pure SAE 40 for fully flooded lubrication. The coefficient of friction in the low speed range is having higher values due to the boundary lubrication then the values of coefficient of friction decreases due to the hydrodynamic lubrication and in the high speed region the coefficient of friction again increases. The bar chart shows the comparison of coefficient of friction and the sliding speed in with composition of nanoparticles starting from the 1%, 0.8%, 0.6%, 0.4%, 0.2% and pure lubricant without nanoparticles. The coefficient of friction decreases as we increase the composition of nanoparticles due to the rolling action provided by the nanoparticles upto 0.6% and as we increase the composition of nanoparticles from 0.6% to 0.8% and then 1% the coefficient of friction again increased.

3.2.2 Study of Coefficient of friction for Starved condition: Figure 4 shows the variation of coefficient of friction with respect to speed at a constant load of 40 N for the different compositions of nanoparticles in the lubricant starting from 1%, 0.8%, 0.6%, 0.4%, 0.2% and Pure SAE 40 for starved lubrication. The coefficient of friction in the low speed range is having higher values due to the higher shear force or contact of asperities then the values of coefficient of friction decreases due to the lesser time of contact between the contact surfaces. The bar chart shows the comparison of coefficient of friction and the sliding speed in with composition of nanoparticles starting from the 1%, 0.8%, 0.6%, 0.4%, 0.2% and pure lubricant without nanoparticles. The coefficient of friction decreases as we increase the composition of nanoparticles due to the rolling action provided by the nanoparticles upto 0.6% and as we increase the composition of nanoparticles from 0.6% to 0.8% and then 1% the coefficient of friction again increased.

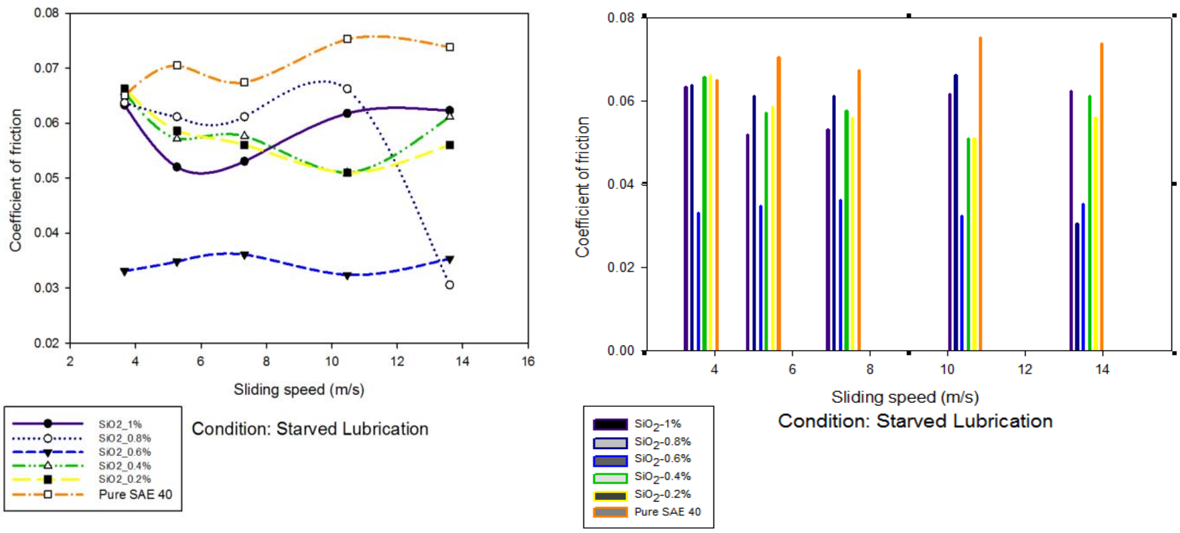

Figure 4: Variation of coefficient of friction with sliding speed for various compositions of Nanofluid in starved condition.

3.2.4 Study of Specific Wear Rate: Figure 5 shows the variation of Specific Wear Rate with respect to sliding speed at a constant load of 40 N for the different compositions of nanoparticles in the lubricant starting from 1%, 0.8%, 0.6%, 0.4%, 0.2% and Pure SAE 40 for fully flooded lubrication. Figure 6 shows the variation of Specific Wear Rate with respect to sliding speed at a constant load of 40 N for the different compositions of nanoparticles in the lubricant starting from 1%, 0.8%, 0.6%, 0.4%, 0.2% and Pure SAE 40 for starved lubrication. The value specific wear rate is almost negligible due to the no wearing of the contact surfaces as the use of nanoparticles in the lubricant results in the formation of a ceramic layer on the contact surfaces which results as a shielding layer for the tribopairs. The specific wear rate in case of lubricant without nanoparticles was evident due to the non formation of ceramic layer.

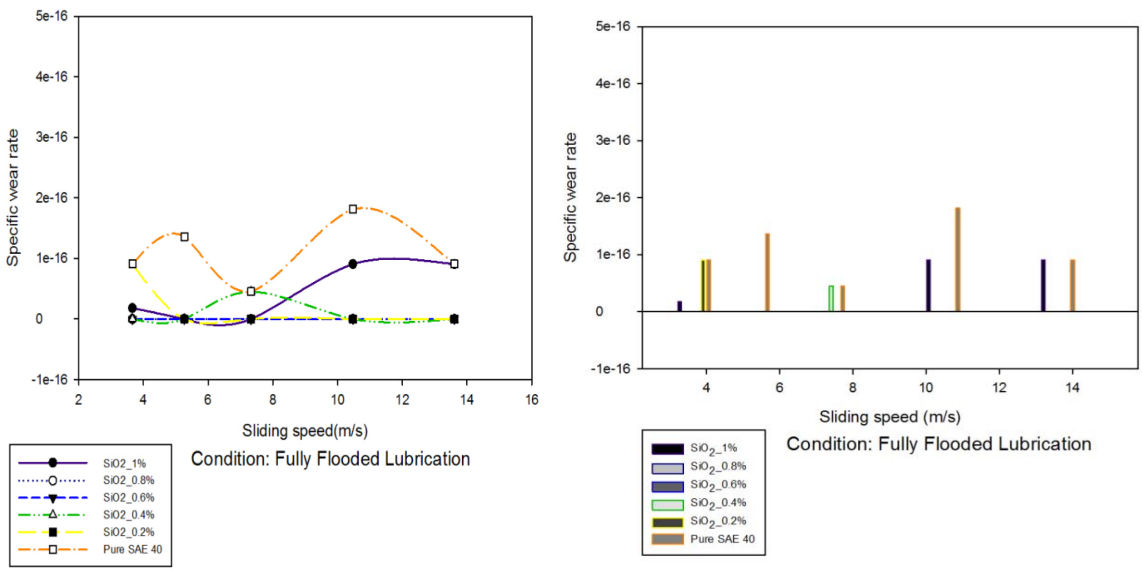

Figure 5: Variation of Specific wear rate with sliding speed for various compositions of nanofluid in Fully Flooded Lubrication.

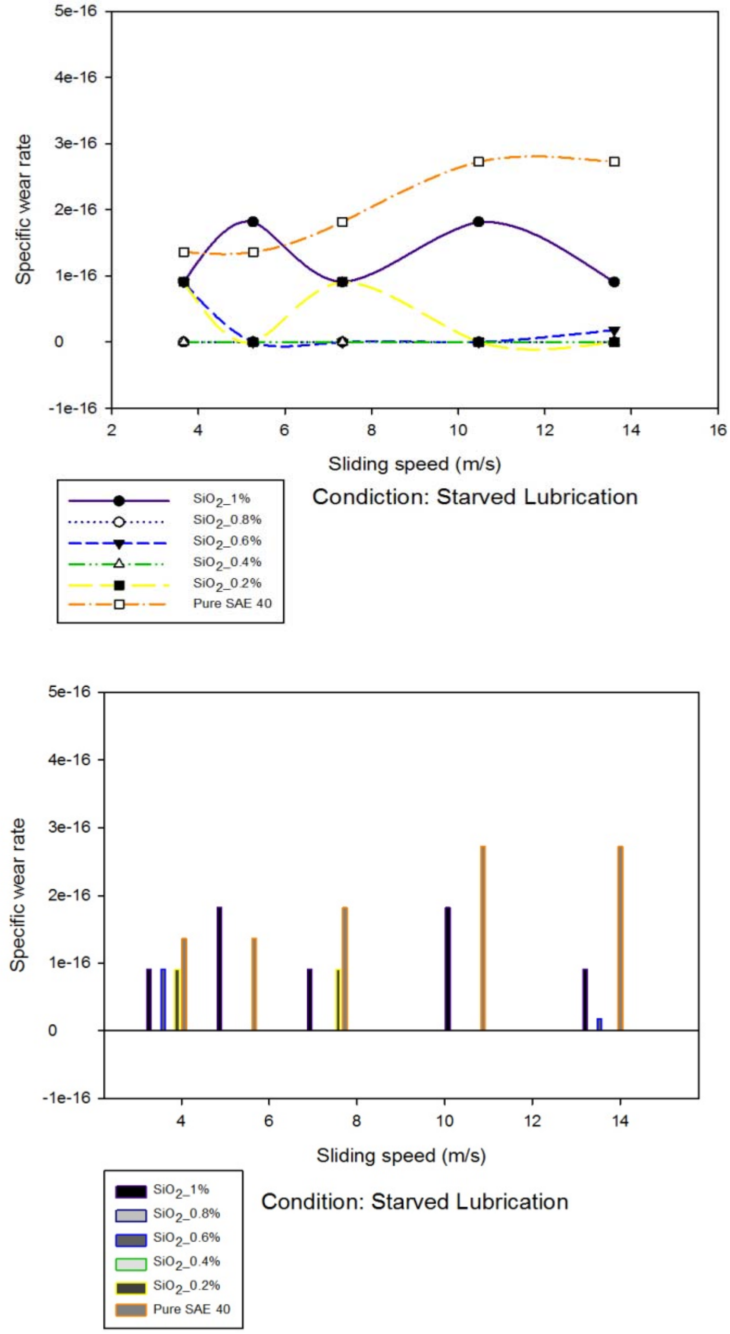

Figure 6: Variation of coefficient of friction with sliding speed for various compositions of Nanofluid in Starved Lubrication.

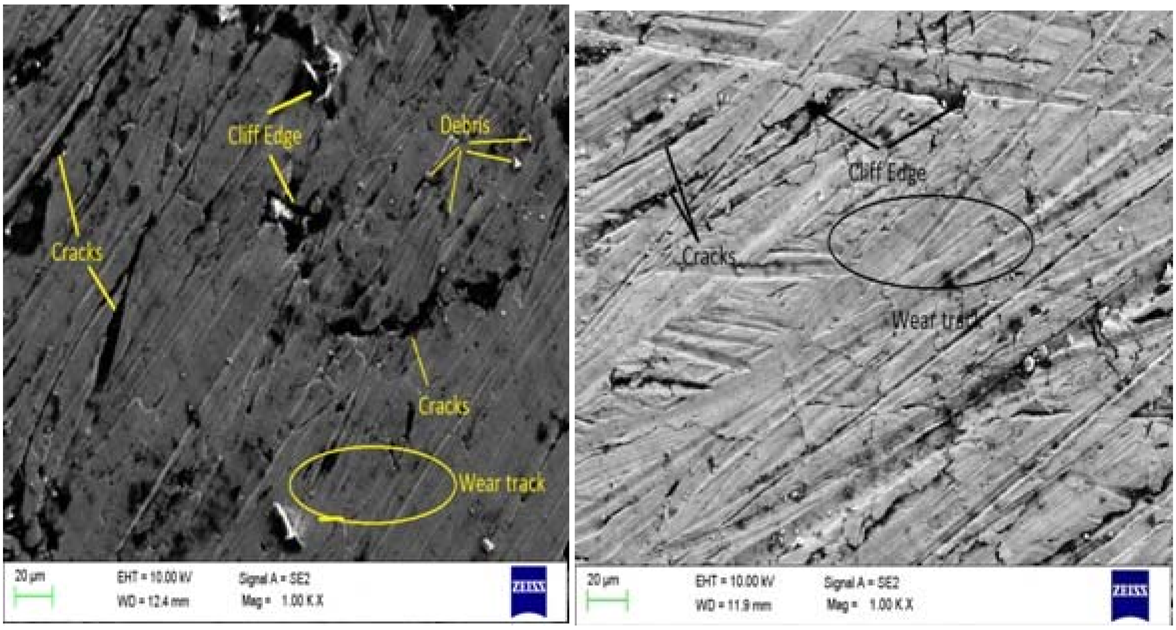

Figure7: SEM imaging of the pin material (a) lubricant without nanoparticles (b) Lubricant with SiO_2 nanoparticles.

In presence of the nanoparticles, there was minimum wear on pin. To study the wear of the pin, the wear pattern of the pin exposed to SEM imaging. The micrographs are shown in Figure7. Wear of the pin was evident in SEM investigation of the pin samples as it showed some wear debris, cliff edge, wear track and cracks. There was a layer of SiO_2 nanoparticles as seen in the SEM imaging of the pin. There were also evidences of the less wearing as the size of cracks, cliff edge and debris were less on the pin which was used with nanoparticles as compared to the pin which was used with plane lubricant. There are also evidences of the healing of cracks on the pin surface by the nanoparticles. All these evidences are the proof for the reduced wear of the tribopairs.

CONCLUSIONS

The experiment has been carried out on the pin on disc wear and friction testing test rig (ASTM G-99) at a constant load of 40 N. The author has observed that the use of nanoparticles in the lubricant improved the tribological properties of the lubricant without harming the service life of the lubricant.

In fully flooded condition the coefficient of friction decreased with the increase in the composition of nanoparticles in the lubricant from 0% to 0.6 % then as the composition was increased further the coefficient of friction starts increasing. The specific wear rate was negligible as with the lubricating oil enriched with nanoparticles as compared to the pure lubricant.

In starved condition, the coefficient of friction has higher values as compared to the fully flooded condition. The coefficient of friction decreased as the composition of nanoparticles in the lubricant increased from 0% to 0.6 % then as the composition was increased further the coefficient of friction starts increasing. The specific wear rate was negligible as with the lubricating oil enriched with nanoparticles as compared to the pure lubricant.

The SEM investigation shows that there was a layer of nanoparticles deposited on the surface of tribopairs that reduced the wear of the pin, moreover the nanoparticles also heals the cracks present on the surface of the tribopairs.

Acknowledgement: The Author is thankful to CSIR for its financial support.

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