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# A predictive system based on experimental study of lubricant blended with composite additives

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**ABSTRACT**

Friction & wear are main reasons for mechanical failures of heavy loaded gearboxes. However, reformed lubricant can be used to control this. This study investigates the tribological behavior of composite Nano size particles with ZDDP as add-on in EP gearbox oil for various concentrations of composite additive - 0.005, 0.01, 0.02 wt.%. All tests have conducted under variable loads (60 N, 80 N & 100N) & sliding velocities (0.65m/s, 1.05 m/s & 1.50 m/s). The experimental reading on antiwear & antifriction parameters for gear EP oil has been tested on pin on disc instrument. The response surface approach was used to build the experiment's design (DOE), which examined the ideal friction coefficient & wear volume loss in EP 220 Lubricant. Outcomes from the experimental study have been compared for two gear EP oils to indicate influence of various parameters like nanoparticles blend %, load and sliding velocity. It is found that the blending of gear EP oil with composite additives & ZDDP diminishes the wear & COF by 11.98 % and 9.81 % individually under various load & speed working conditions.

**Keywords:** Friction, Wear, Nano Composite, Gearbox oil, ANOVA, Predictor

## 1. Introduction

Gearbox devices and other mechanical systems depend on regularly working through a transfer of various types of energy. A major share of this energy source is vanished because of dynamic parts friction. As well, wear loss is the main reason for the mechanical failures of these heavy devices. Gearboxes and heavy loaded devices need a specific type of lubrication oil to battle with wear, friction, and heat energy losses, as well as to reduce losses and enhance efficiency. Typically 35 million tons of oils for every year are utilized universally to progress the routine of the system. The major part of these oils is mineral oil-based, generated from petroleum products.

Lubricants carry out an important function in lessening of wear loss & friction in contacting bodies. Wear of parts is triggered by a resistant force termed friction, which is generated by the relative motion between links. By inserting a part with lower shear strength between two dynamic faces, friction can be minimized.

The lesser speed shaft in the turbine system requires a gear train to boost a revolution per minute of the output shaft to a particular angular velocity used for the generator. When compared to other components in a system, the wind turbine gear transmission has maximum maintenance budget and the most lost time owing to more breakdowns. One of the most significant challenges of turbine systems is that a finest viscosity & challenging-scuffing qualities of lubricants are acquired on heats higher than $80^0$ C [1]. Wear degradation is a critical matter in these applications as of its effect on energy consumption and repair amounts. Extraordinary class-revised lubrication oil is needed in such systems to avoid the issues. Monge et al. [1] have investigated Ionic fluids as an additional in-gearbox lubricant. In experimentation, both fluids have shown a slight friction-changing behavior but a respectable wear shrinking behavior.

Michael N. Kotzalas & Gary L. Doll [2] have presented a detailed analysis on wind turbine system gearbox & lubrication issues in system. Edward Cigno et al. [3] investigated the capability of fluids as additions in the lubricant for gear systems to lubricate. An inclusion of the ionic fluid addition powerfully decreases track volume damage, especially at higher speeds, and reduces COF.

Pedro M.T. et al. [4] have reported the efficiency of a gearbox used through oil. A study presented that glycol contains lubricant, giving better efficiency than other lubricants. Tribological nature of boron-grounded surface action & add-on intended for gearbox oil [5]. An experimental study showed improvement in mechanical properties & wear resistance, respectively after surface treatment. A. Greco et al. [6] have conveyed contact failures of bearings in turbine power transmission systems. The

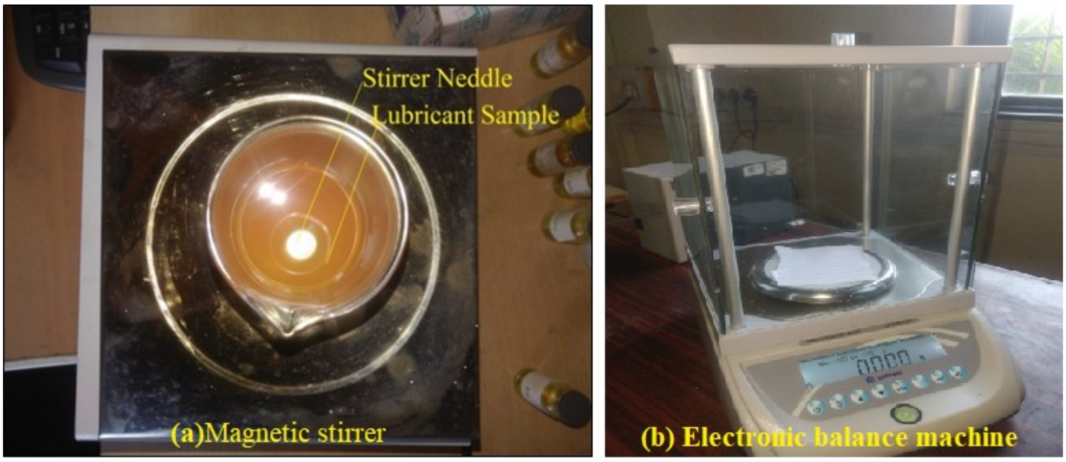


**Figure 1**. *(a)* Magnetic stirrer instrument (b) Electronic balance machine

power defeat in gearbox is stated for rolling type bearings [4, 7]. Naveen Kumar Rajendhran et al. [8] have inspected friction & wear outcome of gear oil in combination with Ni promoted $MoS_2$ Nano additives. The developed combination of Nano additive by the author was good for large pressure areas.

Experimental behavior of IF-$MoS_2$, $MoS_2$ & $WS_2$ as an additive in oil has been studied for engine lubrication. The studied add-ons have reduced wear significantly. Cu particles have been investigated as oil additives that alter wear and friction. [9-14]. An experimental study showed a decline in wear & friction parameters after introduction of Cu nano-additives. Husnawan et al. [15] have established a friction force mathematical model by investigating the behaviour of mineral oil base in combination with palm olein & antiwear add-ons. The RSM has been used in mathematical model development.

Md Jalal Uddin Rumi et al. [16] have predicted wear performance of nano size $Al_2O_3$ composite by using pin on disc. Taguchi and ANOVA approaches have been referred by researchers in order to investigate effect considered parameters on wear. Examination showed tested load expressively affects wear rate. Santwana Mishra & Shipra Aggarwal [17] have critically reviewed an effect of nano oil on behavior of bearing. Nabajit Dev Choudhury et al. [18] have investigated tribological nature of $TiO_2$ mixed Thevetia peruviana & Cucurbita pepo L. blend oils on Fourball. Study revealed that formulated biodegradable blend was good alternative for commercial oil. Ye Zar Ni HTWE et al. [24] have reviewed nanoparticle containing lubricants with composites.

A friction abrasion instrument has been used to test wear and friction behavior of an $Al_2O_3/TiO_2$ Nanocomposite additive in oil [21, 22]. An ultrasonicator instrument has been used for the mixing of nanoparticles in lubricant. An examination represented that a composite combination has improved performance than old a nano additive. Researchers stated that additional studies on engine lubricant with devices like Tribometer and, SEM etc. still limited and have illustrated on end product of Add-on on gearbox lubricant. Also, more investigation completed on effect of single nanoparticles in lubricants but has not explored the influence of composite particles in lubricants. Therefore, the main objective of experimental study is to investigate effect of composite additives in gear EP lubricant under various conditions like load, concentration, & sliding velocity, etc., and to design a predictive system for the performance analysis of oil.

## 2. Experimental details and Methodology

The high pressure gear lubricant utilized in this investigation was acquired from GS Caltex. Table 1 shows the lubricating characteristics. The Gear EP 220 is quality industrial gear oil that is created to safeguard components from wear in closed gears which are subjected to high force and load circumstances. That one also defends from pitting.

**Table 1** Properties of EP lubricant

| S. No | Properties | Value |
|---|---|---|
| 1 | Grade | 220 |
| 2 | Flash Pt. | 256.01 °C |
| 3 | Pour Pt. | -15.0 °C |
| 4 | Viscosity [at $40^0$c], | 206.08 mm$^2$/s |
|  | [at $100^0$c] | 19.61 mm$^2$/s |
| 5 | Density [at 15 $^0$c] | 0.855 g/cm$^3$ |

As per literature survey individually $Al_2O_3$, $SiO_2$ & $ZrO_2$ effectively reduced wear & friction in various working condition & also $Al_2O_3/TiO_2$ Nano composite has performed significantly as compared to simple nanoparticles [16]. Hence, $Al_2O_3/SiO_2/ZrO_2$ Combined nanoparticles were utilized as additives in heavy loaded gear oils -Gear EP 220 in this experiment. Composite nano additives have a density of 0.458 g/cm$^3$. The main components of nanoparticles are Si-Al components, which have to look like a white powder. Table 2 summarizes the chemical, physical, and thermal capabilities of composite nanoparticles.

Wear & friction-dropping capabilities were significantly enhanced by a ZDDP-based nano additive [23]. In this experimental work, the ZDDP liquid has also been utilized to reduce the dominance of $SiO_2$ from the oil being studied.

Table 3 shows properties of ZDDP.

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

| Properties | Value |
|---|---|
| Appearance | White |
| Particle Dimensions | 500.0 nm |
| PH | 5-7 |
| Fall of W.t. for ignition | 0.8 |
| Specific Area in m2/g | 4.83 |

The composite nanoparticles were combined with the gearbox oil at 0.005 %, 0.010 %, and 0.02 % weights in addition to 1.0 % weight of Zinc Dialkyl Dithio Phosphate (ZDDP). Essential amount of nano composites was exactly weighed by an accurate electronic machine, as pointed out in Figure 1(b). As indicated in Figure 1(a), a magnetic stirrer device was used to uniformly combine the additives in the gearbox oil.

**Table 3**. Properties of ZDDP

| Properties | Value |
|---|---|
| APS | Fluid |
| Cleanliness | 90.01% |
| Density | 1.1169 g/cm$^3$ |

Stirring is a technique used in mixers to improve heat and mass exchange and/or create homogenous mixes. Bulk solids and liquids are mixed according to the state of matter aggregation. To create a stable mix, the blending period was set at thirty minutes. The capacity of the add-on particles in Gear Extreme Pressure lubricant to disperse is examined using the light passing influence.

The base plate depicted in Figure 2 houses the tribometer's spindle assembly, load lever assembly, sliding platform assembly (wear track adjustment), and wear and friction force sensors. Because of its sturdy construction, the base unit can absorb all of the force produced during testing, which further lessens vibration.

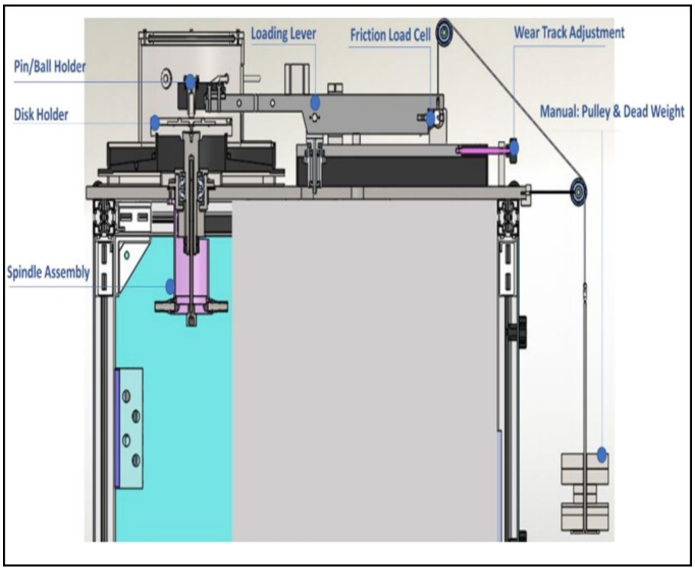


**Figure 2.** Pin on Disc Tribometer

A disc is secured to a holder on the spindle assemblage; it is moved by a servo motor. A holder is fastened to the free-hanging and evenly balanced loading lever, holds the pin or ball in place. The pin or ball is subjected to load through the application of dead weights. Through the loading lever (compression and tension), the friction load cell receives the tangential force or friction force produced by the rotating disc and fixed pin/ball. Wear at the pin/ball/disc interface will shift the wear sensor (linear variable differential transducer) that tracks compound wear. Values for the wear & friction parameters were obtained in actual time. WinDucom® software, which is based on Labview® software, controls the Tribometer and records and shows the linear wear, specimen temperatures, speed, friction force, and friction coefficient. Table 4 displays the details of device that was exercised for testing on a disc's pin.

**Table 4.** Details of Pin on disc Machine

| | |
|---|---|
| Sample | Pin - (dia. in mm) 6, 8 &10 |
| | Material – EN 8 Steel |
| | Sphere -(dia. in mm) 6, 8 and 10 |
| Wear disc size | Dia. -165.0 mm |
| | Thickness – 8.0 mm |
| | Material- EN 31 steel |
| Wear track dia. | 50 mm to 135 mm (2 mm rises) |
| Normal Load | 1.0 kg to 20.0 kg (0.5 increments) |
| Force of friction | 0 N to 200 N |
| Wear | 0 µm to maximum 2000.0 µm |
| General Dimensions | 600 × 620 × 850 mm |
| Disc speed sensor | Proximity type |
| Friction force sensor | Load cell |

Wear loss and friction coefficient are significantly impacted by a number of independent parameters, including sliding speed, normal load, and the weight percentage of composite nanoparticles. Unfortunately, it takes a lot of work to look into how one parameter affects volume loss and COF. Therefore, RSM is considered to investigate effects of three important input variables on wear and friction: normal load, the weight percentage of composite nanoparticles, and gliding velocity. The RSM can jointly determine the ideal values of friction and volume loss by taking into account the proper levels of input parameters.

The Box-Behnken method is used to examine how linked and discrete input variables affect the friction coefficient & wear volume loss. Table 5 lists numerically coded levels of the three primary variables. For each

$$O_R = \beta_0 + \sum_{i=1}^{n} \beta_i Y_i + \sum_{i=1}^{n} \beta_{ii} Y_i^2 + \sum_{i=1}^{n} \beta_{ij} Y_i\, Y_j + \epsilon \tag{1}$$

$$\text{Wear Volume loss} = -0.073764 + (0.003526 \times X) - (4.03684 \times Y) + (0.527664 \times Z) + (0.009785 \times X \times Y) - (0.002344 \times X \times Z) + (0.190499 \times Y \times Z) + (0.000036 \times X^2) + (158.51851 \times Y^2) - (0.092199 \times Z^2) \tag{2}$$

$$\text{COF} = 0.014474 + (0.000825 \times X) + (0.513009 \times Y) + (0.00493 \times Z) \tag{3}$$

variable in Table 5, the values (-1), (0), and (+1) denote the minimum, middle, and maximum levels, respectively. Table 6 displays the recommended combinations of independent input variable trials.

**Table 5.** Input Variables levels

| Codes | -1 | 0 | 1 |
|---|---|---|---|
| Load (N) | 60.0 | 80.0 | 100.0 |
| Concentration % | 0.005 | 0.0125 | 0.02 |
| Sliding velocity (m/s) | 0.65 | 1.05 | 1.5 |

This experimentation started with setup of the test that includes cleaning of machine parts using acetone solution and measuring the weights of pin and disc sample by using a high precision weight machine. After that Sample pin and disc is clamped on to the machine by using Jaws and clamps ensuring correct size of clamp for setup. Subsequently, wear track diameter is set on disc by using Allen key.

**Table 6.** Experiment space as per RSM

| Load (N) | Concen. (%) | Sliding Velocity (m/s) |
|---|---|---|
| 80 | 0.0125 | 1.075 |
| 60 | 0.0125 | 0.65 |
| 80 | 0.02 | 1.5 |
| 80 | 0.0125 | 1.075 |
| 60 | 0.02 | 1.075 |
| 80 | 0.0125 | 1.075 |
| 80 | 0.02 | 0.65 |
| 60 | 0.0125 | 1.5 |
| 80 | 0.005 | 1.5 |
| 100 | 0.0125 | 0.65 |
| 80 | 0.0125 | 1.075 |
| 80 | 0.005 | 0.65 |
| 100 | 0.005 | 1.075 |
| 80 | 0.0125 | 1.075 |
| 60 | 0.005 | 1.075 |
| 100 | 0.0125 | 1.5 |
| 100 | 0.02 | 1.075 |

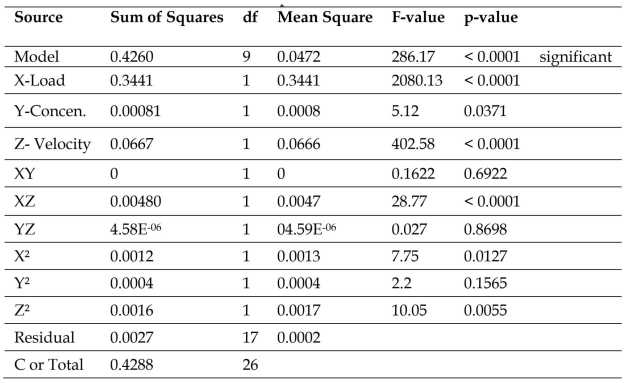
Before starting the trail, machine specific speed is set by using speed control knob and normal load is applied to the pin specimen by using dead weights and loading pan, and then trail is started by pressing start button on machine. The results from the tests are noted from display control unit of machine and from design expert software. On controller achieved test parameters like speed, wear, and frictional force are displayed. Similar values are shown on computer display and graph is plotted at the same time.

Regression models for volume loss and friction coefficient are used to interpret the experimental data. It is composed of multiple independent tribological variables. For linear, quadratic, and interaction terms, the corresponding regression constants are $\beta_i$, $\beta_{ii}$, and $\beta_{ij}$. $Y_i$ is a non-independent variable, and $\beta_0$ is a constant.

## 3. Mathematical model development

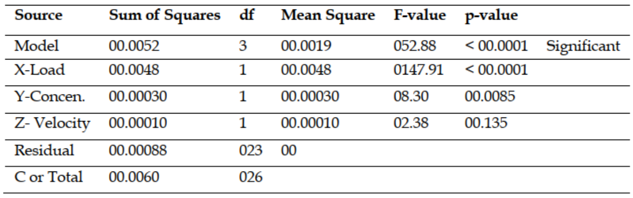
This study examines and forecasts wear & friction nature of EP lubricant combined with composite particles. ANOVA research using F-examination to find relationships between output and input parameters is used to evaluate a mathematical model, which contains the interplay of linear and quadratic coefficients. Using a p-value of 0.05, individual numerical figures of calculated model were explored to evaluate of a degree of appropriateness.

**Table 7.** ANOVA outcomes of wear parameter



| Source | Sum of Squares | df | Mean Square | F-value | p-value | |
|---|---|---|---|---|---|---|
| Model | 0.4260 | 9 | 0.0472 | 286.17 | < 0.0001 | significant |
| X-Load | 0.3441 | 1 | 0.3441 | 2080.13 | < 0.0001 | |
| Y-Concen. | 0.00081 | 1 | 0.0008 | 5.12 | 0.0371 | |
| Z- Velocity | 0.0667 | 1 | 0.0666 | 402.58 | < 0.0001 | |
| XY | 0 | 1 | 0 | 0.1622 | 0.6922 | |
| XZ | 0.00480 | 1 | 0.0047 | 28.77 | < 0.0001 | |
| YZ | $4.58E^{-06}$ | 1 | $04.59E^{-06}$ | 0.027 | 0.8698 | |
| $X^2$ | 0.0012 | 1 | 0.0013 | 7.75 | 0.0127 | |
| $Y^2$ | 0.0004 | 1 | 0.0004 | 2.2 | 0.1565 | |
| $Z^2$ | 0.0016 | 1 | 0.0017 | 10.05 | 0.0055 | |
| Residual | 0.0027 | 17 | 0.0002 | | | |
| C or Total | 0.4288 | 26 | | | | |

**Table 8.** ANOVA outcomes for COF



| Source | Sum of Squares | df | Mean Square | F-value | p-value | |
|---|---|---|---|---|---|---|
| Model | 00.0052 | 3 | 00.0019 | 052.88 | < 00.0001 | Significant |
| X-Load | 00.0048 | 1 | 00.0048 | 0147.91 | < 00.0001 | |
| Y-Concen. | 00.00030 | 1 | 00.00030 | 08.30 | 00.0085 | |
| Z- Velocity | 00.00010 | 1 | 00.00010 | 02.38 | 00.135 | |
| Residual | 00.00088 | 023 | 00 | | | |
| C or Total | 00.0060 | 026 | | | | |

R square is the numerical value of the Adjusted R-square. To assess the merits of the suggested model, the expected and R sufficient accurateness of a mathematical model were examined. An ANOVA analysis indicates that a quadratic & linear calculated model adequately shares through inspection archives for explored yield variables. Equations (2) and (3) demonstrate the projected quadratic calculated models for wear volume loss & linear models for friction parameters grounded on the trial results.

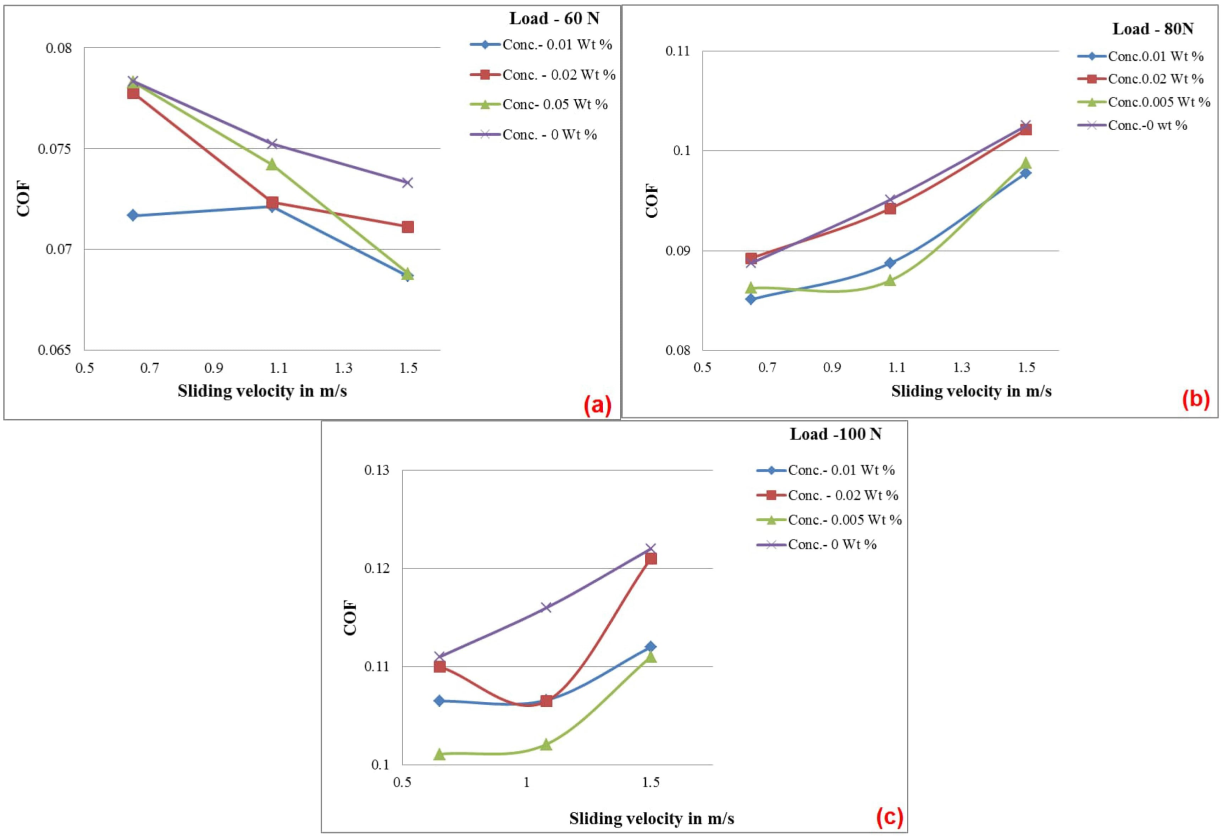


**Figure 3.** Friction behavior (a) at 60 N Load (b) at 80 N Load (c) at 100 N Load

A F-test method is used to examine importance of each term in a generated model using a produced mathematical equation. A larger F constant value displays that the deviation in outcome can be represented through a known mathematical model, & a related p-value is as well utilized to assess whether the F-value is satisfactory. A p-value not more than 0.05 indicate that a calculated equation & aspects derived is important. A '$R^2$' number intended for wear volume loss is a fraction of the inclusive change in output predicted by a calculated model, while 0.9933 for quadratic estimated model indicates an important fit to trial data. A value of 'R Square adjusted' for a projected mathematical model is 0.999, which is also great & demonstrates a reputable connection amongst expected & test-grounded values. For a present model, the 'R square anticipated' value is 0.8831. The '$R^2$' reading for COF is 0.984, representing that model is dependable and noteworthy. The '$R^2$' number for COF represents a percentage of overall change in an output predicted by a recognized mathematical model, & 0.8734 for a linear regression equation indicates an important fit to trial based data.

A p-reading & F-constant of a constructed equation directed at friction parameter proposed that relations XZ, XY, YZ, $Z^2$ and $Y^2$ are insignificant; nonetheless, all other factors were significant. For a linear statistical model (Eq. (2), 3), the statistical figures of calculated model coefficients, 'R-square,' 'adjusted R-square, & forecasted R-square,' convey consciousness of precision and correctness of a projected calculated model. In addition, a regression coefficient is shown in Tables 7 and 8. Among the models examined, a quadratic model is most important regression model for volume loss and a linear model for friction parameter when all pertinent data are taken into consideration.

## 4. Results & Discussion

The experimental results of tribological features such as friction coefficient and wear in basic oil & enhanced lubricant are presented in section. Wear and friction trials have been performed using pin on disc instruments in accord with the G-99 criteria. Trials are conducted at various working conditions and for various blend percentage of composite particles, like 0.02 w.t. %, 0.01 w.t. % & 0.005 wt. % in conjunction with 1.0 wt. % Z.D.D.P.

### 4.1 Coefficient of Friction

The friction for different gearbox fluid blends, including and without composite nanoparticles, is shown below. A force of friction amongst a disc and pin is analyzed for every trial utilizing a load cell positioned on a bracket at a space same to a gap among the sample and the hinge. Figures 3(a, b, c) illustrate COF as a mathematical function of velocity of sliding in meter per seconds for EN31 steel circular discs oiled with gearbox oil and gearbox oil combined with composite enhancer .Figures 3

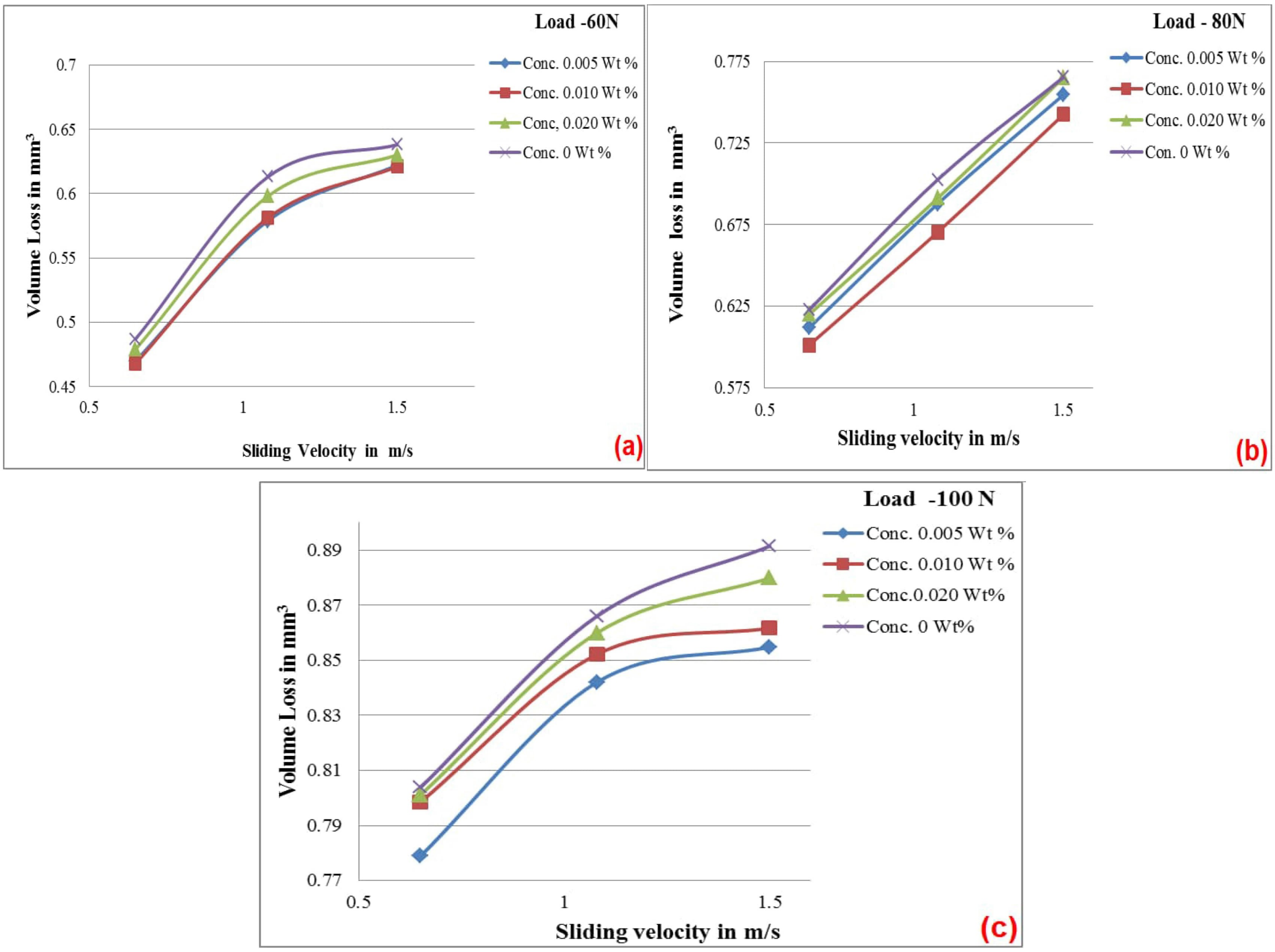


**Figure 4.** Wear behaviour (a) at 60 N Load (b) at 80 N Load (c) at 100 N Load

(a) displays the deepest value of COF with a concentration of 0.01 wt. % of composite particles for a velocity of 1.50 m/s & load of 60N. EP Lubricant + Composite particles reduced friction variable from 0.65 to 1.08 m/s, with a smooth fluctuation among 1.08 & 1.5 m/s at load 60N. Gear lubricant had the bottommost COF at 0.65 m/s velocity and 1.5 m/s in a 60N condition.

Figure 3(b) illustrates a discrepancy of friction parameter with velocity under load-80 N for basic oil & EP oil through composite addition. Steel lubricated with gear lubricant has higher COF values than steel lubricated with Gear lubricant and composite particles.

According to Figure 3(b), the lowermost reading of COF is recorded on 0.650 m/s for add-on concentrations alternating from 0.01 wt.% to 0.020 wt.%. Composite Nano additive + Gear Lubricant Coefficient of friction variation was smoother from 0.65 m/s to 1.50 m/s sliding velocity at force- 80 N.

Figure 3(c) represents an evolution of a friction parameter thru growing sliding velocity under a 100 N load condition. It has been discovered that when the concen. of composite particles declines, friction coefficient steadily lowers, taking lower reading at 0.005 wt. %, velocity- 0.65 m/s below 100 N normal load, & then somewhat increasing for 1.08 m/s to 1.5 m/s velocity.

## 4.2 Wear Volume Loss

Wear volume loss was also examined as a mathematical function of velocity parameter in m/s, as revealed in Figures 4(a, b, c). Under 60N normal load, lower wear volumes loss of steel material was recorded at sliding velocities of 0.65 & 1.08 m/s. However, from 1.08 to 1.5 m/s, there is a transition from modest to severe wear volume loss. This transition is especially difficult when the composite additives are absent from the gear lubricant. Figure 4(b) shows wear volume damage for EP oil & Gear EP Lubricant by way of Composite Additive. The examined volume loss for three blended samples is noticeably lesser than wear volume damage for the base oil. Figure 4(b) shows that with a force of 80 N, lower volume defeat was recorded at sliding- 0.65 m/s. EP oil + composite nano particles increased wear volume loss from 0.65 -1.08 m/s, with smoother fluctuation amongst 1.08 and 1.5 m/s at a blend percentage of 0.005 wt.%.

Figure 4(c) depicts fluctuation of wear loss in mm³ with varying sliding velocity in normal force situations of 100 N. It is found that volume loss gradually drops with decreasing composite nano additive concentration,

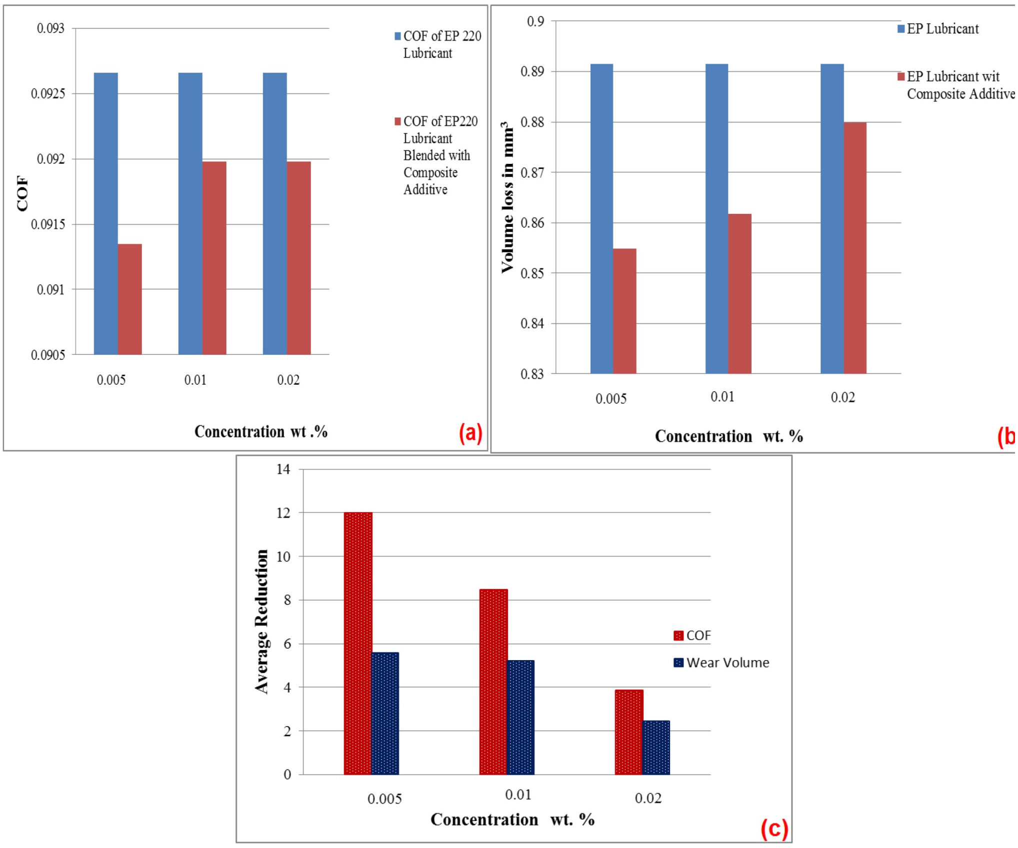


**Figure 5**. (a).COF of steel (b) Wear volume loss (c) Average reduction in COF & Wear after 2000 m sliding distance

yielding a lower value of 0.005 weight percent for entirely velocity mixtures below 100 N normal loads.

### 4.3 Effect of Composite Additive Concentration

To determine the appropriate concentration of composite nanoparticles in a gear lubricant, a friction coefficient and wear volume loss were measured after testing for 2000 m of gliding distance and lubricated by 0.005, 0.01, and 0.02 wt. % composite nano additives.

To investigate the effect of composite additive on COF and wear volume loss in gear oil, the outcomes of EP oil combined with composite particle has been equated to the results of the basic oil. Figure 5(a & b) clearly shows that COF and wear volume loss are smaller for all composite additive concentrations when compared to the wear volume loss in base EP Lubricant. The Histograms of average drop for coefficients of friction and wear volume loss lubricated by gear lubricant in combination with varied $Al_2O_3/SiO_2/ZrO_2$ concentrations in pin on disc apparatus are shown in Figure 5(c).

Addition of merely 0.005 wt. % composite reduces a COF by 11.98 % when related to a standard gear lubricant. The 0.005 wt. % concentration combination has the lowest COF. A mixing of 0.005 wt. % composite particles to gear lubricant reduces wear volume loss by 9.8% as compared to gear EP oil. To examine an influence of composite particle on COF and wear volume loss in 220 grade oil, the outcomes of EP oil combined with composite particles has been equated to results of the basic gear oil.

Table 9 shows the comparative study of analysis on effects of additives like ionic liquids, boron nitride, $MoS_2$, $Al_2O_3/TiO_2$ composite & ZrO2/ SiO2 particles when blended with different lubricants like gear oil, bio-oil, PAO oil.

Blending of ionic liquids with lubricants showed limited effect on reducing the coefficient of friction (COF), but improved wear resistance. Borided surface materials outperformed carburized surfaces in terms of wear resistance when tested with PAO oil. The inclusion of Ni-promoted $MoS_2$ particles in gear oil enhanced both wear resistance and extreme pressure performance. Additionally, blending $Al_2O_3/TiO_2$ composite particles improved the anti-friction and anti-wear properties of the oil.

Furthermore, blending gear EP oil with composite additives and ZDDP reduced wear by 11.98% and COF by 9.81% under varying load and speed conditions.

### 4.4 Effects of Control Factors

Figure 6 (a) displays the unique effects of concen., load, & sliding velocity, as well as their combined effect on wear parameter loss. As the load increases, so does the wear volume loss. The control factors results showed that a residuals downfall on a flat line denoted that an errors are generally dispersed.

**Table 9.** Comparative study of analysis on effects of additives

| Ref. No | Additive & Lubricant | Input Parameter | Investigated Parameter | Findings |
|---|---|---|---|---|
| [1] | Ionic liquids & ISO VG 320 Gear Oil | Load , Time Concentration | COF, Wear | Blending of Ionic liquid not significantly decreased COF however Improvement in wear Parameter reduction Observed. |
| [3] | Ionic liquids & Bio oil | Sliding Velocity, Concentration | | The Mixing of ionic liquid as additive in bio oil has reduced wear parameter; However it did not decrease the coefficient of friction (COF). |
| [5] | Boron Nitride & PAO Oil | Time, Concentration | | Borided surface materials demonstrated superior wear resistance compared to carburized surfaces when tested using PAO oil. |
| [8] | $MoS_2$ & Gear Oil | Load, Time, Concentration | | The inclusion of Ni-promoted $MoS_2$ particles in gear oil significantly improved wear resistance and extreme pressure performance. |
| [19] | $Al_2O_3$/$TiO_2$ & oil | Time, Concentration | | It was observed that blending $Al_2O_3$ /$TiO_2$ composite particles improved the anti-friction and anti-wear properties of the oil. |
| [20] | $ZrO_2$/ $SiO_2$ & oil | | | At an optimum concentration (0.1 wt. %), the average friction coefficient was decreased in studied oil. |
| | $Al_2O_3$/$SiO_2$/$ZrO_2$ + ZDDP & Gear EP 220 Oil | Load , Sliding Velocity & Concentration | | Blending gear EP oil with composite additives and ZDDP reduced wear by 11.98% and the coefficient of friction by 9.81% under varying load and speed conditions. |

Figure 6 (b) shows the parameters that influence the COF. A graph shows how friction is affected by working parameters such as composite particle concentration, load, and velocity. A friction coefficient increases as the normal load, sliding velocity, and concentration increase in an inspected region of study. Figures 7(a) and (b) show the parity plots for linear and quadratic models of COF and volume loss.

Figure 7(a) displays that, the total analysis data points for volume loss are situated in the defined series of experimentation values. Likewise, Figure 7(b) indicates that the proposed mathematical model for a coefficient of friction traces the practical data within a specific range of experimental values.

## 5. Development of predictor

A VB scripting language is used to create the lubricant predictor. The fundamental components of the predicator GUI are the forms and control buttons in this predicator. The predicator's Forms are objects that define their appearance by exposing their properties. The approaches that define behaviors & the events define their relations with a user. It is possible to set the form's properties and write VB code that responds to the events of the form.

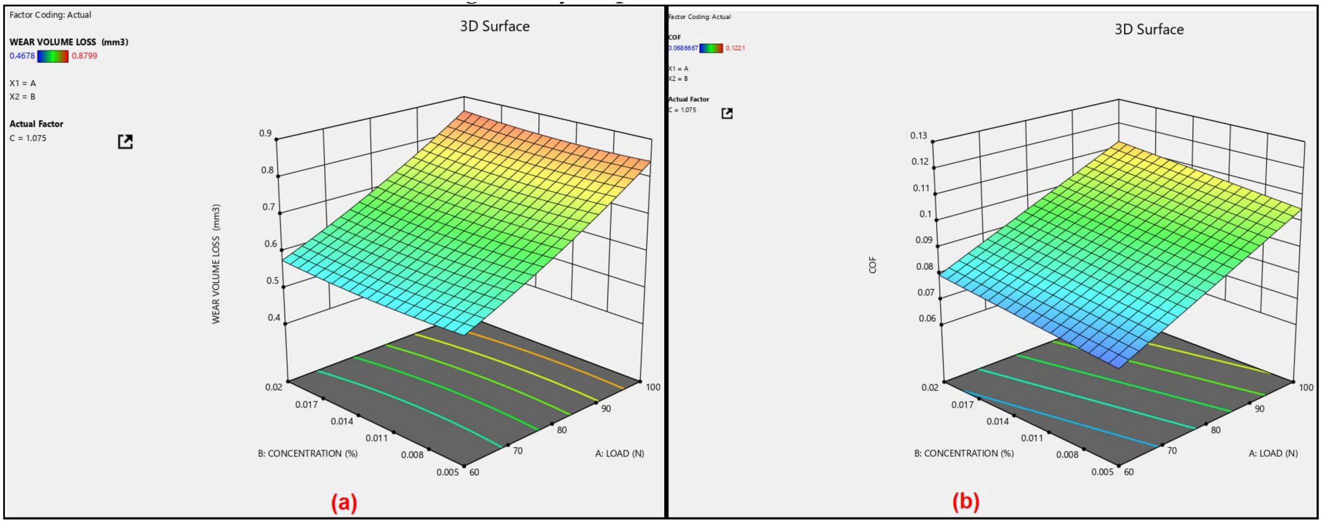


**Figure 6** Effect on (a) Wear loss (b) COF

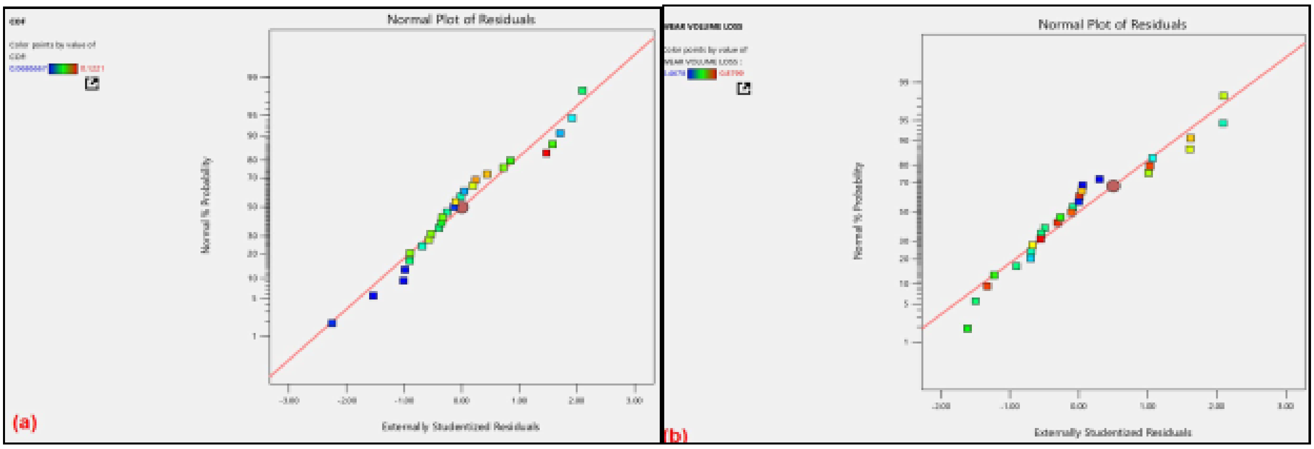


**Figure 7.** Parity graph for an equation of (a) COF (b) Wear Volume loss

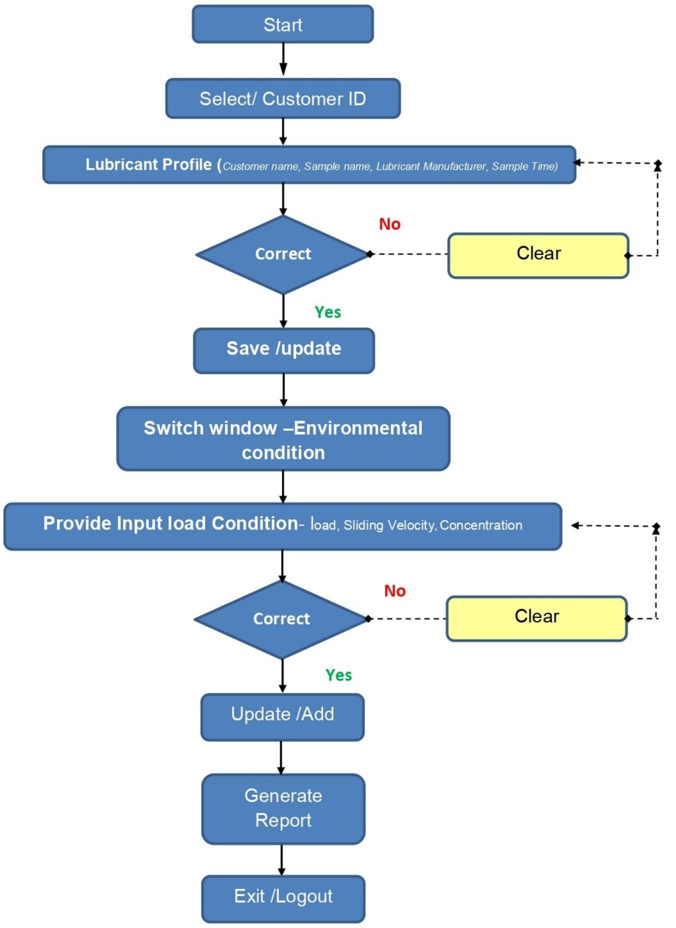
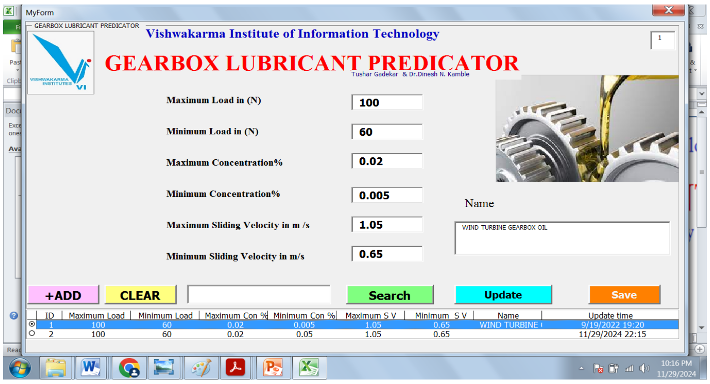


**Figure 8.** Flowchart of Predicator

Figure 8 displays the predicator flowchart. Containing objects are controls. Every control type has a distinct set of attributes, such as properties, methods, and events, which make it appropriate for a given task. The user interface is designed using the following procedures and components.

Controls are enclosed entities. Every form of governor has a distinctive cluster of structures that create it appropriate for exact job, containing properties, approaches, & actions. Subsequent stages & components are referred in a development of UI.



Vishwakarma Institute of Information Technology

GEARBOX LUBRICANT PREDICATOR

Tushar Gadekar & Dr.Dinesh N. Kamble

Maximum Load in (N) 100

Minimum Load in (N) 60

Maximum Concentration% 0.02

Minimum Concentration% 0.005

Maximum Sliding Velocity in m /s 1.05

Minimum Sliding Velocity in m/s 0.65

Name WIND TURBINE GEARBOX OIL

| | ID | Maximum Load | Minimum Load | Maximum Con % | Minimum Con % | Maximum S V | Minimum S V | Name | Update time |
|---|---|---|---|---|---|---|---|---|---|
| ⊙ | 1 | 100 | 60 | 0.02 | 0.005 | 1.05 | 0.65 | WIND TURBINE ( | 9/19/2022 19:20 |
| ○ | 2 | 100 | 60 | 0.02 | 0.05 | 1.05 | 0.65 | | 11/29/2024 22:15 |

**Figure 9.** Lubricant Predicator

Stage 1: Turn on the Developer Tag in Visual Basic and Excel.

Stage 2: Make a User Form

Stage 3: Make Frames

Stage 4: Make Labels and a Command Button

Stage 5: Make a list box in step five.

Stage 6: Produce a report

Figure 10 displays the lubricant predictor with multiple windows. The first window in Lubricant Predictor was created to make it easier for users to enter customer information. The Lubricant Predicator's second window is designed to allow users to enter data based on their needs and operational circumstances.

Table 10 displays the comparison amongst the experimental & predicted outcomes referring to the developed predictor with error percentage. With a maximum error of 13.5%, the friction & wear loss found by proposed forecast model showed respectable settlement with trial-based volume loss & COF. These findings can be used as predictor systems to run into the requirements of the economical prediction methods.

## 6. Conclusion

The motive of this investigational work is to examine an influence of various factors like sliding velocity, load and concentration of Add-on on Tribological factors like COF and Wear, also development of predication tool for the

**Table 10.** Comparison of Predicated vs experimental values

| Load | Concen. | Velocity | Trail based | Predicated | Error % | Trail based | Predicated | Error % |
|---|---|---|---|---|---|---|---|---|
| | | | Wear loss | | | COF | | |
| 80 | 0.02 | 1.5 | 0.765 | 0.7521 | 1.7 | 0.1021 | 0.0982 | 4.0 |
| 100 | 0.0125 | 1.5 | 0.8617 | 0.8696 | -0.9 | 0.112 | 0.1096 | 2.2 |
| 60 | 0.0125 | 0.65 | 0.4678 | 0.4662 | 0.3 | 0.0716 | 0.0723 | -1.0 |
| 100 | 0.005 | 1.08 | 0.8421 | 0.8479 | -0.7 | 0.1021 | 0.1049 | -2.7 |
| 80 | 0.005 | 0.65 | 0.6118 | 0.6156 | -0.6 | 0.08625 | 0.0863 | -0.1 |
| 80 | 0.0125 | 1.08 | 0.6704 | 0.6904 | -3.0 | 0.0887 | 0.0910 | -2.5 |
| 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 | 0.114 | 0.1126 | 1.2 |
| 100 | 0.0125 | 0.65 | 0.7985 | 0.7871 | 1.4 | 0.1065 | 0.1054 | 1.0 |
| 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 | 0.005 | 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 |
| 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 |
| 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 |

performance analysis of lubricant.

This work uses a pin-on-disc to create a tailored predictor by examining wear & friction behaviour of gear EP oil mixed with composite particles ($Al_2O_3$+ $ZrO_2$+ $SiO_2$) in conjunction with ZDPP Lubricant.

An excellent method for estimating the correlation between different dependent and independent variables is to apply the reliable coefficient of wear loss and friction dependent models. Limited experimental results form the basis of the mathematical model. This can be used to estimate wear volume loss and a COF in a variety of scenarios.

In combination with ZDDP, composite nanoparticles $Al_2O_3/SiO_2/ZrO_2$ boost anti-wear & anti-friction qualities of gearbox oil. An experimental tribological evaluation illustrates that the composite nano additive lowers the wear volume loss in the steel by 9.81%. When compared to Basic Gear oil, pin on the disc instrument demonstrated 11.98 % reduction in COF for EP oil when combined with $Al_2O_3/SiO_2/ZrO_2$ composite particles + ZDDP. Under a 60 N load with 1.5 m/s sliding velocities, a smaller reading of a COF (0.06877) was identified at 0.010 weight percent of

$Al_2O_3/SiO_2/ZrO_2$ composite particles in mix with 1 weight percent of ZDDP. At 0.01 weighted percent of $Al_2O_3/SiO_2/ZrO_2$ composite particles in 1 weight percent zinc dialkyl dithiophosphate, the wear volume loss is at its lowest point (0.4678) at 60 N while velocity is 0.65 m/s.

The gearbox oil with 0.005 wt. % of composite nanoparticles blend showed most significant additive combination for studied working conditions than other concentrations. The suggested prediction model yielded the friction and wear volume loss. This prediction tool offers a cost-effective approach to assessing lubricant performance and can be used as a soft prediction tool for gearbox & Engine lubrication applications, contributing to more efficient and durable lubrication systems in practical industrial settings.

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