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Experimental study on gearbox oil blended with composite additives

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KEYWORDS

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Friction
Wear

ABSTRACT

Friction and wear in moving kinematic links is a crucial cause for energy drop in a gearbox system. It can be governed by consuming modified lubricants or investigating the influence of additives on existing oil. The tribological performance of wind turbine Gearbox has unfavorably influenced by aspects such as nature of loading, type of oil and speed, etc. This paper presents an experimental investigation on oil mixed with Al_2O_3/ ZrO_2 /SiO_2 Nanocomposites in combination with Zinc DialkylDithio Phosphate for various conditions. The process variable levels for the four-ball tribometer are designed for concentration in the percentage of weight as 0.005, 0.01, and 0.02. Experimentation on a Fourball tester is performed to determine wear scar dia. and friction coefficient. It is observed that the addition of composite additives in combination with ZDDP reduces COF and wear scar diameter by 1.4 % and 13.4 % individually.

1.0 INTRODUCTION

Petroleum grounded lubricants are extensively utilized in the basic production and industrial areas like automotive, Process, Power Production, etc. to reduce the friction between various referred surfaces. The key role of oil is to diminish friction, avoid specific wear, avoid corrosion, and reduce contamination. Also in certain applications, it's essential that oil must be skillful to flow effortlessly enough to suck in and leave heat energy. Additives mixed in lubricant progress and emphasized its existence. Additives in heavy-duty lubrication system can advance the physical assets of oil while growing performance of it. The quantity of add-ons that exists in

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lubricant depends on its proposed use. The Composite additives in a system can also be utilized as the performance package. The add-ons mixed in lubricant improve and strengthen the lifespan of used lubricants in numerous Mechanical systems such as gearbox, bearing, engine (Monge et al., 2015). The low rpm of a leading shaft within a wind turbine arrangement needs a specific gearbox to raise the revolution per minute of a secondary shaft up to the specific speed utilized for a generator is touched. The wind turbine containing the gearbox has more repair budgets and greater lost time due to more failures as compared to any other components in a system. One of peak key difficulties of the turbine system is the element that optimal viscosity of lubricant and anti-scuffing behavior of lubricants is obtained at a temperature beyond 80° C (Monge et al., 2015). Wear and Friction decline is a serious issue in such areas because it influences effective energy utilization and overall maintenance charges. Extraordinary superiority modified lubrication is essential in this type of system to overcome the problem.

Recent analyses have focused on changing lubricant performance in several lubrication working systems like Gearbox, Engine, and Bearing, etc. Ionic liquids have been used as add-ons in a gearbox lubricant. The tribological behaviour of gearbox oils individually blended with two ionic liquids at 5 wt. % concentration has been studied in experimentation and both liquids have a minor friction changer nature however, a good wear diminishing nature, with [BMP][NTf2] liquid showing healthier than [Choline][NTf2] fluid (Monge et al., 2015).

Kotzalasand Gary (2010) have reported Tribological developments for a wind turbine. The authors have reported a detailed study on turbine system, gearbox and its lubrication issues in wind turbine system. Most of the turbine's gearboxes are considered to handover a torque from less speed to a high speed suitable for an AC generator.

The low-speed step of the system is made up of a planetary gearbox type with helical type gears. A sun in the system pushes an intermediary shaft that in turn rotates a high RPM step. High-RPM steps contain helical gears. Pedro et al. (2014) have investigated the effectiveness of a gearbox in working with gear lubricants. Test results displayed that Polyalkylene Glycol grounded lubricant has achieved better results than other studied lubricants. Pedro et al. (2011) have studied lubrication behaviour of boron grounded face action and additives for turbine system. In an experiment, Boron nitride grounded solid lubricants were produced and plane steel models have been borided by referring electrochemical approach. The test results showed that a borided faces improved the mechanical properties, also improved resistance to wear. Greco et al. (2013) have stated physical wear and fatigue in wind Systems. This study reported the contact behavior of bearings in system. An investigation results displayed that microstructural transmission has been realized near a surface, compared to awhite etching zone.

Carlos and Fernandes (2014) have reported Gearbox power losses in rolling bearings. Rajendhran et al. (2018) have studied the tribological performance of gear lubricant referring Nickel supported ultrathin MoS_2particles. The results showed that developed composition was good for large pressure region. Edward et al. (2017) have studied the lubrication ability of ionic fluids as additives in a bio lubricant for a gearbox. The presence of liquid add-on efficiently reduces the wear volume loss, mainly under greater speed. Cornelioa et al. (2016) have studied the Tribological assets of carbon nanotubes in lubricant and H_2O for a wheel–rail system. The study showed that the presence of nanotubes reduces both COF and wear in both medium studied (oil and water). Laad et al. (2018) have utilized Pin-on-disc tribotester to investigate influence TiO_2 Particles on the friction and wear parameter in Mineral engine oil. The study showed an improvement in Tribological performance of oil. Suryawanshi and Pattiwar (2018) have investigated the behaviour of TiO_2 Nanoparticles in three different Lubricating Oil in Bering application. The investigation of antiwear and antifriction properties for oils has been conducted on Fourball instrument. The investigation showed improvement in the performance of journal bearing over flat bearing working with a similar lubricant.

The talc is studied as a friction inhibitor agent in engine system by using Ball on plate Instrument under various concentrations and temperatures (Rudenko et al., 2013). The study showed that for high temperature condition, additives generate transfer layer on studied surface and decreases both wear and friction in system. An impact of MoS_2, IF-$MoS_2$and WS_2 as add-ons in oil has been investigated for engine lubrication (Charoo et al., 2016; Gullac and Akalin, 2010). The Researchers have conducted a test on Fourball tester according to ASTM D 4172 Standard. The SEM and Energy Dispersive Spectroscopy analysis has been utilized to examine friction parameter and wear behaviour in cylinder and piston pair. The add-ons in studied oil reduced wear effectively up to certain level. Kornaev et al. (2016) have studied impact of the ultrafine oil add-ons on lubrication in journal bearings system. Studied additives expressively reduced the load sustain capacity and COF in system, as well as the vibration level. Zhang et al. (2009) have conducted the Wear experiment by utilizing an Optimol-SRV oscillating wear and friction tester. In this tester higher steel ball Glides reciprocated at some specific amplitude of counter to a static steady steel disc. The wear of bottom disc has been calculated by utilizing a Specific microscope. Larsson et al. (2017) have considered boric acid as a lubricating fuel additive in trials to know fuel saving in a field trial. An influence of nanoparticles of boric acid and copper on oil has been investigated for cast iron (CI) and carburized steel materials by using ball on flat instrument (Vadiraj et al., 2012). The investigation showed that COF rises with growth in volume share of lubricant add-ons and drops with growth in volume share of additives.

Choi et al. (2019) have studied experimental outcomes of Cu nanoparticles as additives in the oil. The COF for base oil and modified lubricant mixed with Cu nanoparticles has been discovered by conducting a trial on a Disc-on-disc instrument in bothregimes. The Cu nanoparticles have presented a lesser COF and wear on the studied surface for raw oil. The tribological outcomes of copper particles have been investigated for various lubricants with variant working conditions (Bao-Sen et al., 2011; Bao-Sen et al., 2008; Juozas et al., 2013; Zhou et al., 2008). The study showed that copper add-on provides a permanent reduction in friction, wear and stretched life of system. Also, for SAE 30 lubricant copper additive diminishes friction efficiently at larger loads and RPM (Tarasov et al., 2002).

Husnawan et al. (2007) have established friction model for mineral lubricant including palm olein and add-ons. A tribological trial was conducted on four ball type instrument anda force model established by using load, time and speed. A response surface approach has been referred in model progress. Chouhan et al. (2020) have optimized performance of Nano Fe_3O_4 included lubricant using mechanical mixing method and Tribometer.Experimental results showed that significant reduction in wear after modification of lubricant.

Sakinah et al. (2016) have stated application of response surface methodology (RSM) in study of the tribological nature of palm lubricant blended in engine lubricant. The Design of experiment has been gathered by referring RSM to decrease experimentation circumstances and to improve a mathematical model. Analysis of variance approach has been used to study acceptability of a realistic models established. Singh et al. (2018) have adjusted friction and wear outcome of a seed lubricant using RSM approach. Experimentaltrials has been completed by utilizing a pin on disc type apparatus. Mathematical model of wear and friction parameters prepared by referring to conductedtrial outcomes. Srivyas et al. (2020) have investigated Tribological outcomes of GNP Nanoparticles for modified steel pair using a reciprocating tribometer. The experimentation showed that GNP particles reduces wear and friction in studied lubricant. Zhang et al. (2014) have summarized tribological outcomes of hybrid and Graphite nanomaterial as an additive in lubricants.

Luo et al. (2014) have investigated friction parameter and wear properties of Al_2O_3 and TiO_2 mixed nano composites in oil by using friction abrasion tester. The Ultrasonicator has been used in experiment to disperse the particles in lubricant. The experimentation showed that Modified Nano particle has better performance than original particles individually.

Researchers have been concentrated on modifying the output of lubricating oil by consuming additives. On a supplementary side there is a slight examination on the impact of a Composite additive on a tribological outcome of lubricant in large load mechanical system like turbine gearbox. As well few of investigator has been examined influence of an ionic fluid as add-ons in a gearbox lubricant consuming specific instrument, however, fall in friction aspect has not detected considerably in analysis. The impact of composite add-ons and their blends like $Al_2O_3\backslash TiO_2$, Graphene\TiO_2, Graphene + MoS_2, etc. on lubrication performance of gearbox oil under various conditions like varying load, temperature, concentration, speed, etc. is the zone for future study. Also, the advancement of the predictive system for performance of oil in applications like gearbox is a scope to work for the development of add-on package.

2.0 COMPOSITE ADDITIVES FOR LUBRICANT

In heavy duty Wind turbine Gearbox lubrication system precise add-ons should be included in oil to boost certain properties like anti-friction, wear, viscosity and anti-corrosion. Another concern in mixing is that a lubricant as a carrying mediator for nanoparticles should be capable to retain the composite add-on in a liquid in all functioning situations. Few researchers have investigated the tribological behaviour of gearbox oil blended with various additives for different working conditions. The recent study revealed that composite or mixed nanoparticles have revealed better tribological outcomes than individual nanoparticles. The different composite additives are tabulated with their advantage in Table.1.

Table 1: Composite Additives and their advantages.

Blends of Additive/Mixture	Properties	Advantages
Al_2O_3 + Tio_2	Friction and wear reducer	More stable Nano composite
		Improve thermal stability
Al_2 O_3 +ZrO_2	Wear resistant	Improve viscosity
		Good dispersion characteristics

2.1 Additive Details

In this study, Al_2O_3/ ZrO_2 /SiO_2 Composite nanoparticles were used as add-ons in industrial gear lubricants KIXX Gear EP 220. The density of Composite nanoparticles was 0.4581 g/cm^3.The nanoparticles chief constituents are prepared up of Al-Si compounds in the form of a white powder. Table 2 shows specific Properties of Composite nanoparticles. These Composite nanoparticles have 20 % wt. completely dispersed in Mineral oil.

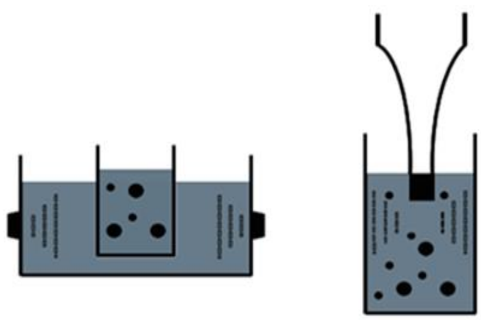
Table 2: Properties of additive.

Chemical and Physical Properties	Value
Nanoparticle Size in nm	500
Colour	White
Reduction of Weight in Drying	0.18
Reduction of weight on ignition	0.8
PH	5-7
Density in g/cm^3	0.458
Specific Surface Area in m^2/g	4.83

2.2 Mixing Method

A chief problem in utilizing nanoparticles is that they are extremely agglomerated. Hence appropriate selection of mixing apparatus is essential in additive blend making. Suryawanshi and Pattiwar (2018) and Luo et al. (2014) previously researcher has utilized the ultra sonication and magnetic stirrer approaches for testing sample preparation.

In the Ultrasonic mixing method, sound waves passthrough the liquid suspension in interchanging high and low cycles of pressure. The Ultrasonic waves can be made in a liquid medium either by dipping an ultrasound probe into the liquid or by filling the sample in the container. This technique is shown schematically in Figure 1(b). In a bath type approach, the sound waves pass through the bath or container liquid (usually water) and the wall of the container formerly reaching the blendshown in Figure 1(a). In the direct sonication technique, a probe is in direct connection with the liquid and hence delivers greater energy into the liquid mixture.



(a) Bath type (b) Probe type

Figure 1: Schematic illustration of ultrasonicator.

Magnetic stirring is an approach to obtain homogeneous blends and strengthens heat and mass exchange in the blenders. Stirring is conducted in the vessels with blending devices. The nature and intensity of blending rest on the design of instruments.

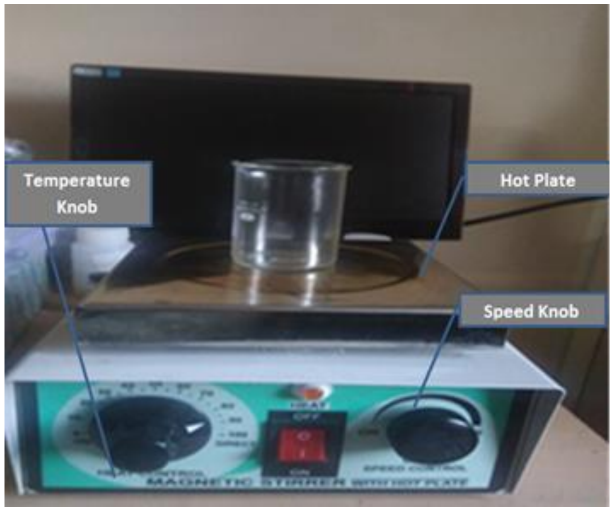


Figure 2: Magnetic stirrer.

Magnetic stirring equipment can be utilized over a wide temperature range. The most common blending is carried out with the help of magnetic stirrers as shown in Figure 2. The equipment consists of two key parts: a motor with a stirring tool and a control panel.

2.3 Lubricant Properties

The extreme pressure industrial gear lubricant is used in this experimental study. The lubricant properties are reported in Table 3. The KIXX Gear EP 220 is an extraordinary performance industrial gear lubricant considered to protect parts against wear in bounded gears functioning under great load and shock load situations. It also provides a micro pitting shield.

Table 3: Properties of lubricant.

Properties	Value
ISO Grades	220
Density at 15°C in g/cm^3	0.856
Kinematic Viscosity @ 40°C in mm^2/s)	206.9
Kinematic Viscosity @ 100°C in (mm^2/s)	19.6
Viscosity Index	108
Pour Point in (°C)	-15
Flash Point in (°C, COC)	256

3.0 EXPERIMENTAL INVESTIGATION

The performance analysis chiefly consists of an examination of friction coefficient, wear scar diameter and viscosity etc. The friction parameter rest upon various factors like load, Speed and concentration of additive, etc. Wear of parts occurs by a plastic motion of surface and adjacent surface material as well as by split-up of particles that produces wear waste material. In thewear trial the particle dimension may vary from mm to 10^{-9}µm. A reciprocating ball on plate tribotester was used for wear performance analysis with a steel ball of diameter 3 mm diameter rubbing against steel test samples in an experiment (Rudenko and Bandyopadhyay, 2013). The X-ray photoelectron spectroscopy and Transmission electron microscopy also used to examine the nanoparticles and surfaces (Sgroia et al., 2015). In gearbox, viscosity parameter is very important at high temperature conditions. In tribological investigation viscosity of oil has been measured before the addition of additives and after addition to examine influence of additive addition on lubricant performance. The main Tribological parameters and their dependency is reported in Table 4.

Table 4: Friction Parameters and its dependency.

Friction Parameter	Depends on
Coefficient of friction	No of Cycles, Sliding speed, Load and Time
Wear	Additives, Sliding speed, Load
Viscosity	Temperature, Concentrator

3.1 Four Ball Tribometer

The tribological nature of oil with and without the additive can be evaluated using various types of tribometer like four balls, Ball on plate and Pin on disc, etc. In this tribological investigation, Experiment analysis of composite additives is conducted on a Fourball tribometer with Standard ASTM D-4172. The Four ball Tester is selected because the gearbox oil is working at high load and high temperature. The detailed specification of Four Ball tribometer TR-30L model is reported in Table 5. The E- 52100 steel balls (diameter = 12.7 mm) are utilized in tribological investigation.

The test parameters for Fourball test were considered by using ASTM D 4172 standard. The Four ball tester relates to equipment and different controllers which do an investigation of Normal load, speed, and oil temperature and friction parameter developed as shown in Figure 3. The records are achieved and presented online. The wear scar dia. on steel spheres is investigated through the help of a microscope/image acquisition method. Graphical behaviour of singular measurement can be produced. In a test, the measured Facts are transferred to a computer. The Optical wear scar measuring image gaining arrangement with a specific image sensor allows the acquisition of wear scar picture on a computer. The wear scar dia. and frictional torque are achieved on PC by using data and image gaining arrangement individually using LabVIEW® based Winducom® software. The selection of appropriate analysis materials and process of the parts authorize noiseless working of all Moving parts. Previously the tribological tester is utilized to examine a COF, load bearing and wear protecting assets of lubricating oil and greases. The Fourball tester is well-suited for both IP and ASTM standards.

In Anti Wear (AW) examination - the mean wear scar diameter on a bottommost 3 spheres is refereed for investigation. The dimension of the wear scar displays the capability of lubricant to avoid wear. A larger diameter of wear scar shows reduced wear preventive properties. Additional provision to control heat and hotness of the Lubricant sample was also given in apparatus at ball pot foot. The loading lever with a loading pan is assembled in an instrument to apply load on the balls.

Figure 3: Fourball tester.

The ball pot is sustained above a load lever arrangement with plunger and bearing. A weight cell is used to calculate the normal force throughout experimentation. The torque applied on 3 spheres is examined by using a frictional force type load cell. The Fourball tester unit includes a cylindrical central body that is rested over the base plate. Inside a corner of the central body, the spindle assembly is attached to revolve the top steel ball. The spindle shaft is driven by using AC motor through a belt drive. The Electric motor is assembled on the backside of an outer body. The Spindle casing is properly secured on the body in an upright direction, to facilitate the fourth ball movement into it from the lower side. The spindle is rested between two ball bearings in the housing to support the large load and speed without heating and run-out problem. The loading pan is suspended at the longer end of the lever arm to place dead weight for applying normal load.

Table 5: Fourball instrument specification.

Properties	Value
Test speed	300-3000 RPM
Test loads	100-10000 N
Temperatures	Ambient to 120°C
Test ball Dia.	Ø 12.7 mm (SKF)
Power	415/ 50/ 3 V/ Hz/ Ø
Scar Diameter	0.01 to 4 mm
Collet Diameter	12.7 mm
Base Plate height from floor	935 mm
Loading arm height from floor	1050 mm
Ball pot height from floor	1235 mm
Loading arm length	1305 mm
Loading arm ratio	1:15
Dead weight	In steps of 1,2 and 5 kg
Motor height from floor	1580 mm
Overall Size of machine	1400 X 700 X 1700
Frictional torque	0-16 Nm

3.2 Material in a gearbox

The steel taken for gear should remain robust to avoid tooth breakings. It should be rigid to restrict the connection stresses and is ductile adequate to restrict impact loads carry out on the gear. The material designated for gear and for solid shaft should be skillful to resist any stresses forced lengthways the shaft.

AISI 52100 steel is great-carbon chromium alloy steel. It is referred to in numerous Mechanical fields as an application. After annealing, this type of steel is relatively simple to machine, yet very extraordinary hardness and abrasion resistance ability can be established by heat treatment methods to develop the steel chiefly suitable for applications needing more wear resistance.

3.3 Preparation of Nano lubricant

The Composite nano add-ons were mixed to a gearbox lubricant at 0.005 % wt., 0.01 % wt. and 0.02% wt. in combination with 1% wt of Zinc DialkylDithio Phosphate (ZDDP). The essential amount of Composite nanoparticles was precisely evaluated utilizing an electronic weight balance Machine and blended with a gearbox lubricant. A Magnetic Stirrer instrument was utilized for mixing the additives consistently in gearbox lubricant as shown in Figure 2. To attain appropriate dispersal of Composite nanomaterial, the test specimen is located on a hot plate and the needle is dipped in modified liquid. The period of agitation is maintained to 30 minutes in order to develop a steady suspension of Blend. The Chemical and physical properties of ZDDP are listed in Table 6. A light transmission influence is referred to evaluate the dispersion ability of Composite additives in a studied lubricant.

Table 6: Properties of LDDP.

Chemical / Physical properties	**Value**
APS	Liqiuid
Purity	90%
Bulk Density in g/cm3	1.1168

Total volume of sample = 30 ml
Weight of Gear EP 220 oil in ‘g’ = volume in ml × density in g/ml (1)

Weight of Composite Additive in ‘g’= Weight of Gear EP 220 oil in ‘g’×0.02 % wt. (2)

Volume of composite Additive = (Weight of Composite Additive)/(Density of Composite Additive) (3)

There are certain input elements such as speed, load, concentration of add-on % wt., and slipping velocity have a great influence on a wear volume and friction parameters. But, the examinationof influence of adistinct parameter on wear andFriction is a period required procedure. Hence, in the current study Effect of Additive Concentration on Tribological performance is investigated. Table 7shows the obtained levels of concentration in experimentation and Table 8 reports the trial combinations for experimentation.

Table 7: Process variables values and levels for fourball test.

Parameters	**-1**	**0**	**1**
Concentration in % wt.	0.005	0.01	0.02

Initially, the machine is switched ON and standard test conditions are set by using the Knob of a Control unit. The Acetone solution is used to remove the dust and clean the balls. A standard torque is applied to clamp the balls into the ball pot. A ball pot is full of an oil sample under test. After setting Collet with steel balls in a chamber the ball pot assembly With Sample is placed inside the chamber with a Flash gutter over the Ball pot Assembly. The loading lever arrangement is used to set the specific load. The START button on the controller front panel initiatesthe commence of the test and simultaneously data is transmitted to PC. The graphs will display Wear, Friction torque, and speed for the different test conditions like Material, size, and velocity.

Table 8: Experimental trials.

Run	Load in N	Concentration %wt.	Speed in RPM	Wear Scar Micron meter	COF
1	392.4	2	1200	728.66	0.10927
2	392.4	1.25	1200	681.66	0.10576
3	392.4	0.5	1200	657.33	0.10454
4	392.4	0	1200	496.67	0.09266
5	392.4	0.005% +1 wt.% ZDDP	1200	429.66	0.09135
6	392.4	0.01 % + 1wt. % ZDDP	1200	435	0.09130
7	392.4	0.02% + 1 wt. % ZDDP	1200	481	0.09200
8	392.4	0.01 % + 2 wt. % ZDDP	1200	494	0.09221

4.0 RESULTS and DISCUSSION

The experimentation outcomes of tribological parameters like Coefficient of friction and Wear for Gearbox base oil and modified oil is presented under. The trials are carried out at load 392.4 N, respectively for a speed 1200 rpm at 75 °C. Each trial is conducted for 3600 seconds duration as per the specified time. The analysis on oil is carried out for various Concentrations of Composite nanoparticles namely 0.005 % wt., 0.01 % wt., and 0.02 % wt. in combination with 1 % wt. ZDDP is represented in Table 8. The Scar diameter and torque are investigated for several combinations of gearbox lubricant.

The values are stored, and analysis is completed in Labview® software. According to the method defined by standard ASTM D 4172, average mean Readings of the frictional torque is utilized for examination and COF is calculated for similar trials. The COF for steel spheres in contact with oil is calculated refereeing the following expression (Suryawanshi et al., 2018):

$$\mu_b = \frac{T_f \times \sqrt{6}}{3 \times w_b \times r} \tag{4}$$

Where w_b , T_f, and r can be represented as normal load on balls (N), frictional torque (N.m), and distance calculated from center of the bottom ball connection surface to the revolving axis (m), respectively.

The coefficient of friction obtained for KIXX Gear EP 220 oil operating without Composite nanoparticles and KIXX Gear EP 220 oil containing Composite nanoparticles in combination with ZDDP are 0.09265and 0.09135 respectively. The frictional torque curve for nanoparticles containing oil is more stable as related to base oil. The frictional torque and COF are measured for each sample for the time duration of 3600 seconds as presented in Figure 4 and 5.

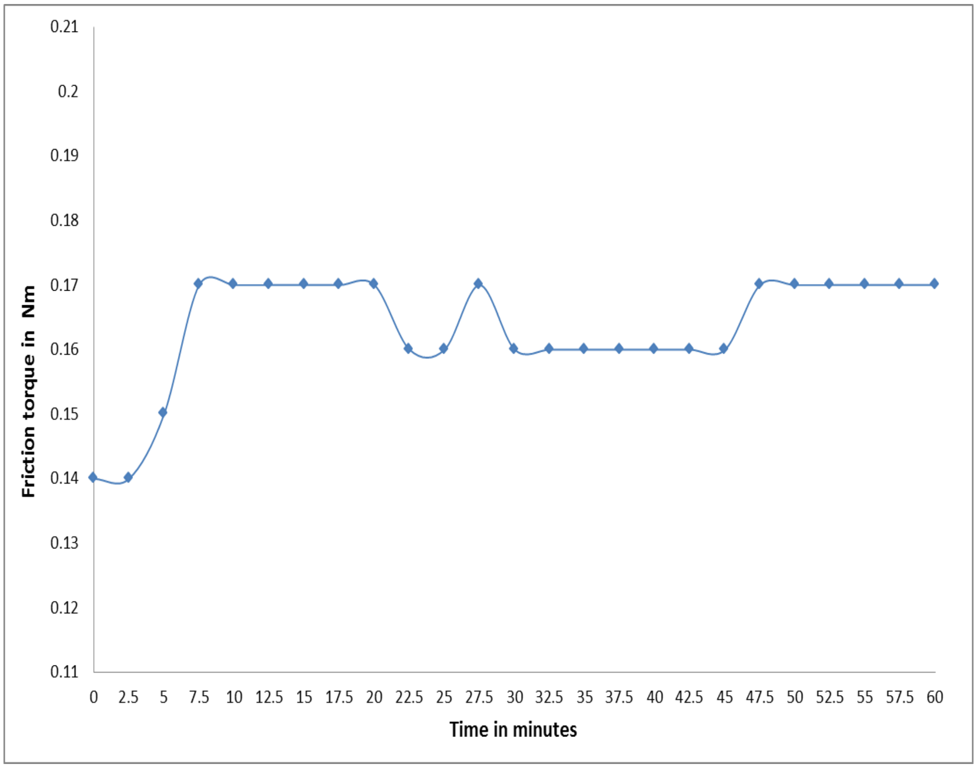


Figure 4: Friction torque behaviour for gear EP lubricant.

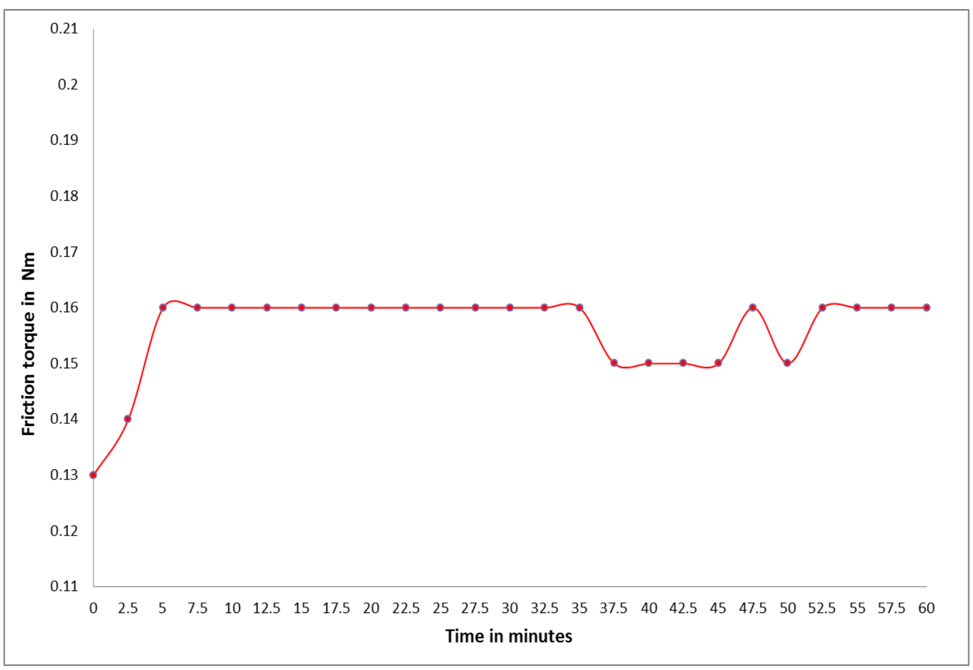


Figure 5: Friction Torque behaviour for Gear EP Lubricant blended with composite additive.

The composites nanoparticles in combination with ZDDP increases the Viscosity of base Lubricant thereby improve the lubricant film depth that diminishes the connection amongst the steel sphere surfaces. A Lubricant film that is developed is well-known as tribochemical response film and it continued Stable throughout the 3600 seconds testing that lessened asperity connection.

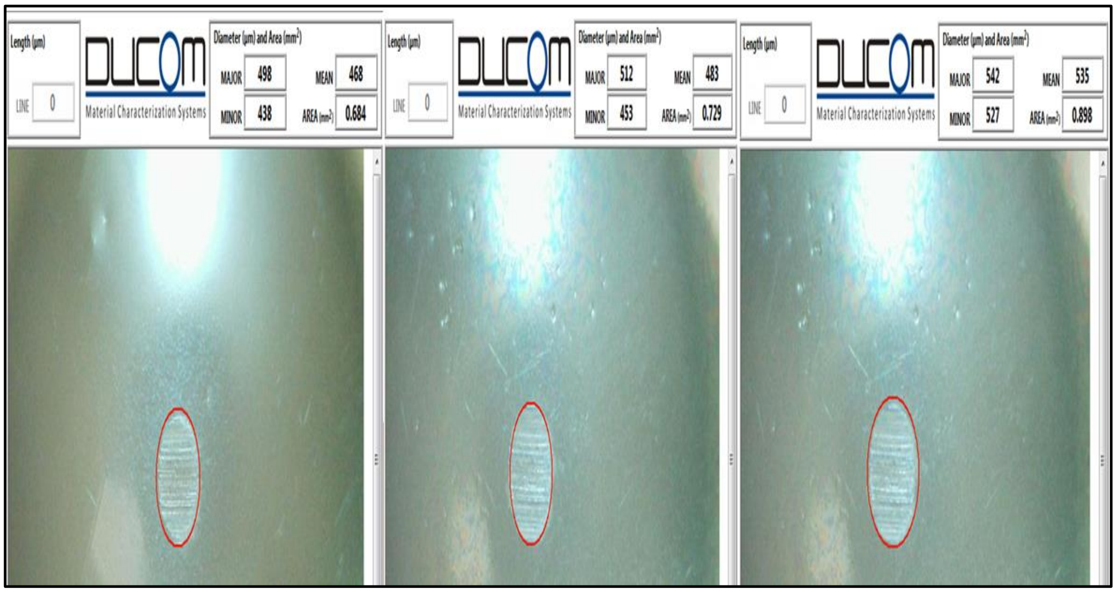


Figure 6: Wear behaviour for gear EP lubricant.

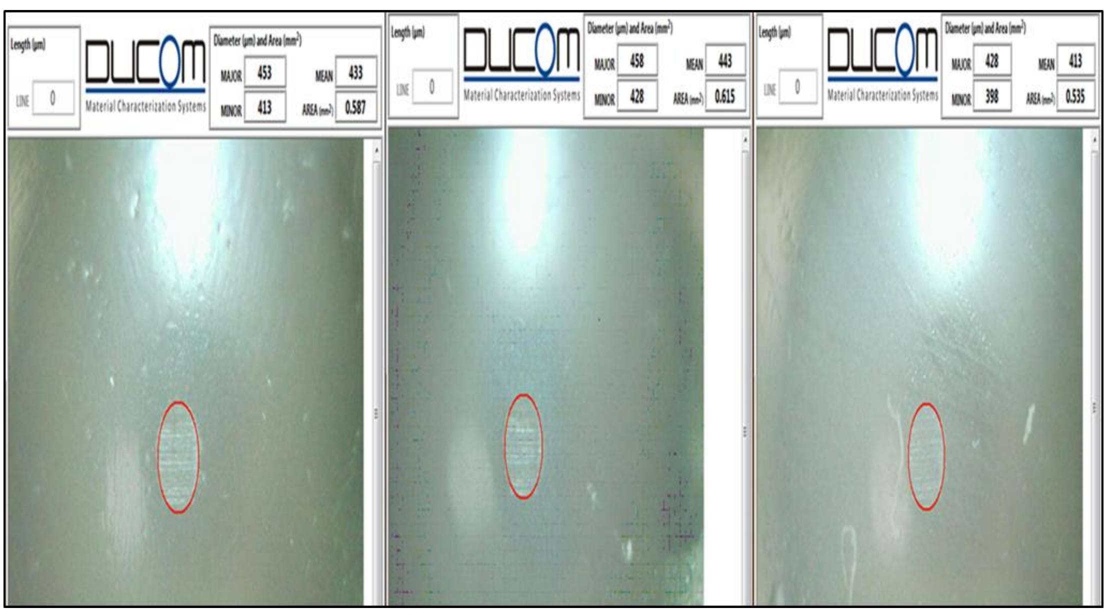


Figure 7: Wear Behaviour for gear EP Lubricant blended with composite additive.

The elliptical apparent is a worn face of the material i.e. investigated with the assistance of image acquisition approach. Wear scar diameter images were examined with image acquisition technique after each four-ball trial, as shown in Figures 6 and 7.The mean diameters of wear surfaces for Gearbox oil without Composite Nanoparticles are 468 µm, 483 µm,535 µm and Gearbox oil with Composite Nanoparticles including ZDDP are 433 µm, 443 µmand413µm. The outcomes are average mean value of three separate examinations. Once a concentration combination is 0 % wt., the anti-friction and Anti-wear excellence of steel ball is meaningfully diminished, which point out heavy scratch happening in steel balls. However, when a concentration is 0.005 % wt. +1 %wt. ZDDP, the superiority of steel ball materials improved once add-on concentration is 0.005 % wt. +1 % wt. ZDDP, a Wear scar diameter is lowest (429.66 µm) and declines through 13.4 %, related with 496.67 µm of original lubricating oil with 0wt. % concentration of additive.The mean diameters of wear surfaces for Gearbox oil without Composite Nanoparticles are 497 µm and Gearbox oil with Composite Nanoparticles including ZDDP are 429.6 µm.

The behaviour of friction torque with time in minutes for a various concentration of additive is compared in Figure 8. When the concentration of composite Additive is lesser than 2 wt.%, a friction torque decreases with a decrease of Al_2O_3/ ZrO_2 /SiO_2nanocomposites in combination with ZDDP.However, the friction torque originates to rise once a particles concentration combination is larger than 0.02 wt. %. Hence, friction falling influence is top at concentration of 0.005 wt. % in combination with 1 wt. % ZDDP, showing in Figure 8.

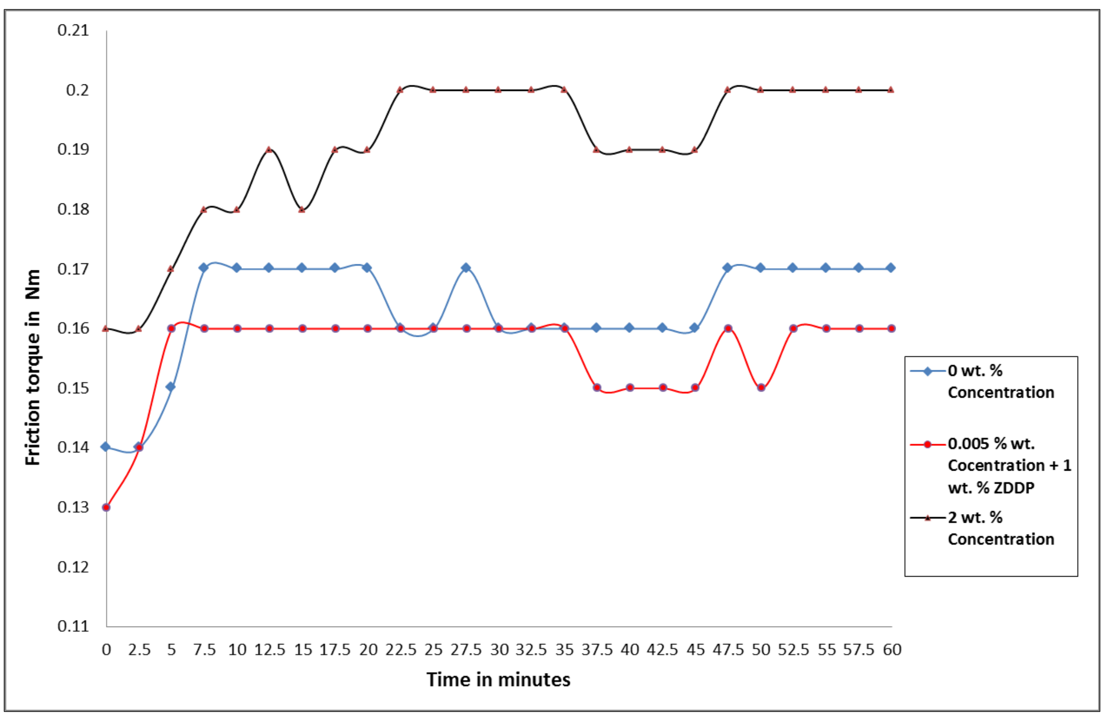


Figure 8: Behaviour of torque with duration in minutes.

4.1 Comparative Analysis of COF and Wear Scar Diameter of Lubricants

The comparative analysis of friction coefficient for studied oil with adding of Composite nano additive is mentioned under. In order to investigate the influence of composite additive on Gear EP 220 oil, the results of Gear EP oil with Composite Additive are compared with the Simple Gear EP 220 oil. Once the concentration is lesser than 0.02 wt.%, a friction coefficient decline with falls of nanocomposites in lubricant.But, a COF initiates to increase once an add-ons concentration is more than 0.02 wt. % as displayed in Figure 9.It is noticeably seen that COF for three blended samples is less as compared to COF for Base lubricant.

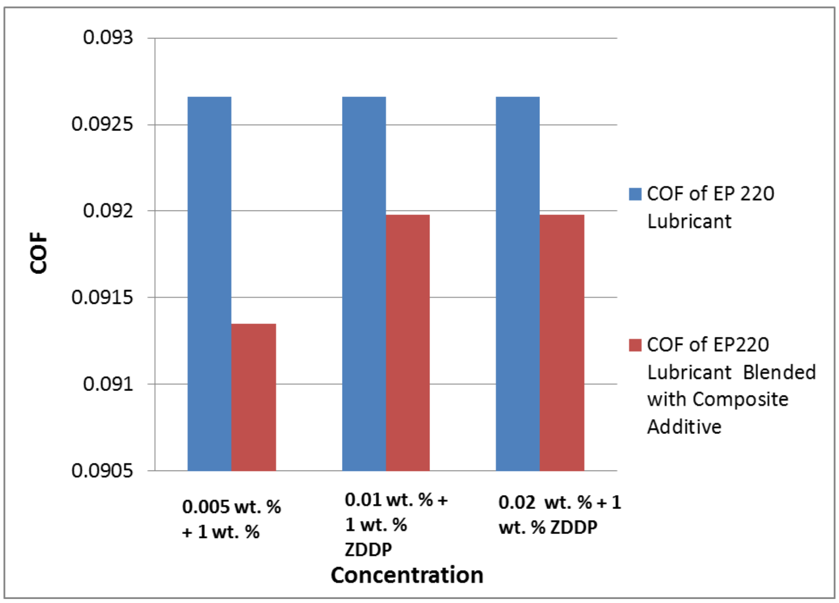


Figure 9: Variation of friction coefficient with time in minutes.

The wear scratch diameters for the lowest three spheres are investigated by using a digital microscope and pictures are generated by using an image acquisition process. It is detected that scar dia. for three blended samples is less as compared to Wear scar diameter for Base lubricant. The adding of composite particles in Gear EP oil enhanced antiwear features; wear was nearby 13.4 % and 12.4 % lesser for Gear lubricant with 0.005% and 0.01 % additive in combination with 1% ZDDP individually linked to base oil lacking additive.

Tests with gear EP oils show that a Composite particle enhanced wear defensive features when utilized to studiedoil, particularly at a combination of 0.005 wt.%+ 1w t. % ZDDP that developed the lowermost wear associated with all lubricant verified is shown in Figure 10.

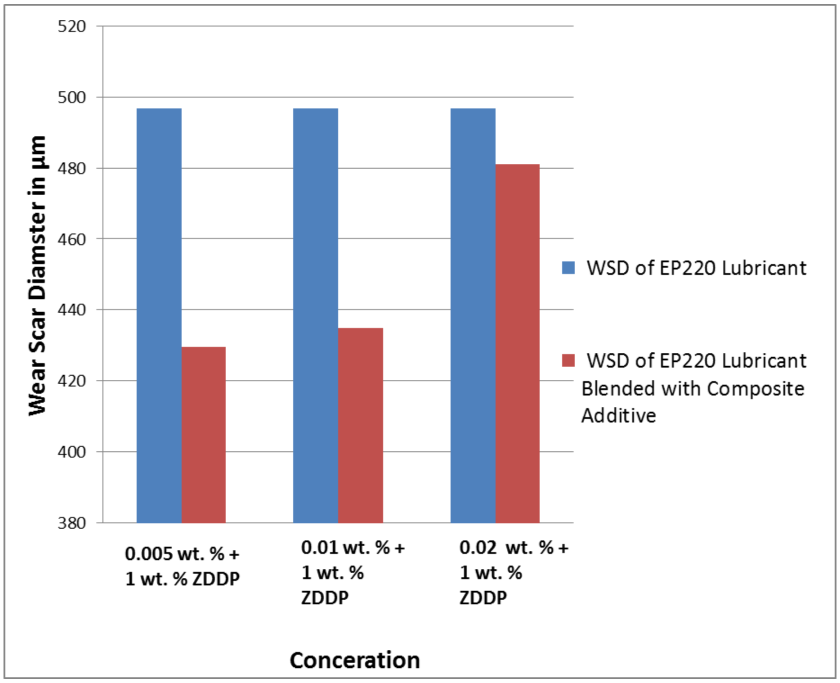


Figure 10: Comparative analysis of wear scar diameter for various samples of gear EP lubricant.

Average reduction for Friction and Wear scar diameter lubricated through oil with different $Al_2O_3/SiO_2/ ZrO_2$ concentrations combinations in four- ball trail is registered in Figure 11. The lubricating oil with 0.005 wt. % $Al_2O_3/SiO_2/ ZrO_2$ nanocomposites in combination with ZDDP shows finest anti-friction and anti-wear influence with a friction coefficient and wear scar Diameter declines by 1.4 %. and 13.4 % respectively.

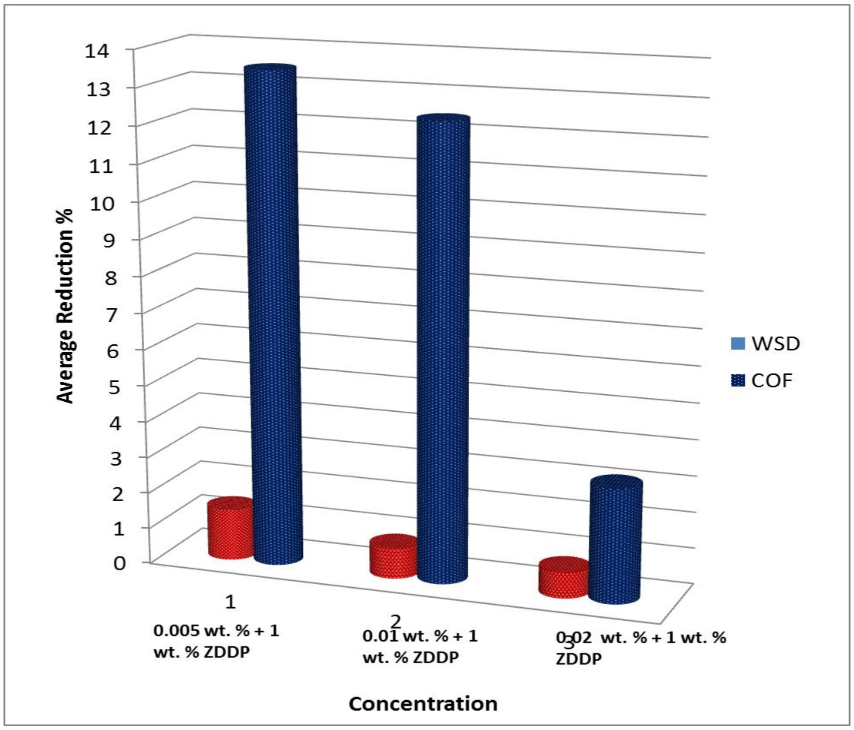


Figure 11: Average reduction in COF and WSD

CONCLUSION

The Gearbox EP oil working with Composite nanoparticles in combination with ZDDP based lubricant is investigated in this experimental study. A Fourball instrument is utilized to investigate Gearbox lubricant outcomes. The Tribological performance characteristics of wind turbine gearbox oil is evaluated and theanti-wear, anti-friction properties are found to be enhanced in this investigation. The finding showsa decrease in a wear scar diameter of a steel ball by 13.4 %. The Fourball test showed 1.4 % reduction in coefficient of friction as compared to Base Lubricant. The least value of friction coefficient parameter 0.09135 is obtained in this study is for 0.005 % of Composite nanoparticles plus 1 % of ZDDP for the load condition of 392 N at 75°C temperature. The minimum Value of wear scar diameter is observed to be 429.6 μm under ASTM D4172 test condition. The impact of composite Nanoparticles like Al_2O_3 /ZrO_2 + ZDDP, ZDDP + MoS_2, etc. on lubrication outcomes of gearbox lubricant under various working conditions like varying loads, temperature, speed, etc. is the zone for future study.

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