International Journal of Applied Engineering Research ISSN 0973-4562 Volume 12, Number 11 (2017) pp. 2855-2861

Tribological Studies of Nanomodified Mineral based Multi-grade Engine Oil

***Meena Laad[1], Deepalekshmi Ponnamma[2] and Kishor Kumar Sadasivuni[3]**

[1]Department of Applied Science, Symbiosis Institute of Technology (SIT), Symbiosis International University (SIU), Lavale, Pune-412115, India.
[2]Center for Advanced Materials, Qatar University, P.O. Box 2713, Doha, Qatar.
[3]Mechanical and Industrial Engineering Department, Qatar University, P.O. Box 2713, Doha, Qatar.
**Corresponding author*
[1]ORCID: 0000-0003-4857-0670, Scopus Author ID: 55383547700

Abstract

This research study investigates the tribological behaviour of mineral based multi grade engine oil reinforced with nanoadditives using a pin on disc tribometer under different frictional conditions. Load, sliding speed, and constant sliding distance were selected as parameters to study the tribological properties of the engine oil with and without nanoadditives. Tests were carried under loads of 40N, 60N and 90N at sliding speeds 0.5 m/s, 1.0 m/s and 1.5 m/s. Nanoparticle concentration in the mineral oil was taken as 1.5 wt%. The test results were compared with engine oil with no nanoadditives. The results show significant improvement in the tribological properties of the engine oil. The wear of Aluminium alloy was observed to be increasing with increased value of the load. However the wear was significantly reduced for the same load when oil reinforced with nanoparticles was used. Wear rate for lubrication oil without nanoadditives was also found to be decreased with increase in sliding speed. Experimental results prove that nanoparticles can be used as a multifunctional additive in lubricating oil to enhance its tribological properties.

Keywords: Nanoadditives, lubricant, friction, tribology, engine oil, wear rate.

INTRODUCTION

Majority of mechanical systems require a variety of efficient lubricants to minimize friction and wear of machine parts coming in contact thereby reducing a significant loss in the total energy onsumed by mechanical systems. The nano sized or colloidal inorganic particles are already extensively used in the field of petroleum chemistry wherein a number of so called over based dispersing additives are made use of since 1950s [1][2]. Many other lubricant additives are supposed to form reversed colloidal self-organizing systems in hydrocarbon solvents. Also, structural changes occur during lubricant degradation due to oxidation at high temperatures, and the latter implies quite specific action (catalytic) mechanism which includes transport phenomena through surfactant layer [3][4]. Thus it can be said that the lubricant compositions including complete additive packages represent complex colloidal systems and that can also be nominated as liquid nanocomposite systems. These systems are most of the time optically transparent and physically stable for longer durations. It can be inferred from these observations that the surface-capped inorganic nanosized particles other than above-mentioned over based detergent composites might considerably improve performance characteristics of modern and advances lubricant systems. This conclusion resulted in a number of experimental efforts to synthesize and to test inorganic nanoparticles as components of liquid lubricants, basically in the field of triboactive compounds.

During the last few years, a number of research studies were conducted to synthesize various inorganic nanoparticles as lubricant additives to improve the lubricating properties of the lubricants [5]. Historically, these syntheses include preparation and tribology testing of surface-modified MoS_2 nanoparticles [6] and titanium oxide nanoparticles [7][8]; CeF_3 nanoparticles [9], ZnS nanoparticles surface-modified with di-n-hexadecyldithiophosphate. Nanosized copper nanoparticles were studied as friction reducing lubricant additives [10][11] .However, comparatively very small information is available in most cases concerning solubility of synthesized samples or stability of their dispersions in hydrocarbons. In present study, nanolubricant is synthesized by dispersing TiO_2 nanoparticles in multigrade engine oil and its tribological properties are studied and compared with lubricating oil without any nanoadditives. The tests were conducted using pin-on-disc tribotester under controlled conditions as per the ASTM standard ASTM G99 95A.

EXPERIMENTAL

TiO_2 nanoparticles of grain size 10–25 nm were used as additives in mineral based multi-grade engine oil Castrol Active 4T SAE 20W 40. It is modern, high quality engine oil developed specifically for 4-stroke motorcycle engines. With Trizone Technology Activ 4T delivers continuous protection to the engine, gearbox and clutch. Table 1 gives the specification of the lubricating oil.

Table 1: Specifications Of Lubricating Oil *Castrol Active 4T SAE 20W 40*	
Density (kgm^{-3})	885
Viscosity at 100 ^{0}C in cSt	14
Viscosity at 40 ^{0}C in cSt	125.4
Viscosity Index	113

The apparent density and the bulk density of TiO_2 nanoparticles were 0.3 g/cm^3 and 0.20 g/cm^3 respectively. The TiO_2 nanoparticles were purchased from Supplier Nanoshel LLC, USA. Aluminium alloy 64432 was used as material for the pins to be used on Pin-on-disc tribometer. The alloying elements are magnesium and silicon. Alloys of this series are moderate in strength (200–350 MPa). The strength is achieved by the heat treatment processing**.**

A pin-on-disc type tribometer (DUCOM TR-20) was used to study the tribological properties of the lubricant. The tribometer consisted of a driven spindle and chuck for holding the revolving disk, a lever-arm device to hold the pin, and attachments to allow the pin specimen to be forced against the revolving disk specimen with a controlled load. The wear track on the disk was a circle, involving multiple wear passes on the same track. The tribometer also had a friction force measuring system (a load cell) to determine the coefficient of friction.

Fabrication of pin

The pins were fabricated from the Aluminium alloy 64432 by using manual labour techniques. The fabrication was done with the help of a cutting saw. The metal pieces were cut into thin rods of dimensions 220 x 12 x 12 mm. Total nine rods were cut and polished. The rods were again filed and chamfered to accommodate it on 3 jaw chuck lathe machine for turning and facing. CNC machine was used to get the rods into perfectly cylindrical shape. The rods were then cut into pieces of desired lengths.

Preparation of Nanolubricant

The nanoparticles were added to the lubricating oil at 1.5 wt% concentration. The required quantity of TiO_2 nanoparticles was accurately weighed using a precision electronic weighing balance and mixed with the lubricating oil. An ultrasonic shaker was used for mixing the nanoparticles as additives in the lubricating oil for uniform dispersion in the oil. The time of agitation was fixed in producing a stable suspension with sufficient time for sedimentation to begin. The TiO_2 nanoparticles were characterized by scanning electron microscopy (SEM).

Pin-on-disc tests

Tribological behaviour of the lubricating oil with and without the TiO_2 nanoparticles addition was evaluated using a pin-on-disc tribometer. Load, sliding speed, and constant sliding distance were selected as parameters to study the tribological properties of the engine oil with and without nanoadditives. Experiments were carried out as per the ASTM standard G99. Pins and disc were polished to make the surface flat and cleaned with acetone. Load was applied on pin by dead weight through pulley string arrangement. Lubricant was applied between the pin and disc in such a way that boundary lubrication conditions prevail. Frictional force is read from the controller and electronic weighing balance was used to measure the weight loss of the pin.

The test parameters for Pin-on-disc were considered in the following range:

- Load: 40 N, 60 N, 90 N
- Sliding Speed: 0.5 ms^{-1}, 1.0 ms^{-1}, 1.5 ms^{-1}
- TiO_2 nanoparticles concentration (%weight): 1.5% wt
- Sliding Distance: 200 m
- All the tests were carried out for a duration of 5 minutes

Pins and disc were polished up to 600 grit size to make the surface flat and cleaned with acetone. Load was applied on pin by dead weight through pulley-string arrangement. Frictional force was measured from the controller and weight loss of the pin was measured using electronic weighing balance (accuracy of 0.1mg). The above procedure was repeated for all the tests. The specimens were cleaned and dried. All dirt and foreign matters were removed from all the specimens before starting the experiment. Non chlorinated, non-film-forming cleaning agents and solvents were used. The disk was inserted carefully in the holding device so that it remained perpendicular to the axis of the resolution. The pin specimen was inserted in the holder and adjusted to make it perpendicular to the disk surface when in contact to maintain the necessary contact conditions. Proper mass was added to the system lever to the selected force pressing the pin against the disk. The electric motor was started and the speed of the disc was adjusted to the desired value. The revolution counter was set to the desired number of revolutions. The experiment started with the specimens in contact under load. The test was stopped when the desired numbers of revolutions were achieved. The specimen was removed and cleaned. The existence of features on or near the wear scar such as: protrusions, displaced metal, discoloration, micro cracking, or spotting were noted. The tests were repeated with additional specimens to obtain sufficient data for statistically significant results with changing load values and sliding speeds for no lubricants, with lubricant and nanolubricant. The WinDucom software was used for data acquisition and display of results. The WinDucom instrumentation and Data Acquisition were used to measure RPM, wear, and frictional force.

RESULTS AND DISCUSSION

Variation in Coefficient of friction with sliding speed :

A series of experiments were conducted to evaluate the friction and wear characteristics of the sliding elements with no lubricating oil, with lubricating oil and nanoparticles reinforced lubricating oil and the variation in friction coefficient with wear rate were studied.

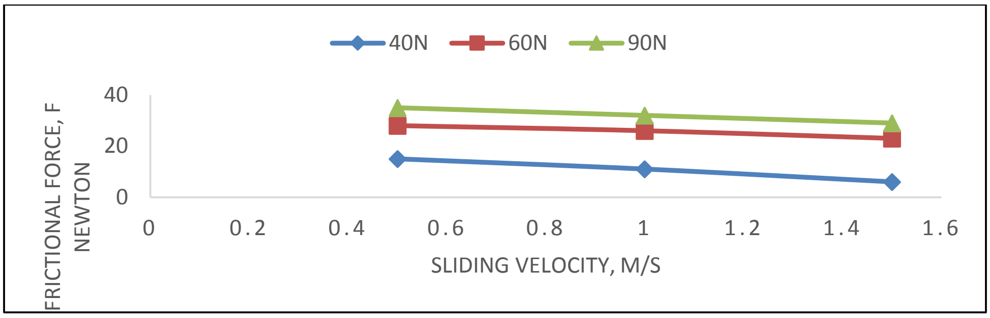

Figure 1: Frictional force Vs sliding speed in dry condition at loads 40N, 60 N & 90 N

Figure 1 shows the variations in force of friction with varying sliding speed at loads 40 N, 60 N and 90 N in the absence of lubricating oil (dry test), with lubricating oil and lubricating oil with 1.5%wt TiO_2 nanoadditives.

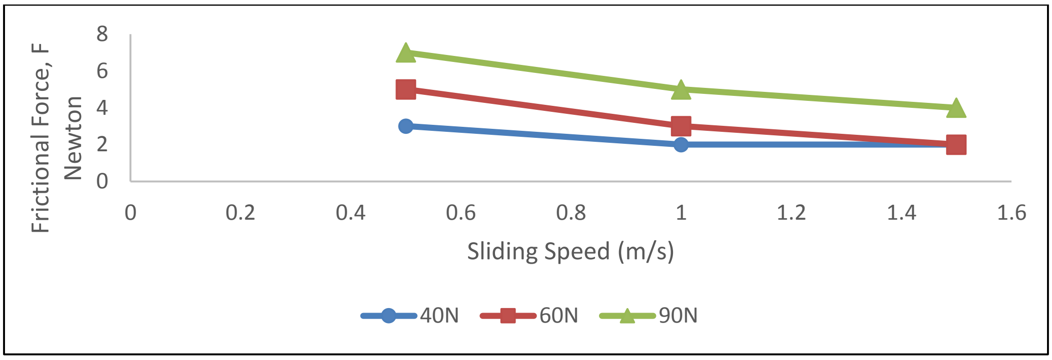

Figure 2: Frictional force Vs sliding speed for lubricating oil without nanoadditives

Figure 2 shows the variation in the average frictional force with sliding velocity in the presence of lubricating oil with different loads. Minimum frictional force is obtained at 1m/s for load 40 N and at sliding speed 1.5m/s at loads 60N and 90N respectively.

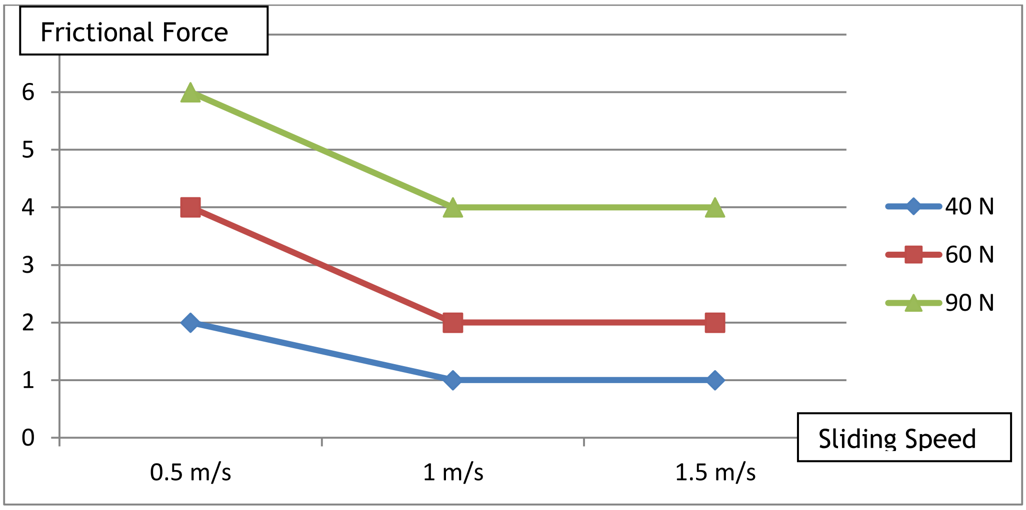

Figure 3: Variation in force of friction with the sliding speed

Figure 3 shows the variation in force of friction with the sliding speed for the lubricant with nanoadditives at loads 40N, 60 N & 90 N. It indicates that there is significant reduction in force of friction with sliding speed. For 40 N, 60 N and 90 N the force of friction becomes minimum at sliding speed 1 m/s and remains constant thereafter.

Variation in frictional force with applied load:

Figure 4 and figure 5 give the variation between frictional force and load at various sliding speeds in the absence of lubricating oil and in the presence of lubricating oil respectively. In both the cases, the maximum frictional force is observed to be at load 90 N and, the minimum friction force at 40N load. Force of friction was also observed to be reducing with increase in sliding speed.

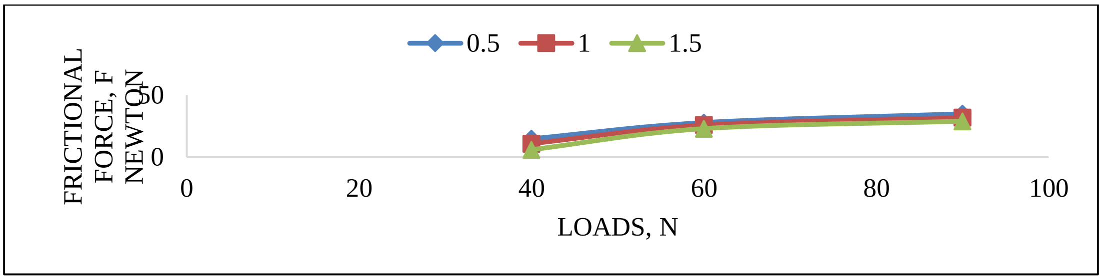

Figure 4: Frictional force Vs Load for Dry Condition for different sliding speeds

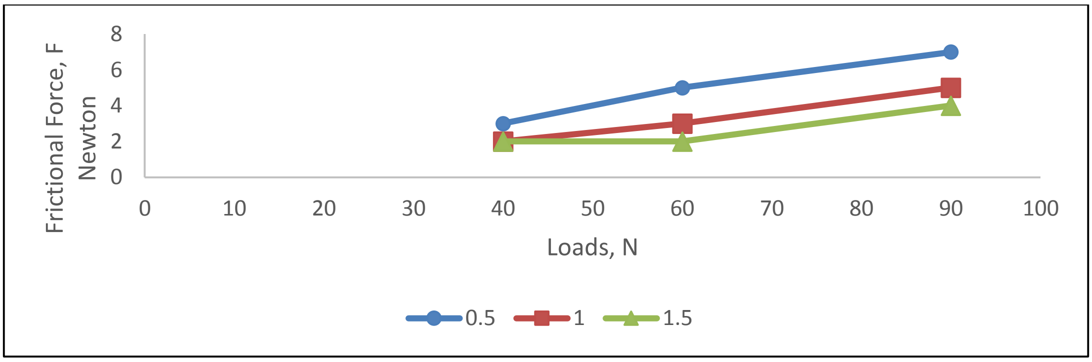

Figure 5: Frictional force Vs Load with lubrication oil for different sliding speeds

Figure 6, 7 & 8 show the variation in force of friction with sliding speed at loads 40 N, 60 N & 90 N respectively for dry condition (no lubricant), wet condition (with lubricant) and with nanolubricant and compares the force of friction in dry , wet and with nanolubricant at the same load. Its obvious from the figures that after addition of nano-particles in engine oil, the friction force reduces to a great extent and is much less in case of nanolubricant. It can also be concluded from the figures that for the given load force of friction reduces with increase in sliding speed.

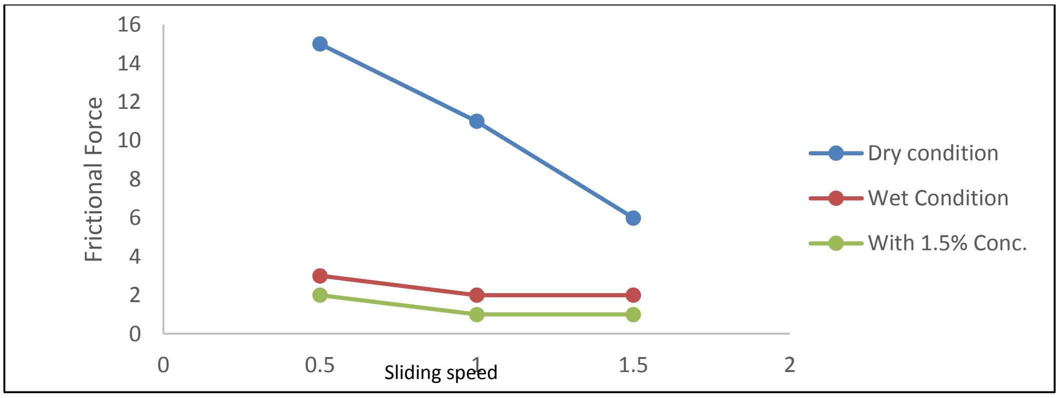

Figure 6: Force of friction Vs sliding speed in dry, wet and with nanolubricant at load 40 N

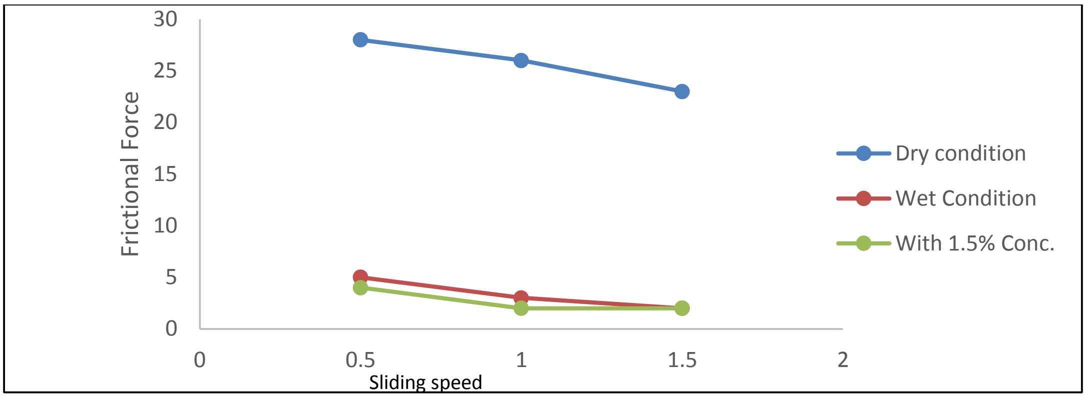

Figure 7: Force of friction Vs sliding speed in dry, wet and with nanolubricant at load 60 N

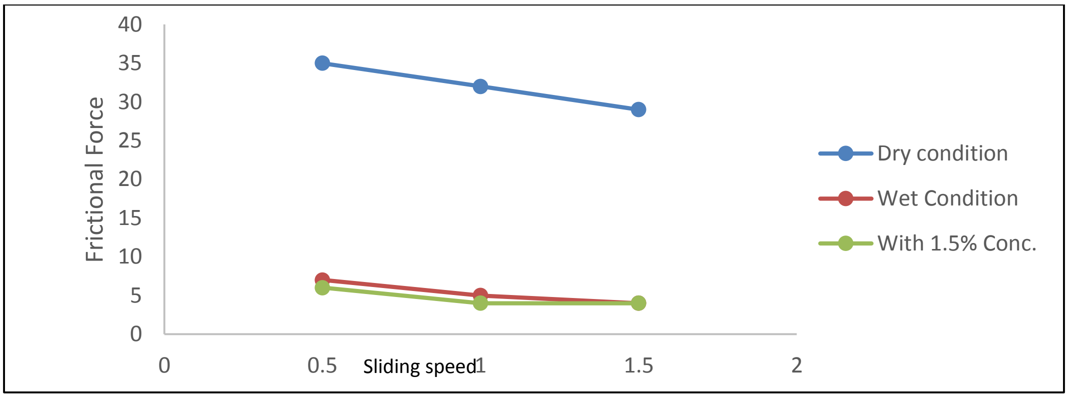

Figure 8 Force of friction Vs sliding speed in dry, wet and with nanolubricant at load 90 N

variation in wear rate with applied load at different sliding speeds :

Tests were also conducted to study the variation between wear rate and loads at different sliding speeds without lubricating oil and in the presence of lubricating oil. The wear rate was observed to be the lowest for 40N load at all the sliding speeds when the tests were performed with no lubricating oil (dry test) as shown in figure 8. Wear rate was observed to be the lowest at the load 60N at sliding speed 0.5m/s and then increased with the increase in load when wet tests were performed only with lubricating oil. At sliding speed 1.5 m/s, the wear rate was found to be the lowest at the load 90N both in dry as well as wet tests.(Figure 9 and Figure 10).

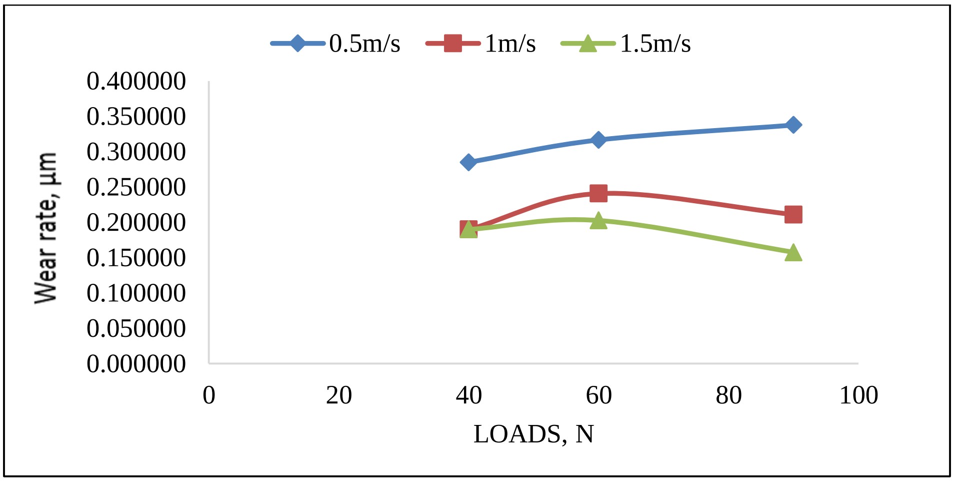

Figure 9: Wear rate Vs Load for Dry Test at different sliding speeds

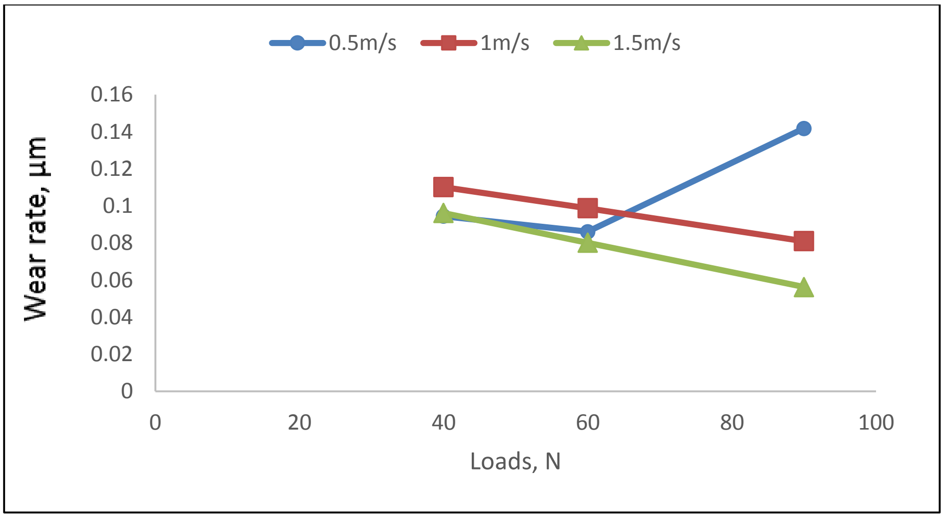

Figure 10: Wear rate Vs Load for Wet Test at different sliding speeds

Variation in wear rate with sliding speed at different loads:

Tests were performed to study the variation of wear rate with sliding velocity for loads of 40N, 60N and 90N in the absence of lubricating oil. Minimum wear rate was obtained at sliding speed 1.5m/s without and with the lubricating oil as shown in Figure 11. Wear rate was observed to be significantly reduced, almost zero with the addition of nanoparticles at sliding speed 0.5 m/s .

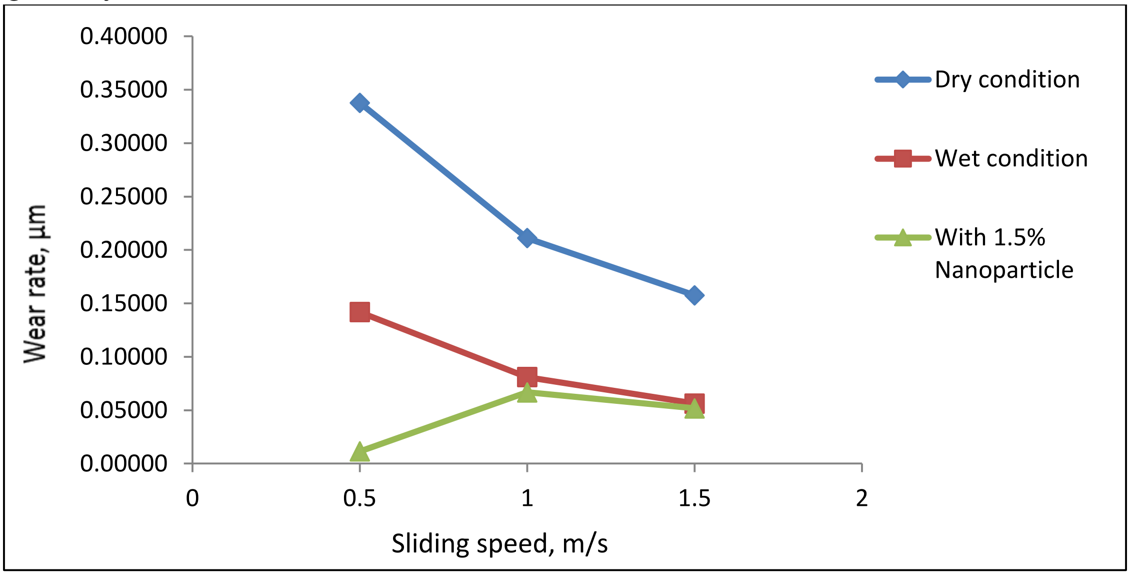

Figure 11: Wear rate versus sliding speed in no lubricant, with lubricant and with nanolubricant

CONCLUSION

The experiments were performed to study the tribological behavior of TiO_2 nanoparticle suspension (nanolubricant or nanofluid) in mineral based multi-grade engine oil. Various tests were performed to study the effect of addition of nanoparticles of TiO_2 in the oil on the wear rate, sliding speed and force of friction. The similar tests were performed with no lubricant and with lubricant without nanoparticles. The experiment results were compared with the tribological behaviour of lubricant with and without nanoadditives. The relation between various parameters such as force of friction, sliding speed, wear rate were studied. Friction reduction and anti-wear properties were obtained using a pin-on-disc tribometer. Tests were carried under loads of 40N, 60N & 90N, sliding speed of 0.5 m/s, 1.0 m/s & 1.5 m/s, nanoparticle concentration of 1.5 wt%. Tribological properties of lubricating oil were enhanced due to the addition of TiO_2 nanoparticles. TiO_2 nanoparticles used as additive in lubricating oil exhibited good friction reduction and anti-wear behaviour. When TiO_2 nanoparticles were added to the engine oil, the co efficient of friction was reduced by 50% with 1.5% concentration by weight of the oil as compared to the oil without TiO_2 nanoparticles for load 40 N and sliding speed 1.5m/s. This effect could be due to the rolling of the sphere like nanoparticles between the rubbing surfaces, thus reducing friction. The coefficient of friction was found to be decreasing with increasing the sliding speed for a given load. The anti-wear mechanism can be attributed to the deposition of TiO_2 nanoparticles on the worn surface, which in turn decreased the shearing resistance, thus improving the tribological properties. Nanoparticles can be considered as nano-bearings on the rubbing surfaces. The TiO_2 nanoparticles are deposited only under mixed and boundary lubrication. Experimental studies report that the deposition of TiO_2 nanoparticles on the rubbing surfaces improves the tribological properties of the base lubrication oil exhibiting reduction in friction and wear.

The wear of Aluminium alloy was observed to be increasing with increased value of the load. However the wear was significantly reduced with TiO_2 nanoparticles as additive for the same load value. Wear rate was observed to be significantly reduced with the addition of nanoparticles. It was noticed that the wear rate becomes independent of sliding speed in case of nanolubricants at 60N load. The wear rate was almost zero at sliding speed 0.5 m/s for nanolubricants and gradually increased with sliding speed at 1m/s and remained constant thereafter. Wear rate for lubrication oil without nanoadditives was also found to be decreased with increase in sliding speed. Thus, TiO_2 nanoparticles can be used as a multifunctional additive in lubricating oil and to enhance its tribological properties.

REFERENCES

[1] Baker, I.L., C.R.; Singleterry, E.M.; Solomon. (1954) Neutral and basic sulfonates. *Ind. Eng. Chem*., 46: 1035–1942.

[2] Marsh, J.F. (1987). Colloidal lubricant additives. *Chem. Ind*. 20(7): 470–473.

[3] Bakunin, V.N.; Suslov, A.Yu.; Kuzmina, G.N.; L.M., Vedeneeva, O.P.; Parenago, C.A.; Migdal; Stott,P.E. (2001) Surface- Capped Molybdenum Sulfide Nanoparticles – a Novel Type of Lubricant Additives. *In: Plenary and Session Key Papers from the 2nd World Tribology Congress, Austrian Tribology Society, Vienna,* 147–150.

[4] Shor, G.I.; Likhterov ,S.D.; Monin, S.V. (1996). Colloidal-Chemical Aspects of Lubrication. *Proceedings 10th Int.Colloquium Esslingen, 9–11 January 1996*, 2: 1079–1078.

[5] Liu, W., Chen, S., (2000). An investigation of the tribological behaviour of surface-modified ZnS nanoparticles in liquid paraffin. *Wear,* 238(2): 120–124.

[6] Zhang, Z.J.; Zhang, J., Xue Q.J.; (1994) Synthesis and characterization of a molybdenum disulfide nanocluster. *J. Phys. Chem.*, 98(49): 12973–12977.

[7] Hu, Z.S.; Dong J.X.; Chen, G.X. (1998) Study on antiwear and reducing friction additive of nanometer ferric oxide. *Tribol.Int*. 31 (7): 355–360.

[8] Laad, M.; Jatti, V.K.S. (2016) Titanium oxide nanoparticles as additives in engine oil. *Journal of King Saud University – Engineering Sciences*
http://dx.doi.org/10.1016/j.jksues.2016.01.008

[9] Qiu, S.Q.; Dong J.X.; Cheng, G.X. (1999) A review of ultrafine particles as antiwear additives and friction modifiers in lubricating oils. *Lub. Science* 11(3): 217–226.

[10] Liu, W.; Zhang Z. Zhang, S. Chen & Q. Xue, 2000. The research and application of colloids as lubricants. *J. Disp. Sci. Technol*. 21(4), 469–490.

[11] Zhou, J.; Yang J.; Zhang, Z.,Liu, W.; Xue, Q. (1999). Study of the structure and tribological properties of surface-modified Cu nanoparticles. *Mater. Res. Bull*. 34(9): 1361–1367.

[12] Tarasov S., A. Kolubaev, S. Belyaev, M. Lerner & F. Tepper,2002. Study of friction reduction by nanocopper additives to motor oil. Wear 252(1–2), 63–69.