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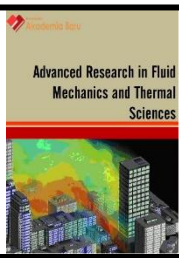

Tribological Analysis of Modified RBD Palm Kernel Containing Anti-oxidant Additive using Four-ball Tribotester

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ABSTRACT

Vegetable oils are becoming increasingly important as an alternative lubricant oil due to their non-toxic, renewability and biodegradability characteristics. They are considered as promising candidate to replace the conventional petroleum based lubricant which are constantly threatening our environment. However, most of the vegetable oils are facing common issue which is low oxidative stability that limits them to be used directly as bio-lubricant oil. This work studied the application of Tertiary-Butyl-Hydroquinone (TBHQ) as synthetic base anti-oxidant agent inside palm kernel oil (PK). The effect of load on the tribological performance of lubricant formulated were tested using four-ball tribo-tester according to ASTM D4172 standard with duration of 60 minutes for each test. The results obtained were compared to the commercialized mineral (MO) and semi-synthetic engine oil (SSO) for the reference purpose. Based on the result obtained, the coefficient of friction of palm kernel is smaller as compared to commercialized petroleum based oil. This is contributed by the presence of long polar fatty acid structure that acts as a protective film between two rubbing surfaces. The addition of anti-oxidant, TBHQ also helps to further reduce the friction coefficient of PK. However, the wear scar diameter of PK and PK+TBHQ are larger compare to MO and SSO. Thus, it can be concluded that TBHQ manage to enhance the friction reducing performance of PK by lowering the value of friction coefficient. However, there is still room improvement for the anti-wear properties of palm kernel oil.

1. Introduction

In recent years, our planet is facing a lot of environmental issues like global warming, climate change and water pollution. Many factors are contributing to these issues including emissions of pollutant gases, improper waste disposal and the usage of non-biodegradable products. According to report, about 50% of total production of mineral lubricants worldwide accumulates in the environment every year and will directly contaminate water sources, cause infections towards human and bring damage to aquatic ecosystem [1,2]. In response to this issue, there are growing interest for the development of renewable energy in Malaysia. The study on the application of nano-

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particle inside various field [3-5], the development of wind turbine [6, 7] and the research on the potential of vegetable oil as lubricant oil [8, 9] are becoming the latest interest for many researchers today.

Recently, vegetable oils are potential substitutes for petroleum based lubricant not only because they are renewable raw materials but also because they are biodegradable and non-toxic. The tribological properties of vegetable oils are excellent and have potential to be used as lubricants such as high-viscosity index, high lubricity and low volatility [10].

However, low oxidation stability is becoming one of the main issue that restricting the industry acceptance towards the application of vegetable based lubricant. In common vegetable oils, oxidation stability is primarily affected by the degree of unsaturated double bonds. Carbon-carbon double bonds are highly tending to act as active sites for many reaction including oxidation [11].

As the level of unsaturation increase, the more double bond present, the easier for the vegetable oil to oxidized [12]. This issue can be progressively solved by reducing the level of unsaturated fatty acid through chemical modification method such as blending, interesterification, hydrogenation and epoxidation [13-15]. However, the excessive modification of vegetable oils will ruin their useful lubrication properties. Thus, a proper balance must be met to produce bio-lubricant which can meet standard requirement for the lubricant oil. Besides that, the oxidation stability of vegetable oils can be enhanced by addition of anti-oxidant packages.

Anti-oxidant is an additive that can interrupt the oxidation process, forming stable molecule and slowing the reaction of double bond with oxygen molecules [16]. Previously, studies on TBHQ as an anti-oxidant oxygen have been carried out by many researchers in various applications. A study was conducted by Munoz *et al.,* to analyse the effectiveness of using TBHQ in stabilizing compounds of biodiesel in long storage time [17]. As the results, the addition of TBHQ was able to prolong induction time. Similarly, it has been reported by the other researchers that TBHQ is considered as the most effective anti-oxidant agent to improve oxidative stability of biodiesel.

Another experimental study was conducted by Hammond *et al.,* (2002) in determining the capability of several anti-oxidant additive such as TBHQ, BHT, hydroquinone and ascorbyl palmitate [18]. 0.01% and 1.28% concentrations of each anti-oxidant agent was added into soybean oil to improve its oxidative stability. Based on the result, it was revealed that TBHQ exhibits the most effective performance in improving the oxidative stability of soybean oil.

2. Methodology

2.1 Apparatus

For this research, the test rig used is four-ball tester type TR-30L. The test rig uses four balls as stated in its name. The important components are the ball pot, collet and ball bearings. The configuration is as shown in Figure 1.

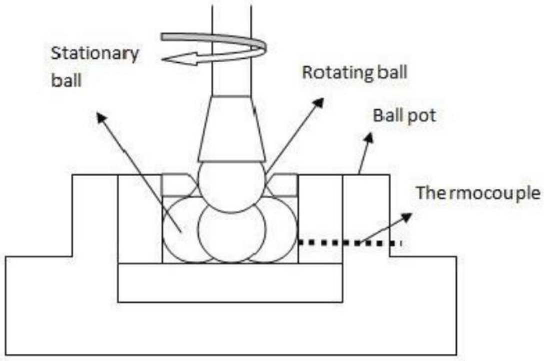

Fig. 1. Four ball tester configuration

2.2 Materials

The balls used in this experiment follows the ASTM D4172 standard which is chrome alloy steel, made from AISI E-5200 with a diameter of 12.7mm. The grade is 25 EP and Rockwell C hardness 64 to 66. Each test used four new balls and were cleaned using acetone before starting the test. It is then wiped dry using industrial tissue.

2.3 Lubricants

In this study, palm kernel oil (PK) is used as lubricant base oil. PK is obtained from the kernel of the palm fruit. The refining process of crude palm kernel oil will produce refined, bleached, and deodorised (RBD) palm kernel oil. The amount of 450ppm (parts per million) of Tertiary-Butyl-Hydroquinone (TBHQ) anti-oxidant additive were added to this vegetable oil as bio-lubricant formulation. TBHQ is considered as synthetic based anti-oxidant agent. Commercial mineral engine oil (MO) and semi-synthetic engine oil (SSO) were used as a benchmark for comparison purpose. General properties of each based lubricant oil tested are tabulated in Table 1.

Table 1
General properties of the lubricant tested

Lubricant	MO	SSO	PK
Specific Gravity (g/cm^3)	0.8660	0.87	0.89
Kinematic Viscosity (Cst)			
@40°C	108.2	112.9	29.40
@100°C	14.1	20.90	10
Viscosity Index	142	211.89	354.37
Free Fatty Acid (FFA %)	-	-	0.02
Peroxide Value (PV)	-	-	-
Pour Point (°C)	-36	<-30	-
Flash Point (°C)	236	>200	-
Iodine Value (IV)	-	-	17.9
Slip melting Point (°C)	-	-	-
Cloud Point (°C)	-	-	-

2.4 Experimental Condition

The experimental condition follows ASTM D4172 standard guide. For this experiment, the speed and temperature are remain constant with a value of 1200rpm and 75^{0}C respectively. Meanwhile, the normal load varies from 40k, 60kg and 80kg. The duration to complete one experiment is 1 hour.

2.5 Friction Evaluation

The friction torque can be obtained directly from the software installed in the computer (Winducom 2010) software that is connected to the four ball machine. The data parameter being extracted are in the value of friction torque and time. Thus, the graph of friction torque versus time can be obtained. The software also displays the value of coefficient of friction. By using the formula shown in equation 1, the values of coefficient of friction can be obtained using friction torque values, (T) , applied load (W) and the distance (r) from the center of contact surfaces on the lower balls to the axis of rotation which is 3.67mm.

$$\mu = \frac{T\sqrt{6}}{3Wr} \tag{1}$$

The wear scar diameter is measured using the Charge-Coupled Device (CCD) microscope. The image is viewed on the computer using the already installed software. The microscope can only viewed one ball at a time. After locating the wear scar spot, the image is captured and saved inside the computer.

3. Results

3.1 Coefficient of Friction (COF)

The results of the coefficient of friction is being presented in Figure 2.

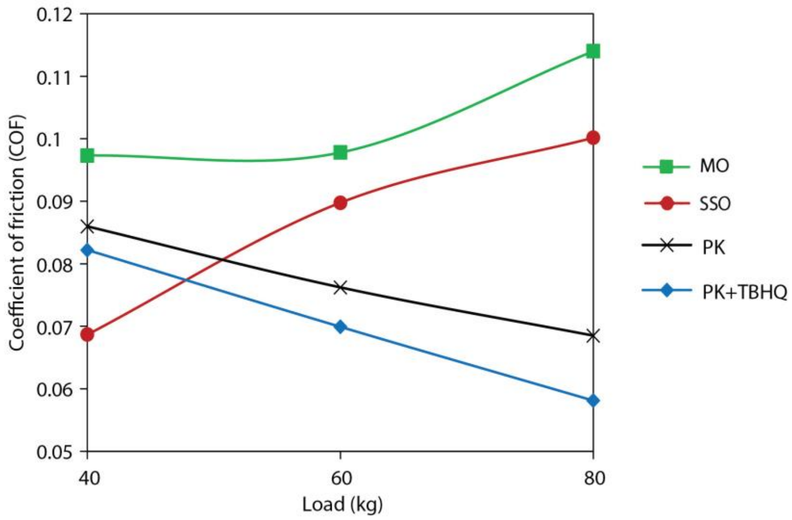

Fig. 2. Graph of Load VS COF for each lubricants and tests

The graph of load against coefficient of friction for MO, SSO, PK and PK+TBHQ are plotted in Figure 2 above. It can be seen that coefficient of friction increases as the load increases for MO and SSO. This is because higher stress concentration in localize region is produced when the load increases [19]. Another reason is because higher loads and temperature cause more metal to metal contact through the destruction of protective film [20]. For SSO, the coefficient of friction values are the highest compare than other lubricants at all loads. At 40kg, MO has the lowest coefficient of friction than other lubricants.

Meanwhile, the values of coefficient of friction decreases as load increases for PK and PK+TBHQ. Furthermore, the graph shows that the values of coefficient of friction for PK are lower compare to MO and SSO at load 60kg and 80kg. This is because PK has a fatty acid structure that acts as a film layer on the surface of the material. The triglyceride structure of the PK provides qualities that are important in a lubricant, since long, polar fatty acid chains provide high strength lubricating films that interact strongly with metallic surfaces. As a result, these films can reduce the friction and wear [21]. In addition, the fatty acids help the lubricant molecules to stick on the ball bearing surface very well and maintain the lubricant layer. The presence of thin lubricant films of lubricant between the ball bearing surfaces minimized the material transfer and adhesion of the two surfaces [22]. Besides that, by having a great affinity for metal surface, it forms a strong additional monolayer or chemical coating between moving surfaces thus reducing the wear tendency significantly [23]. This also supported by Aiman *et al.,* [24] that stated long chain fatty acid can help to reduce the coefficient of friction.

From the graph, it can be seen that PK+TBHQ produced the lowest COF compare to other lubricants in the experiment at all loads. This is because the presence of TBHQ (Tertiary-Butyl-Hydroquinone) in the mixture significantly reduced the rate of the biofuel biodegradation [25]. The highest values of coefficient of friction obtained for the three loads based on the graph is SSO. This is due to the anti-wear additive that is included in the mixture [21]. From the results obtained, it is proven that PK has higher resistant to friction compare than MO and SSO. In addition, the wear resistant can be improved by mixing palm kernel with 450ppm anti-oxidant.

3.2 Wear Scar Diameter (WSD)

The diameters of the wear scar are observed by using CCD microscope. The results obtained can be recorded in Figure 3.

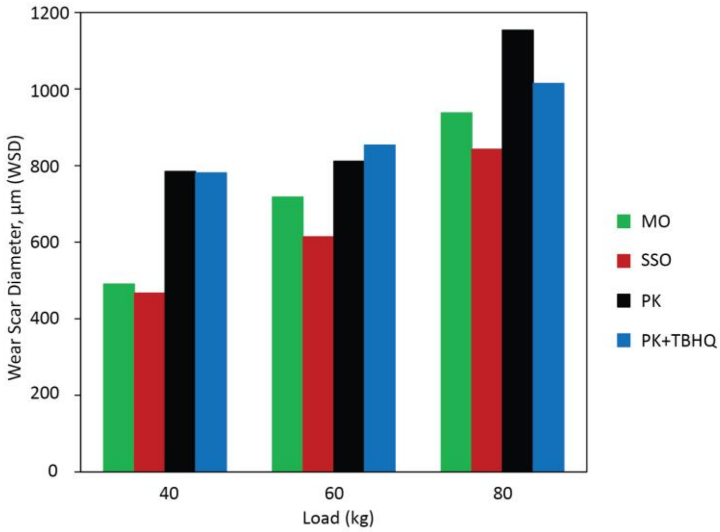

Fig. 3. Graph of Load VS WSD for each lubricants

The graph of load against wear scar diameter for MO, SSO, PK and PK+TBHQ are plotted in Figure 3 above. From the figure, it can be seen that wear scar diameter increases as the load increases for the all lubricants. At all loads, the wear scar diameter of PK and PK+TBHQ are the highest followed by SSO and MO. At load 40kg and 80kg, PK has the highest wear scar than PK+TBHQ. Meanwhile, PK+TBHQ has the highest wear scar diameter at load 60kg compare to PK. At all load, the wear scar diameter of SSO is higher compare than MO. MO has the lowest wear scar diameter compare than PK, SSO and mixture of PK and PK+TBHQ. This is because there was no oxygen element that could trigger oxidation [21]. Another reason is because it is fully formulated lubricant so its properties already shows a desired lubricant compare to the PK [24].

The reason for the increase in wear scar diameter is because of the interaction between the lubricant and the metal surfaces, and the reduction in the pressure. In addition, the increment of the wear scar diameter was also caused by chemical attack on the rubbing surfaces by the fatty acid in PK [22]. High value of wear scar diameter for PK is because it has an oxygen bond in its chemical chain. The oxygen element caused the oxidation on the surface of the ball bearing, and made the structure of the ball bearing brittle, producing a higher wear rate. As a result, the wear scar occurring on this ball bearing is the largest.

Even though the coefficient of friction of PK and PK+TBHQ are lower than MO and SSO, the wear scar diameter is larger. This finding is consistent with the observation of increased wear when vegetable oils are used as boundary lubricants due to the continuous removal of metallic soap film that is formed as a result of the reaction of the oil with the metallic surface during sliding. The metallic film is continuously reformed by further chemical reaction. Since the metallic soaps are of low shear strength, the coefficients of friction will be low [26]. Overall from the graph, it can be seen that the wear scar diameter of mixture of palm kernel with 450ppm anti-oxidant (TBHQ) is lower than Palm Kernel, PK. This is because anti-oxidant concentrations above 100 ppm were effective for maintaining the oxidation stability of the samples [27].

3.3 Wear Worn Surfaces Characteristic

From all the captured images, only the best images for the worn surface of the balls are included. The wear worn surface of 50x magnification can be analyzed from the images in Figure 4.

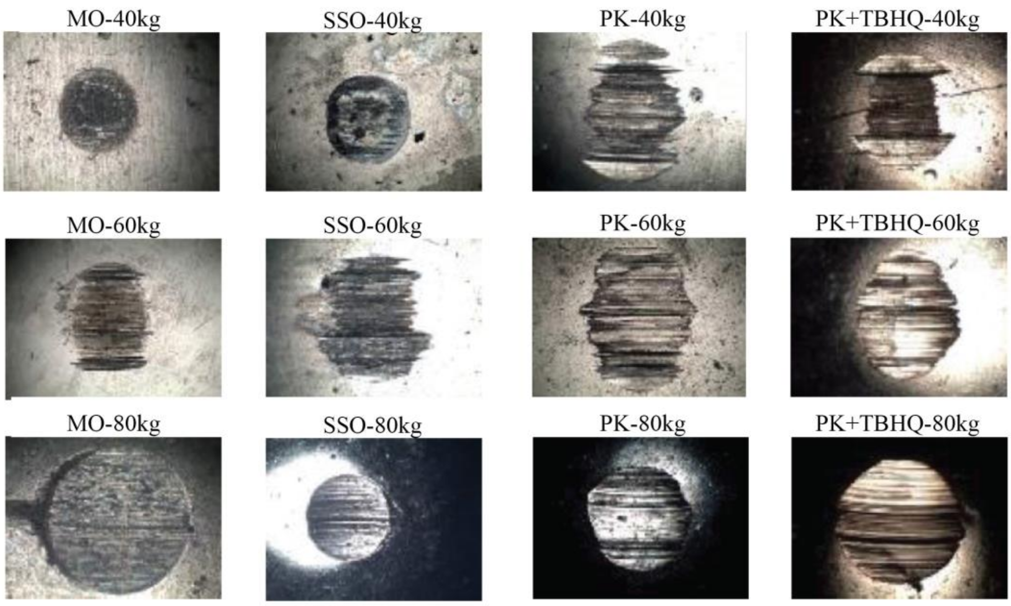

Fig. 4. Wear worn surface for each lubricants (50x magnification)

The figures show 50x magnification of the ball bearing wear scar for PK, MO, SSO and PK+TBHQ. Based on the figures with 50x magnification above, the wear worn surface characteristic can be observed. It can be seen that the wear scar increases as the load increases for all three type of oils. From the figure, the wear scars of ball bearing for MO and SSO were circular in shape at all the normal load conditions. At normal loads 60kg and 80kg, the edge was slightly ragged and obscured by metal particle.

In addition, the worn surface showed abrasive wear and some adhesive wear was found. Meanwhile, the wear scars of ball bearing for PK showed no circular wear scars at 40kg and 60kg loads condition. It can be seen that, the edge of the wear scar was totally ragged that caused no circular shape form. However, the worn surface of the ball bearing showed abrasive wear occurred but no severe adhesive wear was found. Besides that, there were parallel grooves found on the worn surface for all lubricants. Some of the grooves were deep (dark region) and some were shallow (light colour region) [22]. There was also improvement can be seen from the images of the mixture of palm kernel with 450ppm of TBHQ.

4. Conclusions

The coefficient of friction of PK and PK+TBHQ is smaller as compared to MO and SSO. This is contributed to the presence of long polar fatty acid structure that acts as a protective film between two rubbing surfaces. The addition of anti-oxidant also helps to further reduce the friction coefficient of PK. However, the wear scar diameter of PK and PK+TBHQ are larger compare to MO and SSO. Thus, it can be concluded that PK have a good friction reducer property compared to other commercialized petroleum base oil but possess poor anti-wear property.

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