Tribological Behavior as Lubricant Additive and Physiochemical Characterization of Jatropha Oil Blends

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Abstract: This investigation reports on the effect of jatropha oil doped with lube oil on tribological characteristics of Al-7%Si alloy. The factors involved were Jatropha oil percentages, sliding velocities and loadwhich was optimized for weight loss, friction coefficient and specific wear rate characteristics. The conventional lubricant was SAE 40. It is observed that the jatropha oil percentage factor had significant influence on the weight loss, friction coefficient and wear rate of the pin. The optimum result was $A_2B_3C_1$ for pin weight loss, friction coefficient and wear rate. From the experimental result, it is found that the wear scar diameter increases with the increase of load for lube oil and reduced by addition of percentage of jatropha oil. Flash temperature parameter also studied in this experiment and results shown that 15% addition of jatropha oil would result in less possibility to film breakdown. The overall results of this experiment reveal that the addition of 15% jatropha oil with base lubricant produces better performance and anti-wear characteristics. This blend can be used as lubricant oil which is environment friendly in nature and would help to reduce petroleum based lubricant substantially.

Key words: Taguchi · ANOVA · Pin weight loss · Friction coefficient · Wear rate

INTRODUCTION

Around the globe, there are challenges for the industries involved in manufacturing petroleum based lubricant products to face government regulations and also meet latest technological changes to make cleaner environment and reduce pollution caused by them [1-2]. There are various lubricants available around the world which includes synthetic oil, mineral oil and vegetable oil. Lubricants available in the market i.e. mineral oil are derived from crude petroleum oils and are not feasible with the environment as they are non-biodegradable and toxic [3-4]. Also, the disposal of mineral caused pollution to the aquatic and terrestrial ecosystems and combustion of the mineral oil leads to emission of metal traces like, calcium, zinc, magnesium and phosphorous and nano-particles [5-6]. Vegetable oil can be used as an alternative to petroleum based mineral oil as it possesses several advantages which include biodegradability, lower toxicity, lowervolatility and higher lubricity [7-8]. They have triacylglycerol structure which contains long, polar fatty acid composition resulting into formation of thick film between the metal to metal contacts and impart them better anti wear properties [9-10].

There are some drawbacks of vegetable oil based lubricants that they have lower thermal/oxidative stability, higher flash point and high temperature operability leads to higher coefficient of friction [11]. To overcome these limitations, several researches have been carried out. Oxidation stability and low pour point can be modified by partially adding additives and using N-Phenyl-alpha-naphthylamine (Am2) as antioxidant to improve oxidation stability [12-14]. Moreover, transesterification or epoxidation are the solutions to meliorate oxidation stability at low temperature [15-16]. To make vegetable oil based lubricant sustainable, there is a need to improve their narrow range of viscosities [17]. Viscosity is one of the significant factor in determining coefficient of friction between the sliding surfaces as it act as protective film between the surfaces in contact to protect them from wear. To do so, viscosity modifiers can also be used which are friendly with environment. Oleogels based on

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conventional, bio-based lubricant and ethylene-vinyl acetate (EVA) copolymer have been developed. It has been observed that EVA can be used as an effective thickener agent to make vegetable oil as Bio-based lubricant [18]. Viscosity of bio-based lubricant can also be increased by using ethylene-vinyl acetate and styrene-butadiene-styrene copolymers as they increase some amount of kinematic viscosities at 40°C and 100°C temperatures [19].

Taguchi's orthogonal array method is a statisticaltechnique underdesign of experiments which reduces number of experiment trials and provides sufficientinformation about the effect of control factors [20-21]. According to this method, various control factors can be investigated at a time and resulted in optimum significant values. The advantagesof using Taguchi method have been reported by various authors [22-27].

The following is the overview of the literature based on involvement of lubricants using design of experiments. Silica reinforced composites were investigated under various testing parameters which include solid lubricants, Sliding Velocity and load. Solid lubricants were h-BN graphite and MoS_2, Load ranges from 300 to 900N and Sliding Velocity from 3m/s to 9m/s. During this selected domain, MoS_2 proves to be effective wear resistive lubricant and both h-BN and MoS_2 provides higher braking performance at higher Sliding Velocity and load [28]. Experimental design method was used to optimize the production of octyl esters from free fatty acid towards contributing more potential bio-lubricant. During this process waste cooking oil and octanol in a solvent free medium during enzymatic esterification were used. The parameters were temperature, molar ratio of octanol and reaction time. Result revealed that the developed octyl ester have higher flash point, viscosity index and biodegradability greater than 90% as compared to the conventional waste cooking oil used [29]. Cylinder liner/piston ring reciprocating test based on taguchi method were investigated under various testing conditions to optimize minimum piston ring weight loss and friction. The optimum parameters taken were sliding velocity, load and oil type. The interaction between sliding velocity and oil type contributes significant factor in developing minimum weight loss model [30].

It has been concluded from the above literature that very limited work has been done based on bio-based lubricants. The objective of this study is to optimize various control parameters which include jatropha oil blended lubricants, Sliding Velocity and load using taguchi method to determine influence of the control parameter on the minimum material weight loss, friction and specific wear rate.

Experimental Details

Experimental Apparatus: To investigate the tribological behavior of jatropha oil blends variants using Ducom Macro Pad Pin on Disc tribometer according to standard test methods of ASTM G99 which was connected with a personal computer having data acquisition system. LVDT is used for determination of the wear and sensors are mounted to sense the changes in the coefficient of friction. Weight of the pin was determined before the test conducted and after the tested result. Weight loss of pin was determined as a function of different load applied and sliding distances. Weighing was performed with analytic balance Shimadzu AX 200 machine with a sensitivity of 0.1 mg. Specifications of pin on disc tribometer are: Maximum pin diameter = 12 mm; Maximum Load= 200 N; Maximum disc rotating speed= 2000 rpm; Maximum wear measurement range= 2000 µm (Micormeter).

Sample Preparation: The specimens which were used for the experiment are Aluminium Silicon Alloy with 7% silicon and EN31 steel with 60 hardness of 60 HRC. The chemical composition of the Al-7 Si Alloy is as follows: Si 7.39, Mg 0.356, Fe 0.116, B 0.0011, Sn 0.0027, Ti 0.115 and Al balanced and chemical composition of EN31 steel is C 1, Si 0.35, Mn 0.5, S 0.05, P 0.05, Cr 1.3 and Fe balanced.Hemispherical aluminium silicon alloy was used as the pin and the material used for the disc specimen was EN31 steel having maximum diameter of 165 mm. The Pin and disc specifications were: length of pin= 30 mm; Pin diameter= 08 mm; Hemispherical radius of pin= 04 mm; Disc diameter= 165 mm; Thickness of disc= 08 mm; Limit of disc track diameter= 145 mm. Before conducting each experiment ethyl alcohol was used to make it ensure that the surfaces are cleaned properly.

Test Method: The details were as follows: Load= 50,100,150 N; Ambient temperature was taken; Track Diameter= 80 mm (for each experiment);Sliding Velocity= 1.3, 2.5, 3.8 m/s; Sliding distance= 3000 m. For each test, same track diameter was used and emery paper A350 was used for polishing disc after each experiment. After completion of each test, pin and disc specimen was cleaned ultrasonically with ethyl alcohol and stored in vacuum oven furnace to avoid corrosion of the material. For the examination of the worn surfaces, trinocular stereo

Table 1: Physiochemical Properties of Lubricants Undertaken for Study

Properties	JB 0	JB 15	JB 30
Specific Gravity @ 20 °C	0.869	0.904	0.942
Kinematic Viscosity (cSt at 40°C)	172	167	196
Kinematic Viscosity (cSt at 100°C)	8.89	7.5	11
Total Acid Number	0.5679	0.5493	0.7824

Table 2: Factors and levels considered during plan of experiments

Factors	Level I	Level II	Level III
Jatropha Oil (%)	0	15	30
Sliding Velocity (m/s)	1.3	2.5	3.8
Load (N)	50	100	150

Table 3: L9 orthogonal array experimental layout of taguchi

Experiments	Jatropha Oil (%)	Sliding Velocity (m/s)	Load (N)
1	0	1.3	50
2	0	2.5	100
3	0	3.8	150
4	15	1.3	100
5	15	2.5	150
6	15	3.8	50
7	30	1.3	150
8	30	2.5	50
9	30	3.8	100

zoom microscope was used. Mean average value was used after completing each experiment three times to maintain accuracy in the results.

Lubricants Used: In this investigation Jatropha oil was mixed with conventional lubricant (SAE 20W40) in the ratios: 20W40 (JB0); 10 (JB15); 30(JB30) (% by volume). The homogeneous mixing was done by magnetic stirrer. Table 1 show the physiochemical properties of jatropha oil based blended lubricants.

Viscosity and Total Acid Number Test (TAN): Anton paar viscosity meter and TAN/TBN analyzers were used for investigating degradation of the lubricant. The kinematic viscosity was measured at 40°C and 100°C according to ASTM D445 standard. For the TAN analysis, c(KOH)=0.2 mol/l in isopropanol as the titrant was used according to ASTM D664-81 standard.

Wear Scar Diameter: The trinoculur stereo zoom microscope was used to calculate the wear scar diameter of the pin. Suitable magnificationlens was chosen and the focus was adjusted until clear image is shown on the computer screen. After that, view 7 software available in the computer was used for the measurement of wear scar diameter.

Flash Temperature Parameter: Flash Temperature Parameter is a single number used to express the critical flash temperature above which givenlubricant will

fail under given conditions [31]. The following formula has been used for Flash temperature parameter analysis:

Flash Temperature Parameter, $\text{FTP} \left(\frac{N}{mm} \right) = \frac{W}{d^{1.4}}$ (1)

where;
W = load in N, d = mean wear scar diameter (WSD) in mm at this load

Design of Experiments Employing Taguchi Method: Taguchi method developed orthogonal array to study the effect of control factors involved and to minimize number of experiments. The experimental results obtained are then converted to signal to noise ratio (S/N) which measure quality characteristics to understand that the results are deviating from or nearer to the obtained results. There are three categories involved for quality characteristics to analyze S/N ratio. These are: the smaller the better; the larger the better; the nominal the better. These can be calculated according to the below mentioned equations.

The-smaller-the-better: $\frac{S}{N} = -\log \frac{1}{n} \left(\sum_{i=1}^{n} y^2 \right)$ (2)

where, 'n' indicates number of replications and 'y' indicates the observed response value. It is employed where smaller value is desired.

The-nominal-the-better: $\frac{S}{N} = -\log \frac{1}{n} \left(\frac{\mu^2}{\sigma^2} \right)$ (3)

where, 'μ' indicates mean and 'σ' indicates the variance. It is employed where nominal or variation is minimum.

The-higher-the-better: $\frac{S}{N} = -\log \frac{1}{n} \left(\sum_{i}^{n} \frac{1}{y^2} \right)$ (4)

where, 'n' indicates number of replications and 'y' indicates the observed response value.

Process Parameters: In this experiment three control factors with three levels were selected. The details of the factors to be considered and level assigned with them are designated in Table 2. Level indicates the values taken during plan of experiments.

Minitab 16 softwarewas used for the selection of the orthogonal array. L9 orthogonal array was selected and details of the experiments to be investigated is shown in Table 3. Three columnswere considered and each consists of three levels.

The plan of experiments includes 9 row experiments in which first column was assigned to the jatropha oil blended lubricants (%), second to the sliding velocity

(rpm) and the third to the load (N). Responses taken during the experiment were pin weight loss, friction coefficient (μ) and wear rate (mm2/N).

ANOVA: ANOVA stands for analysis of variance and it is a statistical technique which control factors involved and used to determine the percentage contribution of each control factors to reveal the their effect on the quality characteristics. The increase in S/N ratio determines the increase in control factor. It can be used to investigate the different factors including degree of freedom (DF), Sequential sum of square (Seq SS), Adjusted Sum of square (Adj SS), Sequential mean square (Seq MS) and last column indicates the p value for each control parameters. The row having least p value was contributed more to the response involved and the control factor having maximum value than the F value is insignificant.

RESULTS AND DISCUSSIONS

Prediction of Control Factor Effects: Table 4 shows the experimental output for pin weight loss, friction coefficient and specific wear rate at different levels of control factors considered. Responses of each control factors on pin weight loss, friction coefficient and wear rate were determined and analyzed using S/N ratio table. Table 5-7 indicates S/N response tables for pin weight loss, friction coefficient and wear rate. From table 5, it can be revealed that minimum pin weight loss was observed at Level 2 of jatropha oil blends (%) i.e. JB 15, level 3 of sliding velocity i.e. 3.8 m/s and level 1 of Load i.e. 50 N. According to the rank, Jatropha oil Blends (%) has strong influence for this response. 15% contamination of jatropha oil with lubricant provides less pin weight loss as it will act as barrier to the metals in contact during tribo test. From table 6, it is observed that minimum friction coefficient was at level 2

Table 4: Experimental output for pin weight loss, friction coefficient and specific wear rate

Pin Weight Loss (mg)	Friction Coefficient	Specific Wear Rate (mm2/N)	S/N Ratio PWL	S/N Ratio FC	S/N Ratio SWR
0.0009	0.0117	4.98E-04	60.9151	38.6363	66.0554
0.0011	0.0142	1.40E-04	59.1721	36.9542	77.0774
0.0013	0.0126	2.60E-04	57.7211	37.9926	71.7005
0.0011	0.0119	3.11E-04	58.9128	38.4891	70.1448
0.0014	0.0138	3.78E-04	57.0774	37.2024	68.4502
0.0005	0.0108	1.20E-05	66.0206	39.3315	98.4164
0.0031	0.0436	2.31E-03	50.1728	27.2103	52.7278
0.0019	0.0346	8.38E-04	54.4249	29.2185	61.5351
0.0021	0.0377	1.00E-03	53.5556	28.4732	60.0000

Table 5: S/N response table for pin weight loss

Level	Jatropha Oil Blends (%)	Sliding Velocity (m/s)	Load (N)
1	59.27	56.67	60.45
2	60.67	58.89	57.21
3	52.72	59.10	54.99
Delta	7.95	2.43	5.46
Rank	1	3	2

Table 6: S/N response table for friction coefficient

Level	Jatropha Oil Blends (%)	Sliding Velocity (m/s)	Load (N)
1	37.86	34.78	35.73
2	38.34	34.46	34.64
3	28.30	35.27	34.14
Delta	10.04	0.81	1.59
Rank	1	3	2

Table 7: S/N response table for specific wear rate

Level	Jatropha Oil Blends (%)	Sliding Velocity (rpm)	Load (N)
1	71.61	62.98	75.34
2	79.0	69.02	69.07
3	58.09	76.71	64.29
Delta	20.92	13.73	11.04
Rank	1	2	3

Main Effects Plot for Pin Weight Loss (mg)
Data Means
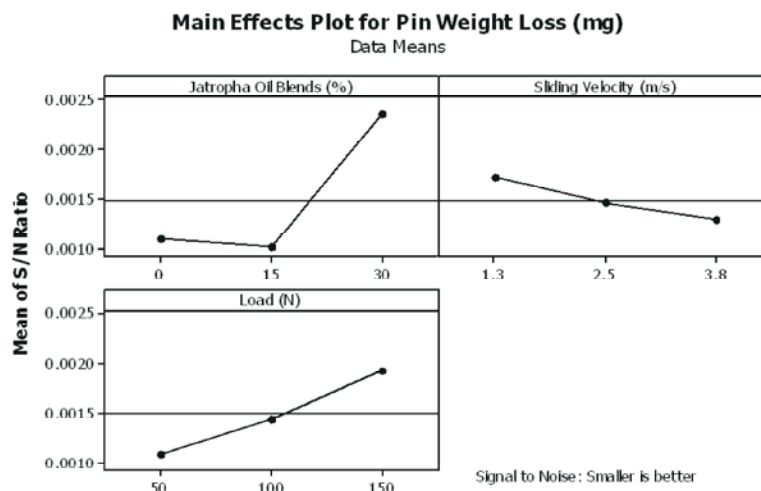
Fig. 1.a: Main effect plot for Pin weight loss

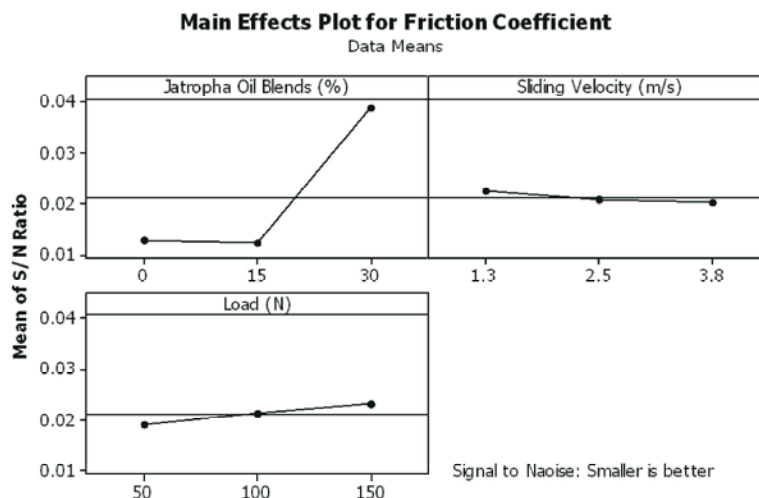**Main Effects Plot for Friction Coefficient**
Data Means

Fig. 1.b: Main effect plot for friction coefficient

of jatropha oil blends (%) i.e. JB 15, level 3 of sliding velocity i.e. 3.8 m/s and level 1 of Load i.e. 50 N. According to the rank, Jatropha oil Blends (%) has strong influence for this response and after that load influences friction coefficient. Table 7 also provides the same combination of the levels as stated above but specific wear rate was influenced more by applied load and then jatropha oil blends (%).

Fig. 1: a-c shows the main effect plot for S/N ratios. From these graphs, optimum results for the factors included could be determined.

Figure 1 a-c shows the main effect plot for S/N ratios. Among the JB 0, JB 15 and JB 30, JB 15 (15% blend with conventional lubricant) shows minimum pin weight loss, friction coefficient and wear rate as it provides better protective film between metal to metal contact in comparison to JB 0 and JB 30. This could be attributed to

the fatty acid composition of the jatropha oil based lubricants. These fatty acid compositions consists of molecules which form a long chain covalently bonded hydrocarbon chain and act as an efficient barrier for protecting sliding surfaces contact and provides better wear protection than conventional hydrocarbon based lubricants. Esters have polar functional group which provides better affinity to metal surface and contributed towards formation of protective layer between metal surfaces. Minimum pin weight loss, friction coefficient and wear rate were observed at higher sliding velocity and lower load. In comparison to sliding velocity, load had significant effect on the responses considered during the analysis. With increase of load, friction force increases which results in more pin weight loss, friction coefficient and specific wear rate. JB 15 shows better result with increase of sliding velocity due to higher
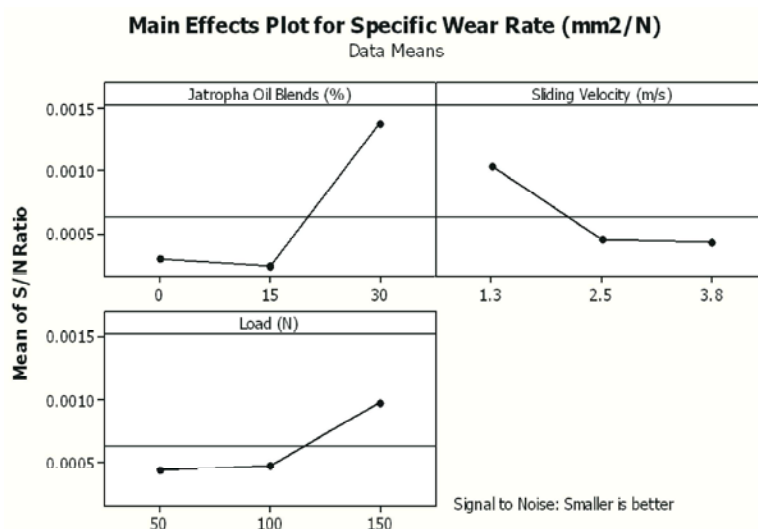
Fig. 1.c: Main effect plot for specific wear rate

viscosity of jatropha oil which provides better protective layer with increase of sliding velocity and cannot provide better lubricity at lower sliding velocity. Another reason behind the better results at higher sliding velocity is the increase of temperature which reduces viscosity making it responsible for the formation of excellent tribo layer. Aluminium has an inherent property of forming an oxide layer on its outer periphery. When sliding at high velocity, the temperature increases over the contact surface, making the material to oxidize. This phenomena leads to the transferring of materials, forming Mechanically Mixed Layer (MML), also called tribo layer. As the velocity increases, this tribo layer will act as a barrier or lubricant between the two surfaces decreasing the coefficint of friction, wear rate and pin weight loss [32]. Optimum results for the control factors considered were determined from Main effect plots for pin weight loss, friction coefficient and specific wear rate. The optimum result for all the responses i.e pin weight loss, friction coefficient and wear rate was A2B3C1. This means that the level second of Jongamia oil blends

(%) i.e. JB 15, third level of Sliding velocity i.e. 3.8 m/s. and first level of Load applied i.e. 50 N was considered as better control factors.

ANOVA Analysis: Table 8-10 shows the ANOVA table for pin weight loss, friction coefficient and specific wear rate. From Table 8, the jatropha oil blends percentage (57.5%) and load (27.9%) had significant influence on the pin weight loss and the contribution of Sliding Velocity (6.1%) was least as compare to other two control factors. The reason behind significant influences of the jatropha oil percentage and load was stated earlier. Among the interactions, sliding velocity with load (10.7%) had significant influence on pin weight loss. It can be observed from Table 9 that jatopha oil percentages influenced more the friction coefficient as compared to load and sliding velocity. Frictional forces had significant influence on the friction coefficient according to the below formula-

$$\mu = F/N \tag{5}$$

Table 8: The ANOVA for pin weight loss

Source	DF	Seq SS	Adj SS	Seq MS	F	P	Pct (%)
Jatropha Oil (%)	1	0.0000024	0.0000003	0.0000024	8.07	0.105	57.5
Sliding Velocity (m/s)	1	0.0000003	0.0000002	0.0000003	0.85	0.455	6.1
Load (N)	1	0.0000010	0.0000003	0.0000010	3.49	0.203	24.9
Jatropha oil(%)*Sliding Velocity (m/s)	1	0.0000000	0.0000003	0.0000000	0.03	0.881	0.2
Jatropha Oil (%)*Load (N)	1	0.0000000	0.0000003	0.0000000	0.10	0.779	0.7
Sliding Velocity (m/s)*Load	1	0.0000004	0.0000004	0.0000004	1.50	0.345	10.7
Error	2	0.0000006	0.0000006	0.0000003			
Total	8	0.0000048					

Note: DF-Degrees of Freedom; Seq SS-Sequential Sum of Squares; Adj SS-Adjacent Sum of Squares; Seq MS-Sequential Mean of Squares; F-Fisher's test; Pct-Percentage.

Table 9: The ANOVA for Friction coefficient (μ)

Source	DF	Seq SS	Adj SS	Seq MS	F	P	Pct (%)
Jatropha Oil (%)	1	0.0009985	0.0000828	0.0009985	8.18	0.104	85.2
Sliding Velocity (m/s)	1	0.0000061	0.0000460	0.0000061	0.05	0.844	0.5
Load (N)	1	0.0000277	0.0001186	0.0000277	0.23	0.681	2.4
Jatropha oil(%)*Sliding Velocity (m/s)	1	0.0000000	0.0000704	0.0000000	0	0.991	0.0
Jatropha Oil (%)*Load (N)	1	0.0000128	0.0001017	0.0000128	0.10	0.777	1.0
Sliding Velocity (m/s)*Load	1	0.0001269	0.0001269	0.0001269	1.04	0.415	10.8
Error	2	0.0002441	0.0002441	0.0001221			
Total	8						

Table 10: The ANOVA table for specific wear rate

Source	DF	Seq SS	Adj SS	Seq MS	F	P	Pct (%)
Jatropha Oil (%)	1	0.0000018	0.0000001	0.0000018	12.71	0.070	48.0
Sliding Velocity (m/s)	1	0.0000006	0.0000001	0.0000006	4	0.183	15.1
Load (N)	1	0.0000004	0.0000006	0.0000004	3.08	0.221	11.6
Jatropha oil(%)*Sliding Velocity (m/s)	1	0.0000000	0.0000006	0.0000000	0.20	0.697	0.8
Jatropha Oil (%)*Load (N)	1	0.0000004	0.0000009	0.0000004	2.89	0.231	10.9
Sliding Velocity (m/s)*Load	1	0.0000005	0.0000005	0.0000005	3.59	0.199	13.6
Error	2	0.0000003	0.0000003	0.0000001			
Total	8	0.0000039					

where F = Frictional Force in Newton and N is the applied load (Newton)

Among the interactions, sliding velocity with load (10.7%) had significant influence friction coefficient.

From Table 10, the jatropha oil percentage (48%) and sliding velocity (15.1%) had significant influence on the specific wear rate and the contribution of load (11.6%) was least as compare to other two control factors. Among the interactions, sliding velocity with load influenced more followed by jatropha oil with load (10.9%).

Model Adequacy: After performing ANOVA analysis, model sufficiency was conducted to verify the normality assumption of the residual. Fig 2-4show normal probabilityplots of the residuals and figures obtained indicates that almost all the normal probability plot follow a straight line pattern.

Correlation: Linear regression equation was used to correlate control factors (Jatropha oil Percentages, Sliding Velocity and load) and the Responses (Pin weight loss, Friction coefficient and wear rate).
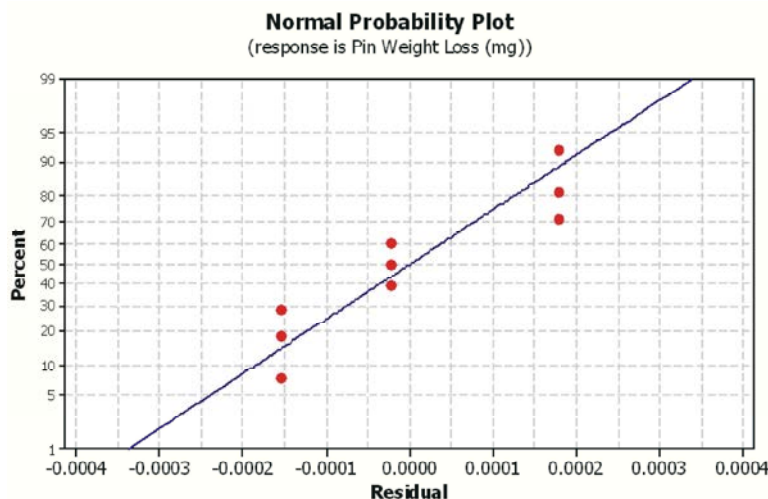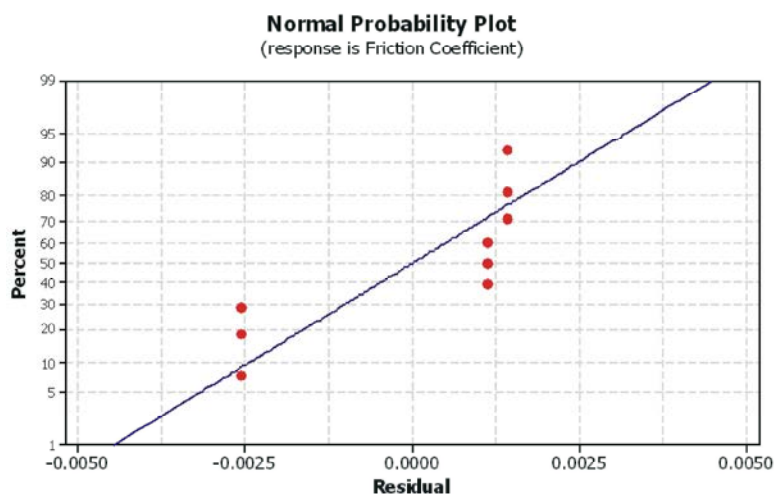

Fig. 2: Normal residual plot for pin weight loss

Normal Probability Plot
(response is Friction Coefficient)

Fig. 3: Normal residual plot for friction coefficient

Normal Probability Plot
(response is SWR (mm2/N))

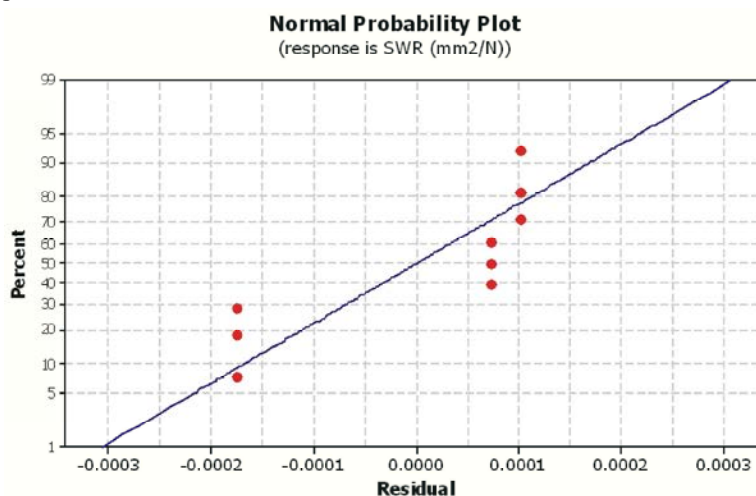Fig. 4: Normal residual plot for specific wear rate

The Equations Are:

Pin Weight Loss (mg) = 0.000441 + 0.000042 Jatropha Oil Blends (%)
- 0.000164 Sliding Velocity (m/s) + 0.000008 Load (N)
R-sq= 96%   (6)

Friction Coefficient = 0.0061 + 0.000860 Jatropha Oil Blends (%)
- 0.00081 Sliding Velocity (m/s) + 0.000043 Load (N)
R-sq= 97%   (7)

Specific Wear Rate (mm2/N) = 0.000180 + 0.000036 Jatropha Oil Blends (%)
- 0.000243 Sliding Velocity (m/s) + 0.000005 Load (N)
R-sq= 92%   (8)

Validation of Model: The last step was to confirm the predicted model with the experiment for the quality characteristics. With new set of control factor $A_2B_3C_1$, experiment were performed for the pin weight loss, friction coefficient and wear rate. The predicted experiment for the pin weight loss can be performed according to the following equation:

$$\square = T + (A_2 - T) + (B_3 - T) + (C_1 - T) \qquad (9)$$

where,
$\square$ = Estimated average
T = Overall experimental average
A_2, B_3, C_1 are the mean response for the control factors.

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Table 11: Results of the confirmation experiments for pin weight loss, friction coefficient and wear rate

	Optimum control factors	
	Predicted value	Experimental value
Level	A2B3C1	A2B3C1
S/N ratio for pin weight loss (dB)	58.4	59.12
S/N ratio for Friction Coefficient (dB)	32.5	33.8
S/N ration for wear rate (dB)	69.0	70.3

Table 12: Confidence Interval values for pin weight loss, friction coefficient and wear rate

Parameters	Max. Value	Min. Value
Weight loss of pin	61.15	55.65
Friction coefficient	35.79	29.21
Wear Rate	71.04	66.96

An experiment were conducted for the new set of the control factors and the output was compared with the output obtained from the predicted equation as shown in Table 11.

The following equation was used to obtain confidence interval for the predicted mean of the confirmation test [33].

$$CI = \pm \left[\frac{F(1,\square_2) \times V_e}{N_e} \right]^{0.5} \quad (10)$$

where
CI=confidence interval
$F(1,\square_2)$= F value at required confidence interval at DOF 1
V_e= Error variation from ANOVA
N_e= Number of replications

The calculated confidence level for pin weight loss = ±2.75 *dB*

The calculated confidence level for friction coefficient = ±3.29 *dB*

The calculated confidence level for wear rate = ±2.04 *dB*

The 95% confidence interval for the predicted mean of the confirmation test was shown in Table 12.

Wear Scar Diameter Analysis: Figure 5 shows the wear scar diameter of Al-7% Si alloy pin with jatropha oil blends percentage at different load and sliding velocity. Wear scar diameter increases with increase of load and maximum wear scar diameter was observed at 150 N load for each blend considered. This is due to increase in friction force applied with increase of load. Minimum wear scar diameter was found at 3.8 m/s sliding velocity and maximum at 1.3 m/s sliding velocity. It reduces with
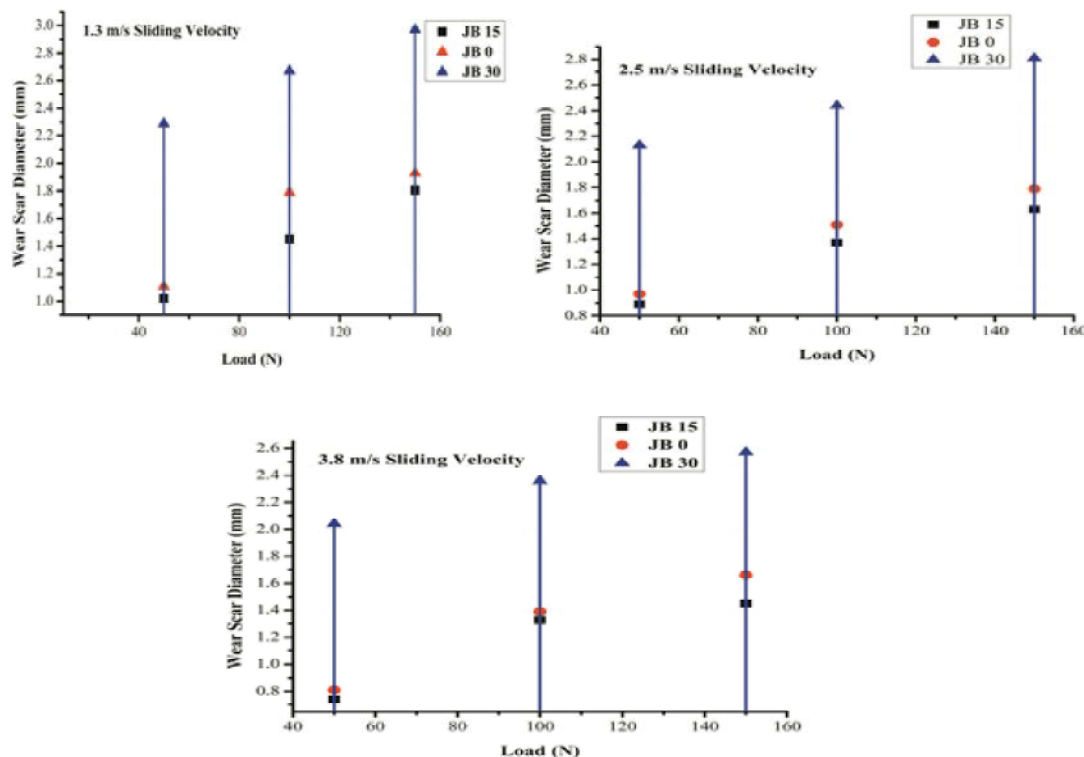

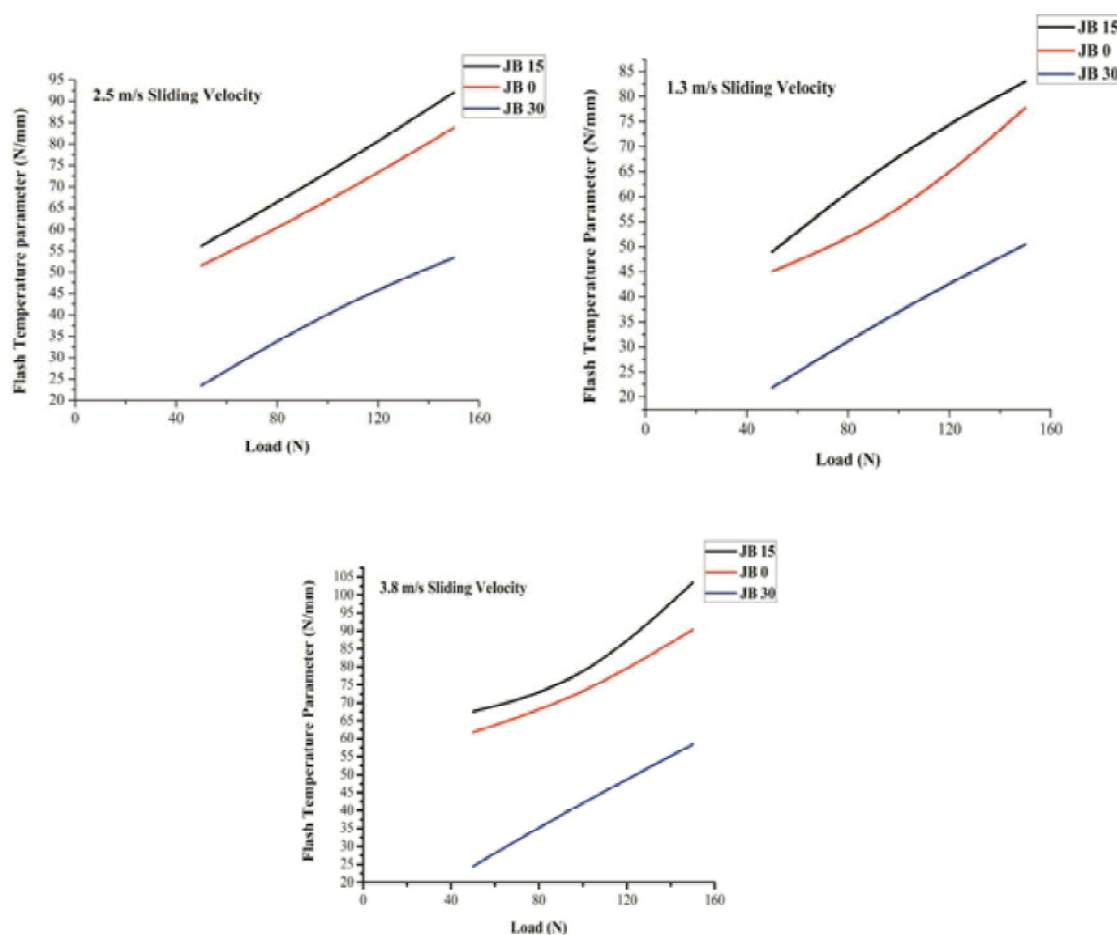Fig. 5: Wear scar diameter at various loads and sliding velocity for jatropha oil blends

Fig. 6: Effect of jatropha oil blends on Flash temperature parameter at different load and sliding velocity

increase of sliding velocity due to formation of tribo layer acting as lubricant which was formed due to increase of temperature with increase of sliding velocity. JB 15 shows minimum wear scar diameter among all the jatropha oil blends as it provides better protective layer between metal to metal contacts.

Flash Temperature Parameter Analysis: Figure 6. Shows the effect of jatropha oil blend on flash temperature parameter at different load and sliding velocity. Generally by observation, the trend of flash temperature parameter is increased when the load is increased from 50 N to 150 N due to increase in frictional force with increase of load. For 1.3 m/s Sliding velocity, the lubricant performance was improved by 15% contamination of jatropha oil with conventional lubricant as viscosity provides protective film layer with increase of sliding velocity. JB 15 shows higher flash temperature parameter compared to other percentage of contamination. It proves that JB 15% was potential anti-wear additive for conventional lubricant.

Higher flash temperature ability of JB 15 makes this blend more compatible at high temperature. The lowest value of FTP was found to be atJPB 30.

While for 3.8 m/s sliding velocity test, figure shows 15% of jatropha oil was the highest value of FTP. Means, 15% of jatropha oil was the best additive for fresh lube oil at the temperature of 40^0C, in order to reduce wear phenomena. The lowest value was occurred at 30% of jatropha oil. That means, both 30% contamination of jatropha with lubeoil was making much wear on metal surface in contact at 40°C.

Degradation of Lubricant: Viscosity is a significant factor in determining the degradation of lubricant as it provides a protective film thickness between the surfaces in contact and protect wear of metal surfaces during sliding. It is also contribute towards identification of oil grades and for monitoring the change in range of viscosity while the vehicle is in service. The deterioration of used oil can be due to oxidation or by contamination which indicates
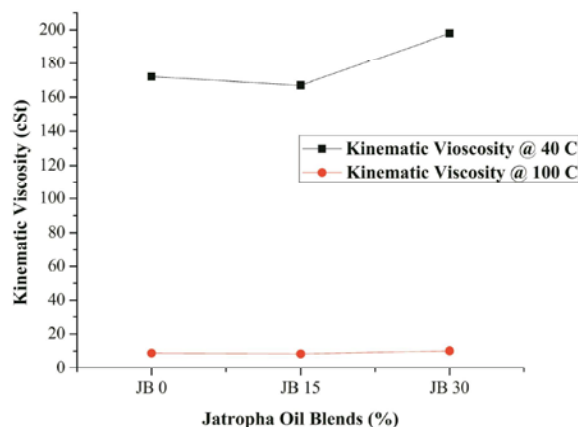
Fig. 7: Variation of jatropha oil blendpercentages with kinematic viscosity @ 40 and 100⁰C.
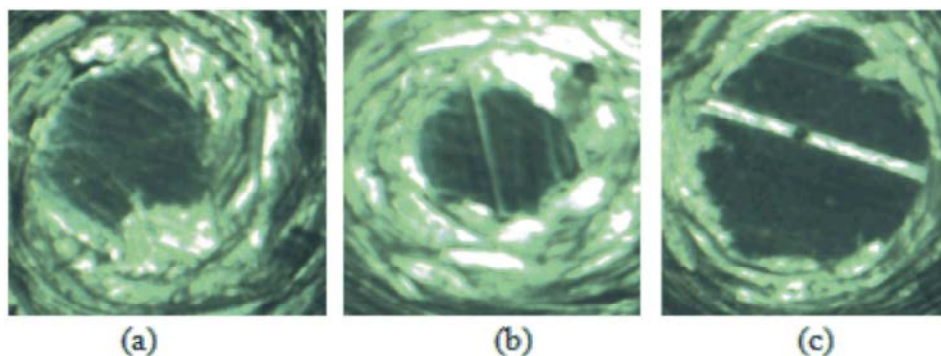

Fig. 8: wear surface image of the various jatropha oil blends at 3.8 m/s sliding velocity and 50 N load.

the increase in viscosity while dilution of lower viscosity oil or fuel contributed towards decrease in viscosity. Fig 7. Shows the variation of viscosity with jatropha oil percentages at different loads. It can be revealed from Fig 7 that the viscosity increased with increase in load due to the oxidation process which results into the sludge formation or contamination of insoluble particles. This contributes towards increment of the length of molecular chainwhich results into increased viscosity of the used oil. From the figure, it shows that for the contamination of jatropha oil with lube oil, the highest value wasstated for 15%. Means, 15% of jatropha oil was the best contamination with lube oil in order to maintain the anti-wearcharacteristic such as kinematic viscosity. The figure also showed that normally the values of kinematic viscosity forall samples at 40°C were higher than 100 centistokes (cSt.). It stated that basically the kinematic viscosity of thesesamples was lower than the samples at 40°Cwhich is about below 20 cSt. The lower value of kinematic viscositywas affected by the temperature. With higher the temperature, the kinematic viscosity will be lower due to theliquidity of the samples lubricant.

Wear Mechanism: Figure 8 shows the wear surface image of the various jatropha oil blends at 3.8 m/s sliding velocity and 50 N load.

From the left to the right side of the figure, wear surfaces were for the JB0, JB 15 and JB 30 at 50 N Load and 3.8 m/s Sliding Velocity. Minimum wear surface were for jatropha Oil at 15% (JB 15). As the JB 15 makes a thick film between the sliding surfaces in contact and protect from wear in comparison to other contaminated jatropha Oil blends i.e.JB 30 and JB 0.

CONCLUSION

The taguchi method was applied to optimize the pin weight loss, friction coefficient and wear rate at different control factors. The results are summarized as follows:
- Taguchi method was suitable to optimize the tribological behavior of different jatropha oil blends at various sliding velocities and loads.
- The optimum condition for the pin weight loss, friction coefficient and wear rate was A2B3C1. It can be revealed at level 2 of first control factor (JB 15), third level of sliding velocity (3.8m/s) and third

control factor was better at first level (50N). Also as a result of the design method ANOVA, the factor Jatropha Oil blends percentage has the maximum contribution in controlling the friction and wear behavior of Pin against the disk.

- The pin weight loss was influenced primarily by jatropha oil blend percentage, the applied load and sliding velocity. The friction coefficient was influenced maximum byjatropha oil blend, Load and then sliding velocity. The specific wear rate was influenced primarily by jatropha oil blend percentage, sliding velocity and the applied load.
- Generally, it was observed that the interactions between the control factors have significant influences on the pin weight loss, friction and wear rate of Aluminium alloy pin.
- Deviations between actual and predicted S/N ratios for pin weight loss, friction coefficient and wear rate are negligibly small with 95% confidencelevel.
- The wear scar diameter (WSD) increases with increase of load and decreases with increase of sliding velocity. That means, at lower loads the WSD under jatrophacontaminated lubricant are lower, where at higher loads, the WSD are higher.
- The results shows that the contaminations of lube oil at 30% of jatropha oil at 1.3 m/s Sliding Velocity and 150 N Load give higher WSD. At 15% of jatropha oil, the value of WSD stated that it was the lowest which means 15% of Jatropha oil got the lesser scars and made it the best anti- wear.
- The higher value of flash temperature parameter (FTP) clearly observed when 15% of jatropha oil was used. The 15% of jatropha oil improves the lubricant (SAE 40) performance, indicating less possibility of lubricant film breakdown.
- From the observations on worn surfaces of these specimens, 15% of jatropha oil contaminated conventional lubricant shows better anti-wear lubricant properties than others.
- For the contamination of jatropha oil with lube oil, the highest value of kinematic viscosity was stated for 15% at both two temperatures tested (40°C and 100°C).

According to the experimental result, 15% of jatrophaoil contaminated with the base lubricant showed better performance in terms of wear and friction characteristics and can be the alternative lubricant for the automotive application.

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