Jurnal Teknologi
Full paper

Influence of Normal Load and Temperature on Tribological Properties of Jatropha Oil

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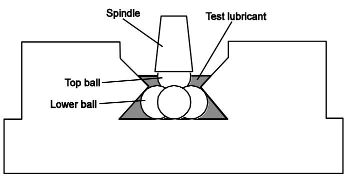
Article history

Received :19 June 2014
Received in revised form :8 July 2014
Accepted :17August 2014

Graphical abstract



Abstract

This research investigated tribological properties of Jatropha oil (vegetable oil)to find clean, new, and renewable lubricant source of industrial applications. The study was performed utilizing a fourball tribotester, CCD camera, scanning electron microscope (SEM)and viscometer. The experiment was conducted using different normal loads (300, 400, and 500 N) and temperatures (75, 95 and 105°C). The test was followed ASTM D4172 standard. The evaluation was focused on the viscosity, flash temperature parameter, coefficient of friction, wear scar diameter and worn surface observation. All results of Jatropha oil were compared with mineral hydraulic oil to evaluate the lubricity performance of Jatropha oil. The results indicated that the Jatropha had better anti-friction and anti-wear ability than hydraulic mineral oil under various temperature and loads. In conclusion, Jatropha oil has bright possibility to be produced as commercial industrial lubricant.

Keywords: Fourball tribotester; Jatropha oil; coefficient of friction; wear scar diameter.

1.0 INTRODUCTION

Mineral oils are from fossil raw substantial that was made million years ago in forests when the biomass became covered by sediments under high pressures and temperatures. In this condition the biomass was converted very slowly to mineral oil and bitumen. Lubricant oils are one of the main productions from mineral oils as around 90% of lubricant oil derived from mineral oil. Annually more than 35 milion tons lubricant oils are used in the world and according to report Environmental Protection Agency and Coordinating European Council, less than 50% of mineral oils are biodegradable. More than 17 million tons of lubricants are nonrenewable. In addition, more than 2400 kilo tons of this amount is waste oil; around 72% of waste oil is collected but more than 674 kilo tons of waste oil uncollected and is entered into environment. Lubricant oils based mineral are potentially harmful to nature and human health due to oil mist appearance, oil leakage and spillage into environment. The respiratory tissue's dysfunction and several kinds of skin diseases are some of the direct impact of them on the healthiness [1]. Lubricant oils based mineral can enter into the environment and resulting is pollution water, soil and atmosphere. Researches show that 6.8 liter of lubricant oil based mineral can create an oil layer with 1mm thick on a lake with size 7000m^2. Lubricant film on water can reduce the transition of light into the water and, resulting, decrease the amount of photosynthesis that cause to reduce oxygen production into the water. The lubricant film also can prevent of oxygen moving from the air to the water and it is a great threat to aquatic organisms. In other hand lubricants are an integral part of industrial application and in automobile engine and, the consumption of lubricant oil increases around 1.5% till 2% annually; thereby eliminating or reducing them is now impossible [2]. In resulting on of the best suggestion of this problem is finding new and clean source of lubricant oils. Vegetable oils are alternative sources of lubricant oil. These big families are renewable, cheap, nontoxic, clean and environmental friendly. Vegetable oils are mainly triglycerides that is includes carboxyl chains of fatty acids. Randles [3] presented that long chains of fatty acid in vegetable oil are able to improve lubricant properties due to their intrinsic boundary lubrication ability. The fatty acid chains make high strength lubricant layer between strongly interact metallic contact parts that cause to reduce friction and wear. The strong intermolecular interactions cause to increase viscosity or high viscosity coefficient [4]. Vegetable oils have presented high lubricant properties in laboratory scale study and display lower wear and coefficient of friction, same scuffing and higher pitting resistance compare to mineral oil [5,6]. There are several researches about different kind of vegetable oil as lubricant such as palm oil, sunflower oil, soy bean oil and castor oil [7,8]. The physical properties such as anti-wear, anti-friction, viscosity index and flash parameter point of palm fatty acid distillate (PFAD) and Jatropha with base lubricant were investigated according to ASTM condition, number D4172, method B using fourball tribotester and the results were compared with the physical properties of two mineral lubricant [9]. Rathore and Madras [10] studied a supercritical method of biodiesel production of methanol and ethanol from Jatropha oil. They fixed a 50:1 of alcohol to oil molar ratio under 20 MPa at 300°C. The tests were conducted 10 minutes time.

This paper presents and discuses about physical properties of Jatropha oil in varying temperatures and normal loads with fourball tribotester and compared with commercial hydraulic oil. Results show that Jatropha oil has a potential to be developed as a industrial lubricant.

■2.0 MATERIALS AND METHODS

2.1 Experimental Method

In this research, a fourball tribotester was utilized for determining the lubricity of test lubricant. This machine consists of four steel balls; the first ball is in top part of machine and it is connected to the drive motor and will be driven by it. The rotating speed of the motor could be determined by the user. Another three balls were fixed together by a ball ring at the bottom part as shown in Figure 1. Three balls and a ring are clenched together with lock nut. Balls were immersed in the test oil before starting the experiment. The heat needed created by a heater inside the ball pot. The temperature for the test lubricant was measured by a thermocouple. A desired force will be set in the bottom of the three balls. Three balls will be pressed to the top ball. Furthermore, researchers used acquisition software to record the friction torque whilst the motor running. The experimental work was conducted for 1 hour. After the experimental work, CCD camera and scanning election microscope (SEM) were used for measuring the wear scar diameter and worn (wear) condition on the three lower balls [11].

2.2 Ball Specification

The balls used in this experiment are chrome alloy steel made of AISI E-52100, diameter of 12.7 mm, extra polish (EP) grade of 25 and hardness of 64 to 66 HRC. For each new test, another new four balls would be used. Beforehand, all of them were clean with acetone and wiped using a fresh lint free industrial wipe.

2.3 Test Oil

Jatropha oil and commercial hydraulic oil (representative for mineral oil) were used in this research. Jatropha oil is a vegetable oil and manufactured from the seeds of the Jatropha tree. Jatropha is a deciduous tree with 3-5m in height [12]. Jatropha tree can grow in appropriate condition until 8-10m. For growing, jatropha tree need to 3.68 and 2.52 mmol of CO_2 and H_2O. [13]. Jatropha can be cultivated on non-agricultural and marginal land. Jatropha seed can produce 35% oil with extraction method and there is 1375 seeds/kg. This tree can be used 35 to 50 years. There are some properties of Jatropha oil e.g. Acid value (10.37mg KOH g^{-1}), Water content (0.05%), Specific gravity (0.92g ml^{-1}), Ash content (0.09 %), Density (917kg/m^3), Calorific value (39.071MJ/kg), mass fraction for Carbon (76.11 %, w/w), Hydrogen (10.52%, w/w), Nitrogen (0%, w/w) Oxygen (11.06%, w/w) and Sulphur (0%, w/w) [14].

2.4 Experimental Condition

In the first part, tests were carried out with different temperatures (75, 95 and 105°C). The rotor speed was fixed at 1200rpm and normal load of 400N. In the second part, tests were carried out with different normal loads (200, 400 and 600 N). The rotor speed was 1200rpm and temperature was fixed at 75°C. All the experimental works were followed the American Society for Testing and Materials (ASTM D4172). Experimental work was conducted for 1 hour.

2.5 Experimental Procedure

All parts of the fourball machine (Figure 1) and balls were cleaned with acetone before each experiment. The fourball was set up with desired speed, load, temperature and time. Three clean balls were inserted into the ballpot. The ball lock ring was put in to the ballpot. The lock nut was clenched on the ball pot and a torque wrench with the force 68N used to tighten it. One ball inserted in the tapper at the end of motor spindle. Around 10 ml of test lubricant was added into the ballpot. The ballpot assembly was placed on the antifriction disk inside the machine, located under the spindle. The thermocouple was connected to the ballpot assembly. Suitable load was added to the loading arm until the digital monitoring showed the desire load for experiment.

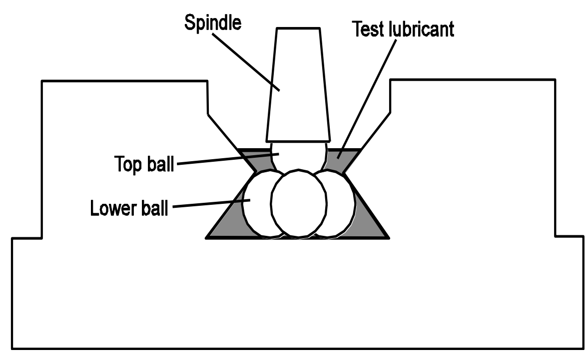


Figure 1 Fourball tribotester apparatus

2.6 Viscosity

Viscosity is generally used for defining the internal friction of liquid or gas. Viscosity of liquid has a direct correlation with the thickness of liquid film. Viscosity plays important role in lubricant ability, as it effects on the wear rate between sliding surface. Viscosity is used for recognizing the individual grades of oil and for monitoring the changes occurring in the oil while in service. Increasing the viscosity usually shows the used oil has been deteriorated by contamination or oxidation. Also, decreased viscosity usually indicates dilution in the oil [15]. In this study, the viscosity was measured by viscometer for Jatropha and hydraulic oils at vary temperature (55°C to 125°C). Figure 2 shows the kinematic viscosity for Jatropha and hydraulic oil. This figure indicates that, in 35°C viscosity of Jatropha oil was less than hydraulic oil, but with increasing the temperature, Jatropha oil had relatively similar viscosity with hydraulic oil. Also in higher temperature, Jatropha oil and hydraulic oil had similar viscosity. This figure also shows that, the viscosity increase with decrease the temperature of the oils because viscosity has an inverse relationship with temperature, this means that, viscosity decreases with increasing temperature. More than that, with the increment of the viscosity the fluidity and dilution of lubricant increases and the lubricant can move or flow easier. Usually, higher viscosity has better anti friction ability, however increase the viscosity sometime is caused the lubricant begins to deteriorate with oxidation or contamination [11].

2.7 Wear

Wear is a process of removing material from a sliding contact and solid surfaces. It results damages to the contact surface. There are several types of wear such as abrasion, plough, fatigue, cavitation and erosion. Some wear results are known as irreversible changes in contact surface and developments the gap between contacting parts [16]. CCD camera was used to capture and measure the wear scar diameter (WSD) on the ball surface. The wear was measured with the average of horizontal and vertical scars with CCD camera. Average of wear scar diameter is arithmetic mean value of the three average diameters of bottom specimen ball scar according to ASTM D4172-94 (Reapproved 2009) standard on the ball surface.

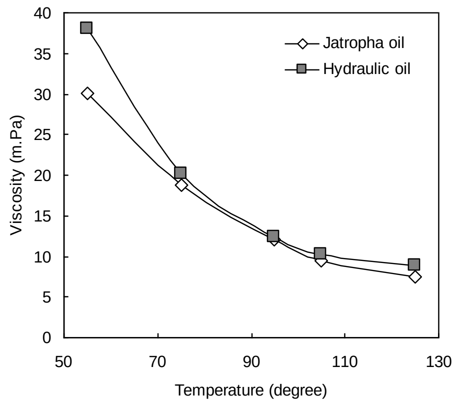


Figure 2 Kinematic viscosity measured for Jatropha and hydraulic oil under different tested temperature

3.0 RESULTS AND DISCUSSION

The lubricant properties of Jatropha oil was investigated with fourball tribotester and results were compared with commercial hydraulic oil.

3.1 Flash Temperature Parameter (FTP)

Recently, the FTP value becomes a recognized limiting factor in the mechanical performance such as cutting and forming tools. FTP value was calculated from the frictional generation in the contact area between two rubbing surfaces and this area acts as a heat source. FTP physical meaning is the lowest temperature for convert liquid to vapor. Higher FTP is a positive point of lubricants. Lubricant with high FTP does not evaporate in low temperature and could prevent the shrink of lubricant film thickness. The FTP value for Jatropha and hydraulic oil in different temperatures had been calculated using Equation (1). According to Equation (1), there is an inverse ratio between FTP and wear scar diameter in constant load. Figure 3 and 4 clearly show that the Jatropha oil has higher FTP value compare to hydraulic mineral oil for both different temperature and normal load conditions.

$$FTP = \frac{W}{d^{1.4}} \tag{1}$$

where W is the load in kilograms, and d is wear scar diameter (WSD) in millimeters [17].

3.2 Effect of Temperature and Normal Load on the Coefficient of Friction (COF).

Equation (2) shows relationship between coefficient of friction and normal load. Coefficient of friction has inverse relation with normal load. Figure 5 shows the influence of increment of temperature on the coefficient of friction for Jatropha and hydraulic oil in 75, 95 and 105°C. In Figure 4, it can be clearly seen that Jatropha oil has lower coefficient of friction compared to hydraulic oil. With the increment of temperature, coefficient of friction of Jatropha oil and hydraulic do not show any significant changes. This figure shows that the Jatropha oil has better anti-friction ability than hydraulic mineral oil. Figure 6 indicates the effect of normal load on the coefficient of friction. This figure clearly shows that coefficient of friction increases with the increment of normal load for Jatropha oil and hydraulic. However, thevalueof coefficient of friction for Jatropha oil is less than hydraulic oil. Coefficient of friction is calculated using Equation (2) [18].

$$\mu = \frac{T\sqrt{6}}{3Wr} \tag{2}$$

where, μ is the coefficient of friction, T is the frictional torque in kg/mm, W is the normal load in kg, r is the distance from the center of the contact surfaces on the lower balls to the axis of rotation, which is 3.67mm.

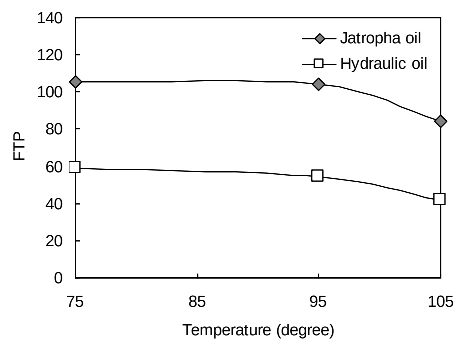


Figure 3 Flash temperature parameter for Jatropha and hydraulic oil at different temperatures.

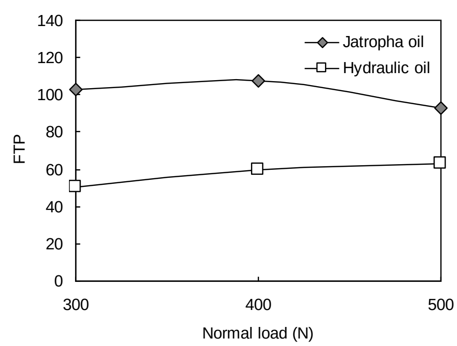


Figure 4 Flash temperature parameter for Jatropha and hydraulic oil at different normal loads.

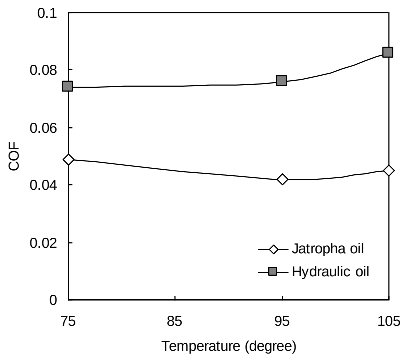


Figure 5 Effect of Temperature on coefficient of friction for Jatropha and hydraulic oil in 75, 95 and 105 °C

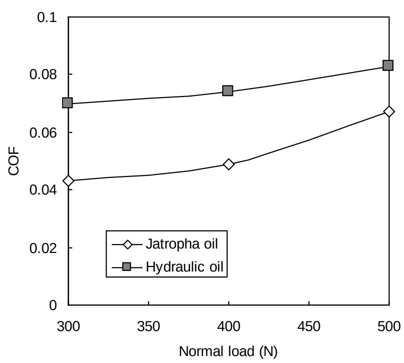


Figure 6 Effect of load on coefficient of friction for Jatropha and hydraulic oil in300, 400and 500N

3.3 Effect of Temperature and Normal Load on the Wear Scar Diameter (WSD).

The wear scar diameter of Jatropha and hydraulic oil at vary experimental temperature is shown in Figure 7. According to this figure, the wear scar diameter of ball lubricated with hydraulic oil is higher compared to those lubricated with Jatropha oil. Both lubricants show no obvious different of wear scar diameter value with the increment of experimental temperatures. Figure 7 shows wear scar diameter of Jatropha and hydraulic oil in different loads condition. This figure clearly shows that the Jatropha oil had lower wear scar diameter rather than hydraulic oil. Also according to Figure 8, wear scar increases with the increment of normal load. In average, the amount of wear scar in balls specimen of Jatropha oil was less than hydraulic oil and this show that, anti-wear ability Jatropha is more than hydraulic mineral oil.

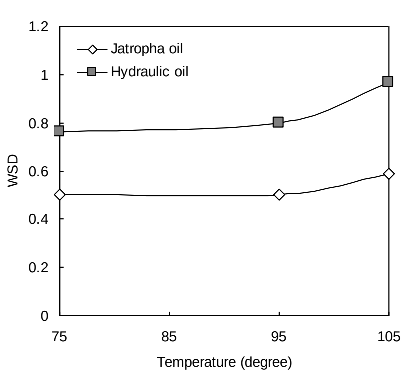


Figure 7 Effect of Temperature on Wear Scar Diameter (WSD) for Jatropha and hydraulic oil at 75, 95and 105°C

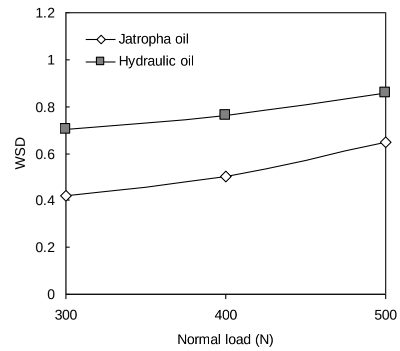


Figure 8 Effect of load on wear scar diameter for Jatropha and hydraulic oil at 300, 400and 500N

3.4 Effect of Temperature and Normal Load on Wear Characteristic.

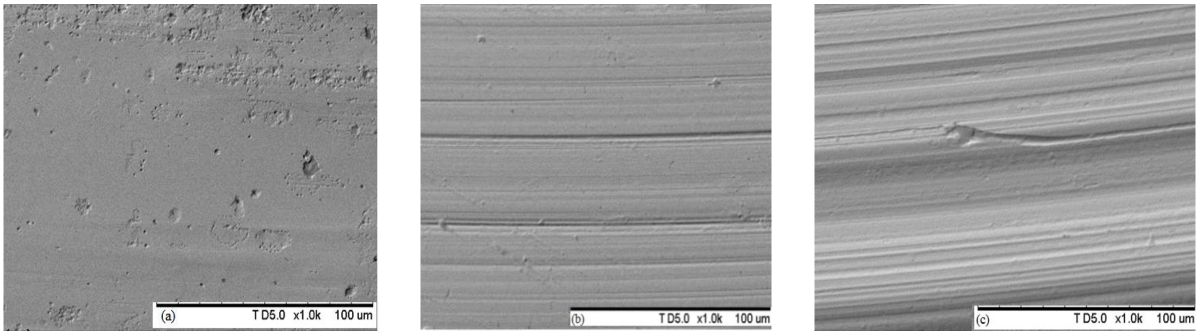
Worn surface for all balls lubricated with the Jatropha and hydraulic oil were observed using scanning electron microscope (SEM) as shown in Figures9 to 12. Figures9 and 10 show the worn surface on the ball specimen lubricated with Jatropha and hydraulic oil in different temperatures. These figures show that wear scar on the balls surfaces of experiment oil increase with increasing the temperature. Furthermore, comparing Figure 9 and 10 clearly shows that wear scar on Jatropha balls specimen are smaller than wear scar on hydraulic oil balls specimen. Figures 11 and 12 show wear scar on balls specimen of test oils in different normal load conditions. In these figures, it can be observed that wear scar has direct relationship with the increase of loads for both test oils.

Figure 9 shows wear scar on balls specimen of Jatropha oil in different temperatures. This figure clearly shows that the balls surfaces of Jatropha oil in temperature 75°C (Figure 9a) is covered with small pits. Small pits appear on the balls surfaces due to material transfer between contact parts, as reported by [19]. Also several parallel grooves were observed on balls specimen of Jatropha oil in temperature 95 and 105°C. The debris from the detached ball bearing can create abrasion on the ball surface as parallel grooves without material transfer [20].

Figure 10 shows the wear scar on the balls surface of hydraulic oil in different temperatures. It can be seen clearly metal transfer and shallow grooves at temperature 75°C. Adhesive wear occur between surfaces if the lubricating film was broken down and it cannot totally separate the contact parts from each other that cause to material transfer between contact parts [21]. At the same time, deep grooves with several pits were observed on the hydraulic balls specimen on temperature 95°C. Light ploughs on the worn surface with spots of material transfer exhibiting that abrasive wear was the dominant wear mechanism (Figure 10b). Furthermore, deep plough on the worn surface with spots of material transfer exhibiting abrasive wear was the dominant wear mechanism on hydraulic ball surface 105°C, as shown in Figure 10c.

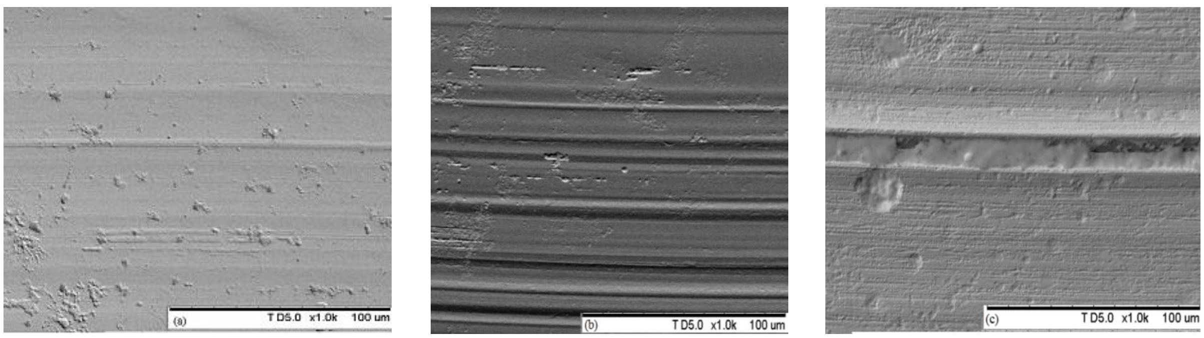
Figure 11 shows the wear scar on the balls specimen lubricated with Jatropha oil with different normal loads. From the figure, for normal load of 200N, several micro cutting on the balls surfaces was observed (Figure 11a). Micro cutting happen when the adhesive wear occurs between surfaces and the lubricating film was broken down. Also, the balls surfaces of Jatropha oil in load 400 and 600N were covered with deep parallel grooves and material transfer from contact surface (Figure 11b and 11c).

Figure 12 indicates wear scar on the hydraulic balls specimen in different loads. According to this figure, small pits and shallow



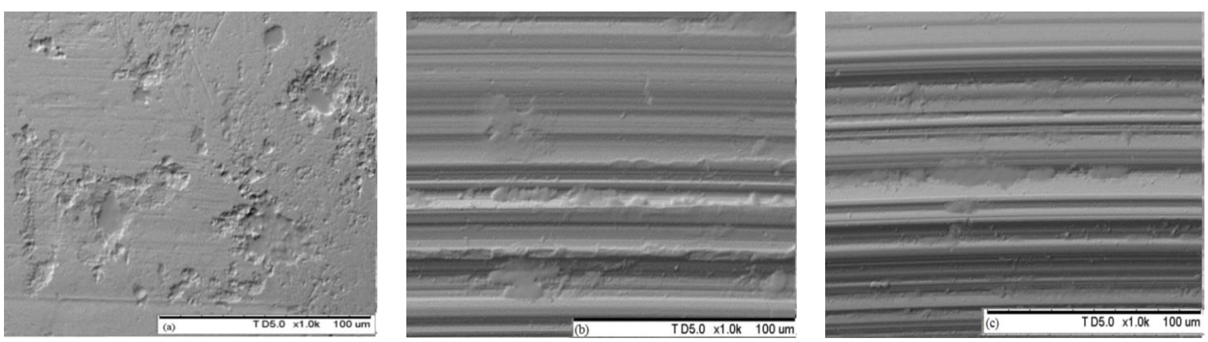
(a) (b) (c)

Figure 9 Wear scar on the balls specimens at different temperature of jatropha oil (a) 75°C, (b) 95°C, (c) 105°C



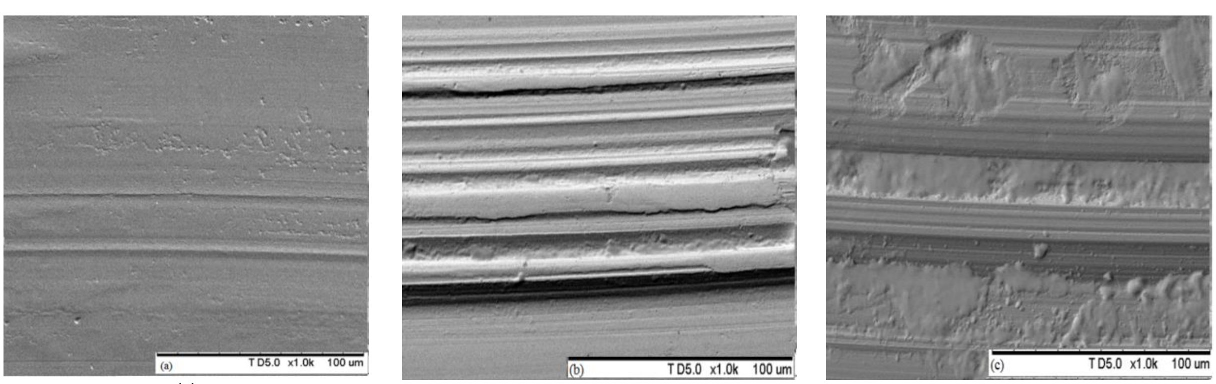
(a) (b) (c)

Figure 10 Wear scar on the balls specimens at different temperature of hydraulic oil(a) 75°C, (b) 95°C, (c) 105°C



(a) (b) (c)

Figure 11 Wear scar on the balls specimens at different loads of Jatropha oil. (a) 300N, (b) 400N (c) 500N



(a) (b) (c)

Figure 12 Wear scar on the balls specimens at different loads of hydraulic oil. (a) 300N, (b) 400N (c) 500N grows were observed on the balls surfaces of hydraulic oil for load 200 N (Figure 12a) and deep ploughs with micro cutting surface was observed for load 400 N (Figure 12b). Figure 12c shows deep ploughs and plastic deformation on the balls surfaces of hydraulic oil. The plastic flow on the surface cause by adhesive wear in the mechanism and usually left some cavities on the surface; this phenomenon indicate that the lubricant layer had thinned out the risk of lubricant film breakdown was higher [22].

■4.0 CONCLUSION

The tribological performance of Jatropha oil at different temperature and normal load were conducted at rotating speed 1200 rpm. Jatropha oil has lower coefficient of friction and wear scar diameter compared with commercial hydraulic oil. The trend of the increment value of coefficient of friction and wear scar diameter versus increment of temperature and normal load for Jatropha oil was similar with hydraulic oil, which is friction of friction is increase with the increasing of temperature and normal load. From these results, it can be concluded that Jatropha oil has a good potential to be produced as an industrial lubricant oil.

Acknowledgement

The authors thank the Faculty of Mechanical Engineering at the Universiti Teknologi Malaysia for their support and cooperation during this study. The authors are also grateful for the Research University Grant from the Universiti Teknologi Malaysia, the Ministry of Higher Education (MOHE), and the Ministry of Science, Technology and Innovation (MOSTI) of Malaysia for their financial support.

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