Investigation of Physical Properties for Jatropha Oil in Different Temperature as Lubricant Oil

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Abstract: The purpose of this research is to investigate physical properties of Jatropha oil for find new, clean and renewable source of lubricant oil. In this study examines the experimental result of anti-friction, anti-wear, flash temperature parameter (FTP) and viscosity index (VI) for Jatropha oil. The experiments are performed with standard test method ASTM D 4172 and using a four ball tribotester, CCD Camera, digital microscope and viscosity meter. This experiment was carried out in various temperatures, 55, 75, 95, 105 and 125 °C, load 392 N, speed 1200 rpm and in 60 minutes. All results of Jatropha oil were compared with hydraulic oil as mineral commercial oil with based lubricant to evaluate the lubricant ability of Jatropha oil. Results show that Jatropha oil had higher lubricant ability versus friction and wear than engine and hydraulic oil based- lubricant.

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Keywords: Jatropha oil, four-ball tribotester, wear scar diameter, Friction, flash temperature parameter

1. Introduction

Friction and wear are two harmful phenomena in many of industrial applications and car engine. For example, friction is caused to west useful energy by prevent from sliding motion between contact parts or produce heat of different parts. The best solution of this problem is using from lubricant oil. Lubricant oils are able to reduce or remove friction and wear between contact parts. Lubricant oil is one of the important products from mineral oil and round 80% of all lubricant oil in the world product from mineral oil. But, mineral oils are the main sources that can increase the environmental pollution in the world. This increasing is harmful for humans, animals and plants. Many research indicate that the main sources for environmental pollution is mineral oil and other derivatives (Mercurio et al., 2004, Grant et al., 2008, Bartz, 1998, Nadkami, 2004). In recent years were done many researches to find new alternative source of lubricant oil. Vegetable oils are the alternative sources for replacing with mineral oil; these kind of oils are renewable, cheap, nontoxic, clean and environmental friendly(Randles, 1992, Battersby et al., 1992). In recent decade was investigated some kind of vegetable oil such as palm oil, sunflower oil, soya been oil and rapeseed oil of replace with mineral oil and derivation it such as hydraulic liquid and lubricant oil(Adhvaryu et al., 2005, Husnawan et al., 2007, Wan Nik et al., 2005). Maleque investigated the effects of friction and wear of blended palm oil methyl ester lubricant with tribological properties and showed that at lower load and temperature, the wear rate using palm oil methyl ester lubricant was low, under 5%, but in higher loads, the wear rates will be increase(Maleque et al., 2000). Masjuki did a number of researches on the palm oil and mineral oil with based commercial lubricating oil for the use in engine and compare friction, wear, viscosity, lubricant degradation and exhaust based on the same experimental conditions (Masjuki. H. H, 1999). Wan Nik has done some experiment about conversion palm oil to hydraulic oil (Wan Nik et al., 2005). Much research has been done about the physical and chemical properties of vegetable oils. Also some of these researches confirmed that vegetable oil can be replaced instead mineral oil (Castro et al., 2005, Gawrilow, 2003, Aluyor and Ori-Jesu, 2010, Adhvaryu et al., 2006, Kuliev et al., 1995). Jatropha oil was introduced as new vegetable oil in recent years. Jatropha oil collected from the Jatrophaseeds with extract method and find in different origins such as Malaysia, Indonesia and Thailand. Some physicochemical properties for Jatropha oil were evaluated. Emil and Yaakob with using gas chromatography (GC) show that, linoleic acid (28.8–34.6%) and oleic (42.4–48.8%) are the dominant fatty acids present in the Jatropha seed oil and also The saturated fatty acids such as palmitic and stearic acid lie in the range 13.25–14.5 and 7–7.7%, respectively more than it, the observed major triacylglycerol (TAG) composition was OOL (22.94–25.75%) and OLL (15.52–20.77%) (Emil Akbar, 2009). There are little researches about Jatropha oil as lubricant until now. Jatropha oil was investigated as additive material in mineral oil to increase lubricant ability; different percentage of Jatropha oil was added to mineral oil; results show that 5% Jatropha oil add to mineral oil based lubricant has more lubricant ability rather than pure mineral oil (Liaquat et al., 2012). In other research physical ability of Jatropha oil was compared with mineral oil based lubricant in ASTM condition, results depicts that Jatropha oil had higher anti-friction and anti-wear rather than test mineral oil based lubricant(Golshokouh et al., 2012). This paper presents and discuses results about physical properties of Jatropha oil in varying temperature and standard condition with four ball machine tester and compare it with two main derivation of mineral oil for show anti friction and anti-wear ability and introduce new alternative source for lubricant oil.

2- Experimental Method

The four balls wear tester machine was used for determining friction torque for lubricants. In this machine there are four balls; the first ball is in top part of machine and it is connected to the drive motor and will be driven by it. Other balls are fixed together with a ball ring. These three balls and ring are clenched together with lock nut. More than it three balls were immersed in the test lubricant before starting the experiment. The heat needed will create with a small heater that is inside the ball pot and will be measured by a thermocouple, temperature for the test lubricant. As for the loading condition or desired test method, suitable force will be set in the bottom of the three balls and three balls will be pressed to the top ball. Also researchers used from the acquisition software, CCD Camera and microscope for measuring and comparing the wear scar on the three lower balls (A. S. M. A. Haseeb, 2010).*Fig1.* shows schematic diagram of four balls tribotester.

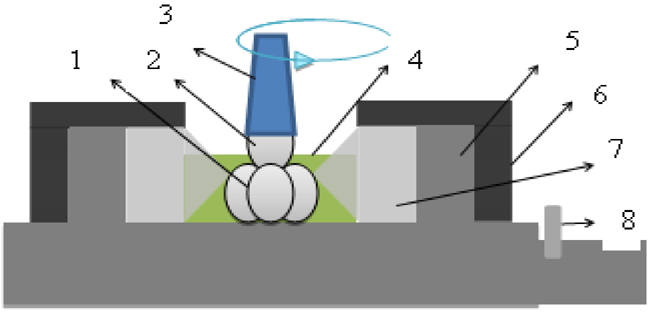

Figure1. Schematic diagram of four ball wear geometry:
1 –stationary ball 2 – Rotating single ball 3 – Rotating gripper for upper ball 4 – Test lubricant
5 – Cup for griping stationary three balls 6-lock nut 7-balls ring 8-thermocouple

2.1 Balls Model

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.

2.2 Lubricant Oils

For this research was used of Jatropha oil and two high quality lubricant oil of mineral oil (engine oil and hydraulic oil). Jatropha oil is a vegetable oil produced from the seeds of the Jatropha tree. Jatropha is a deciduous tree with 3-5m in height(Ariza-Montobbio and Lele, 2010). This tree can grow in suitable condition until 8-10m. Jatropha need to 3.68 and 2.52 mmol of $CO2$ and $H2O$ for growing. These amounts indicate that, Jatropha is resistant tree(Lim and Teong, 2010). Jatropha tree can be cultivated on marginal and non-agricultural land. With extraction method Jatropha seed can produce 35% oil and there is 1375 seeds/kg. This tree can be used 35 to 50 years(Ariza-Montobbio and Lele, 2010). There are some properties of Jatropha oil e.g. Acid value (10.37mg KOH g−1), Specific gravity (0.92g ml−1), Water content (0.05 %), Ash content (0.09 %), Density (917±1kg/m3), 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) (Xu et al., 2011, Chen et al., 2009, Zuidema, 1959)

2.3 Experimental Condition

These tests were carried out in the American Society for Testing and Materials (ASTM) condition and usage from ASTM D4172 method test B . Conditions: Temperature: (75 ± 2)°C, Speed: (1200 ± 60) rpm, Time: (60 ± 1) minute sand Load: (392 ± 2) N and in different temperature conditions viz, 55, 75, 95, 105 and 125 °C

2.4 Experimental Procedure

Before starting the experiment, all balls and their parts were cleaned with acetone and wiped. The four-ball machine was set up with desired speed, temperature and time. Three clean balls were inserted to ball pot. Then the ball lock ring was inserted into the ball pot around the three balls. The lock nut was clenched on the ball pot and a torque wrench was used to tighten it with the force 68 Nm. One clean ball was inserted in the collet to tapper at the end of motor spindle. Test lubricant was added to the ball pot assembly around 10 ml, and the lubricant height must be 3 mm from above the tip of the ball. The ball pot assembly was placed on the antifriction disk inside the machine and under the spindle. The thermocouple wire was connected to the ball pot assembly. Additional load was added to the loading arm until the digital monitoring showed the desire load for experiment.

2.5 Viscosity

Usually used to viscosity for describe the internal friction a liquid or gas. Viscosity of the liquid layer thickness is a direct correlation and normally higher viscosity is of thinker liquids. Viscosity has important role in lubricant ability, as it affects the film thickness and therewith the wear rate of sliding surface. It is use for the identification of individual grades of oil and for monitoring the changes occurring in the oil while in service. Increasing the viscosity normally shows that the used oil has been deteriorated by contamination or oxidation. Also, decreased viscosity usually indicates dilution in the oil (Zuidema, 1959). In this study, the viscosity was measured with a viscosity meter for the particular three oils in the experiment temperature (35, 55, 75, 95, 105 and 125° C). *Fig. 2* shows the kinetic viscosity index for Jatropha, engine and hydraulic oil in ASTM condition and different temperature. This figure indicates that, in 35°C viscosity of Jatropha oil is less than engine oil and hydraulic oil, but in this temperature viscosity for engine and hydraulic oil is very near together. With increasing the temperature, condition of Jatropha oil was better and in 50°C, Jatropha oil was relatively similar viscosity with hydraulic oil and very near to engine oil. Also in higher temperature, Jatropha oil and hydraulic oil had similar viscosity. Although the engine oil viscosity with little different was more than Jatropha and hydraulic oils. This figure also shows that, the viscosity increase with decrease the temperature of the oils tested because viscosity is an inverse relationship with temperature, this means that, viscosity decreases with increasing temperature. More than it, with increase the viscosity the fluidity and dilution of lubricant also increases and the lubricant can move easier. Normally, higher viscosity has better anti friction ability, although the increase in viscosity causes the lubricant begins to deteriorate with oxidation or contamination (A. S. M. A. Haseeb, 2010).

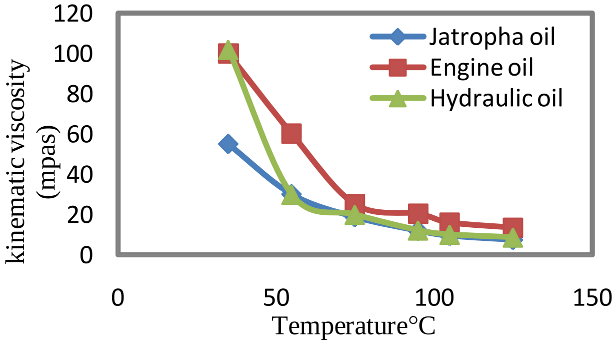

Figure 2. Kinematic viscosity measured for Jatropha, engine and hydraulic oil under different tested temperature

2.6 Wear

Wear is a gradual process of removing material from solid surfaces and a sliding contact and the results are damages contact surface. There are various patterns of wear e.g. abrasion, fatigue, plough in Corrugation, erosion and cavitation. Some wear results are known as irreversible changes in contact surface and developments the gap between contacting parts(Zmitrowicz, 2006). Using of CCD camera to capture and measure the wear scar diameter (WSD) in ball surface. The wear was measured with the average of horizontal and vertical scars with CCD camera. Average of scar diameter is arithmetic mean value of the three average diameters of bottom specimen ball scar according to ASTM D4172-94 (Reapproved 2009) standard from the ball surface(Zmitrowicz, 2006)

3- Result and discussion

The lubricant properties of Jatropha oil was investigated with tribotester tester and results founded in the ASTM condition and in different temperature parameter. The tests present are a good opportunity for discussing about anti friction and anti-wear ability and comparing it with mineral lubricant oils.

3.1 Flash temperature parameter (FTP) Analysis

Actually of the last few decades the FTP becomes a recognized limiting factor in the mechanical performance such as cutting and forming tools. FTP made with frictional generation in the contact area between two rubbing surfaces and this area acts as a heat source. FTP of a fickle material is the lowest temperature that it can vaporize to form an ignitable mixture in air (Blok, 1963). FTP is the lowest temperature at which the liquid becomes to vapor. Higher flash point temperature is a positive point of lubricants oil because lubricant doesn't evaporate in low temperature and Layer thickness of the lubricant is not less. Liaquat was measured amount of FTP for Jatropha oil in temperature 75°C, load 392 N and speed 1200 rpm with four ball tribotester and compared pure Jatropha oil with Jatropha oil added lubricant. In other experiment, amount of FTP was calculated 111.44(Liaquat et al., 2012). The value of the FTP had been carried out of Jatropha, engine and hydraulic oil in ASTM condition and also in different temperature. This evaluation of FTP has been calculated using equation (1) with using of four ball tribotester. According to equation (1), there exist an inverse ration between FTP and wear scare diameter in constant load. *Fig.3* clearly seen that the value of FTP were decreased for Jatropha and engine oil while the sliding temperature increased, also FTP for hydraulic oil decreased with increase the temperature until 105°C but it has one dramatically increase in 125 °C. Critical Flash Temperature Parameter FTP has been calculating with below formula for four ball wear machine tester.

$$(FTP) = \frac{W}{d^{1.4}} \qquad (1)$$

Where W is the load in kilograms, and d is wear scar diameter (WSD) in millimeters(Lane, 1957)

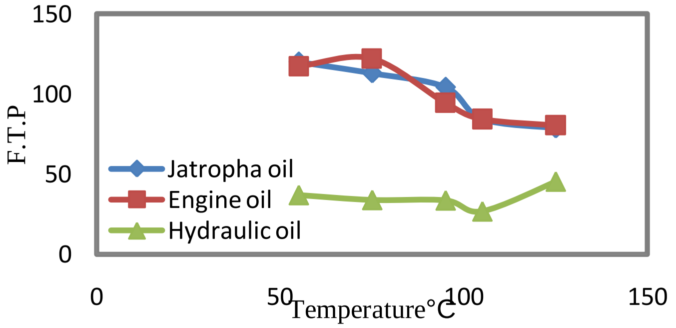

Figure 3. Flash temperature parameter on ball bearings lubricated with Jatropha, engine and hydraulic oil under ASTM condition and indifferent temperature.

3.2 Effect of temperature on Coefficient of Friction and Friction Torque

Equation (2) shows that relationship between coefficient of friction, frictional torque and loads. According to this formula, coefficient of friction has direct impact with friction torque and inverse ration with load. In this experiment, load is constant. In result, with increasing or decreasing the friction torque, coefficient of friction will increase or decrease. Friction torque also measured with four ball tribotester. *Fig.4* shows and compares the influence of temperature on the coefficient friction for Jatropha, engine and hydraulic oil in 55, 75, 95, 105 and 125°C. In *Fig. 4* it can be clearly seen that the Jatropha oil had a little down and ups between 55 and 95°C, then, the graph has a tendency to increase with increasing temperature. More than it, this figure shows that the optimize point of Jatropha oil is in 75°C. *Fig. 4* also shows that engine oil had maintain stability versus temperature changes, although in 105°C engine oil had better condition instead coefficient of friction then other temperatures and in this point engine oil has highest anti friction ability than other points. For hydraulic oil, Potential for anti-friction is reduced with rising temperature until 105°C, after this temperature and until125°C, coefficient of friction decrease with increase the temperature. This Figure also shows that in this experimental condition, Jatropha oil has better anti friction ability than engine and hydraulic mineral oil with base lubricant. After Jatropha oil, engine oil has better condition versus friction. Also these experiments clearly indicate that, there is a direct relationship between coefficient friction and temperature and with increase the temperature, coefficient of friction also increase. *Fig. 5* also indicates effect of temperature on the friction torque. This figure also shows that the lowest amount of coefficient of friction for Jatropha oil and hydraulic oil is between 60°C until 90°C and for engine oil is between 100°C until 125°C. Distance from the load to center of spindle motor is 80mm and amount of load is 40kg. Also the coefficient of friction was calculated with use of this formula (M. Husnawan, 2007):

$$\mu = \frac{T\sqrt{6}}{3Wr} \quad (2)$$

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

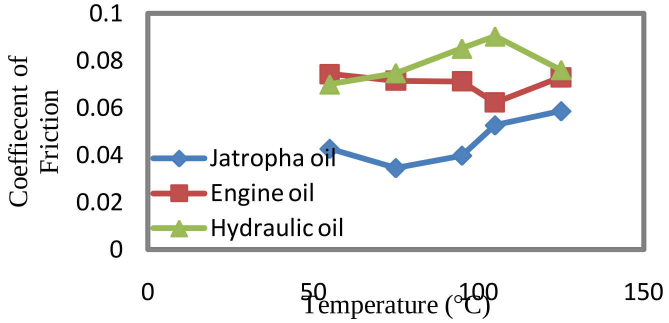

Figure 4. Effect of Temperature on coefficient of friction for Jatropha, engine and hydraulic oil in55, 75, 95, 105 and 125°C

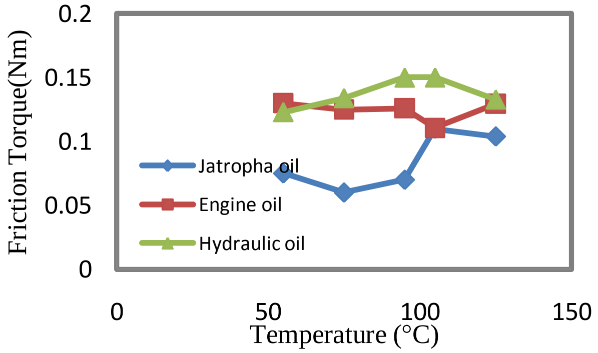

Figure 5. Effect of Temperature on friction Torque for Jatropha, engine and hydraulic oil in 55, 75, 95, 105 and 125°C

3.3 Wear Scar Diameter (WSD) Analysis

The average of wear scar diameter lubricated for Jatropha, engine and hydraulic oil are shown in *Fig.6*. According to increasing coefficient of friction with increase the temperature and also, decreasing the flash point temperature with increase the temperature in previous parts, excepted that increased the wear with rising the temperature because increased coefficient of friction and reduce the flash has a direct impact in increasing corrosion. Also, Equation (3) was extract of Eq(1) and Eq(2) for show the relationship between all experimental parameters in this study.

$$According\ to\ Eq(1)\ and\ (2){:}\ w = \frac{T\sqrt{6}}{3\mu r}\ \ and\ w = (FTP).d^{1.4} \implies \frac{T\sqrt{6}}{3\mu r} = (FTP).d^{1.4}$$

$$\implies \mu = \frac{T\sqrt{6}}{(FTP).3rd^{1.4}} \quad (3)$$

Fig. 6 confirms predictions about wear. This figure show that the WSD average of Jatropha and engine oil increased with increased the temperature. However the hydraulic oil showed a different trend compared with other experiment oil. The average WSD for hydraulic had increased trend until 105°C and decrease trend until 125°C. In generally Jatropha oil and engine oil have very near condition in reduce wear on the ball surface. In average, amount of wear scare in balls specimen of Jatropha oil was less than oils and this show that, anti-wear ability Jatropha is more than engine and hydraulic mineral oil.

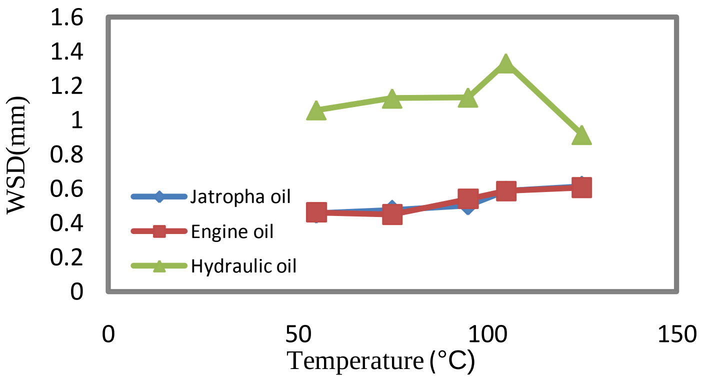

Figure 6. Effect of Temperature on Wear Scar Diameter (WSD) for Jatropha, engine and hydraulic oil in 55, 75, 95, 105 and 125°C

3.4 Wear worn surface characteristics Wear worn surface

Fig.7-11 show the worn surface of Jatropha, engine and hydraulic oil after one hour tests under different temperatures. The influence of temperature on the wear surface for Jatropha oil, engine and hydraulic mineral oil were investigated and results were compared together. At lower temperature, the lubricant film between contact parts with parallel grooves to prevent contact and produce smooth surface regions. In this area abrasion was occurred and the balls specimens were covered with shallow and deep grooves in different parts of surfaces. With increase the temperature and in higher temperature, the thin lubricant layer was broken and cause to create adhesive wear in this region. The balls specimen of test oils was covered with deep grooves and material transfer was observed from one surface to another. The chain fatty acid molecules in Jatropha oil structure are the main reason to reduce the wear and friction between contact parts(Farooq et al., 2011). During the experiment with mineral oils, the balls were heated till the austenizing in contact part and then cooled by lubricant oil; this cause to breakdown the hydrocarbon in contact part and increase carbon caused by the diffusion of the gas and carbon in zone part(Ing et al., 2012). As reported by Heseeb, the fatty acid in vegetable oil produce an oxidation process as inorganic oxide that play major role of lubricant oil (Heseeb et al., 2010). The color of the lubricant oil becomes darker due to contamination of the inorganic oxides as shown in *Fig. 7*. According to reported by Waleska, the best methods to find impurities is using Fourier transform infrared (Castro et al., 2006). Furthermore, the stearic acid in vegetable oil shows a good ability to be absorbed into the steel surfaces(Farooq et al., 2011). The interaction between steel surface and acid molecules create chemically polymerized molecules is resulting a tribochemical reaction, which play major role to decrease wear and friction in contact surface. *Fig. 12-16* show the wear scar behavior of the balls surfaces lubricated for Jatropha, engine and hydraulic oil by using SEM microscope. Overall observation of balls specimen surface of Jatropha oil at lower working temperature (*Fig. 12a and 13a*) showed there were shallow grooves on the worn surface, which indicate abrasive wear on these temperature. The chain fatty acids in Jatropha oil help to keep lubricant film between balls surface and prevents metal to metal contact in lower temperature. In these temperatures (55 and 75 ◦C) the amount of coefficient of friction was lower than other experimental conditions. Increasing the temperature is caused to breakdown fatty acid chain and resulting coefficient of friction increase. As shown in *Fig. 12a*, there were few sallow grooves on the worn surface of Jatropha oil in 55◦C. This grooves created by small debris that was between balls contact part. *Fig. 13a* shows several small and big spots on the worn surface of Jatropha oil in 75◦C. these spots indicate the abrasive wear on the wear mechanism. At an experiment temperature of 95◦C , various depths and sallow parallel grooves could clearly be seen in *Fig.14a*; parallel grooves resulting from stiff particulate debris are caused to create parallel grooves as reported by(Singh and Gulati, 1991). Jatropha oil film breakdown at higher temperatures of 105and 125◦C. *Fig. 15a and 16a* show the rough region from the discontinuous plastic deformation caused by adhesive wear on the Jatropha balls surface, which show the breakdown of the oil film(Masjuki and Maleque, 1997). Also, the weld or fuse phenomena occurred in most severe conditions. The coefficient of friction for Jatropha increased with an increase the temperature because the vegetable oil could oxidize in higher temperatures(Xu et al., 2010). For engine oil at working temperature 55 and 75 ◦C, was observed light ploughs with several spots of material transfer that indicate abrasive wear on this surface as shown in *Fig 12b and 13b*. In these temperatures plastic deformation and uneven grooves was observed of hydraulic oil as shown in *Fig. 12c and 13c*. 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(Ren et al., 2010). *Fig. 14b and 16c* show a typical of crack on the ball surface in temperature 95◦C for engine oil and 125◦C for hydraulic oil respectively. This crack was created from cumulative metal adhesion that makes typical surface layer, which this layer creaked by repeating sliding contact and in result wear occurs(Lubis et al., 2011). At a working temperature of 95 and 105◦C (*Fig. 14c and 15c*), parallel grooves with sallow and deep and no material transfer observed of hydraulic balls surface. This could be related with abrasion create by the debris from the detached surface(Ren et al., 2010). Polishing process may happen in this area, resulting is decreasing coefficient of friction (Kim et al., 2011). *Fig. 15b and 16b* also show deep pits on the worn surface with spots of material transfer of engine oil, exhibiting that abrasive wear was the dominant wear mechanism.

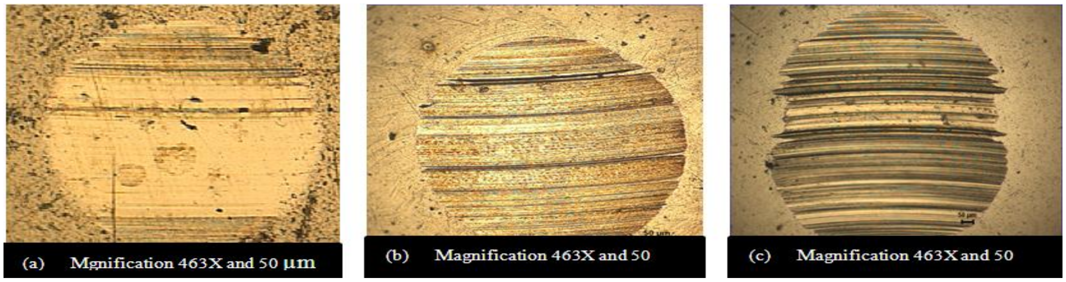

Figure 7. *Optical micrographs of wear area on the balls surface and in 55◦C. (magnification 463X and Pome 50 µm): (a)Jatropha oil, (b) engine mineral oil, (c) hydraulic mineral* oil.

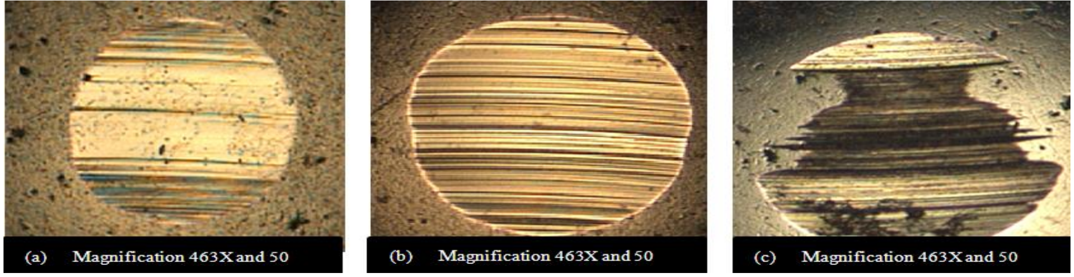

Figure 8. *Optical micrographs of wear area on the balls surface and in 75◦C. (magnification 463X and Pome 50 µm): (a)Jatropha oil, (b) engine mineral oil, (c) hydraulic mineral oil*.

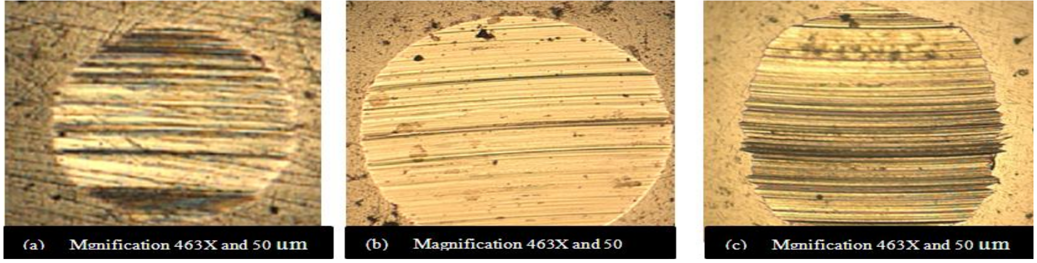

Figure 9. *Optical micrographs of wear area on the balls surface and in 95◦C. (magnification 463X and Pome 50 µm): (a)Jatropha oil, (b) engine mineral oil, (c) hydraulic mineral oil.*

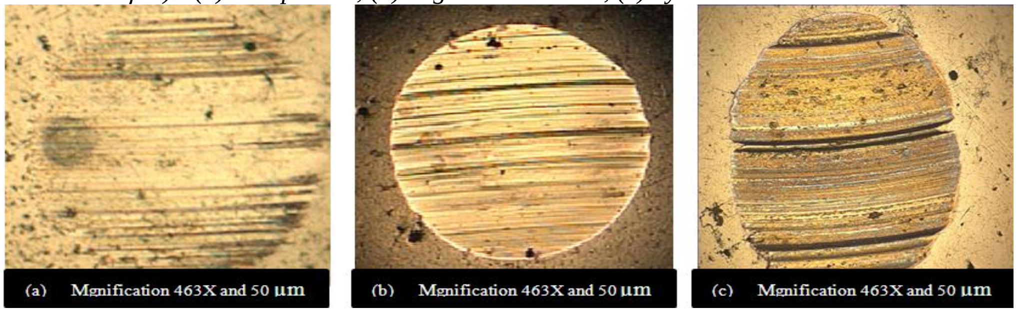

***Figure 10.** Optical micrographs of wear area on the balls surface and in 105◦C. (magnification 463X and Pome 50 µm): (a)Jatropha oil, (b) engine mineral oil, (c) hydraulic mineral oil.*

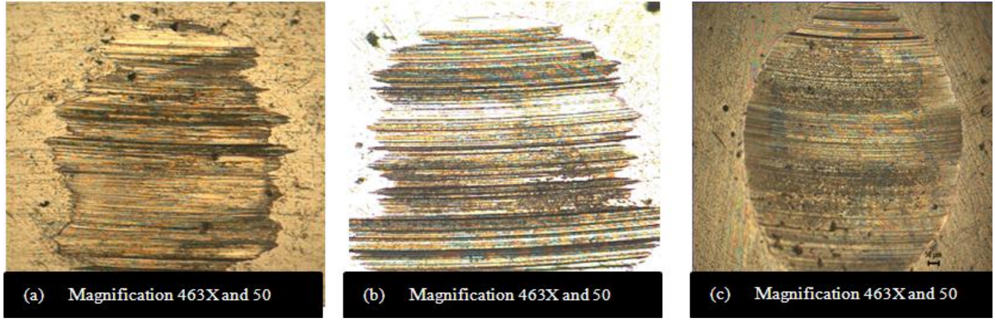

***Figure 11.** Optical micrographs of wear area on the balls surface and in 125◦C. (magnification 463X and Pome 50 µm): (a)Jatropha oil, (b) engine mineral oil, (c) hydraulic mineral oil.*

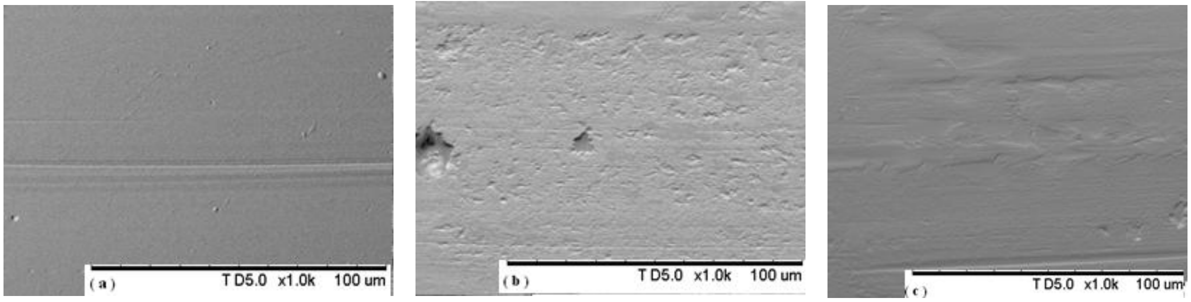

***Figure12.** SEM micrograph of worn surface for(a): Jatropha, (b): engine, (c): hydraulic in temperature 55◦C*

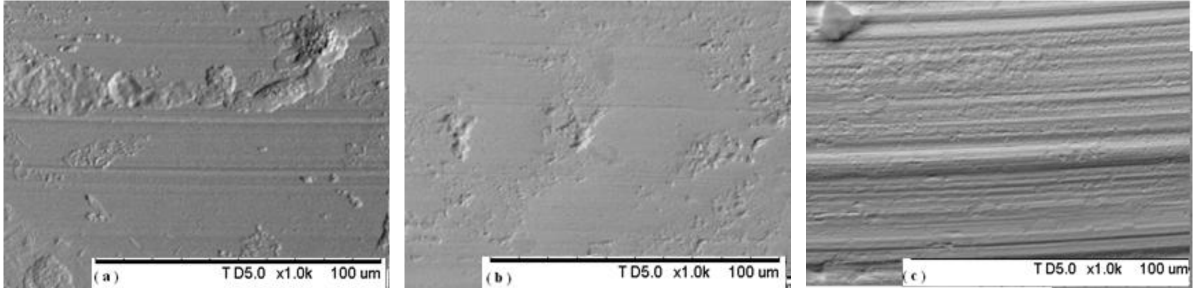

***Figure13.** SEM micrograph of worn surface for(a): Jatropha, (b): engine, (c): hydraulic in temperature 75◦C*

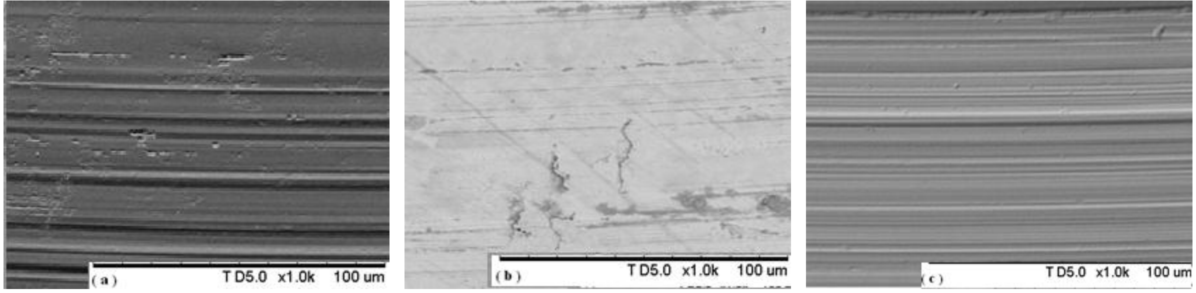

***Figure14.** SEM micrograph of worn surface for(a): Jatropha, (b): engine, (c): hydraulic in temperature 95◦C*

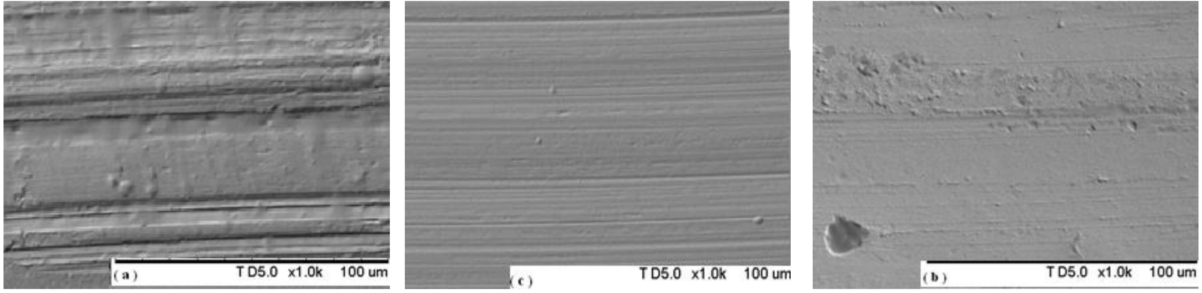

***Figure15.** SEM micrograph of worn surface for(a): Jatropha, (b): engine, (c):hydraulic in temperature 105◦C*

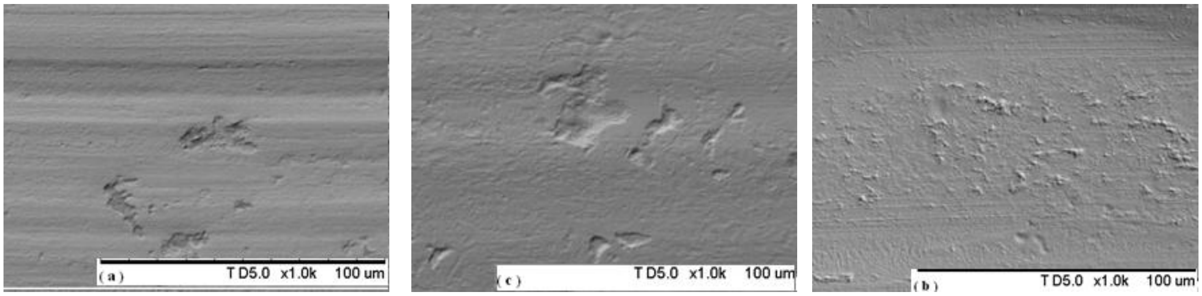

Figure16.*SEM micrograph of worn surface for(a): Jatropha, (b): engine, (c):hydraulic in temperature 125◦C*

4. Conclusion

For the tests performed on different temperature and ASTM condition for Jatropha, engine and hydraulic oil with base lubricant and on four ball tribotester. Results show that the coefficient of friction, friction torque and wear scar diameter increase with increase the temperature. The FTP decreases with increase the temperature. Jatropha oil has higher anti friction and anti-wear ability than engine oil and hydraulic oil and the highest value for FTP was for Jatropha oil. However the highest value for Viscosity index was for engine oil.

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