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STATISTICAL EVALUATION OF VEGETABLE OIL AS LUBRICANT FOR ALUMINIUM 6063

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Abstract - *The present work investigates the performance of vegetable oil as a lubricant for wear behavior of Aluminum on pin on disc apparatus. Statistical approach was used to evaluate performance of different vegetable oil. In this research, the Density of vegetable oil is taken as parameter and five different oils (sunflower oil, soybean oil, Palmolive oil, and peanut oil) which include straight cutting oil for performance comparison are considered. Different density, RPM, load and sliding distance were selected for control factor and output response were friction force (FF), wear rate and pin temperature were selected to evaluate the lubrication performance. Taguchi based design of experimental method was opted where L25 orthogonal array was used for design of experiment. For statistical analysis, "Analysis of Variance" (ANOVA) was performed to determine the impact and contribution of individual factor on all the output parameter. We found that increased density of oil provide better lubrication for relative higher load and RPM. Performance of vegetable oil was better from straight cutting oil for lubrication point of view but not for temperature control.*

Key Words: Lubrication, Vegetable oil, Wear rate, Frictional Force. Oil density.

1. INTRODUCTION

Vegetable oil plays an important roles in food product and industrial application. They helps in transport of fat soluble vitamins A,D,E and K. they also provide linoleic and linolenic acid helps in physical growth and they are one of the main ingredient used to manufacture soaps, cosmetics and pharmaceutical products. In today's lubrication technology environmental aspect are prime concern. Increased renewable and biodegradable lubrication are required for reduction of contamination of environment. The majority of vegetable oils consist primarily of triacylglycerides. Riacylglycerides, also termed triglycerides, are glycerol molecules with three long chain fatty acids attached at the hydroxyl groups via ester linkages. The triglyceride structure of vegetable oils provides Qualities desirable in a lubricant. The base oil is the source of fatty acid. The lower rate of oxidation disturbs the acceptance of oil as biodegradable lubricant [1]. Lubrication performance is hampered by oxidation. Lower the oxidation grater the lubrication effect. Addition of anti-oxidant to oil is also another method to do so[2].

Limited research has been done on collective approach on study of food grade vegetable oil for lubrication effect on any material. Palm oil has been evaluated on aluminum alloy on pin on disc apparatus to determine the effect of load and friction on wear. It was found that friction coefficient of palm at higher load was lower with increased in sliding speed. Better lubrication was found for lower volume loss at lower load. Similar pattern was also found out in chemical treated oil. By calculation of surface roughness it was found that palm oil shows better result than convention lubrications oil at relatively lower operating temperature[4]. One of the main problems of vegetable oils is their poor performance when working at high temperature. In the worst cases, the oxygen bond in vegetable oils can lead to metal oxidation and weaken the structure of the metal. For this theory jatropha oil, palm oil RBD and distilled palm oil were used and compared with commercial stamping oil and hydraulic oil. For coefficient of friction vegetable oil showed better result at extreme pressure. At room temperature palm oil, flow was restricted due to semi solid state and lubrication film breaks down easily. Rest two oil maintained the lubrication film at room temperature. However, for wear scar stamping oil and hydraulic oil showed better performance at higher speed and temperature. The reason for that is when a ball bearing rotates and high pressure is applied, the oxygen double bond tends to react with another element, most probably the material of the ball bearing. This causes the material of the ball bearing to oxidize and become brittle. The material would have a high wear rate due to a third body abrasion mechanism. The metal-to-metal contact between the top and bottom ball bearing would increase the frictional resistance. As a result, the coefficient of friction increases[5].

Pongamia oil as lubrication was tested at different load and sliding distances. Different blend of bio lubricant was prepared with SAE 40 oil. Among the entire blend PB 15(15 % veg oil) showed best result for wear rate to withstand higher load. As the load increases, viscosity of all the bio-lubricants increases. All the bio-lubricants meet the ISO VG 100 requirement at 40oC except PB 50. According to the experiment, at 3.8 m/s sliding velocity and 50 to 150 N load excellent tribological behavior was observed for all blends bio lubricant[6].
Another study on double fractionated palm oil (DFPO) as bio lubricant on wear behavior of pure aluminum A1100 was conducted. At higher load higher wear rate was observed for all lubricant. For higher COF at higher sliding distant and load, DFPO showed best result. Oxidation was the main cause of wear rate, which was observed, and other chemical Interaction between pin and plate[7]. Pongam and jatropha vegetable oil was used for tribological studied on AISI 1040 steel. Various blends were developed using methyl ester and comparison was done with mineral oil. Comparative study revealed that vegetable oil showed better performance than vegetable oil. However there modified version of both oil exhibits slightly higher friction at lower load operation. Pongam, jatropha and epoxide jatropha raw oil showed more wear resist and then petroleum oil. Lubrication film was very much stable for both vegetable oil[8]. Tribological Evaluation of coconut oil was done. Coconut oil was used at 2T oil in engine lubrication. On four ball tester and two stroke I.C. engines on test rig it was revealed that higher wear rate compare to commercial lubrication oil was observed and hence cannot be recommend for 2T oil. However, antiwear and extreme pressure properties can be improved by adding additives to modify oxidation properties. Due to biodegradable characteristic coconut oil can be used in modified form to achieve certain lubrication properties as a lubricant[11].

2. METHODOLOGY

2.1 Material

Pin material was Aluminum-silicon alloy 6063-T6 commercial grade used as test specimen. These alloys have high impact strength and toughness. Material was procured from Ganpati alloys, Aurangabad and composition testing of alloy was done at S.N metallurgical service, Aurangabad. Chemical composition is given below in table 2.1

Table 2.1: Chemical Composition

Sr.No	Compound	Observation (%)
1	Cu	0.002
2	Si	0.44
3	Fe	0.14
4	Mn	0.003
5	Ni	0.001
6	Mg	0.56
7	Zn	0.001
8	Pb	0.016
9	Sn	0.006
10	Ti	0.031
11	Al	98.8
	Total	100

Disc material was EN-31 steel with 61 HRC hardness, which was specified in manual of pin on disc apparatus provide from DUCOM manufacturer.
Vegetable oil was procured from Kasbekar Tel Bhandar, Aurangabad and Straight cutting oil is from Servo cut. The density was calculated and mention in the table 2.2 below.

Table 2.2: Oil Density

Oil	Density,Kg/m^3
St.Cutting	835.1
Sunflower	838.8
Soybean	842.7
Palm oil	856.3
Groundnut	871.8

2.2 Wear Test

The pin specimen was prepared with dimension of average length of 25 mm and 10 mm diameter for 25 Experiments. A single pin type pin on disc test apparatus was used to carry out test of composite as per ASTM G99-95 standards. The tests are carried out under lubrication condition at room temperature. A single pan electronic weighing machine precisa 205 ACSC swiss quality with least count of 0.0001g was used to measure the initial and final weight of the specimen as well as mass for 10 ml of oil to measure density of vegetable oil. The cylindrical pin flat-ended specimens of size 10 mm diameter and 25 mm length were tested against EN31 steel disc by applying the load. After running through a fixed sliding distance, the specimens were removed, cleaned with acetone, dried, and weighed to determine the weight loss due to wear. The difference in the weight measured before and after test gave the sliding wear of the composite specimen and then the wear rate was calculated. The sliding wear rate of the composite was studied as a function of the load, rpm, sliding distance and density of oil. The dry sliding wear tests were carried out at controlled parameter levels. Parameters and levels of parameter are as shown in the table 2.5

Table 2.5: Parameter and Levels

Sr.No	Parameter	1	2	3	4	5
1	Oil	STC	Sunflower	Soybean	Palm	Peanut
2	RPM	400	700	1100	1400	2000
3	Load (Kg)	2	4	6	8	10
4	Distance (m)	750	1000	1250	1500	1750

Density of oil was measure at room temperature and it was taken as parameter of tribological study. Wear rate was calculated by the equation (1)

$$\frac{(M1-M2)/density}{load*sliding\ distance} \quad (1)$$

Where M1 & M2 are initial and final mass of pin. The unit is m^3/Nm. Friction force was measured by load cell on machine and pin temperature was measured by K-type thermocouple.

2.3 Experimental design

Taguchi technique was used in this study of wear behavior of Al 6063-T6 under lubrication condition. A major step in the DOE process is the selection of control factors and levels, which will provide the desired information. Taguchi creates a standard orthogonal array to accommodate the effect of several parameters on the output parameter and defines the plan of experiment. Four process parameters at five levels led to the total of 25 test for different lubricant under different density. The experimental results are analyzed using analysis of variance (ANOVA) to study the influence of parameters on wear rate. A linear regression model is developed to predict the wear rate of the composites. The major aim of the present investigation is to analyze the influence of parameters like load, RPM, Sliding distance, and Density of various oil for wear rate of aluminum 6063-T6. The array is given below in the table 2.6

Table 2.6: L25 Orthogonal Array

Sr.No	Oil	RPM	Load	Sliding distance	Wear rate, 10^{-16} mm³/N	Friction force	Pin temp
1	1	1	1	1	25.366075	2.9	30
2	1	2	2	2	9.512278	2.6	31
3	1	3	3	3	8.117144	2.2	34
4	1	4	4	4	10.463506	1.8	35
5	1	5	5	5	11.523445	1.6	35
6	2	1	2	3	20.242128	2.1	31
7	2	2	3	4	17.756252	1.8	32
8	2	3	4	5	17.937439	1.6	35
9	2	4	5	1	1.354548	2.4	35
10	2	5	1	2	19.024556	2.2	34
11	3	1	3	5	2.427896	1.2	33
12	3	2	4	1	9.702524	2.1	34
13	3	3	5	2	4.565893	1.9	35
14	3	4	1	3	15.219645	1.7	34
15	3	5	2	4	8.370805	1.5	35
16	4	1	4	2	9.512278	1.6	36
17	4	2	5	3	9.131787	1.4	36
18	4	3	1	4	26.888039	1.2	35
19	4	4	2	5	16.850321	1	35
20	4	5	3	1	8.455358	1.9	35
21	5	1	5	4	14.712323	1.1	32
22	5	2	1	5	43.484700	0.9	33
23	5	3	2	1	12.683037	1.8	34
24	5	4	3	2	6.341519	1.6	35
25	5	5	4	3	4.565893	1.4	37

Averages reading are mention for each parameter and each output.

3. RESULT AND DISCUSSION

Statistical analysis of experimental data was carried out in three stages. First taguchi was applied to L25 orthogonal array experiment in order to identify the optimal values for all output parameter. Later statistical ANOVA was performed to observe the parameter affect significantly the wear behavior of aluminum under lubrication at different density. Last mathematical model for all output parameter were developed with the multiple regression technique. Using a Minitab 16 analysis of the influence of each control factor on output parameter has been performed with SNR response. The result with calculated SNR for all output parameter are furnished in the table 3.1 below.

Table 3.1: Signal to Noise Ratio

Sr.No	SNR(WEAR)	SNR(FF)	SNR(PT)
1	-28.0851	-9.24796	-29.5424
2	-19.5657	-8.299467	-29.8272
3	-18.1881	-6.8484536	-30.6296
4	-20.3935	-5.1054501	-30.8814
5	-21.2316	-4.0823997	-30.8814
6	-26.1251	-6.4443859	-29.8272
7	-24.987	-5.1054501	-30.103
8	-25.0752	-4.0823997	-30.8814
9	-2.63589	-7.6042248	-30.8814
10	-25.5863	-6.8484536	-30.6296
11	-7.7046	-1.5836249	-30.3703
12	-19.7377	-6.4443859	-30.6296
13	-13.1905	-5.575072	-30.8814
14	-23.6481	-4.6089784	-30.6296
15	-18.4553	-3.5218252	-30.8814
16	-19.5657	-4.0823997	-31.1261
17	-19.2111	-2.9225607	-31.1261
18	-28.5912	-1.5836249	-30.8814
19	-24.5322	-0.000125	-30.8814
20	-18.5426	-5.575072	-30.8814
21	-23.3536	-0.8278537	-30.103
22	-32.7667	0.91514981	-30.3703
23	-22.0645	-5.1054501	-30.6296
24	-16.0439	-4.0823997	-30.8814
25	-13.1905	-2.9225607	-31.364

3.1 Signal to Nose ratio.

The SNR response table of test process for all output parameter at each level of control factor is depicted and it is found that it changes at each level. Taking the difference between the values, control factor with highest influence is determined. Higher the difference more the influence of control factor. Smaller is better condition was opted. According to mention table the SNR mean value with main effect plots for all output parameter is deduced and shown in the fig 3.1, fig 3.2 and fig 3. it is observed that greater the SNR, smaller is the variance of wear rate around desired value. To determine the optimal testing condition is very easy in this approach. The plot shows the change of SNR when setting of control factor changes from one level to another. The best value for wear rate, friction force, pin temperature and oil density is found at higher SNR value. From fig 3.1, fig 3.2 and fig 3.3 it can be deduced the optimum condition for all out put parameter which are shown as SNR response table in table 3.1, table 3.2 and table 3.3

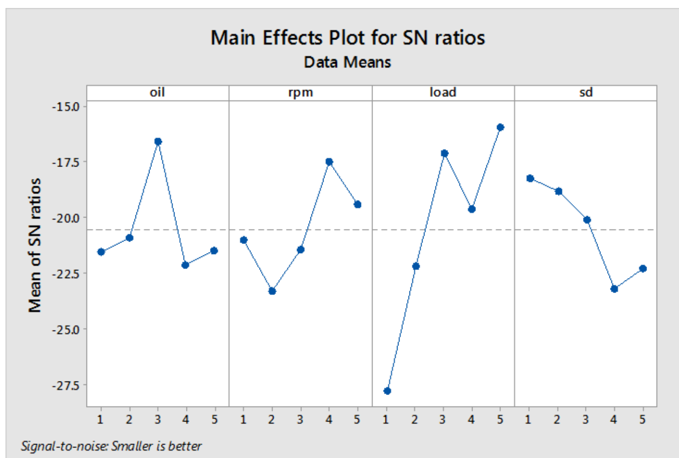

Fig 3.1: SNR and mean of wear rate

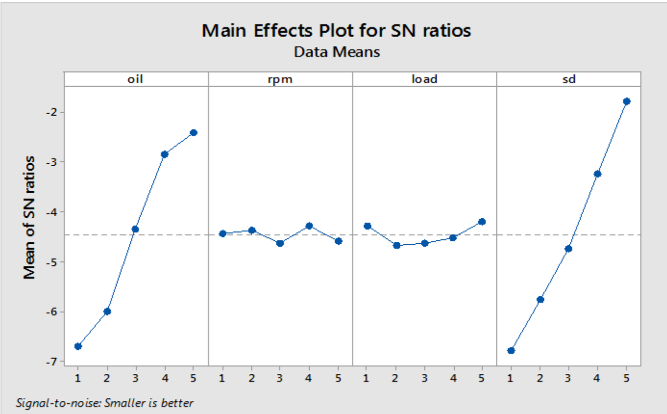

Fig 3.2: SNR and MEAN of Frictional force

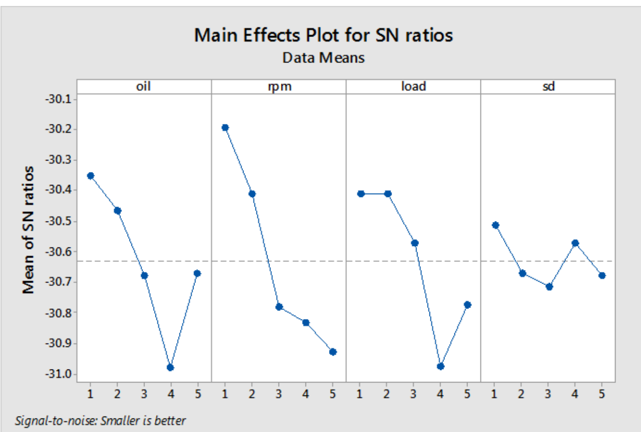

Fig 3.3: SNR ratio and MEAN of Pin Temp

From the table it is found that for wear rate of sample load plays very important factor as it provide extreme pressure condition for operations followed by the rotational speed. RPM thus contributes to the frictional force generated. RPM also decides lubrication film thickness on disc. Higher the RPM lower the lubrication thickness as it is flown outwards radially. From SNR graph, it is seen that for higher RPM, LOAD and sliding distance soybean oil is best performed lubricant. Similarly, for friction force more the distance contact surface covers more friction it generates. Thus from table it is deduced that Sliding distance and the counterpart i.e. lubrication film produce friction force. From SNR graph it is deduced that for higher sliding distance higher density oil is required so that lubrication film must be maintained thus palm oil and groundnut oil is best-performed lubricant. For pin temperature, it was found that RPM and oil density was main factors for its generation. For lower rpm, density would not matter but at higher RPM, higher density must require to maintain lubrication film at contact surface. Palm oil was the best-performed lubricant in this aspect.

Taguchi Analysis: wear rate versus oil, rpm, load, sd

Table 3.1: Response Table for Signal to Noise Ratios
Smaller is better

Level	Oil	RPM	Load	SD
1	-21.49	-20.97	-27.74	-18.21
2	-20.88	-23.25	-22.15	-18.79
3	-16.55	-21.42	-17.09	-20.07
4	-22.09	-17.45	-19.59	-23.16
5	-21.48	-19.4	-15.92	-22.26
Delta	5.54	5.8	11.81	4.94
Rank	3	2	1	4

Taguchi Analysis: FF versus oil, rpm, load, sd

Table 3.2: Response Table for Signal to Noise Ratios
Smaller is better

Level	Oil	RPM	Load	SD
1	-6.717	-4.437	-4.275	-6.795
2	-6.017	-4.371	-4.674	-5.778
3	-4.347	-4.639	-4.639	-4.749
4	-2.833	-4.28	-4.527	-3.229
5	-2.405	-4.59	-4.202	-1.767
Delta	4.312	0.359	0.472	5.029
Rank	2	4	3	1

Taguchi Analysis: PIN TEMP versus oil, rpm, load, sd

Table 3.3: Response Table for Signal to Noise Ratios
Smaller is better

Level	Oil	RPM	Load	SD
1	-30.35	-30.19	-30.14	-30.51
2	-30.46	-30.41	-30.14	-30.67
3	-30.68	-30.78	-30.57	-30.72
4	-30.98	-30.83	-30.98	-30.57
5	-30.67	-30.93	-30.77	-30.68
Delta	0.63	0.73	0.57	0.2
Rank	2	1	3	4

3.2 ANOVA and Regression model

ANOVA was used to determine the design parameters significantly influencing the wear rate. The following table shows the results of ANOVA for all output parameter. This analysis was evaluated for a confidence level of 95% that is for significance level 0.5. The last column of the tables shows the percentage of contribution of each parameter on the wear rate, indicating the degree of influence on the result. The adequacy of models are checked using normal probity plot of residual for all output parameter as as show in the fig 3.4, fig 3.5 and 3.6 it is observed that point which are close to the normal probality line thus evidence the modal accuracy. Another way of confronting the modal accuracy is by plotting the residuals against fitted values of all output parameter. Reinforcement Analysis of variance (ANOVA) is carried out using MINITAB 16 software to investigate difference in average performance of the factors under test. ANOVA breaks total variation into accountable sources and helps to determine most significant factors in the experiment. R-sq signifies the accuracy of the modal developed and be confirmed by the confirmation test by conducting the experiment. The F-test value and P-test value are formulated in tabular form in table 3.4, table 3.5 and table 3.6 from where contribution of each input factor are calculated for particular output factor. This approach gives the detail information on how each parameter perform under lubrication condition.

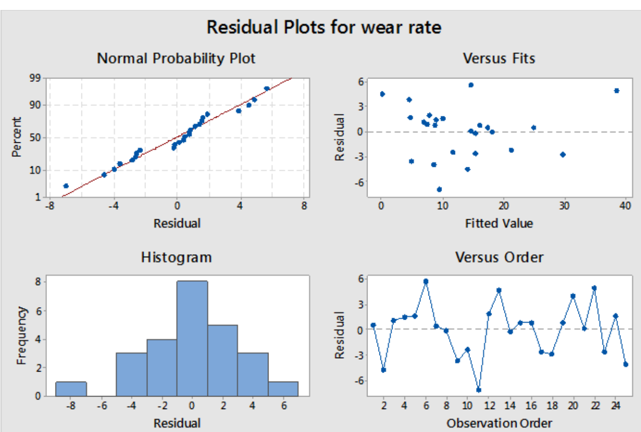

Fig 3.4- Residual plot

Table 3.4: Analysis of Variance for wear rate

Source	DF	Adj SS	Adj MS	F-Value	P-Value	% Contribution
Oil	4	207.5	51.89	1.79	0.225	11.83
RPM	4	211.2	52.8	1.82	0.219	12.02
Load	4	1038.8	270.96	9.33	0.004	61.67
SD	4	245.1	63.53	2.19	0.161	14.48
Error	8	232.3	29.03			
Total	24	1988.9				

Table 3.5: Model Summary for wear rate

S	R-sq	R-sq (adj)	R-sq (Pred)
5.38824	88.32%	64.97%	0.00%

Regression Analysis: wear rate versus oil, rpm, load, sd
Regression Equation

Wear Rate = 22.14 + 0.563 oil - 1.600 rpm - 3.857 load + 1.971 sd

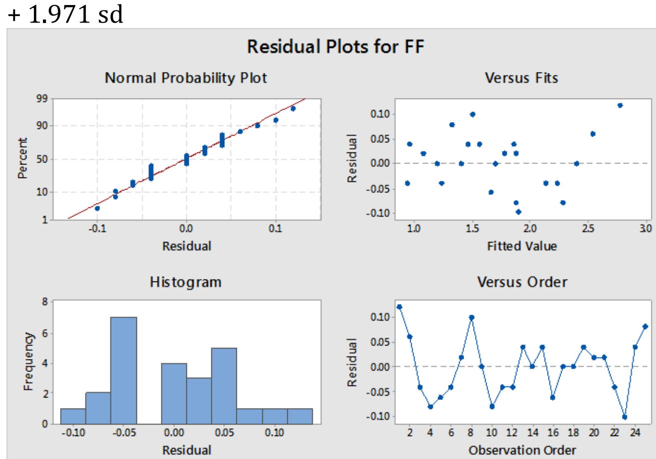

Fig 3.5: Residual plot

Table 3.6: Analysis of Variance for friction force

Source	DF	Adj SS	Adj MS	F-Value	P-Value	% Contribution
Oil	4	2.796	0.699	69.90	0.000	48.20
RPM	4	0.020	0.005	0.50	0.737	0.34
Load	4	0.052	0.013	1.30	0.348	0.90
SD	4	2.932	0.733	73.30	0.000	50.56
Error	8	0.080	0.010			
Total	24	5.880				

Table 3.7: Model Summary for friction force

S	R-sq	R-sq (adj)	R-sq (Pred)
0.1	98.64%	95.92%	86.71%

Regression Analysis: FF versus oil, rpm, load, sd
Regression Equation

FF = 3.3060 - 0.2320 oil - 0.0180 rpm - 0.0300 load - 0.2420 sd

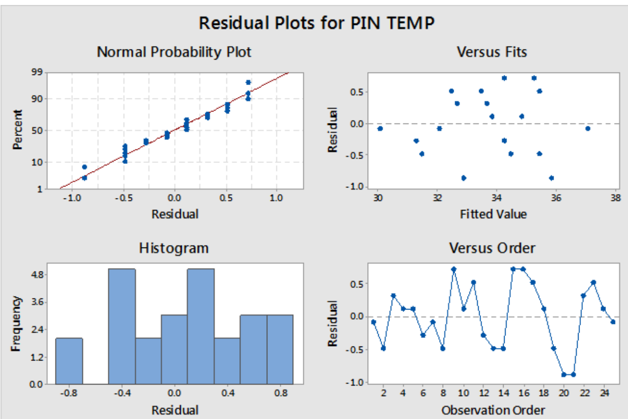

Fig 3.6- Residual plot

Table 3.8: Analysis of Variance for pin Temperature

Source	DF	Adj SS	Adj MS	F-Value	P-Value	% Contribution
Oil	4	16.96	4.24	6.14	0.015	25.90
RPM	4	28.160	7.04	10.20	0.003	43.03
Load	4	18.16	4.54	6.58	0.012	27.77
SD	4	2.16	0.54	0.78	0.567	3.30
Error	8	5.520	0.690			
Total	24	70.960				

Table 3.9: Model Summary for pin Temperature

S	R-sq	R-sq (adj)	R-sq (Pred)
0.830662	92.22%	76.66%	24.03%

Regression Analysis: PIN TEMP versus oil, rpm, load, sd
Regression Equation

PIN TEMP = 28.820 + 0.440 oil + 0.720 rpm + 0.500 load + 0.080 sd

4. CONCLUSION

1. Test for lubrication charactistic of vegetable oil was successfully done at various load and RPM
2. As density of oil was taken as a factor it was found that higher the density better the stability of film at room temperature
3. force it was found that more the contact surface time more friction is generated and thus oil density played an important role in this matter to control this particular factor.
4. Temperature was contributed by almost all parameter but mostly RPM was important. At particular oil density and load, variation in RPM led to change in pin temperature.
5. Probability graph showed the authentication of data collection and provide firm ground for model developed. Most of the data points lies near probability line as indicated.
6. With confidence level of wear 95% that is for significance level 0.5 which was kept higher due to error generation, it was found that R-sq. for wear rate was 88.32%, for frictional force was 98.64%, and pin temperature was 92.22%.
7. Finally, it was found that sunflower oil and soybean oil performed well compare with other oil taken density as parameter. For wear rate control, soybean oil was more effective and for pin temperature and friction control, sunflower oil was more effective.
8. It was found that higher density fluid could not sustain the lubrication film at higher RPM as it word break easily.

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