International Journal of Mechanical, Industrial and Aerospace Sciences
ISSN: 2517-9950
Vol:10, No:7, 2016

Friction and Wear Characteristics of Pongamia Oil Based Blended Lubricant at Different Load and Sliding Distance

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***Abstract*—**Around the globe, there is demand for the development of bio-based lubricant which will be biodegradable, non -toxic and environmental friendly. This paper outlines the friction and wear characteristics of Pongamia oil (PO) contaminated bio-lubricant by using pin-on-disc tribometer. To formulate the bio-lubricants, PO was blended in the ratios 15, 30 and 50% by volume with the base lubricant SAE 20 W 40. Tribological characteristics of these blends were carried out at 3.8 m/s sliding velocity and loads applied were 50, 100, 150 N. Experimental results showed that the lubrication regime that occurred during the test was boundary lubrication while the main wear mechanisms were abrasive and the adhesive wear. During testing, the lowest wear was found with the addition of 15% PO, and above this contamination, the wear rate was increased considerably. With increase in load, viscosity of all the bio-lubricants increases and meets the ISO VG 100 requirement at 40 ^{o}C except PB 50. The addition of PO in the base lubricant acted as a very good lubricant additive which reduced the friction and wear scar diameter during the test. It has been concluded that the PB 15 can act as an alternative lubricant to increase the mechanical efficiency at 3.8 m/s sliding velocity and contribute in reduction of dependence on the petroleum based products.

***Keywords*—**Pongamia oil, sliding velocity, load, friction, wear.

I. Introduction

SEVERAL efforts around the globe have been attempted to improve environmental friendliness, dependability and energy efficiency in the automotive sector. Advancement in the technological solutions like use of lightweight materials, exhaust gas after treatment, less harmful fuel and controlled combustion are the few possible means to decrease the environmental troubles created by vehicles and machines [1]. Requirement of effective lubrication at desired operating conditions for safe and reliable operation of an automotive vehicle is mandatory to reduce friction and wear, particularly in engines and drive trains. Mineral, synthetic and semi synthetic oil have been used as a lubricant for automotive applications but their disposal leads to the degradation of both aquatic and terrestrial ecosystems [2]. Furthermore, emissions of metal traces like calcium, magnesium, iron particles and zinc due to combustion of these lubricant leads to the concern of environmental degradation [3]. Moreover, current and future prospects of these lubricants have been predicted as bleak in future due to availability of finite resources of petroleum crude oil [4]. The depletion of crude oil reserves and increased hike in oil prices have led to an innovative global search for developing and using alternative lubricant to protect the environmental deterioration caused by the lubricating oils and their uncontrolled spillage. Vegetable oil based lubricant can be considered as an alternative to conventional lubricants, especially in environmental sensitive areas such as agriculture, forestry, mining as they have less toxicity and higher biodegradability [5]-[7]. Vegetable oil-based lubricants exhibit high lubricity, higher flash point, lower volatility and higher viscosity index [8]-[12]. Due to the presence of long chain fatty acid and polar groups in the structure of vegetable oil make them suitable for both boundary and hydrodynamic lubrications [13]-[16]. Non-edible vegetable oil are the potential feedstock's for their use as bio-lubricants due to their ability to overcome the problems related to edible vegetable oils like food versus fuel debate, environment, energy issues [17], [18]. Moreover, they can be planted near railways, roads, irrigation canals, poverty stricken areas, degraded forests, land unsuitable for cultivation. They are well adapted to desiccate; semi-desiccate conditions and advancement in growth can be achieved without fertility and moisture. Soil enrichment through seed cakes can be achieved after extraction from oil bearing seeds [19]. Several non-edible plant oils could be considered as sustainable feedstock's for bio-based lubricant production which may differ from country wise [20], [21]. There are limitations of bio-based lubricants which include more oxidization due to lower thermal stability and contributes in gumming effect [22], [23]. Oxidation stability and low pour point can be modified by partially adding additives [24], [25]. Moreover, transesterification or epoxidation are the solutions to meliorate oxidation stability at low temperature and deficient property does not affect much in tropical countries [26], [27]. To make bio-based lubricant sustainable, there is a need to improve available range of viscosities [28]. Viscosity is one of the important factor in determining coefficient of friction between the sliding surfaces as it act as protective film between the surfaces in contact to prevent them from wear. To do so, viscosity modifiers can also be used which are friendly with environment. Oleogels based on 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 for Bio-based lubricant applications [29]. Viscosity of bio-based lubricant can also be increased by using EVA and styrene-butadiene-styrene copolymers as they increase some

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amount of kinematic viscosities at 40 °C and 100 °C temperatures [30]. In spite of having advantages over conventional lubricants, the attempted made to develop bio-based lubricants and their applications are very few. In this study, tribological bahaviour of PO based bio-lubricant were investigated at different loads and fixed sliding velocity. It is selected as it can compete with the edible oils which are also used for the food applications and also it can be planted on the marginal or semi-desiccate lands.

II. Experimental Details

A. Test Apparatus

To investigate the friction and wear behaviour of bio-based lubricant variants Ducom Macro Pad Pin on Disc tribometer were used 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. Specification of the pin on disc tribometer is shown in Table I and the schematic image of the experimental set up is shown in Fig. 1. 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.

TABLE I
Specifications of Pin on Disc Tribometer

Parameters	Min	Max
Pin Diameter	3 mm	12 mm
Disc Diameter		165 mm
Disc rotation speed	200 rpm	2000 rpm
Normal Load	0	200 N
Frictional force	0	200 N
Wear measurement range	0	1200 µm
Wear track diameter	50	145

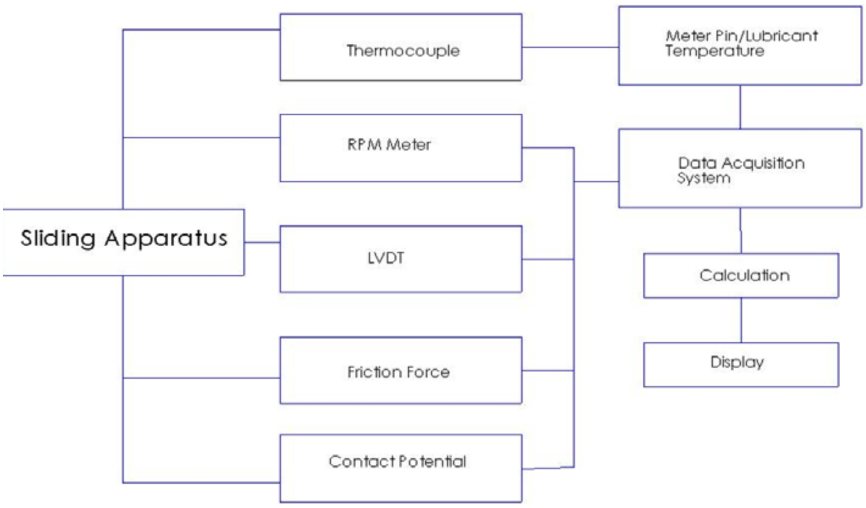

Fig. 1 Schematic image of Pin on disc tribometer Apparatus

B. Sample Preparation

The specimens which were used for the experiment are Aluminium Silicon Alloy with 7% silicon and EN31 steel as per ASTM G99. Hemispherical aluminium silicon alloy was used as the pin and the material used for the disc specimen was EN 31 steel with hardness 60 HRC. 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.

C. Test Method

The details were as follows: 50, 100, 150 N; Ambient temperature was taken; Track Diameter, 80 mm (for each experiment); Sliding Velocity, (3.786 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 zoom microscope was used. Mean average value was used after completing each experiment three times to maintain accuracy in the results.

D. Lubricants Used

Study of friction and wear behavior was performed with PO which was mixed with conventional lubricant (SAE 20W40) in the ratios: 20W40 (PB0); 10 (PB15); 30 (PB30); 50 (PB50) (% by volume). The homogeneous mixing was done with magnetic stirrer.

International Journal of Mechanical, Industrial and Aerospace Sciences
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E. Viscosity and Total Acid Number Test (TAN) test

Anton paar viscosity meter and TAN/TBN analyzers were used for investigating degradation of the lubricant. The kinematic viscosity was measured at 40^{o}C and 100^{o}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.

III. Results and Discussions

A. Specific Wear Rate Analysis

Fig. 3 shows the specific wear rate of the pin for different biolubricant variants as a function of sliding distance at various loads. It can be observed specific wear rate increases rapidly at the beginning of the test and becomes stable as the sliding distance increases for 50 N load. But when the load increases from 100 N to 150 N, there is an emergent jump in the specific wear rate for various PO blends. The maximum wear was observed for PB 50 for all the loads while the minimum wear was occurred for PB 15 which was nearer to PB 0. PB 15 has the ability to protect contact of sliding surfaces and withstand its ability throughout the experiment while it is least for PB 50 among the various blends. It can be revealed from the Fig. 2 that maximum specific wear rate were observed for PB 30, PB 50 while PB 15 shows lower wear rate among various blended lubricants.

Fig. 3 shows the weight loss of the material for different polanga oil blends at different loads. It seems quite clear that the PB 50 shows the highest loss of material among various blends for all the loads and it is lowest for the PB 15. It can be understood from the results that PB 15 shows minimum loss of material from the pin which is almost nearer to the PB 0 for all the loads.

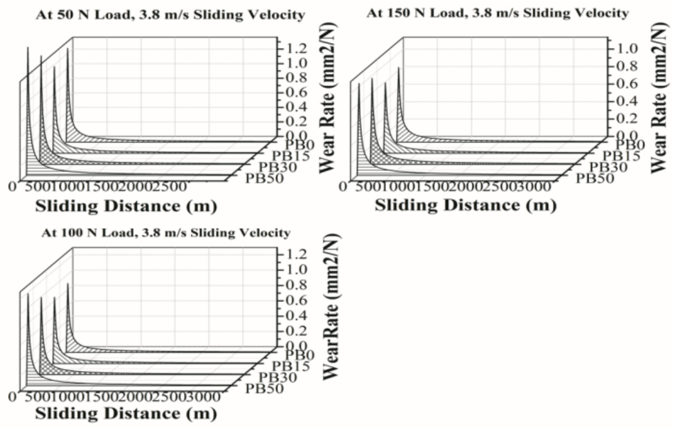

Fig. 2 Variation of Specific wear rate with sliding distance for various blends at 50 N, 100 N & 150 N loads

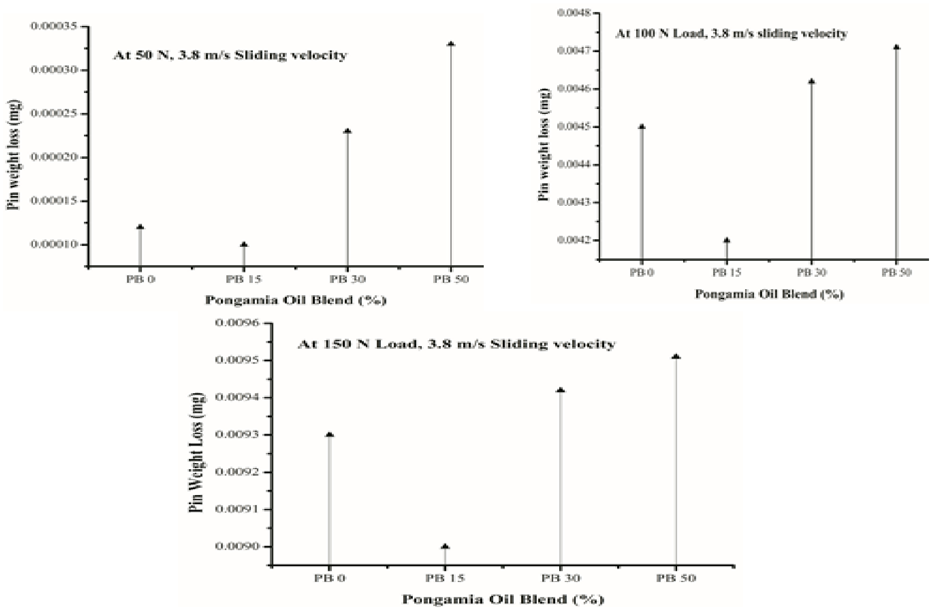

Fig. 3 Weight loss of the pin material vs PO blends percentages

B. Friction Coefficient Analysis

Variation of coefficient of friction with sliding distance for various blends at different loads is shown in Fig. 4. The test results depicted that the lubricant regime for all the blends comes under boundary lubrication (μ=0.001-0.2). It can be predicted that the with increase of load and sliding distance, friction coefficient increases s for different blends while PB 50 decreases which is due to decrease in viscosity which makes more precise film between the sliding surfaces of the metals in contact. There is minimum variation between friction coefficient for various blends at 50 N load and there is large between various blends when the load increases from 100 N to 150 N. This is due to metal to metal contact between pin and disc material which is minimum at 50 N load. PB 15 shows better result among the various blends at 100 and 150 N. This is attributed to the fatty acid composition of the polanga 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 convention 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.

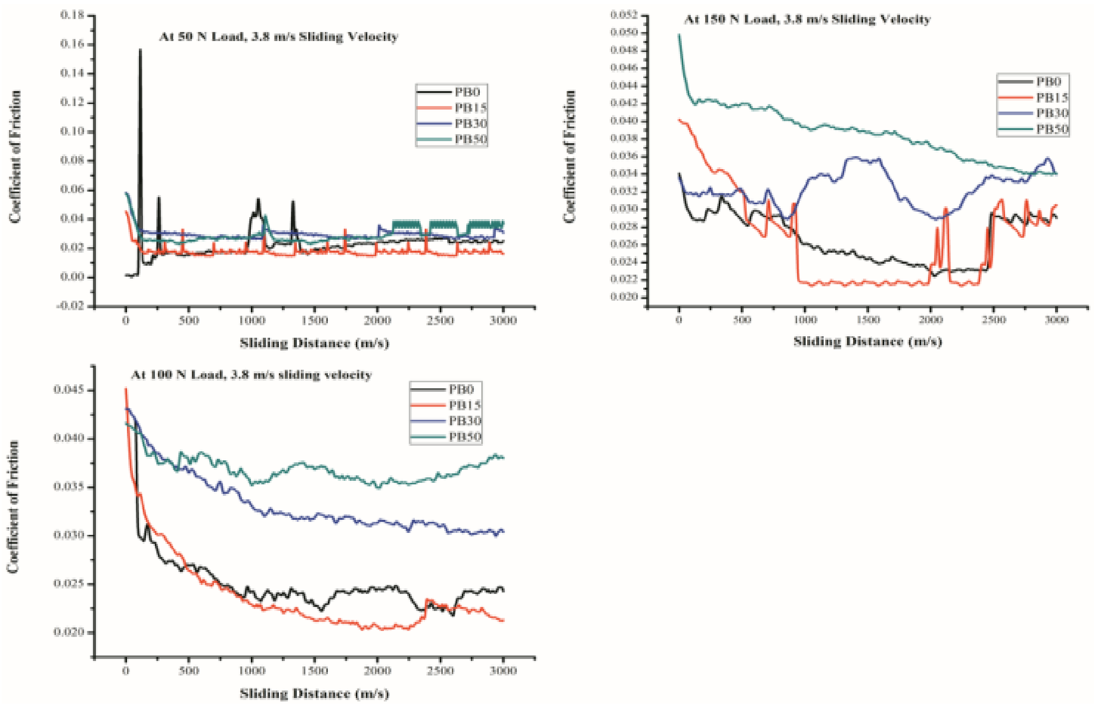

Fig. 4 Variation of coefficient of friction with sliding distance for different blends at 50, 100 and 150 N Load

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 the increase in viscosity while dilution of lower viscosity oil or fuel contributed towards decrease in viscosity. Fig. 5 shows the variation viscosity with PO percentages at different loads. It can be revealed from Fig. 5 that the viscosity increased with increase in load due the oxidation process which results into the sludge formation or contamination of insoluble particles. This contributes towards increment of the length of molecular chain which results into increased viscosity of the used oil. Table II shows viscosity grade requirement for the lubricants according to International standard organization (ISO) [31]. According to this, it can be revealed that PB 50 did not meet the standard ISO VG 100 requirement at different loads while PB 0, PB 15 and PB 30 meet all the International standard organization requirements.

Fig. 6 shows the variation of TAN with different blends at various loads. A higher drop is obtained at PB 50 blend as compare to other blends. As the load increases, drop in TAN increases due to depletion of additives in conventional lubricant indicating maximum susceptibility of the sliding surfaces to corrosion. These experiments were conducted according to ASTM D664 standard. Among all the blends, PB 15 contributes better results at each load.

TABLE II
VISCOSITY GRADE REQUIREMENTS ACCORDING TO THE INTERNATIONAL STANDARD ORGANIZATION (ISO) [31]

Kinematic Viscosity	ISO VG32	ISO VG46	ISO VG68	ISO VG 100
40^{o}C	>28.7	>41.3	>61.3	>90
100^{o}C	>4.1	>4.1	>4.1	>4.1

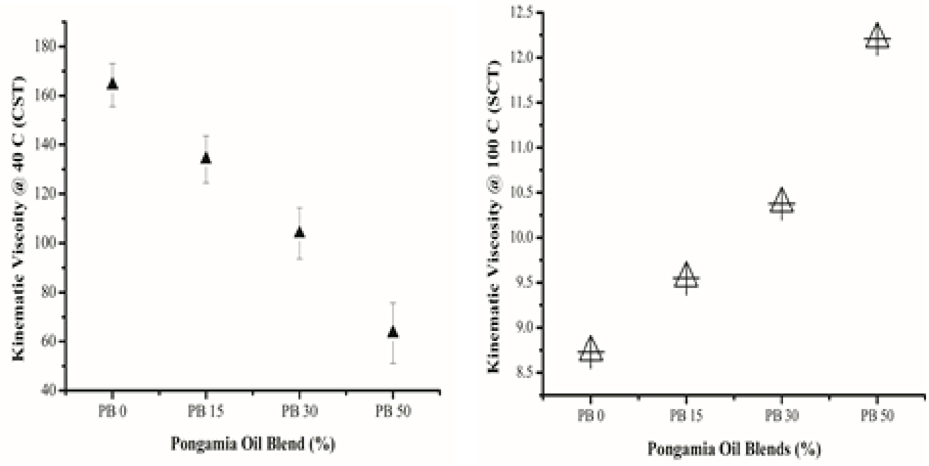

Fig. 5 Variation of PO blend percentages with kinematic viscosity @ 40 and 100^{0}C

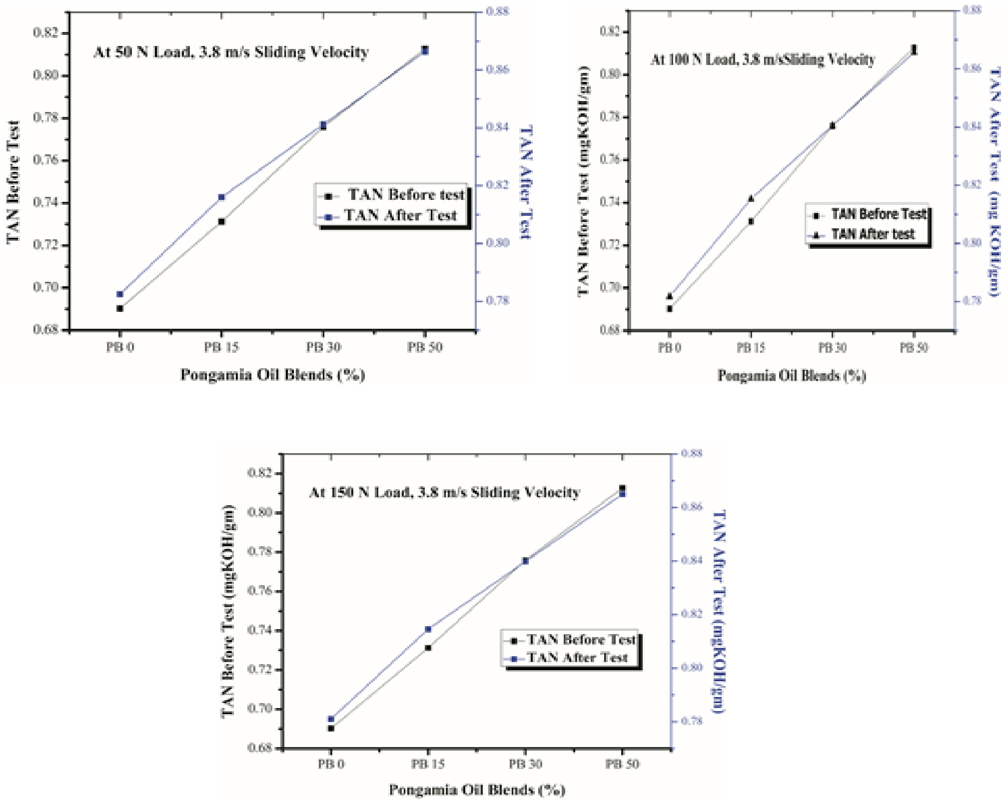

Fig. 6 Variation of PO blend percentages with total acid number (TAN) at 50, 100 and 150 N Loads

D. Worn Surface Characterization of Pin Material

Figs. 7 (a)-(d) show the appearance of wear scar on the surface of the pin for different PO blends at different loads. Worn surface examination was done with the help of trinocular stereo zoom microscope. With increase in load, abrasive wear and marks on the surface increases. PB 50 shows maximum wear while PB 15 shows minimum wear as compare to other blends. In protecting surface wear, chemical reactivity of additives contributes significant factor. Anti-wear additives protect metal to metal surface contact resulting in less adhesive wear [32]. Increase in biolubricant percentages results into decrease of anti-wear additives due to which PB 50 shows maximum surface wear.

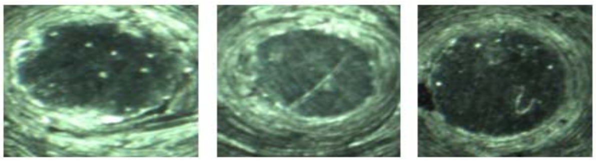

Fig. 7 (a) Worn surface images of PB 0 at 50 N, 100 N and 150 N Loads

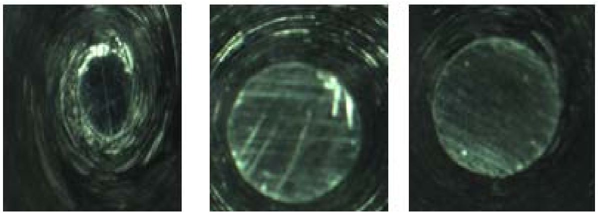

Fig. 7 (b) Worn surface images of PB 15 at 50 N, 100 N and 150 N Loads

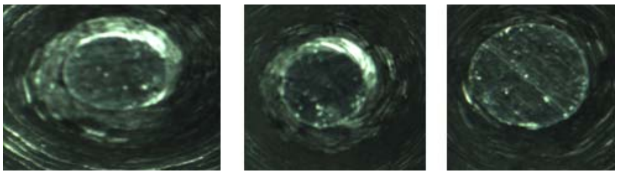

Fig. 7 (c) Worn surface images of PB 30 at 50 N, 100 N and 150 N Loads

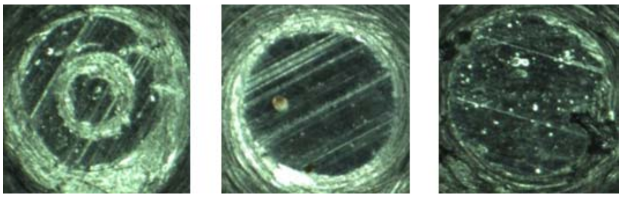

Fig. 7 (d) Worn surface images of PB 50 at 50 N, 100 N and 150 N Loads

IV. Conclusion

Assessments of the friction and wear behavior were carried out using pin on disc tribometer. The results are as follows**:**

1. The specific wear rate of various percentages of PO based bio-lubricant was different. Among all the blends, PB 15 show minimum specific wear rate among all the blends.
2. At different load applied, PB 15 shows better results among all the blends. It has the ability to withstand its properties at various load applied.
3. Among various percentages of bio-lubricants, PB 15 shows better result in terms of friction behavior. However, all the blends come under the prevalence of boundary layer regime (μ=0.0001-0.2).
4. As the load increases, viscosity of all the bio-lubricants increases. All the bio-lubricants meet the ISO VG 100 requirement at 40^{o}C except PB 50.
5. Also TAN value of the blends increases with increase in the loads and maximum increase in TAN value is obtained for PB 50 and PB 15 shows almost closer values to the conventional lubricant PB 0 (20 W 40).
6. Higher WSD was obtained for the PB 50 and least for the PB 15 with respect to increase in load. It reveals that the increase in PO percentages results in decrease of film strength between the sliding surfaces.
7. According to the experiments conducted at 3.8 m/s sliding velocity and 50, 100, 150 N loads, PB 15 showed excellent tribological behavior among JB 0, JB 30, JB 50 and had potential in terms of coefficient of friction, wear rate when the load increases from 50 to 150 N.

Acknowledgement

The author would like to thank department of mechanical engineering, college of engineering studies, University of Petroleum and Energy Studies, Dehradun, India to make this study possible.

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