Chapter 8

# Development of Eco-Friendly Biodegradable Biolubricant Based on Jatropha Oil

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Additional information is available at the end of the chapter

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## 1. Introduction

Various types of lubricants are available all over the world including mineral oils, synthetic oils, re-refined oils, and vegetable oils. Most of the lubricants which are available in the market are based on mineral oil derived from petroleum oil which are not adaptable with the environment because of its toxicity and non-biodegradability [1, 2]. Unknown petroleum reserve and the increasing consumption, which made concern to use petroleum based lubricant thus, to find the alternative lubricant to meet the future demand is an important issue [3]. Therefore, vegetable oil can be played a vital role to substitute the petroleum lubricant as it possesses numerous advantage over base lubricant like renewability, environmentally friendly, biodegradability, less toxicity and so on [4-8]. It has been reported that yearly 12 million tons of lubricants waste are released to the environment [9]. However, it is very difficult to dispose it safely for the mineral oil based lubricants due its toxic and non-biodegradable nature. To reduce the dependency on petroleum fuel, legislations have been passed to use certain percentage of biofuel in many countries, such initiative also required for lubricant as well [10]. Vegetable oils are mainly triglycerides which contain three hydroxyl groups and long chain unsaturated free fatty acids attached at the hydroxyl group by ester linkages acids favors triglycerides crystallization [11, 12]. The unsaturated free fatty acid which is defined as the ratio and position of carbon-carbon double bond, one two and three double bonds of carbon chain is named as a oleic, linoleic, and linolenic fatty acid components respectively [13]. The main limitations of vegetable oil are its poor low temperature behavior, oxidation and thermal stability and gumming effect [14, 15]. These stabilities and pour point behavior can be ameliorated by transesterification. Moreover the inferior flow property does not affect much in the tropical countries. Quinchia et al. [16] stated that, improving the potentiality of biolubricants some technical properties including available range of viscosities are need to improved. To do so, environmentally friendly viscosity modifier can be used. viscosity is the most important property for the lubricants since it determines the amount of friction that will be encountered between sliding surfaces and whether a thick enough film can be build up to avoid wear from solid-to-solid contact. Since little chance of viscosity with fluctuations in temperature is desirable to keep variations in friction at a minimum, fluid often are rated in terms of viscosity index. The less the viscosity is changed by temperature, the higher the viscosity index. Ethylene–vinyl acetate (EVA) and styrene–butadiene–styrene (SBS) copolymers were used to increase the viscosity range of high-oleic sunflower oil, in order to design new environmentally friendly lubricant formulations with increased viscosities. The maximum kinematic viscosities, at 40 and 100 ◦C, were increased up to around 150–250 cSt and 26–36 cSt, respectively [17].

Despite of having lot of advantages of biolubricant over petroleum based lubricant, the attempt to formulate the biolubricant and its applications are very few. Thus, in this article we sought to extend our investigation and to test the tribological characteristics and compatibility of non-edible Jatropha oil based biolubricant for the automotive application. The reason of selecting Jatropha oil as a base stock is it does not contend with the food and can be grown in marginal land.

## 2. Experimental

### 2.1. Lubricant sample preparation

There were six different types of lubricant sample were investigated in this study. The lubricant SAE 40 was used as a base lubricant and comparison purpose. Others samples were prepared by mixing of 10%, 20%, 30%, 40% and 50% Jatropha oil in SAE 40. The samples were mixed with the base lubricant by a homogeneous mixture machine.

### 2.2. Friction and wear evaluation

The apparatus used in the friction and wear testing process were Cygnus Friction and Wear Testing Machine which is connected with a personal computer (PC) with data acquisition system. It is a tri-pin-on-disc machine which is conducted by using three pins on a disc as testing specimens. Specifications of the Cygnus Test Machine are tabulated in Table 1. The block diagram of friction and wear testing are shown in Fig. 1. During the test the load of 30N and rotational speed of 2000 rpm were applied on pin.

| Parameter | Value |
|---|---|
| Test Disc Diameter | 110.0 mm |
| Test Pin Diameter | 6.0 mm |
| Test Disc Speed Range | 25 to 3000 rpm |
| Motor | Tuscan; (2000 rpm, 1.5 kW) |
| Load Range | 0 KG to 30 KG |
| Electrical Input | 220 Volt AC 50 Hz |

**Table 1.** Specification of Cygnus wear testing machine

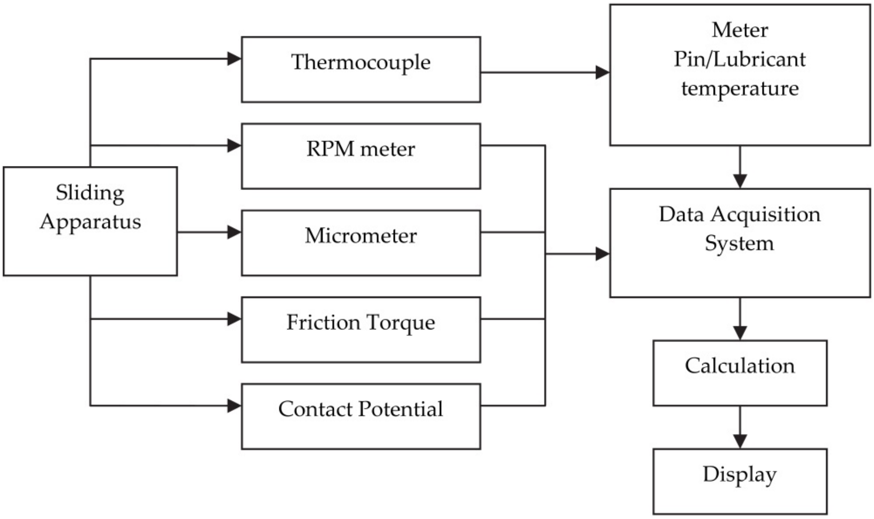
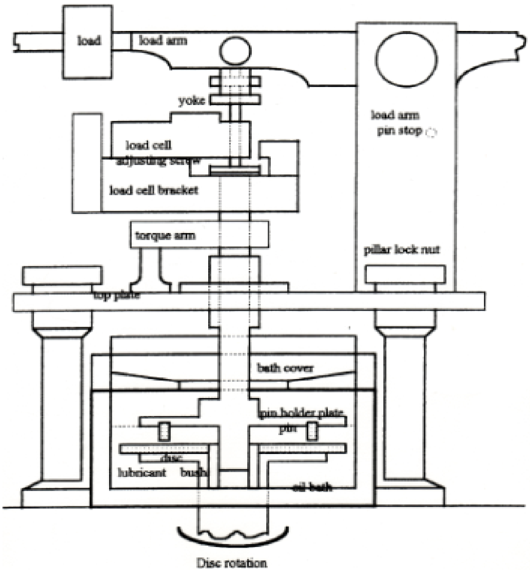



**Figure 1.** Block Diagrams of Friction and Wear Testing

### 2.3. Preparation of the specimen

The specimens were prepared from aluminum and cast iron material. Aluminum was used to build three pin and cast iron is used for disc specimen. The construction geometry and the dimension are shown in Fig. 2. Prior to conduct the test it was ensured that the surface of the specimens are cleaned properly i. e, free from dirt and debris. Alcohol was used for cleaning purpose.



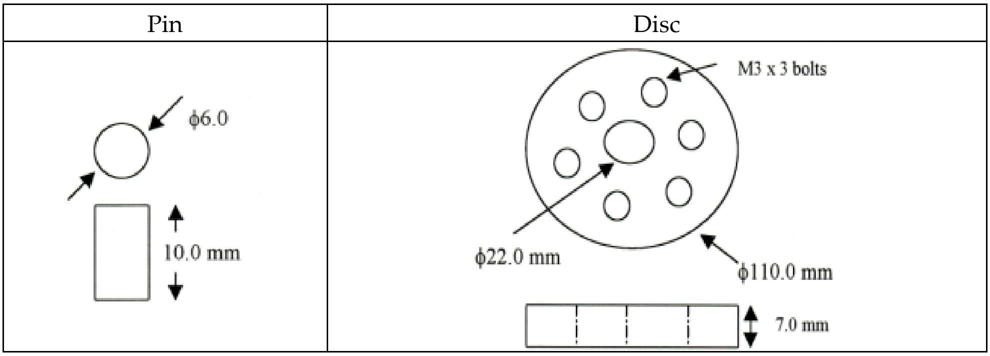



**Figure 2.** Schematic diagram of the experimental set up and dimensions geometry's of pins and disc specimen

### 2.4. Lubricant analyses

Multi element oil analyzer (MOA) was used to measure the wear elements in the lubricants by Atomic Emission Spectroscopy (AES). Whereas, for viscosity measurement the automatic Anton Paar viscosity meter was used with standard ASTM D 445. Viscosity was measured for both 40°C and 100°C controlled bath temperatures.

## 3. Results and discussion

### 3.1. Friction and wear characterization

Fig. 3 show the pins wear as a function of sliding time for various Jatropha oil blended biolubricants. At the operating condition of 2000 rpm and 30 N loads, the linear pin wear varied from 0.02 to 0.05 mm. It is observed that the maximum wear occurred in the beginning of the experiment using biolubricants. It can be seen form the Fig. 3, that the maximum wear was occurred for JBL40 while the minimum wear was observed for JBL10. The results can be attributed to the maximum ability of the JBL 10 biolubricant film to protect metal to metal contact and keep consistency throughout the operation time while this ability is least for JBL40. It can also be seen that the rate of wear throughout the time is almost identical for the biolubricants whereas, the reducing trend is observed for the base lubricant. At the beginning of the test, the wear rate was very fast for few minutes which are known running-in period. During this period, the asperities of the sliding surface are cut off and the contact area of the sliding surface grows to an equilibrium size. After certain period of time, equilibrium wear condition between pins and disc surface was established and thereby the wear rate became steady. It can be identified from the Fig. 3 that the biolubricants JBL 30, JBL 40 and JBL 50 showed high wear while base lubricant, JBL 10 and JBL 20 impart low pin wear and their values are nearly same with each other.

Fig. 4 sows the loos of material from the pin for different percentage of biolubricant samples. It seems quite clear that the loos of material from the pins are highest for 50% biolubricant and that is least for base lubricant. It can also be interpreted that the loos of material from

JBL 10 is almost similar with base lubricant and this loos of material is increasing with increasing biolubricant percentages.

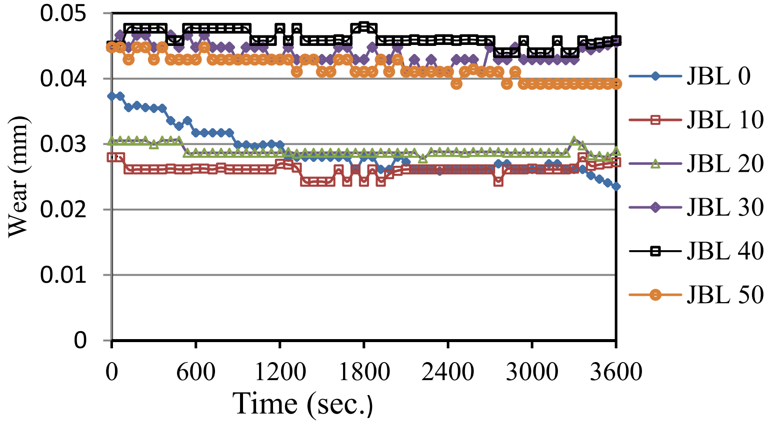



**Figure 3.** The linear pin wear as a function of sliding time for various Jatropha oil biolubricants.

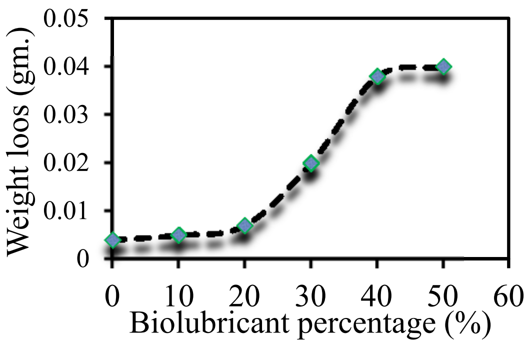



**Figure 4.** Loos of material form the pin for various biolubricant percentages

## 3.2. Coefficient of friction

Fig.5 shows the friction coefficient plotted against the sliding time for various Jatropha oil biolubricants. The results of the figure depict that the lubricant regime that occurred during the experiment were the boundary lubrication with the value of friction coefficient for boundary lubricant in the range of 0.001 to 0.2 except for 50% of Jatropha oil biolubricant. For JBL 0, it can be seen that the coefficient of friction is highest at the beginning and then it fell down rapidly and became least with compared to all tested samples after half of the operation time. The biolubricant percentage from 10 to 40% showed likely to be similar coefficient of friction (μ) which is almost 0.15. Whereas, the 50 % added Jatropha oil showed the coefficient of friction value of ~ 0.225 throughout the operation time. The fatty acid component of biolubricants formed multi and mono layer on the surface of the rubbing zone and make stable film to prevent the contact between the surfaces.

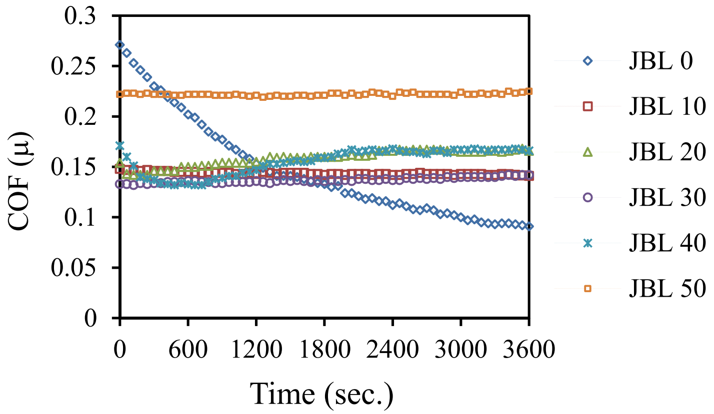



**Figure 5.** The Coefficient of friction as a function of sliding time for various Jatropha oil biolubricants

### 3.3. Lubricants temperature

Fig.6 shows the relationship of the averages oil temperature of varies percentage of Jatropha oil biolubricants with the sliding time. The rise of temperature during the running hour (1 h) for JBL 10 is least while the highest change is occurred for JBL 40 which is 11.77°c and 25.49°C respectively. The temperature rises of other samples are of 12.8°C, 18.65°C and 13. 66°C for 20% 30% and 50% Jatropha oil added biolubricants respectively. The results of the Fig. 6 show that the JBL 10 has the highest potentiality to retain its property without much changing its temperature. From the figure it can also be interpreted that up to 30 minutes rate of change

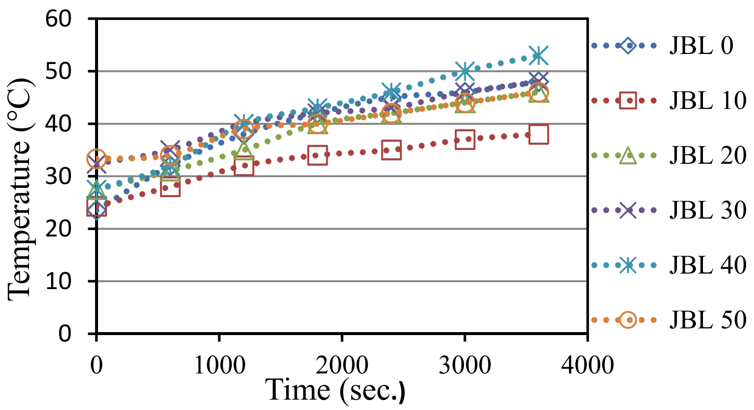



**Figure 6.** The Lubricant Temperature as a function of sliding time for various Jatropha oil biolubricants

of temperature is high while the changing rate is low for second half of the operation time. It can be explained that during second half of the operation time heat produced in the lubricant due friction and the heat dissipated to the outside is nearly equilibrium.

### 3.4. Viscosity

Viscosity is the measure of resistance to flow [18]. Table 2 shows the viscosity grade requirement for the lubricants set by International standard organization (ISO), while Fig. 7 shows the viscosity of tested different biolubricant samples. The comparison of the results of the Fig.7 with that of ISO grade illustrates that in case of 40°C, the biolubricants JBL 40 and JBL 50 did not meet the ISO VG100 requirement. On the other hand all other biolubricants meet the entire ISO grade requirement as well. It can also be noted that the viscosity of biolubricants are much higher than standard requirements

| Kinematic viscosity | ISO VG32 | ISO VG46 | ISO VG68 | ISO VG100 |
|---|---|---|---|---|
| @ 40°C | >28.8 | >41.4 | >61.4 | >90 |
| @ 100°C | >4.1 | >4.1 | >4.1 | >4.1 |

**Table 2.** ISO Viscosity grade requirement [19]

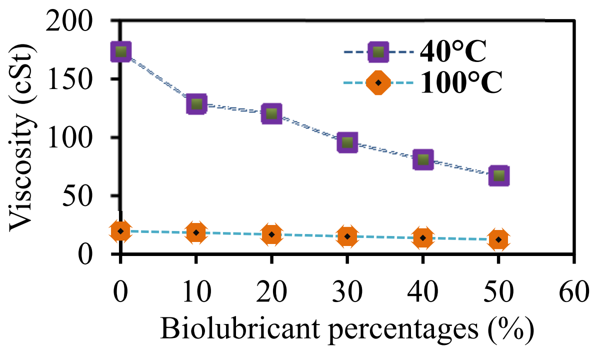



**Figure 7.** The viscosity of various percentages of biolubricants at 40°C and 100°C

### 3.5. Elemental analysis

The aim of the elemental analysis by using Multi Element Oil Analyzer (MOA) is to determine the kinds and amount of metal contain in the lubricating oil. Table 3 shows the elemental analysis of tested lubricant sample by using MOA before and after the test. From the Table 3, it can be noticed that the base lubricant contains higher Silver (Ag), Zinc (Zn), Phosphorus (P), Magnesium (Mg) and Boron (B) with in high percentage compared to other element while, in pure Jatropha oil, Calcium (Ca) and Silicon (Si) are the higher element compared with other element. Some of the elements are used as additive in the lubricant to ameliorate the lubricants tribological properties. From the results, increasing number of iron

| Parameters | Types of Lubricant | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | JBL 0 | | JBL 10 | | JBL 20 | | JBL 30 | | JBL 40 | | JBL 50 | | Jatropha oil |
| Test | Before | After | Before | After | Before | After | Before | After | Before | After | Before | After | |
| Iron (Fe) | 0.00 | 2.00 | 1.00 | 2.00 | 1.00 | 3.00 | 1.00 | 3.00 | 1.00 | 6.00 | 2.00 | 6.00 | 2 |
| Aluminum (Al) | 0.00 | 15.00 | 0.00 | 81.00 | 0.00 | 188.00 | 0.00 | 205 | 0.00 | 211.0 | 0.00 | 76.00 | 0 |
| Copper (Cu) | 0 | 1.00 | 0.00 | 3.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 7.00 | 2.00 | 5.00 | 3 |
| Lead (Pb) | 3 | 4.00 | 4.00 | 5.00 | 2.00 | 4.00 | 3.00 | 4.00 | 3.00 | 3.00 | 3.00 | 2.00 | 0 |
| Tin (Sn) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.00 | 0.00 | 2.00 | 2.00 | 4.5 |
| Nickel (Ni) | 2.00 | 2.00 | 3.00 | 3.00 | 1.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 2.00 | 2.00 | 1.5 |
| Titanium (Ti) | 0.00 | 0.00 | 1.00 | 1.00 | 0.00 | 1.00 | 0.00 | 1.00 | 0.00 | 0.00 | 1.00 | 1.00 | 1 |
| Silver (Ag) | 108 | 103 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| Molybdenum (Mo) | 3.00 | 3.0 | 4.00 | 6.00 | 2.00 | 3.00 | 4.00 | 3.00 | 4.00 | 6.00 | 3.00 | 4.00 | 1.5 |
| Zinc (Zn) | 1000 | 771 | 903 | 716 | 1000 | 829.0 | 911.0 | 851.0 | 942.00 | 900.0 | 946.00 | 832.00 | 1 |
| Phosphorus (P) | 500.00 | 428 | 471 | 441 | 462.00 | 440.0 | 435.00 | 408.0 | 387.00 | 394.0 | 348.00 | 294.00 | 45 |
| Calcium (Ca) | 18.00 | 17.00 | 21.00 | 29.00 | 23.00 | 21.0 | 28.00 | 27.0 | 35.00 | 33.00 | 37.00 | 30.00 | 40 |
| Magnesium (Mg) | 748.00 | 637.0 | 572. | 616.00 | 557.00 | 435.0 | 503.00 | 527.0 | 508.00 | 483.0 | 409.00 | 211.00 | 27 |
| Silicon (Si) | 5.00 | 4.00 | 6.00 | 10.00 | 6.00 | 15.0 | 8.00 | 12.0 | 9.00 | 13.0 | 14.00 | 7.00 | 16 |
| Sodium (Na) | 2.00 | 1.00 | 2.00 | 5.00 | 2.00 | 2.0 | 3.00 | 4.00 | 5.00 | 4.00 | 3.00 | 4.00 | 4 |
| Boron (B) | 60.00 | 54.00 | 52.00 | 58.00 | 52.00 | 28.0 | 52.00 | 32.0 | 44.00 | 44.0 | 40.00 | 21.00 | 0.5 |
| Vanadium (V) | 0.00 | 1.00 | 0.00 | 1.00 | 0.00 | 0.00 | 1.00 | 0.00 | 1.00 | 0.00 | 1.00 | 1.00 | 1 |

*All values are in ppm

**Table 3.** Elemental analysis of tested lubricant sample

(Fe) and aluminum (Al) molecules are observed with increasing percentages of Jatropha oil in the base lubricants. The source of Fe and Al are mainly cast iron plate and aluminum plate. Due to lower hardness of the aluminum pin the extraction of aluminum molecule form the pin is much higher than cast iron plate. The changes of other elements were observed before and after the test. It is clear from the elemental analysis that, most of elements were decreased after the test, by oxidizing and the chemical interaction among the elements.

### 3.6. Surface texture analysis

There are various types of wear in the mechanical system, such that abrasive wear, adhesive wear, fatigue wear and corrosive wear. Since the lubricant regime occurred in this experiment was boundary lubrication thereby, abrasive wear, adhesive wear, fatigue wear and corrosive wear were observed in to the rubbing zone. All these wears mechanisms found in this experiments but the mostly the wear phenomenon were abrasive and adhesive wear. This is because of an existence of straight grooves in the direction of the sliding direction. These grooves exist because the asperities on the hard surface (disc) touched the soft surface (pins) and hade a close relationship with the thickness of lubrication film. The optical images of the tested cast iron plate using various types of biolubricants are shown in Fig. 8. Referring to the Fig. 8, it is found that the wear increases with increasing percentage of Jatropha oil in the biolubricants. Reduction of lubricant film thickness leads to the surfaces to come closer to each other and cause higher wear.

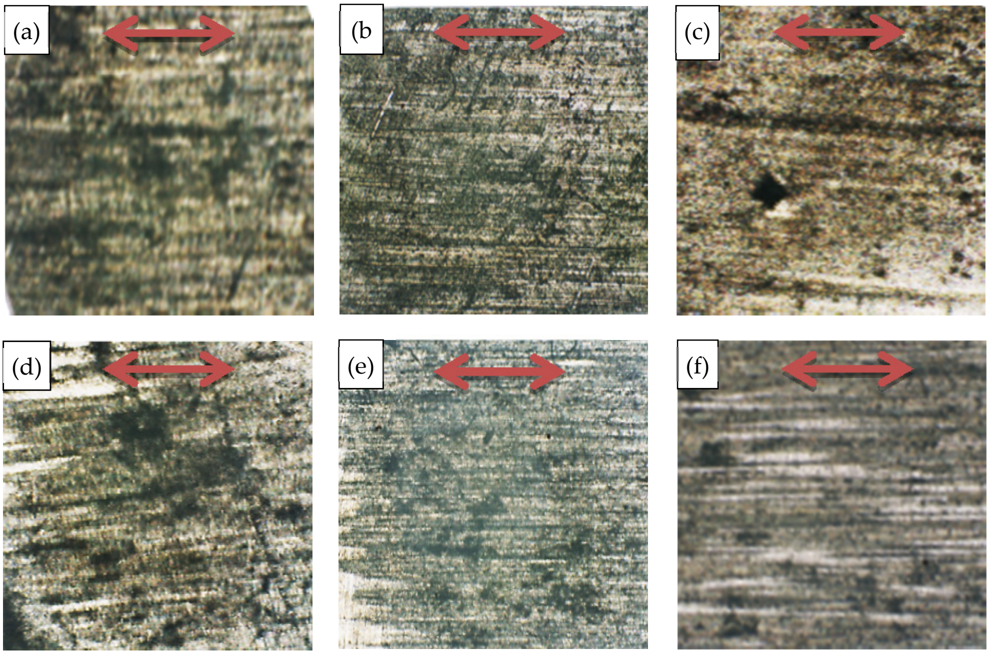



**Figure 8.** Optical image of the surface of the cast iron plate for different biolubricants (magnification 30 ×): (a): JBL 0, (b): JBL10, (c): JBL 20, (d): JBL 30, (e): JBL 40, (f): JBL 50

## 4. Conclusions

Based on the experimental study the following conclusion can be drawn:

1. The rates of wear for various percentage of biolubricant were different. Moreover the wear rate for 10% Jatropha added biolubricants were almost identical with base lubricant.
2. Lower the resistance to wear, higher coefficient of friction.
3. At the beginning of the test rate of wear as well as rise in temperature were high. With respect to wear rate and rise in temperature during entire operation time, the JBL 10 biolubricant showed best performance in terms of its ability to withstand its properties.
4. From the elemental analysis of the biolubricants, it is found, Iron and Aluminum were increased after the test due to the loos of material from the pin and the disc while, some element like Phosphorus, Calcium and Magnesium were decreased by oxidizing and due to other chemical interaction.
5. In terms of viscosity, almost all biolubricants met the ISO viscosity grade requirement whereas, 40% and 50% addition of Jatropha oil do not meet the ISO VG 100 requirement at 40°C.

According to the experimental result, it can be recommended that the addition of 10% Jatropha oil in the base lubricant is the optimum for the automotive application as it showed best overall performance in terms of wear, coefficient of friction, viscosity, rise in temperature etc.

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