Vol. 45, No. 4 (2023) 579-590, DOI: 10.24874/ti.1461.03.23.07

Tribology in Industry

www.tribology.rs

RESEARCH

Experimental Study on Gear EP Lubricant Mixed with $Al_2O_3/SiO_2/ZrO_2$ Composite Additives to Design a Predictive System

Tushar D. Gadekar[a,*], Dinesh N. Kamble[a], Nitin H. Ambhore[a]

[a]*Vishwakarma Institute of Information Technology, Pune-411048, India.*

Keywords:

Friction
Wear
Nano composite
Gearbox oil

* Corresponding author:

Tushar D. Gadekar
E-mail: tdgadekar13.scoe@gmail.com

Received: 11 March 2023
Revised: 7 May 2023
Accepted: 3 July 2023

A B S T R A C T

The friction and wear volume loss is the main cause for a failure & energy losses in heavy-duty gearboxes and it can be controlled by using a modified lubricant mixed with nano additives. This study investigates the wear and friction behaviour of gear EP oil blended with composite nano additives ($Al_2O_3/SiO_2/ZrO_2$) in combination with Zinc dialkyl dithiophosphate. All trials were conducted under various concentrations of composite nanoparticles, at loads of 60-100 N and sliding velocities of 0.65-1.5 m/s. The experimental study on antiwear and anti-friction properties for the oil was conducted on a pin-on-disc apparatus. The design of experiment was developed using response surface approach to investigate optimum friction coefficient and wear volume loss in lubricant. It is found that blending of nano composite add-ons blended with Zinc dialkyl dithiophosphate in gear EP lubricant significantly diminishes a wear volume loss, friction coefficient by 15.62 % and 20.6 % respectively as compared to a base lubricant. The findings of this investigation and the obtained correlations were converted in to customized visual basis based soft tool as a predictor for future aspects.

1. INTRODUCTION

The friction & wear is the main cause of performance lack in heavy-duty gearboxes [1-3]. The modified lubricants are used now days to improve the performance of such systems [4,5]. It is found that blending of nano composite add-ons in lubricating oil significantly diminishes a wear volume loss under the higher load and high-speed working conditions. Nano additives have better tribological properties than old-style solid oil additives, according to an experimental study Ionic liquids are given a slight modification in friction and effective modification in wear [6]. Nanomaterial's exhibit unusual physical and chemical properties due to their atomic sizes and surface effects and have been extensively studied in the discipline of tribology. The power losses in the gearbox are reported for rolling bearings [7]. Edward Cigno et al. [8] have examined Lubrication capability of ionic liquids as add-ons in bio oil for gear application. Experimentation includes analysis using a pin-on-disk machine and surface spectroscopy technique. The experimental study discovered that the addition of additives greatly decreases wear volume loss in a worn track, mainly at upper speeds examined, representing a potentially considerable increase in parameter.

Yashvir Singh et al. [9] referred RSM approach to optimize the tribological assets of seed oil. Tribological investigation was carried out utilizing a pin-on-disc machine. Statistical modeling of specific wear parameter and Coefficient of friction variable has also been performed using trial data.

Rajendhran et al. [10] presented tribological behaviour of lubricant in combination with Ni-promoted MoS_2 particles. The results show that Ni and MoS_2 nanosheets have superior dispersibility and are better lubricant additives for high pressure zones.

Laad et al. [11] conducted an experimental study on engine oil in combination with TiO_2 nano particles by utilizing Pin-on-disc instrument. The analysis represented an important enhancement in the antiwear volume loss & antifriction outcomes of lubricant. The Cu nanoparticles have been studied as wear and friction changing Add-ons in oil [12,13]. Mohammad Hemmat Esfe et al. [14] have studied viscosity outcome of MWCNT and Zno particles in 5W50 oil. The viscosity of modified oil has been predicated by mathematical model developed by referring RSM method. The addition of nanoparticle combination in engine oil reduces damages in engine at cold start condition.

Jia et al. [15] proposed Cu/MoS_2 nanocomposites and analyzed tribological assets as oil additives. The experimental findings shown that the finest concentration of nanoparticles is 0.5 wt. %, & typical COF and wear scar were decreased by significant percentage matched with another additive in studied oils, respectively. Furthermore, dispersing graphene-based nanocomposites into base lubricants found strong antifriction and antiwear effects. Luo et al. [16] studied the lubrication qualities of Al_2O_3/TiO_2 nanocomposites as lubricant additives and found that nanocomposites have better tribological performances than pure Al_2O_3 or TiO_2 nanoparticles.

M. Sgroi et al. [17] have studied friction outcome for engine oil mixed with IF-MoS_2. The experimental study presented the characterization of nano oil using bench test apparatus, also techniques and methods like TEM & XPS has been by author for further study.

Song et al. [18] prepared MoS_2/graphene (MoS_2/G) composite add-ons and studied tribological outcomes. The analysis showed that MoS_2/G nanocomposites can improve antifriction and antiwear properties.

Zhao et al. [19] proposed sandwich-like nanoparticles of Mn_3O_4 additive & graphene sheets by specific synthesis technique. The examination represented that the COF and wear depth were decreased significantly in comparison with studied oil. Suryawanshi and Pattiwar [20] investigated friction outcomes and wear outcomes of TiO_2 nano additive in oil by conducting a trial on a Fourball tester. The MEA and DEE have been used as add-on in SI engine consuming waste lubricant blends [21]. The investigation results showed that a growth in efficiency & decline in fuel depletion realized with oil in combination with MEA, Also reduction in smoke and emissions is observed. The DEE effectively reduced the NO_x emission of engine.

The Response surface method based experimentation has been conducted by the author to produce a mathematical model amongst parameters such as specific wear rate, friction, speed of rotation, concentration % & considered load [22]. J.L. Viesca et al. [23] investigated the lubrication outcomes of an ionic liquid employed as a polar oil additive. The investigation results revealed that all lubricant samples had a similar coefficient of friction; nevertheless, various wear outcomes were discovered at different loads. This examination does not investigate the influence of temp. & gliding speed on lubricant wear and friction characteristics. Rozita Monsef et al. [24] have reported use of Ultrasound technique for synthesis of nano catalyst. Also many methods were stated for determination of purity. Atefeh Panahi et al. [25] have stated the application of sonochemical technique in nanocomposites synthesis. S. Baskar et al. [26] have studied friction and wear nature of bearing for different lubricants. The experimental findings shown lesser COF for CMRO mixed with nano copper oxide as compared to reaming oils.

The literature reported more studies on engine oil using instruments like Pin on disc Tribometer, Fourball tester, SEM etc. however only few literatures has addressed on effect of additive on gearbox oil [26,27].

The researchers have studied the effect of an ionic fluid as an additive on gear oil using a tribometer instrument, but decline in friction factor was not significant in the analysis [6]. In some of a cases an investigators have used combination of modified surfaces and advanced nanoparticles in order to reduce the friction and wear within contacting surfaces [28]. Also some of researchers have consumed single nanoparticles and customized surfaces to tackle lubrication complications in gearboxes like overheating, wear and friction but has not investigated the effect of composite additives in gearbox oil.

Hence an effect of composite add-ons and their blends such as ($Al_2O_3/SiO_2/ZrO_2$) and ZDDP on the lubricating behaviour of gear oil in several conditions like changing load, concentration, speed was tested in this work. As per the previous literature survey, a combination of ($Al_2O_3/SiO_2/ZrO_2$) and ZDDP have not been investigated in gear lubricant for stated working condition. As well as the predicator for performance of oil have not been developed for the gear EP oil.

2. EXPERIMENTAL DETAILS AND METHODOLOGY

The main lubricant under testing is gear extreme pressure 220 oil. It is industrial gear oil established to protect parts in wear condition for closed gears working under high speed and loads. Gear EP Lubricant chemical properties are showed in Table 1. AISI 420 C steel balls were tested against AISI 52100 steel discs.

Table 1. Gear oil chemical properties.

S. No	Properties	Value
1	ISO Grades	220
2	Flash Point in (°C, COC)	256
3	Pour Point in (°C)	-15
4	Viscosity - 40°C in (mm^2/s)	206.09
5	Viscosity -100°C in(mm^2/s)	19.61
6	Density at 15°C in g/cm^3	0.856
7	AGMA	5EP

The composite nanoparticles in this experimentation are commercially availed blend from US Research Nanomaterials incorporation USA. The density of $Al_2O_3/SiO_2/ZrO_2$ composite nanoparticles is 0.458 g/cm^3. The core constituents of these composite nanoparticles are Al_2O_3 and SiO_2. Table 2 lists the chemical characteristics of composite nanoparticles. According to literature study [16], Al_2O_3 based composite additives greatly reduced friction and wear parameters at 0.1 wt. % concentration when compared to single nano particles, hence the Al_2O_3 based composite additives were chosen in this experimental study. The Zinc dialkyl dithiophosphate based nano additive demonstrated significant effect on wear & friction reducing properties [29]. Also, In order to diminish the dominance of Sio_2 from studied oil the Zinc dialkyl dithiophosphate liquid has been used in this experimental study which availed from Afton Chemical, India.

Table 2. Chemical and physical properties of composite nano add-on.

Chemical / Physical properties	Value
Colour	White
Nanoparticle Size in nm	500
PH	5-7
Reduction of weight on ignition	0.8
Reduction of weight on drying	018
Specific Surface Area in m2/g	4.83
Chemical Content	Zirconium oxide-15 %, Aluminum Oxide -34 % Silicon Dioxide- 50 %

At 0.005 percent weight, 0.0125 percent weight, & 0.02 percent weight, the composite nanoparticles and zinc dialkyl dithiophosphate liquid were added to the gear extreme pressure 220 oil.

A precision electronic scale is used to precisely weigh the required quantity of composite nanoparticles, which is then blended in gear extreme pressure 220 oil. A magnetic stirrer is used for mixing composite nanoparticles homogeneously in the gear extreme pressure 220 oil as shown in figure 1. Stirring is a method used in mixers to achieve homogeneous mixtures and (or) to increase heat and mass exchange. Liquids and bulk solids are combined in line with the condition of matter aggregation. The time of blending was set as 30 minutes to make a stable blend. While mixing a nanoparticle in oil, speed setting has set medium & temperature is varied between 60^0c to 80^0c to maintain circular motion of a needle in lubricant suspension. The light passing influence is referred to examine the dispersion capability of additive particles in the KIXX gear EP 220 oil. Table 3 lists the physical characteristics of Zinc dialkyl dithiophosphate.

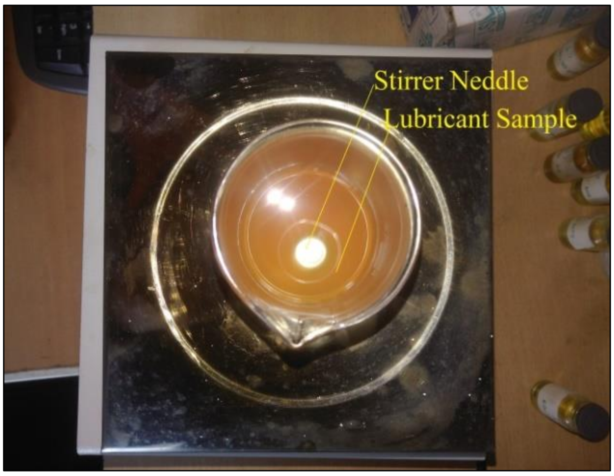


Fig. 1. Magnetic stirrer instrument.

Table 3. Physical and chemical properties of zinc dialkyl dithiophosphate.

Chemical / Physical properties	Value
APS	Liquid
Purity	90%
Bulk Density in g/cm^3	1.12
Solubility	Insoluble in water
Odor	Sugary Perfumed

The Pin on disc tribometer includes assembly of a spindle, loading lever, and sliding plate as shown in figure 2. It is also provided with wear and friction force sensors on a base plate. It includes assembly of a spindle, loading lever and sliding plate. The structure of the instrument base unit is robust and it absorbs the whole force generated during experimentation and hence reduces vibration. The disc is fastened to a holder rested on a spindle assembly which is driven by using a motor. The pin is attached to a holder rested on the freely hanging and well-balanced loading lever. The test load is imparted on a pin or ball via dead weights. A fixed pin and rotating disc produce a tangential force or force of friction that is transmitted through a load lever to a load cell. Wear at a contact region of a pin & disc will move a LVDT sensor that investigates compound wear. Wear and friction investigations are in real-time. A Tribometer is governed by Lab view-based WinDucom software that also obtains and shows a friction force, COF, speed, and inline wear.

Fig. 2. Pin on disc instrument.

The specifications of the instrument referred for test on Pin on the disc are shown in Table 4.

Table 4. Specification of pin on disc machine.

Specimen	Pin size- (diameter in mm) 3, 6, 8 and 10
	Material -EN8 Steel
	Ball Size -(diameter in mm) 4, 6, 8 and 10
Wear disc size	Diameter -165 mm
	Thickness- 8 mm
	Material- EN 31 hardened
Diameter of the wear track	Minimum 50 mm, maximum 135 mm in 2 mm increments
Normal load	Minimum 1 kg, maximum 20 kg dead weights in 0.5-kilogramme increments
Force of friction	0 N minimum, 200 N maximum 0.1 N is the lowest count.
Wear	Minimum 0 μm, maximum 2000 μm, Least Count 1μm
Overall dimensions	620 × 600 × 850 mm
Height of the base plate	700 mm
Maximum height	240 mm
Length of the loading lever	400 mm
Disc speed sensor	Proximity sensor
Friction force sensor	Beam type load cell
Wear sensor	LVDT
Electricity	220 v × 1ϕ × 50 Hz

There are several independent factors like normal load and composite nanoparticles concentration wt. % and sliding speed have a large effect on wear loss and friction coefficient. On the other hand, investigating an influence of a single parameter on volume loss and COF is a time-taking procedure. Thus Response Surface Methodology (RSM) with 3 significant input variables i.e. normal load, composite nanoparticles concentration wt. % and gliding velocity is utilized to examine the impact of these factors on wear & friction. The RSM can jointly consider the appropriate levels of input parameters for finding the optimum figures of volume loss and friction. The Box-Behnken approach is referred to investigate the influence of discrete and connected input variables on wear volume loss and friction coefficient.

The numerical coded levels of 3 main variables are listed in Table 5. In Table 5, (-1), (0), and (+1) represent a minimum level, middle level & maximum level correspondingly for each variable. The suggested combinations of experiments of independent input variables are shown in Table 6.

Table 5. Specification of pin on disc machine.

Levels Coding	-1	0	1
Load in N	60	80	100
Concentration wt. %	0.005	0.0125	0.02
Sliding velocity in m/s	0.65	1.05	1.5

Table 6. Design of experiment using response surface methodology.

Load in N	Concentration wt. %	Sliding velocity in m/s	Weight loss in (g)
100	0.02	1.075	0.006751
80	0.0125	1.075	0.004653
60	0.0125	0.65	0.003672
80	0.02	1.5	0.006005
80	0.0125	1.075	0.004653
60	0.02	1.075	0.004695
80	0.0125	1.075	0.004653
80	0.02	0.65	0.004867
60	0.0125	1.5	0.004875
80	0.005	1.5	0.005301
100	0.0125	0.65	0.006268
80	0.0125	1.075	0.005399
80	0.005	0.65	0.004803
100	0.005	1.075	0.006218
80	0.0125	1.075	0.004653
60	0.005	1.075	0.00454
100	0.0125	1.5	0.00676

The experimental results are analyzed using regression model for volume loss and friction coefficient. It is formed by several independent variables of tribological variables. The regression constants for linear, quadratic, and interaction terms are β_i, β_{ii}, and β_{ij} respectively. β_0 is constant and Yi is a non-independent variable.

$$O_R = \beta_0 + \sum_{i=1}^{n} \beta_i Y_i + \sum_{i=1}^{n} \beta_{ii} Y_i^2 + \sum_{i=1}^{n} \beta_{ij} Y_i Y_j + \in \quad (1)$$

3. MATHEMATICAL MODEL DEVELOPMENT

The mathematical model includes the interaction of linear and quadratic coefficients and this evaluation is implemented by ANOVA. The F-test is considered to obtain relations amongst output and input parameters. Each numerical value of a model has been investigated to estimate the degree of fit using a p-value of 0.05. The numerical figure of Adjusted R-square, R square Predicted, and R adequate accuracy of the mathematical model is inspected to evaluate the merits of the proposed model.

An ANOVA examination recommends that a quadratic and linear model relates with examination records appropriately well for the investigated output variables. Based on the experimental results, the proposed quadratic mathematical models for wear loss and linear models for COF are shown by Equations (2) & (3), respectively.

The F-test approach is referred to investigate the significance of every single term in the developed model. Greater F constant value shows that variation in yield can be described by an established mathematical model.

$$\text{Wear volume loss} = -0.073765 + (0.003527\times A) - (4.03685\times B) + (0.527665\times C) + (0.009786\times A\times B) - (0.002343\times A\times C) + (0.190498\times B\times C) + (0.000037\times A^2) + (158.51852\, B^2) - (0.092198\times C^2) \quad (2)$$

$$COF = 0.014474 + (0.000826\times A) + (0.513008\times B) + (0.00494\times C) \quad (3)$$

The p-value lesser than 0.05 shows that produced mathematical equation and factors are significant. The ‘R^2’ value for wear loss shows a fraction of overall modification in an output anticipated by an established mathematical model and 0.9934 intended for the quadratic regression equation approves a significant fit to experimental data. The numerical figure of 'R Square adjusted' for a proposed model equation is 0.99 which is as well large and shows a respectable relationship between anticipated and trial-based values.

The 'R square predicted' value for a current model equation is 0.8831. The 'R^2' value for COF is found as 0.984 which shows the model is reliable and significant. The 'R^2' value for COF shows a fraction of overall modification in an output anticipated by an established mathematical model and 0.8734 intended for the linear regression equation approves a significant fit to experimental data.

Table 7. ANOVA results for wear loss.

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	0.4261	9	0.0473	286.16	< 0.0001	Significant
A-Load	0.3442	1	0.3442	2080.13	< 0.0001	
B-Concentration	0.0008	1	0.0008	5.11	0.0372	
C-Sliding velocity	0.0666	1	0.0666	402.59	< 0.0001	
AB	0	1	0	0.1621	0.6923	
AC	0.0048	1	0.0048	28.76	< 0.0001	
BC	4.59E-06	1	4.59E-06	0.0277	0.8697	
A^2	0.0013	1	0.0013	7.74	0.0128	
B^2	0.0004	1	0.0004	2.2	0.1566	
C^2	0.0017	1	0.0017	10.05	0.0056	
Residual	0.0028	17	0.0002			
C or Total	0.4289	26				

Table 8. ANOVA results for COF.

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	0.0053	3	0.0018	52.87	< 0.0001	Significant
A-Load	0.0049	1	0.0049	147.92	< 0.0001	
B-Concentration	0.0003	1	0.0003	8.31	0.0084	
C-Sliding velocity	0.0001	1	0.0001	2.39	0.136	
Residual	0.0008	23	0			
C or Total	0.006	26				

The p-value and F-constant values of a calculated model established aimed at friction coefficient suggested that interactions AC, AB, BC, C^2 and B^2 are not significant; however, entirely further terms showed significance. The numerical figures of statistical mathematical coefficients, 'R-square', 'adjusted R-square' and 'predicted R -square', for a linear statistical model (Eq. 3) provide awareness of the precision and accuracy of a proposed mathematical model. Furthermore, a Regression coefficient is presented in Table 7 and Table 8. Taking all of the relevant information into consideration, it is possible to determine that a quadratic mathematical equation is the most significant mathematical model for wear volume loss and linear for COF among the models considered.

3.1 Results and discussion

A testing of tribological variables like COF, Wear volume loss in base lubricant and mixed gearbox lubricant with composite nanoparticle is studied. The wear and friction trails are conducted on Pin on disc test apparatus according to G-99 standard. Tests are completed at loads 60 N, 80 N, and 100 N respectively for sliding velocity - 0.65 m/s, 1.075 m/s, and 1.5 m/s over a sliding distance of 2000 meters each. The experimental analysis of lubricant is conducted for several concentrations of nanoparticles namely 0.005 weight %, 0.0125 weight %, & 0.02 weight % in grouping with 1 wt. % of Zinc dialkyl dithiophosphate.

For each trial, a force of friction amongst pin and disc is calculated by using a load type cell attached to a plate at a space equal to the space amongst Pivot and specimen.

Figure 3 displays the COF as a relational function of sliding velocity in m/s of AISI 52100 steel discs touching AISI 420 C steel balls oiled with extreme pressure gearbox oil and gearbox oil mixed with composite nanoparticles.

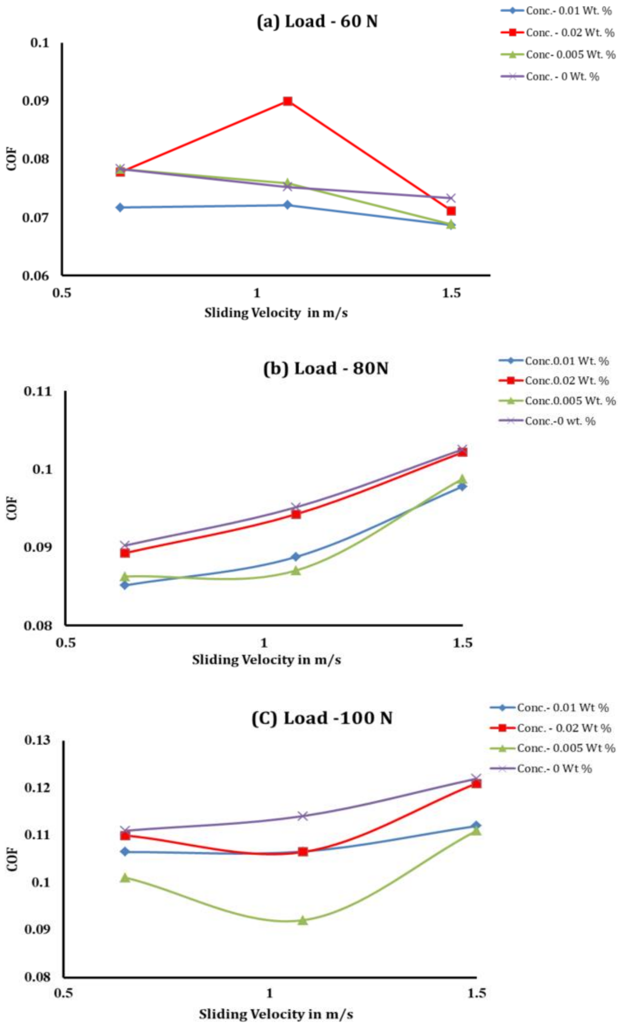


Fig. 3. Friction behaviour for (a) 60N load (b) 80N load (c) 100N load.

The least value of the COF is observed for concentration 0.01wt. % of the composite additive at load 60N at a slipping velocity of 1.5 m/s as shown in figure 3(a). At load 60N, EP lubricant + composite nanoparticles demonstrated a smoother drop in COF from 0.65 to 1.08 m/s sliding velocity, with a dramatic reduction between 1.08 and 1.5 m/s. Gear EP lubricant presented the lowest friction coefficient at a slipping velocity of 0.65 m/s and 1.5 m/s for 60N load. The behaviour of friction coefficient with velocity in m/s at normal load 80 N for gear EP lubricant and gear EP lubricant with composite nano additive is shown in figure 3(b). The COF of steel oiled with gear lubricant have advanced values as compared to steel oiled gear lubricant mixed with a composite nano additive. Figure 3(b) showed that the lowest numerical value of the COF is observed at 0.65 m/s for 0.01 wt. % to 0.02 wt. % concentrations respectively at 80N load condition. Gear lubricant + composite nano additive presented smoother variation in coefficient of friction from 0.65 m/s to 1.5 m/s velocities at normal load 80 N. Figure 3(c) depicts the fluctuation of the COF with varying sliding velocity under 100 N load conditions. It is detected that as the concentration of composite nanoparticles decreases, the friction coefficient reduces gradually, takes a lesser value at 0.005wt. %, sliding velocity 1.08 m/s under 100 N normal load and then slightly increases for sliding velocity 0.65 to 1.5 m/s.

The wear volume loss for gear lubricant and Gear lubricant with composite nano additive for various sliding velocities, load and concentration wt. % is reported in figure 4. The wear loss of ΔV of a pin specimen for each trial is calculated as under,

$$\Delta V = \frac{w_1 - w_2}{\rho} \tag{4}$$

Where, ρ is the density of the sample, w_1 is the wt. of the sample before conducting a trials, w_2 is the wt. of the sample after a trial. Wear loss as a function of slipping velocity in m/s was also investigated and is shown in figure 4(a-c). Lesser wear volume loss of steel material was observed at velocities 0.65 and 1.08 m/s under 60N normal load. But, a changeover from minor to volume loss is observed from 1.08 to 1.5 m/s. This changeover is particularly severe once composite additives don't exist in a gear lubricant.

Figure 4(b) Illustrates that under a load of 80 N, a smaller volume loss was observed at a slipping velocity of 0.65 m/s. EP lubricant + composite nanoparticles presented a drastic increment in wear volume loss from 0.65 to 1.08 m/s & a smoother variation was seen between 1.08 & 1.5 m/s at concentration 0.005 wt. %.

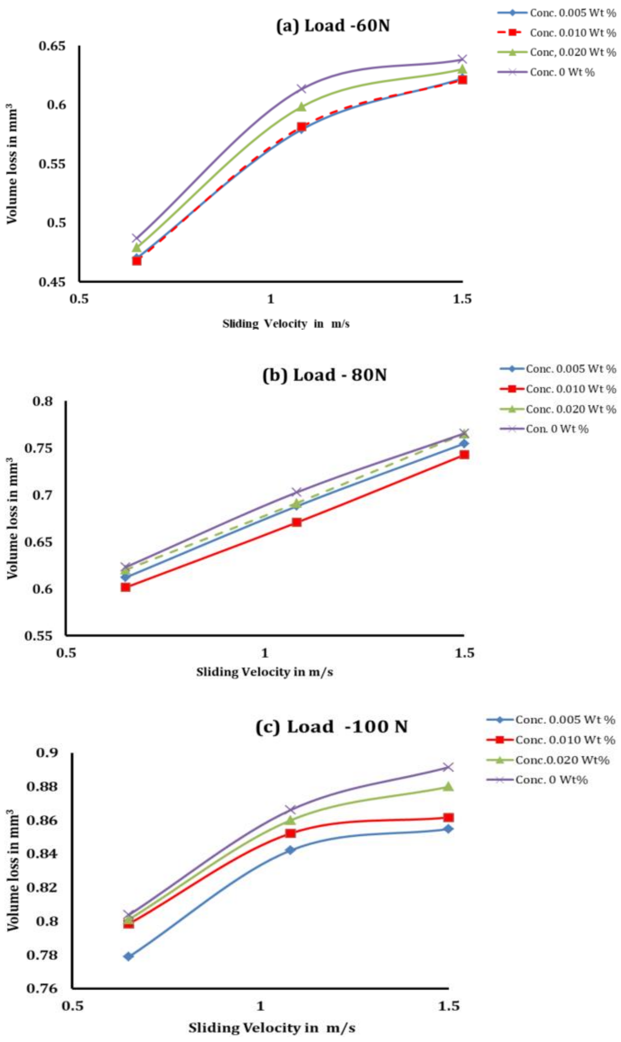


Fig. 4. Wear volume loss for (a) 60N load (b) 80N load (c) 100N load.

Figure 4(c) shows the variation of wear volume loss in mm^3 with various velocities under 100 N normal load conditions. It is noticed that as the concentration of composite nano additive declines, volume loss reduces gradually, showing a lesser value at 0.005 wt.%, for all sliding velocity combinations under 100 N normal loads.

The distinct influence of concentration, load and sliding velocity and their collective influence on wear loss is shown in Figure 5. The perturbation graph shows the influence of all the aspects at a specific point in the studied design space. From plot it is clear seen that as the load raises a wear volume loss also get rises. Figure 6 shows the normal Residual plot of linear models for Wear volume loss.

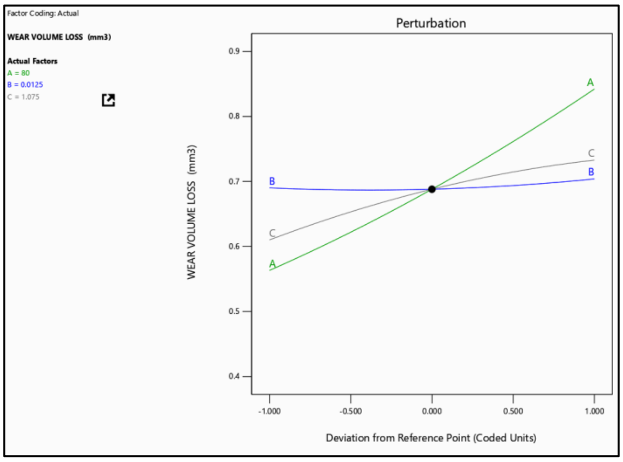


Fig. 5. Perturbation plot for wear parameter.

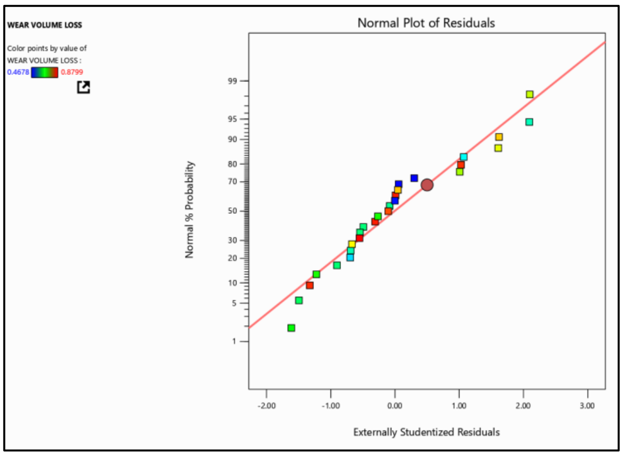


Fig. 6. Normal residual plot for wear parameter.

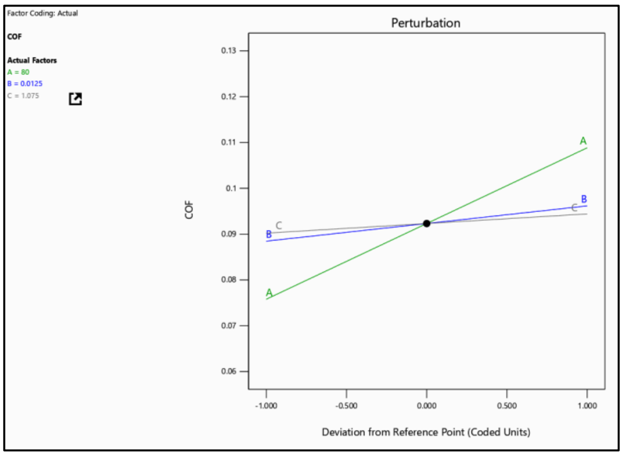


Fig. 7. Perturbation plot for COF.

The individual influence of concentration, load & sliding velocity and their shared influence on COF is shown in Figure 7. From figure 7 it is easily realized that as the load increases a COF get increases.

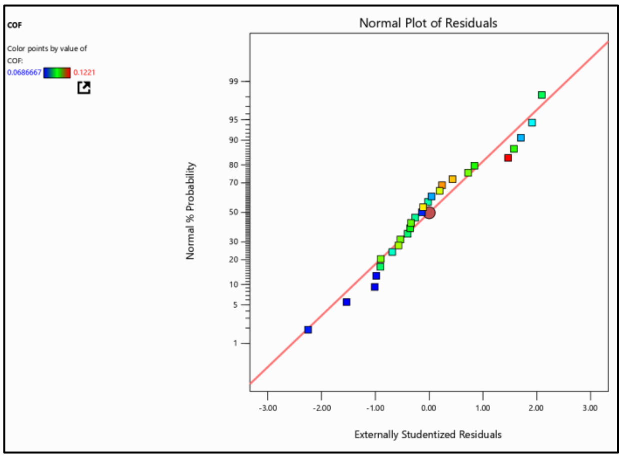


Fig. 8. Normal Residual plot for COF.

Figure 8 shows the normal Residual plot of linear models for COF. The Residual plots for Wear volume loss & COF revealed that the residuals drop on a straight line denoting that the errors are normally distributed.

4. DEVELOPMENT OF PREDICTOR

The lubricant predicator is developed by using a VB script language. In this predicator the Forms & control buttons are the basic building blocks of predicator GUI.

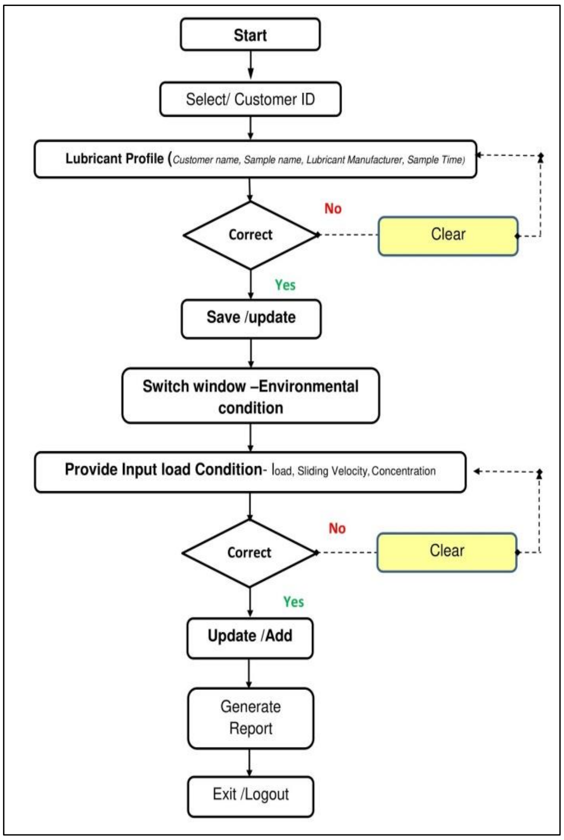
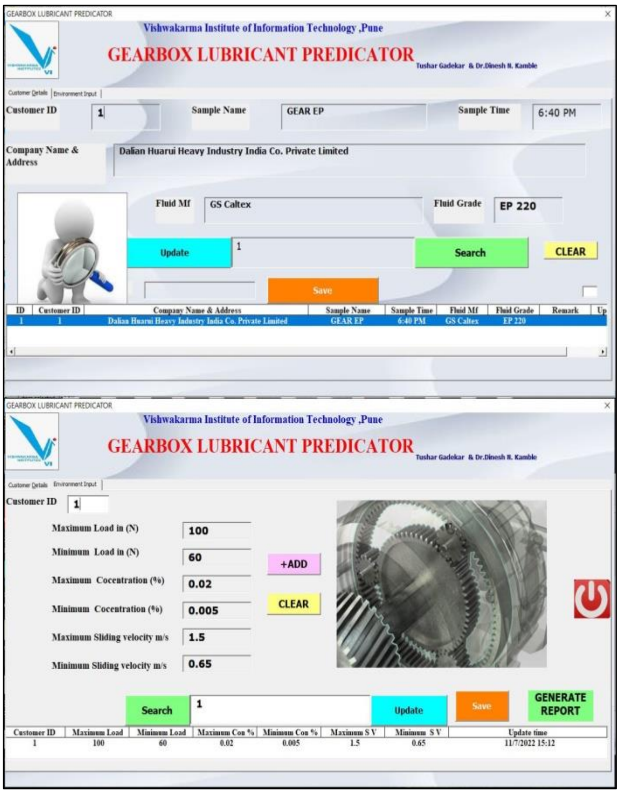


Fig. 9. Flowchart of predicator.

The Forms in predicator are objects to expose their properties to define their appearance. The methods that define the behaviour and the events define their interaction with the user. The properties of the form can be set, and VB code can be written to react to the form's events. The flowchart of predicator is shown in figure 9.

Controls are contained objects. Each type of control has a unique set of features that make it suitable for a specific task, including properties, methods, and events. The following steps and elements are used in the design of user interface.

Step 1 - Activate Developer Tab in Excel & Visual Basic Option
Step 2 - Create User Form
Step 3 - Create Frames
Step 4 - Create Command Button & Labels
Step 5 - Create List Box
Step 6 – Generate report



Customer ID 1
Sample Name GEAR EP
Sample Time 6:40 PM
Company Name & Address Dalian Huarui Heavy Industry India Co. Private Limited
Fluid Mf GS Caltex
Fluid Grade EP 220

ID	Customer ID	Company Name & Address	Sample Name	Sample Time	Fluid Mf	Fluid Grade	Remark	Up
1	1	Dalian Huarui Heavy Industry India Co. Private Limited	GEAR EP	6:40 PM	GS Caltex	EP 220		

Customer ID 1
Maximum Load in (N) 100
Minimum Load in (N) 60
Maximum Cocentration (%) 0.02
Minimum Cocentration (%) 0.005
Maximum Sliding velocity m/s 1.5
Minimum Sliding velocity m/s 0.65

Customer ID	Maximum Load	Minimum Load	Maximum Con %	Minimum Con %	Maximum S V	Minimum S V	Update time
1	100	60	0.02	0.005	1.5	0.65	11/7/2022 15:12

Fig. 10. Lubricant predicator.

The lubricant predicator with various windows shown in figure 10. In lubricant Predictor first window has been developed in order to facilitate the input of customer information to user. The Second window in Lubricant predicator is developed to insert input as per the customer's requirement & as per working condition.

Table 9. ANOVA results for wear loss.

Load	Concentration	Velocity	Experimental	Predicated	Error %	Experimental	Predicated	Error %
			Wear Volume loss			COF		
100	0.0125	1.5	0.8617	0.8696	-0.9	0.112	0.1096	2.2
80	0.02	1.5	0.765	0.7521	1.7	0.1021	0.0982	4.0
60	0.0125	0.65	0.4678	0.4662	0.3	0.0716	0.0723	-1.0
80	0.005	0.65	0.6118	0.6156	-0.6	0.08625	0.0863	-0.1
100	0.005	1.08	0.8421	0.8479	-0.7	0.1021	0.1049	-2.7
80	0.0125	1.08	0.6704	0.6904	-3.0	0.0887	0.0910	-2.5
60	0.005	1.08	0.5789	0.5693	1.7	0.0816	0.0719	13.5
80	0.02	0.65	0.62	0.6281	-1.3	0.0892	0.0940	-5.1
60	0.0125	1.5	0.621	0.6284	-1.2	0.0686	0.0765	-10.3
100	0.02	1.08	0.86	0.8645	-0.5	0.1140	0.1126	1.2
100	0.0125	0.65	0.7985	0.7871	1.4	0.1065	0.1054	1.0
80	0.005	1.5	0.7545	0.7372	2.3	0.09875	0.0905	9.1
60	0.02	0.65	0.4789	0.4805	-0.4	0.07776	0.0775	0.3
60	0.005	0.65	0.4699	0.4710	-0.2	0.07833	0.0698	12.2
60	0.0125	1.08	0.5555	0.5649	-1.7	0.06912	0.0744	-7.2
60	0.02	1.08	0.5981	0.5800	3.0	0.08999	0.0796	13.0
60	0.02	1.5	0.6301	0.6443	-2.3	0.07112	0.0817	-12.9
60	0.005	1.5	0.6222	0.6323	-1.6	0.06879	0.0740	-7.0
80	0.0125	0.65	0.6012	0.6119	-1.8	0.08512	0.0888	-4.2
80	0.0125	1.5	0.7424	0.7342	1.1	0.09777	0.0930	5.0
80	0.02	1.08	0.6912	0.7075	-2.4	0.09421	0.0961	-2.0
80	0.005	1.08	0.6878	0.6938	-0.9	0.08701	0.0884	-1.6
100	0.0125	1.08	0.8522	0.8455	0.8	0.1044	0.1075	-2.9
100	0.02	0.65	0.8011	0.8053	-0.5	0.11	0.1105	-0.5
100	0.02	1.5	0.8799	0.8894	-1.1	0.1221	0.1147	6.4
100	0.005	0.65	0.7789	0.7899	-1.4	0.1011	0.1028	-1.7
100	0.005	1.5	0.8548	0.8716	-2.0	0.1024	0.1070	-4.3

The comparison in between experimental results and predicated results from developed predicator with error percentage is shown in Table 9. The friction and wear volume loss discovered by the suggested prediction model demonstrated good agreement with the experimental wear volume loss & COF, with a maximum error of 13.5 %, and can be used as predictor tool systems to satisfy the needs of the cost-effective means for prediction.

5. CONCLUSION

The Anti-wear and Anti-friction things are enriched for gearbox oil functioning with composite nanoparticles $Al_2O_3/SiO_2/ZrO_2$ in combination with Zinc dialkyl dithiophosphate. The experimental tribological study shows 15.62 % decrease in wear volume loss in the steel with composite nano additive as compared to base lubricant. The Pin on disc tester showed a 20.6 % drop in coefficient of friction for gear EP oil mixed with $Al_2O_3/SiO_2/ZrO_2$ composite nanoparticles + Zinc dialkyl dithiophosphate as equated to base gear lubricant. The lesser value of a coefficient of friction (0.06877) was detected at 0.010 wt. % of $Al_2O_3/SiO_2/ZrO_2$ composite particles in blend with 1 wt. % of Zinc dialkyl dithiophosphate under a load of 60 N at 1.5 m/s sliding velocities. The minimum value of wear volume loss (0.4678) is observed at 0.01 wt. % of $Al_2O_3/SiO_2/ZrO_2$ composite particles + 1 wt. % Zinc dialkyl dithiophosphate under a load of 60 N at 0.65 m/s sliding velocities.

The friction and wear volume loss obtained by the proposed prediction model shows a good agreement with maximum error 13.5 % with experimental wear volume loss and COF. This can be adopted as predication soft tool to meet the needs of the cost-effective means for prediction.

REFERENCES

[1] W. Teng, X. Ding, X. Zhang, and Z. Ma, “Multi-fault detection and failure analysis of wind turbine gearbox using complex wavelet transform,” *Renewable Energy*, vol. 93, pp. 591–598, Aug. 2016, doi: 10.1016/j.renene.2016.03.025.

[2] W. Teng, Y. Huang, L. Song, and Z. Ma, “Fault detection of planetary subassemblies in a wind turbine gearbox using TQWT based sparse representation,” *Journal of Sound and Vibration*, vol. 490, p. 115707, Jan. 2021, doi: 10.1016/j.jsv.2020.115707.

[3] K. Holmberg and A. Erdemir, “Influence of tribology on global energy consumption, costs and emissions,” *Friction*, vol. 5, no. 3, pp. 263–284, Sep. 2017, doi: 10.1007/s40544-017-0183-5.

[4] H. M. Mobarak *et al.*, “The prospects of biolubricants as alternatives in automotive applications,” *Renewable & Sustainable Energy Reviews*, vol. 33, pp. 34–43, May 2014, doi: 10.1016/j.rser.2014.01.062.

[5] F. Sundus, M. A. Fazal, and H. H. Masjuki, “Tribology with biodiesel: A study on enhancing biodiesel stability and its fuel properties,” *Renewable & Sustainable Energy Reviews*, vol. 70, pp. 399–412, Apr. 2017, doi: 10.1016/j.rser.2016.11.217.

[6] R. A. Monge *et al.*, “Ionic liquids as an additive in fully formulated wind turbine gearbox oils,” *Wear*, vol. 328–329, pp. 50–63, Apr. 2015, doi: 10.1016/j.wear.2015.01.041.

[7] C. Fernandes, P. M. T. Marques, R. C. Martins, and J. Seabra, “Gearbox power loss. Part II: Friction losses in gears,” *Tribology International*, vol. 88, pp. 309–316, Aug. 2015, doi: 10.1016/j.triboint.2014.12.004.

[8] E. Cigno, C. T. Magagnoli, M. S. Pierce, and P. Iglesias, “Lubricating ability of two phosphonium-based ionic liquids as additives of a bio-oil for use in wind turbines gearboxes,” *Wear*, vol. 376–377, pp. 756–765, Apr. 2017, doi: 10.1016/j.wear.2017.01.010.

[9] Y. Singh, P. Singh, A. Sharma, P. Choudhary, A. Singla, and N. K. Singh, “Optimization of wear and friction characteristics of Phyllanthus Emblica seed oil based lubricant using response surface methodology,” *Egyptian Journal of Petroleum*, vol. 27, no. 4, pp. 1145–1155, Dec. 2018, doi: 10.1016/j.ejpe.2018.04.001.

[10] N. Rajendhran, S. Palanisamy, A. P. Shyma, and V. Rajendran, “Enhancing the thermophysical and tribological performance of gear oil using Ni-promoted ultrathin MoS 2 nanocomposites,” *Tribology International*, vol. 124, pp. 156–168, Aug. 2018, doi: 10.1016/j.triboint.2018.03.030.

[11] M. Laad and V. K. S. Jatti, “Titanium oxide nanoparticles as additives in engine oil,” *Journal of King Saud University: Engineering Sciences*, vol. 30, no. 2, pp. 116–122, Apr. 2018, doi: 10.1016/j.jksues.2016.01.008.

[12] M. Scherge, R. Böttcher, D. Kürten, and D. Linsler, “Multi-Phase friction and wear reduction by Copper nanoparticles,” *Lubricants*, vol. 4, no. 4, p. 36, Oct. 2016, doi: 10.3390/lubricants4040036.

[13] F. L. G. Borda, S. J. R. De Oliveira, L. Lazaro, and A. J. K. Leiroz, “Experimental investigation of the tribological behavior of lubricants with additive containing copper nanoparticles,” *Tribology International*, vol. 117, pp. 52–58, Jan. 2018, doi: 10.1016/j.triboint.2017.08.012.

[14] M. H. Esfe, A. A. A. Arani, and S. Esfandeh, “Improving engine oil lubrication in light-duty vehicles by using of dispersing MWCNT and ZnO nanoparticles in 5W50 as viscosity index improvers (VII),” *Applied Thermal Engineering*, vol. 143, pp. 493–506, Oct. 2018, doi: 10.1016/j.applthermaleng.2018.07.034.

[15] X. Jia, J. Huang, Y. Li, J. Yang, and H. Song, “Monodisperse Cu nanoparticles MoS_2 nanosheets as a lubricant additive for improved tribological properties,” *Applied Surface Science*, vol. 494, pp. 430–439, Nov. 2019, doi: 10.1016/j.apsusc.2019.07.194.

[16] T. Luo, X. Wei, H. Zhao, G. Cai, and X. Zheng, “Tribology properties of Al_2O_3/TiO_2 nanocomposites as lubricant additives,” *Ceramics International*, vol. 40, no. 7, pp. 10103–10109, Aug. 2014, doi: 10.1016/j.ceramint.2014.03.181.

[17] M. F. Sgroi *et al.*, “Friction reduction benefits in Valve-Train system using IF-MOS_2Added engine oil,” *Tribology Transactions*, vol. 58, no. 2, pp. 207–214, Dec. 2014, doi: 10.1080/10402004.2014.960540.

[18] W. Song, J. Yan, and H. Ji, “Fabrication of GNS/MoS_2 composite with different morphology and its tribological performance as a lubricant additive,” *Applied Surface Science*, vol. 469, pp. 226–235, Mar. 2019, doi: 10.1016/j.apsusc.2018.10.266.

[19] J. Zhao, Y. Li, Y. He, and J. Luo, “In situ green synthesis of the new sandwichlike nanostructure of MN_3O_4/Graphene as lubricant additives,” *ACS Applied Materials & Interfaces*, vol. 11, no. 40, pp. 36931–36938, Jul. 2019, doi: 10.1021/acsami.9b08993.

[20] S. R. Suryawanshi and J. T. Pattiwar, “Effect of TiO_2 Nanoparticles Blended with Lubricating Oil on the Tribological Performance of the Journal Bearing,” *Tribology in Industry*, vol. 40, no. 3, pp. 370–391, Sep. 2018, doi: 10.24874/ti.2018.40.03.04.

[21] B. Pappula, P. Periyasamy, R. K. Chaitanya, and N. K. Geetha, "MEA and DEE as additives on diesel engine using waste plastic oil diesel blends," *Sustainable Environment Research*, vol. 28, no. 3, pp. 142–147, May 2018, doi: 10.1016/j.serj.2018.01.001.

[22] M. H. Sakinah, A. K. Amirruddin, K. Kadirgama, D. Ramasamy, M. M. Rahman, and M. M. Noor, "The application of response surface methodology in the investigation of the tribological behavior of palm cooking oil blended in engine oil," *Advances in Tribology*, vol. 2016, pp. 1–11, Jan. 2016, doi: 10.1155/2016/6545904.

[23] J. L. Viesca *et al.*, "Lubrication performance of an ammonium cation-based ionic liquid used as an additive in a polar oil," *Tribology International*, vol. 116, pp. 422–430, Dec. 2017, doi: 10.1016/j.triboint.2017.08.004.

[24] R. Monsef, M. Ghiyasiyan-Arani, and M. Salavati-Niasari, "Application of ultrasound-aided method for the synthesis of $NdVO_4$ nano-photocatalyst and investigation of eliminate dye in contaminant water," *Ultrasonics Sonochemistry*, vol. 42, pp. 201–211, Apr. 2018, doi: 10.1016/j.ultsonch.2017.11.025.

[25] A. Panahi, R. Monsef, M. K. Imran, A. A. Mahdi, A. A. K. Ruhaima, and M. Salavati-Niasari, "$TmVO_4/Fe_2O_3$ nanocomposites: Sonochemical synthesis, characterization, and investigation of photocatalytic activity," *International Journal of Hydrogen Energy*, vol. 48, no. 10, pp. 3916–3930, Feb. 2023, doi: 10.1016/j.ijhydene.2022.10.226.

[26] S. Baskar, G. Sriram, "Tribological Behavior of Journal Bearing Materia under Different Lubricants," *Tribology in Industry*, vol. 36, no. 2, pp. 127-133, 2014.

[27] M.S. Charoo, M.F. Wani, "Tribological Properties of IF-MoS_2 Nanoparticles as Lubricant Additive on Cylinder Liner and Piston Ring Tribo-pair," *Tribology in Industry*, vol. 38, no. 2, pp. 156-162. Jun. 2016, doi:10.1002/ls.1366

[28] A. Greco, K. Mistry, V. Sista, O. L. Eryilmaz, and A. Erdemir, "Friction and wear behaviour of boron based surface treatment and nano-particle lubricant additives for wind turbine gearbox applications," *Wear*, vol. 271, no. 9–10, pp. 1754–1760, Jul. 2011, doi: 10.1016/j.wear.2010.11.060.

[29] V.N. Bakunin, G. N. Kuzmina, M. Kasrai, O. P. Parenago, and G. M. Bancroft, "Tribological behavior and tribofilm composition in lubricated systems containing surface-capped molybdenum sulfide nanoparticles," *Tribology Letters*, vol. 22, no. 3, pp. 289–296, Jul. 2006, doi: 10.1007/s11249-006-9095-7.