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The tribological performance of modified RBD palm kernel oil under extreme pressure load test

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Trans-esterification
Coefficient of friction
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Hertz line

ABSTRACT

Lubrication is one of the most used components globally in various types of applications. The hiking in demand of lubrication oil annually rise several issues such as environmental wastage and oil supply. This paper discussed the alternate option of lubricant oil performance from renewable resources that helps to preserve the environment and support the current mineral oil supply. Refined Bleach and Deodorised Palm Kernel Oil was used in this research as tested lubricant undergone normal load test (ASTM D4712) and extreme pressure (ASTM D2783) according to the ASTM test standards. The Refined Bleach and Deodorised Palm Kernel Oil was tested at two conditions of semi-solid form and liquid form. A liquid form of Refined Bleach and Deodorised Palm Kernel Oil was synthesized with transesterification process to convert the semi-solid form into liquid at room temperature. Results shows that Refined Bleach and Deodorised Palm Kernel Oil performance was comparable to the fully synthetic oil in terms of COF, WSD, and surface roughness while in the extreme pressure test shows that ISL of palm-based oil are slightly lower than fully synthetic oil by 127N.

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1.0 INTRODUCTION

Lubricant commonly produced from petroleum based oil which is limited to the extinction due to the high demand in the future market. Petroleum based oil also contributed to the environmental issues for its properties which are toxic and cannot be dispose. Several studies to replace the lubricant resources had been done by modifying vegetables oil properties which proved to have a capability as a lubricant (Rewolinski, 1985a). Rewolinski, 1985b, also studies the lubrication effect of blended biodiesel oil by using resources from sunflower oil. Another study made by Fernando et al., (2007), proved that bio-based products lubricity performance is better compared to diesel fuel lubricant. This effort includes the usage of palm oil based products such as palm olein, palm kernel oil, palm stearin and palm fatty acid distillate. Flider, 1995, found that rapeseed oil from vegetable resources is one of the potential candidates for biodegradable lubricant. The statements strengthen by Anon, 1995, which stated that with technological development in research, it is possible to use vegetable oil as a host application. Researchers had done a various research involving the vegetables suitability as lubricant oil (Serddari and Fragioudakis, 2000; Agarwalet al., 2008; Ramdhas et al., 2005; Hossain and Davies, 2010; McCormick et al., 2001; Augustusa, and Jayabalan, 2002).

The study of vegetable oils suitability as a lubricant was conducted by comparing tribological performances between palm fatty acid distillate and commercial engine oil at different speeds and comparing oil performance between jatropha oil and commercial engine oil at different temperatures (Golshokouh, et al., 2013a; Golshokouh, et al., 2013b). Malaysia is one of the world's largest palm oil manufacturers; it has the advantage of producing palm oil-based lubricant in large quantities at a lower cost. It is assumed that one hectare of palm trees can produce almost 10 times as much oil as other sources of vegetable oil. Lubricant creates a thin layer that reduces friction and protects parts from wear. Friction defines the efficiency and reliability of various machinery components, e.g. in automotive engines. It is estimated that approximately 20–25 percent of the energy generated by combustion is lost to frictional dissipation (Maliar, et al., 2015). This wear causes up to 80–95 percent of failures and damage to the surfaces (Sapawe et al., 2014).

Among all listed palm oil products, palm olein are widely used as a cooking oil products and are not recommended by the palm oil community to be use as others categories products since it will interfere with the consumer needs and price hiking. The tribological performance of palm based oil has been proved for its competitiveness with commercial engine oil (Ing et al., 2012b; Zuan et al., 2017). Some of the study had improved the palm oil properties by adding additives to enhance the capabilities of palm oil for different purposes (Madihalli et al., 2016; Liu et al., 2016; Basso et al., 2010). The test conducted using palm based oil also had been test in several applications such as fourball tribotester (Syahrullail et al., 2013b), pin-on-disk tribotester (Zuan et al., 2017b), cold forward extrusion (Syahrullail et al., 2005) , four stroke engine (Mannekote and Kailas, 2011) and etc.. The properties of long polar ester group is believed to contribute to the reduction of wear and friction in the moving parts. However, not all palm based oil existed in the liquid form for example RBD Palm Stearin is in semi-solid and PFAD is in solid state physical form. Most of the studies done on particular palm based oil need to be heated at their respective melting point before been proceed to the test. To avoid misconception regarding the physical form of lubricant, the effort to change it into liquid form has to be done.

This article is discussing the tribological performance of modified RBD PKO by transesterification method to change the semi-solid form into liquid at room temperature. The test conducted was according to the ASTM 4172B for normal load test and ASTM 2783 for extreme pressure test. Both test was conducted using fourball tribotester machine with modified RBD PKO as a lubricant. Genuine RBD PKO and conventional oil had also been test under same condition as a direct tribological performance comparison.

2.0 EXPERIMENTAL PROCEDURE

RBD Palm Kernel Oil used was produced from Keck Seng (M) which existed in a semi-solid state at room temperature. The trans-esterification process done was to convert the semi-solid state of RBD Palm Kernel Oil into a well-known lubricant state which is in liquid. Trans-esterification process theoretically been used to removes FFA content in oil as this method widely used in biodiesel production. Free fatty acid content is believed the reason of crystalline structure of RBD Palm Kernel Oil at low temperature.

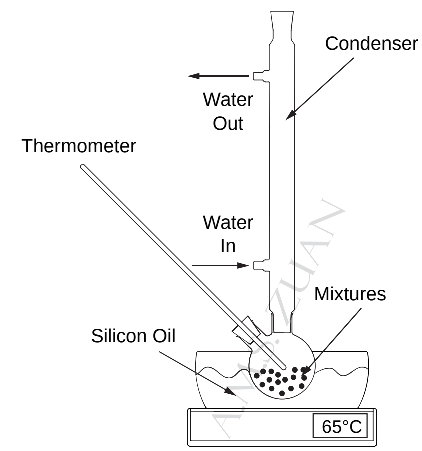

Figure 1: Trans-esterification schematic diagram.

In this study, RBD Palm Kernel oil was mixed with methanol in the presence of Calcium Oxide, CaO catalyst for a varied reaction time of 3 hours, 4.5 hour and 6 hours with constant reaction temperature at 65°C. The trans-esterification test setup was illustrated as in Figure 1. After the trans-esterification reaction, the final products are filtered to separate the catalyst from methyl ester and been kept cool in the refrigerators at 0°C to monitor the ester liquid structure sustainability of the modified oil before proceed to Four-ball tribotester machine. CaO catalyst was been calcine in the oven with temperature of 70°C overnight then further process in the furnace for 3 hours at 900°C and kept cool at room temperature. This process was to removes any moistures and impurities in the catalyst.

Four-ball tribotester machine was used in this study to evaluate Anti-Wear (AW) test. Figure 2 shows the schematic diagram of four-ball tribotester main components such as oil cup assembly, collet and ball bearings. The test was conducted using a ball bearing with a diameter of 12.7 mm composed of chrome alloy steel, made from AISI E-52100 with grade 25 extra polished and have a Rockwell C hardness of 64 to 66. One ball bearing is moving rotationally at certain speed is in contact with three stationary ball bearings which immersed in the tested lubricant under a certain load. The experiment was done according to ASTM D 4172. The top bearing rotates against three stationary ball bearings at 40kg of load, speed of 1200 rpm and temperature of 75°C for duration of 60 minutes for each test.

The coefficient of friction value was determined to evaluate the performance of lubricant. This data was generated automatically by four-ball tribotester based on coefficient of friction Equation (1). The coefficient of friction was measured based on the average of frictional force. The coefficient of friction indicates the transmission efficiency of the moving components. Higher in efficiency means less resistance to the moving parts, hence in terms of lubricity, less friction is desirable.

$$COF = \frac{T\sqrt{6}}{3Wr} \qquad (1)$$

Where T is the coefficient torque in kg/mm, W is the force applied in kg and r is the length between the centres of the contact surface on the lower balls to the rotation axis (3.67 mm).

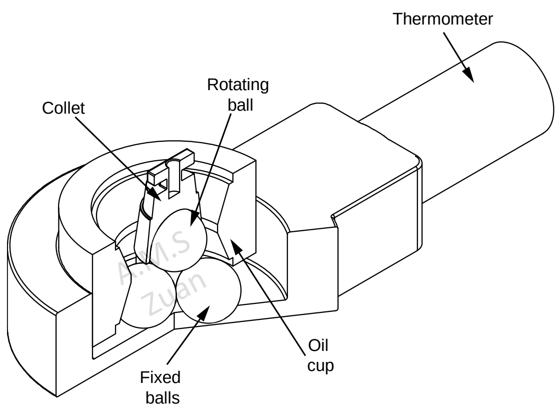

Figure 2: Main parts of the four-ball tester

The lubricant performance was also determined from the mean wear scar diameter. Wear scar diameter was measured from the three pieces fixed balls using charge couple device (CCD) microscope to capture the photomicrograph. Generally, the bigger the wear scar diameter means the more severe the wear.

All modified bio-based oil from trans-esterification which succeed in liquefy are proceed into the fourball tribotester machine to test for its lubricity and COF performance. This test compared the modified bio-based oil with semi-synthetic oil to observe the performance where 10mL of oil are used for each 60 minutes' test according to ASTM standards. Three static balls are immersed in the tested lubricant while one balls are rotating at constant speed of 1200rpm with normal load of 40kg been applied upward. The test is repeated three times and data for COF and wear are taken as average value from all static balls. In extreme pressure test, the lubricants tested according to ASTM D2783 standards procedure with increasing loads until the maximum yield has occurred whether the 4mm of wear scar diameter or the weld point had occurred which indicates the failure of the lubricants properties.

3.0 RESULTS AND DISCUSSION

3.1 Effects of Normal Load Test

One of the tribology characteristic can be discuss is the coefficient of friction of tested lubricants. Figure 3 presented the results from fourball tribotester machine tested on fully synthetic, RBD PKO, modified RBD PKO 3h, 4.5h and 6h at normal load condition. Based on Figure 4, fully synthetic oil recorded lowest COF value at 0.083 while highest recorded by 4.5h at 0.0958. Even though the COF performance for modified RBD PKO are higher compared to fully synthetic oil but the value recorded was differ only by 13% at most by 4.5h modified oil. During trans-esterification process to convert the semi-solid RBD PKO into liquid, the fatty acid composition of RBD PKO has changed. The change was effecting the decrease in long fatty acid chain by producing more free fatty acids. Long fatty acids chain is better in reducing COF value in lubricants oil than a single free fatty acid. However, by producing proper amount of free fatty acids could contribute to improve the COF value as in 6h modified oil performance a better than RBD PKO. The stearic acid contained in the palm oil helps to maintain a good lubricant layer film (Ing et al., 2012a; Jayadas et al., 2007). Fully synthetic oil is well engineered with a good viscosity value which could maintain enough lubricant layer thickness to separate two moving surfaces while keeping lower oil shear stress to help improved the COF value.

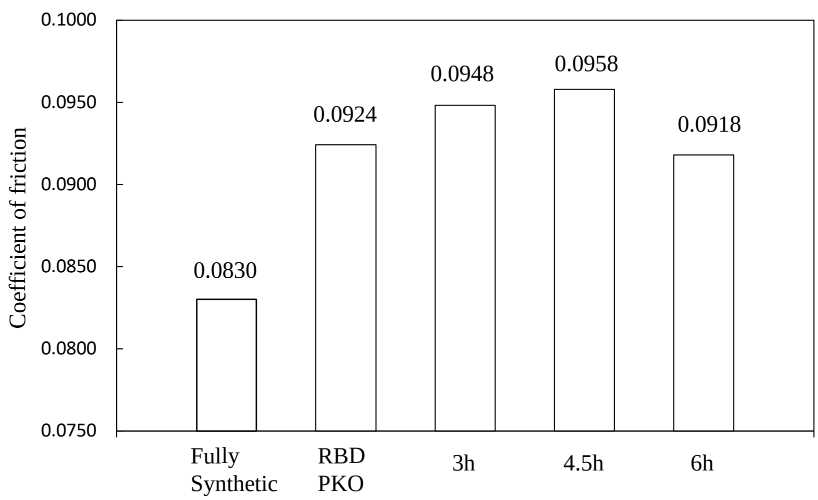

Figure 3: Graph for coefficient of friction for all tested oil under normal load test.

During experiments of normal load test using fourball tribotester machine, three static steel balls are being used in one experiments as a subjects to study the lubricants tribology behaviour including wear scar diameter. The wear scar diameter was taken from the average of all three balls wear scar measured using optical microscope. The wear scar diameter for lubricants; RBD PKO, fully synthetic, modified RBD PKO 3h, 4.5h and 6h oil was recorded in Figure 4. Fully synthetic oil recorded lowest wear scar diameter at 465μm while highest wear scar recorded by RBD PKO at 575μm. Others modified oil recorded WSD of 516μm (3h), 534μm (4.5h) and 559μm (6h). Compared with the fully synthetic oil performance, all palm-based oil WSD were slightly differ by 11-24% in value which the performance of RBD PKO and modified oil were competitive with the conventional lubricant tested. The advantage of long fatty acid chain in the RBD PKO composition creates a thin monolayer film to reduce a direct contact between two sliding surfaces (Sharma et al., 2008). The study using palm oil as lubricants also has been proved to have a good lubricity property (Syahrullail et al., 2013b).

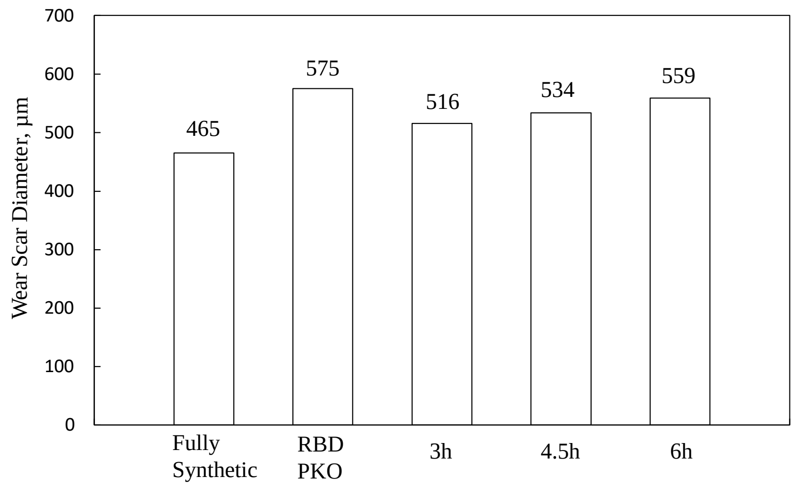

Figure 4: Graph for wear scar diameter for all tested oil under normal load test.

Surface roughness of the steel balls has been taken by surface profilometer to study the roughness occurrence from the normal load experiments. The evaluation of surface roughness indicates the lubricants performance to provide smoother surface thus reducing the damage to the sliding steel surfaces. The data has been recorded as in Figure 5. Highest surfaces roughness recorded by RBD PKO at 0.0738mm while lowest by 4.5h oil at 0.0266mm. Fully synthetic oil, 3h and 6h recorded surfaces roughness value at 0.0419, 0.0421 and 0.0295mm respectively. It can be seen that after trans-esterification process, the surface roughness value had been reduced almost half of the value from RBD PKO. Since various types of wear mechanism can cause the wear on ball specimen surfaces such as abrasion, corrosion/chemical, and adhesion and fatigue (Stokes, 2013). It is said that by reducing the long fatty acids chain can improve both WSD and surfaces roughness value, however, excess of free fatty acids can contribute to chemical attack on the ball surfaces which weaken and increase wear.

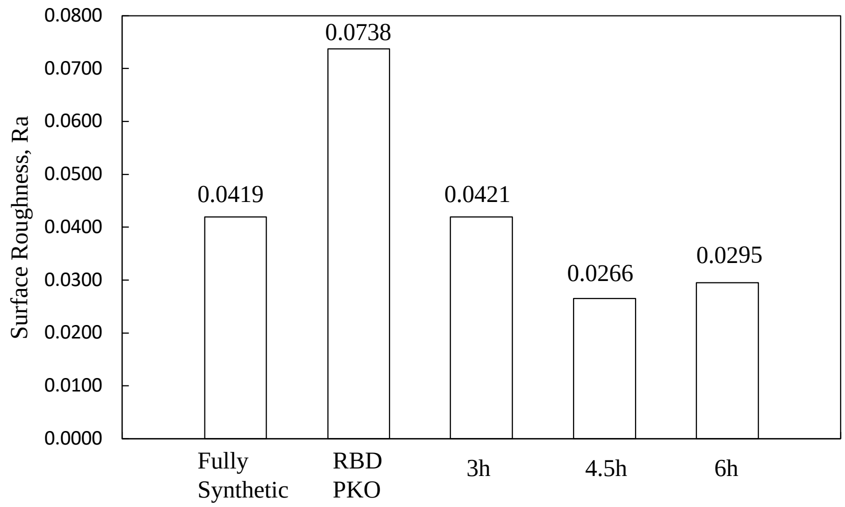

Figure 5: Graph for surface roughness for all tested oil under normal load test.

3.2 Effects of Extreme Load Test

All lubricants tested has gone through the extreme pressure test according to the ASTM D2783 standards to study the oil maximum shear stress by applying extreme loads until the lubricant film failed at which the seizure has occurred by steel ball welding phenomenon or the 4mm WSD has been observed.

Table 1: Summary of extreme pressure test results for tested lubricants.

Lubricants	Observation at ISL			2.5 s SDL (N)	Observation just before WL			WL (N)	FTP (max)	PWI
	ISL (N)	d (mm)	P_m		WL (N)	d (mm)	P_m			
3 hour	491	0.80	399	618	1236	3.71	47	1373	8.75	17
4.5 hour	491	0.45	1260	618	981	3.42	44	1128	7.19	38
6 hour	491	0.42	1594	618	981	3.67	38	1079	6.88	17
RBD PKO	491	0.62	709	618	1236	3.05	69	1373	20.10	41
Fully Synthetic	618	0.70	656	784	1236	3.12	71	1570	22.97	34

It is proven that in Figure 6 that WSD are increased slowly while load been increased until ISL point and a sudden increase in WSD occurred between ISL and 2.5 s SDL point. Then the WSD for all lubricants tested increased slowly after 2.5 s SDL point while the load increased before WL occurred. The same pattern was observed for all lubricants with different value of ISL, 2.5 s SDL and WL through increasing loads. In ISL region it is observed that the WSD is approximately same size where this region known as an antiwear region where the lubricant film been absorbed into steel ball surfaces to resists the increase in WSD. The sudden increase in WSD between ISL and 2.5 s SDL was contributed from the increase in temperature and partial desorption of thin lubricant film. The P_m at contact point decreases dramatically from ISL to 2.5 s SDL, the P_m for fully synthetic decreases from 656 to 71N/mm^2, whereas RBD PKO P_m decreases from 709 to

61N/mm^2 while 3h decreases from 399 to 47N/mm^2. Similarly, for 4.5h and 6h the P_m value decreases at ISL to 2.5 s SDL from 1260 to 44N/mm^2 and 1594 to 38 N/mm^2 respectively.

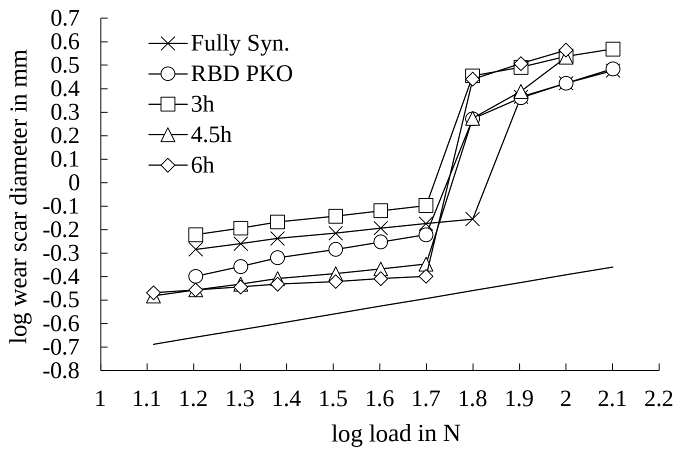

Figure 6: Effect of load on wear scar diameter for tested lubricants.

In these experiments, conventional oils used are formulated with the additives to support the oil performances in wear scar and coefficient of friction while RBD PKO is purely depending on its composition to protect the sliding surfaces. It is shown that palm-based lubricant oil has recorded lowest ISL at 491N followed by fully synthetic at 618N. With the additives capabilities in conventional lubricant oils, semi-synthetic recorded highest WL at 1570N while RBD PKO and 3h had the lowest weld load of 1373N.

4 CONCLUSION

In this research articles, the work has been done using liquid form of RBD PKO at room temperature which liquefied through the trans-esterification process to convert the original semi-solid form of RBD PKO into liquid (Zuan et al., 2017). The test conducted for three different modification oil parameters of trans-esterification reaction time of 3h, 4.5h and 6h. After the test, modified oil showed a promising tribological performances compared to the original RBD PKO and fully synthetic oil in normal load and extreme pressure load test. At normal load, the modification of RBD PKO through transesterification process does not interfere the COF performance where there are only slight differences between RBD PKO and modified oil even though recorded higher reading compared to fully synthetic oil. Contradict with COF result, WSD and surface roughness of modified oil showed an improvement by reduced results compared to RBD PKO. Meanwhile, RBD PKO and modified oil has the same ISL and 2,5s SDL value but ended with different weld load which showed 4.5h and 6h modified oil has recorded early weld condition, In the future, the modified liquid RBD PKO properties had a huge chances of improving its ability as a lubricants by implementing additional additives such viscosity modifier, anti-wear, anti-friction to compete with the existing conventional lubricants oil available in the market while having an advantages of renewable and environmental friendly properties.

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