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MECHANICAL PROPERTIES OF PALM KERNEL OIL-COPPER OXIDE NANOLUBRICANT

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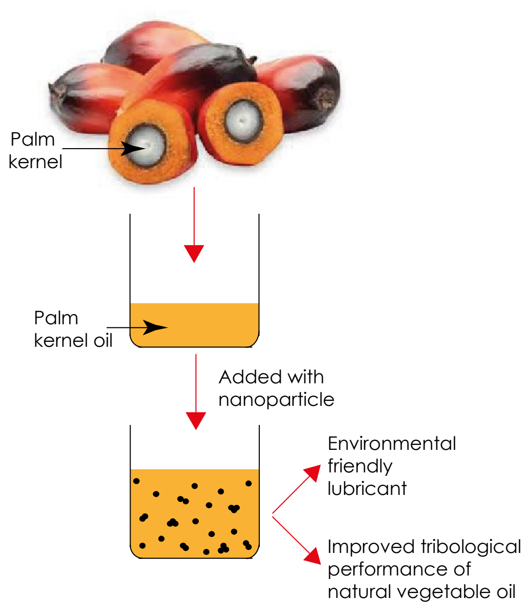
Graphical abstract



Abstract

Since the last decade, vegetable oil has received tremendous attention as an alternative lubricant because of worsening state of environmental health and finite resources of mineral oil. However, the use of vegetable oil is restricted due to the poor low temperature fluidity and thermal-oxidative stability. These drawbacks can be enhanced by adding additive into the solution of vegetable oil. Thus, objective of this research is to investigate the influence of adding nanoparticle additive on tribological performance of palm kernel oil. The type of nanoparticle used throughout this study is copper oxide, which serves as anti-wear additive. Palm kernel oil (PKO), palm kernel oil-copper oxide nanoparticle (PKO-CuO), mineral oil (SAE-40), synthetic oil (SAE15W-50) are used as lubricant. Tribological properties if the used lubricants are evaluated using fourball tribotester under standard load and extreme pressure tests. Experimental results showed that the presence of nanoparticles in natural palm kernel oil improved tribological performances of friction and wear. The friction coefficient and wear scar diameter are reduced by approximately 5.0% and 3.5% respectively. The highest enhancement in friction coefficient value of ~20% was obtained under extreme pressure condition. Addition of nanoparticle also is found to improve load carrying capacity of PKO by 15%.

Keywords: Palm Kernel Oil, Copper-Oxide, Nanoparticle, Nanolubricant, Vegetable oil

1.0 INTRODUCTION

At moving surfaces, lubricant is a key role in preventing metal-to-metal contact, so that friction and wear behaviour could be minimize. Another purpose of applying lubricant is to reduce heat and remove foreign particles in a system. Basically, lubricant is classified into a few groups, such as mineral lubricants, synthetic lubricants, bio-lubricants and solid lubricants. Since the usage of mineral-based lubricant creates several environmental problems such as pollutions and depletion of natural resources, vegetable-based oil lubricant is gaining more attention. Vegetable oils are more favourable than mineral oil because of they are biodegradable, non-toxic and environmental friendly. Apart from that, vegetable oils also have desired physicochemical properties as alternative lubricant like high viscosity index, high flash-point and low volatility.

However, the extensive use of vegetable oils is restricted due to the inefficient performance at low temperature, low hydrolytic and thermal oxidative stabilities [1]. These drawbacks can be mitigated through chemical modifications of the oil structure. One of the method is by adding nanoparticle into the vegetable oil. A few researchers reported that by adding the nanoparticles into lubricant, both wear and friction values were reduced significantly [2]. Besides that, nanoparticle can be used as extreme pressure and antiwear additives. Theoretically, the friction-reduction and anti-wear performance depends on the size, shape and concentration of the nanoparticles [3]. The commonly size used for any research has been mostly in the range of 20 – 150 nm. Therefore, the objective of the present study is to evaluate the tribological properties of palm kernel oil-CuO nanolubricant as an alternative lubricant.

2.0 METHODOLOGY

2.1 Lubricant

In this research, there are six types of lubricants to be used as tested lubricant: Palm Kernel Oil (PKO), Palm Kernel Oil + copper oxide nanoparticle (PKO-CuO), Mineral Oil (SAE-40) and Synthetic Oil (SAE15W-50). The amount copper oxide added into palm kernel oil is 0.34 wt.%. Then, the mixture was stirred thoroughly for 40 minutes in order to avoid sedimentation of nanoparticles at the bottom. The physical property of all tested lubricants like density and viscosity are provided as in Table 1 and Table 2.

Table 1 Density of tested lubricants

Type of lubricant	Density @ 25°C, g/cm³
Palm Kernel Oil	0.90
Palm Kernel Oil + 0.34 wt% CuO	0.91
SAE15W-50 Engine Oil	0.85
SAE-40 Engine Oil	0.90

Table 2 Viscosity of lubricants at different temperature

Type of lubricant	Kinematic viscosity (mm²/s)		
	25°C	40°C	100°C
Palm Kernel Oil	43.09	37.12	17.34
Palm Kernel Oil + 0.34 wt% CuO	42.39	35.09	16.50
SAE15W-50 Engine Oil	280.83	114.47	26.96
SAE-40 Engine Oil	299.68	161.37	25.65

2.2 Fourball Tribotester

Tribological properties of tested lubricants are evaluated by using fourball tribotester machine as presented in Figure 1 and the specification of the machine is provided in Table 3. All lubricants were evaluated at two conditions of standard load test and extreme pressure test. Details of the test condition is provided as such in Table 4.

Table 3 Specification of fourball tribotester machine

Parameter	Description
ASTM Standard	D4172, D2783
Speed (RPM)	300 – 3000
Maximum Axial Load (N)	10000
Temperature (°C)	Ambient – 100
Scar Range (Micron)	100 – 4000

Table 4 Experimental conditions of standard load and extreme pressure tests

Experimental condition	Standard Load Test	Extreme Pressure Test
Load (kg)	40	From 70 kg until WSD reach 4 mm
Duration	1 hour	10 s interval
Temperature	75 C	35
Speed (RPM)	1200	1760

Figure 1 Fourball tribotester machine

The experimental conditions are rotating spindle rotates at 1200 r.p.m, temperature of 75ºC with load of 40 kg and for the duration of 60 minutes. While, a ball bearing used in the study is made of chromium alloy steel and its specification according to ASTM D4172-94 is tabulated in Table 5. Tribological performance of the tested lubricant is evaluated according to the surface of ball bearing.

Table 5 Specification of balls used in fourball machine

Items	Description
Material	Chromium Alloy Steel, AISI E-52100
Outer Dimension (mm)	12.7 mm
Polish Grade	25
Rockwell C Hardness	64 – 66

The tribological performances for each lubricant are evaluated in terms of coefficient of friction (COF), wear scar diameter (WSD), surface roughness (Ra) and morphology analysis of worn surface. The wear scar diameter and morphology analysis worn surface observation are determined by using optical microscope with 500 magnification, while surface roughness is measured by means of surface profiler. The COF, μ is calculated by using Equation 1.

$$\mu = \frac{T\sqrt{6}}{3W_r} \quad (1)$$

whereby, T represents the frictional torque (Nm), W is the applied load (kg) and r is the distance from the centre of contact surface on the lower balls to axis of rotation, which is 3.67 mm. The COF value is calculated for each 600s for duration of 3000 s.

3.0 RESULTS AND DISCUSSION

3.1 Standard Load Test

Coefficient of friction (COF) can be defined as ratio between maximal friction force that the surface exerts and the force pushing the object toward the surface. Figure 2 showed the average coefficient of friction during 3600 s duration of experiment, while Figure 3 presented the average COF value of each lubricants.

From Figure 2, all lubricants experienced a drastic increased in COF value during the first 600 s. this indicated that during that time, lubrication film of all lubricants was conquered by boundary lubrication regime. After that, the regime slowly changed to the mixed lubrication regime as COF values slightly decreased with time before achieving steady state starting from 1800 s [19]. COF values decreased with time because of the lubricant started to develop full film condition where the film was thicker than the length of surface asperities [20]. From 1800 s onwards, the lubrication film has been dominated by hydrodynamic regime []. From the graph, it can be found that the lowest COF values was demonstrated by SAE-40 for the entire test, while PKO gave the highest values.

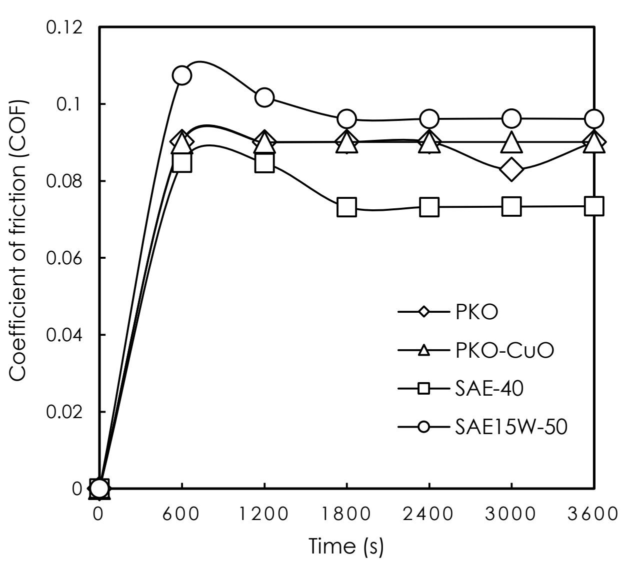


Figure 2 COF of tested lubricants during 1 hour standard load test

Besides that, as can be seen in Figure 3, SAE-40 exhibited the lowest COF value 0.07273, followed by PKO which is 0.7993 and PKO-CuO of 0.0858 respectively. The highest COF values of 0.10948 was obtained when using natural vegetable oil PKO.

A least value of coefficient of friction is demanded in any mechanical system because it will prolong the life span of the mechanical equipment. The results showed that the presence of nanoparticle in the vegetable oil slightly enhanced tribological behaviour of natural palm kernel oil since its friction value was a bit lower than natural palm kernel oil. The surface condition of the ball bearing surface was used to determine wear performance of the tested lubricant. Figure 4 demonstrated the values of wear scar diameter of palm kernel oil, palm kernel oil-copper oxide, mineral oil of Sae 40 and synthetic oil of SAE15W-50.

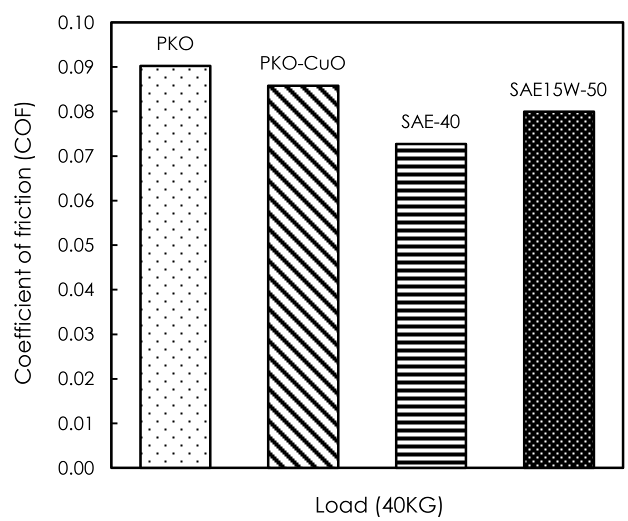


Figure 3 Average COF values of all tested lubricants

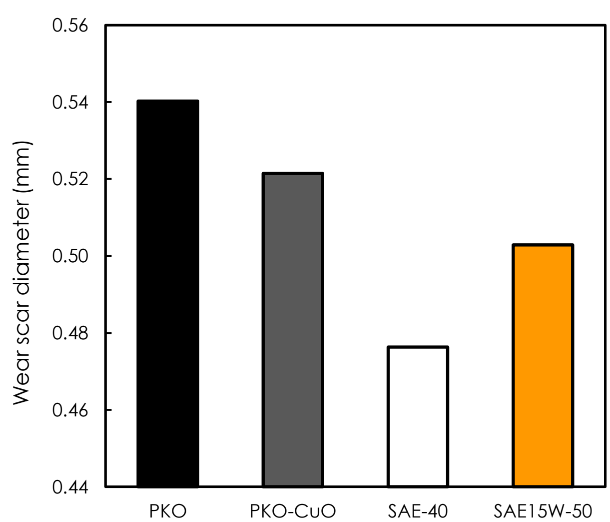


Figure 4 WSD of steel ball for each tested lubricants under standard load test

From the above figure, it was very conspicuous that smallest measurement of wear scar diameter (WSD) belongs to the SAE-40 mineral-based lubricant. It is no doubt that a commercial lubricant performed much better than others and natural palm kernel oil own the highest WSD value. In other word, a metal surface which contact with vegetable oil possesses highest corrosion rate. According to Bowden and Tabor [4], a long chain fatty acid present in chemical structure of vegetable oil attacked the metal surface. Although, this fatty acid is capable to forming a very effective protective film against friction, the film is still vulnerable to protect the surface of ball bearing against wear phenomenon. A chemical reaction between vegetable oil and contact surface induced wear [5]. Sharma *et al.* [6] highlighted that when fatty acids of vegetable oil absorbed or reacted to the contacting surface, a protective film which contains of hydrocarbon is formed. The strength of this film is greatly depending on the strength of intermolecular forces of the fatty acid. If this force cannot stand oxidation or fatty acid is removed from the contacting surface, phenomenon of wear become worse [7-9]. However, the presence of copper oxide nanoparticle in natural palm kernel oil is capable to form a strong protective layer on the contacting surface than that of pure kernel oil. Thus, reducing the wear rate and slightly reduced the WSD value. It was believed that the structure of fatty acid has been interrupted by nanoparticles. Similar observation has been reported before by Zhang *et al.* [10], who claimed that copper oxide nanoparticles can be performed as well as anti-wear additives in protecting the metal surface.

If wear scar diameter of ball bearings larger, it is expected that the surface roughness of the surface also higher. Figure 5 illustrated a measurement of surface roughness for each lubricants. The trend of surface roughness of the lubricants is identical to the wear performance as presented in Figure 4, where PKO > PKO-CuO > SAE15W-50 > SAE 40.

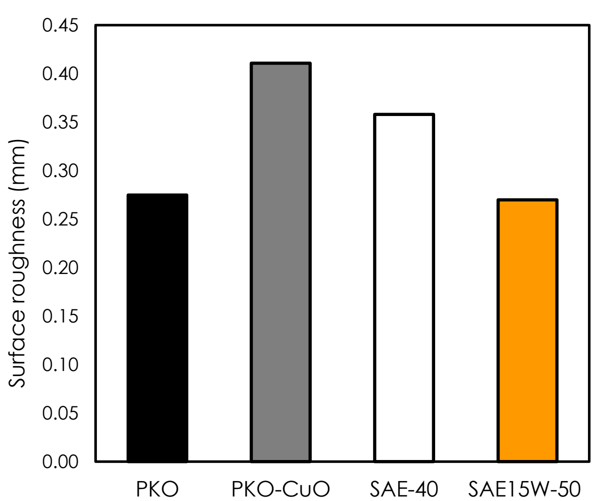


Figure 5 Surface roughness of steel ball of all tested lubricants

In addition, the appearance of wear scar on the surface of balls bearing have been evaluated by using optical microscope at 500 magnification as presented in Figure 6. As elucidate in the figure, all surface morphologies of ball bearings consist of furrow and groove, it can be concluded that only one kind of wear detected, an abrasive wear. It was observed that an occurrence of corrosive dot was very conspicuous when applying PKO in between metal-to-metal surface. The presence of corrosive dot was found to lessen when adding copper oxide nanoparticle into PKO. This indicated that nanoparticles could be used anti-wear additives. As for the commercial mineral oil of SAE-40, morphologies of the wear surface are quite fine and have shallow grooves in comparison with a deeper groove produced by PKO-CuO lubricant.

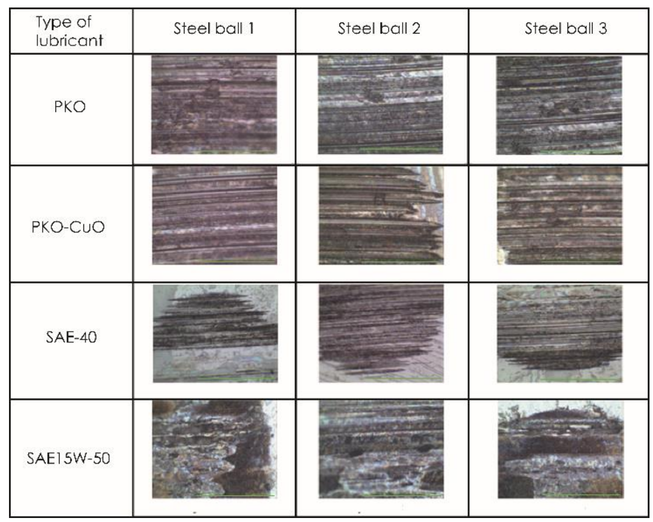


Figure 6 Morphology of steel worn surface using different types of lubricants

3.2 Extreme Pressure Test

The main purpose of conducting extreme pressure test is to investigate whether the tested lubricant can be function effectively or not at a critical condition. Figure 7 exhibited COF of all lubricant at variant load before failure and the COF value increased with increasing load before failure.

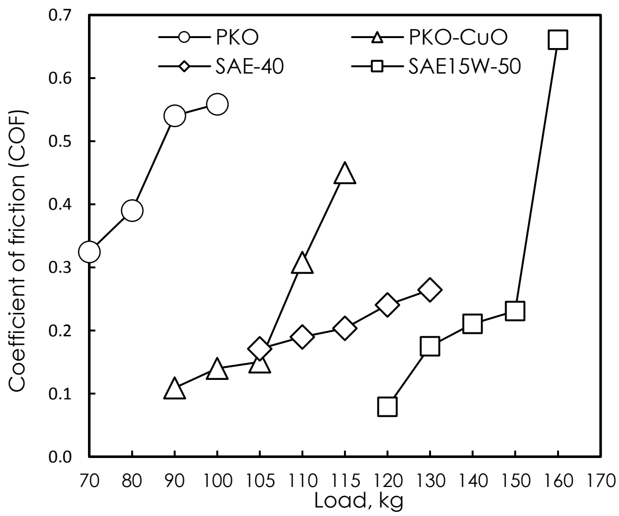


Figure 7 COF of tested lubricants under extreme pressure test

It can be seen that the highest load of 160kg could be sustained by SAE15W-50 while PKO capable to sustain load until 100 kg only. This showed that PKO exhibited poorest lubricity performance compare with others lubricants because of lubrication film created by PKO tend to break faster. Lubricity performance of lubricant is strongly affected by the viscosity value [11, 12]. Even though viscosity of PKO and other lubricants was not so much different at 100 ºC, the oil still not capable to effectively performed when subjected to extreme pressure and temperature condition. However, it was found that the addition copper oxide nanoparticle has improved the capability of natural PKO to sustain more load by 15 kg.

Figure 8 presented the wear scar diameter (WSD) of lubricant before reaching 4mm. from the graph, it was very conspicuous that WSD value augmented linearly with increasing load.

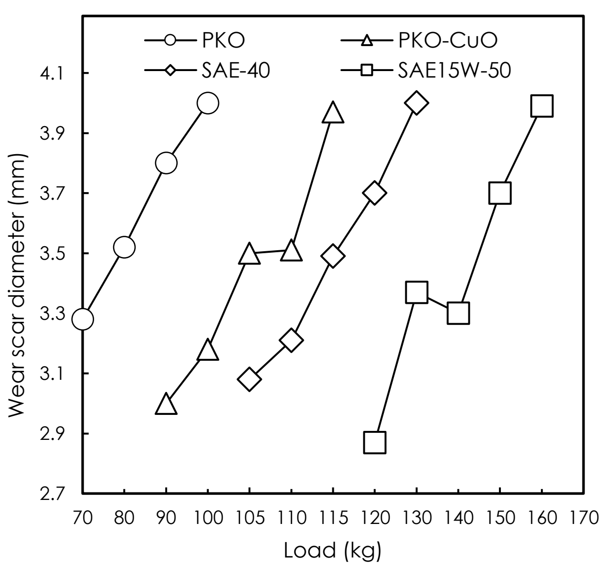


Figure 8 WSD of steel ball for variants lubricants under extreme pressure condition

This result demonstrated that higher load has induced high shear stress at metal-to-metal surfaces, hence transformed the existing mild wear into a severe wear [13-15]. Apart from that, it was found that the solution of PKO-CuO gave the lowest WSD number of 3.51 mm at 110 kg before failure, followed by mineral oil-based lubricant of SAE15W-50 (3.7 mm at 120 kg) and SAE-40 (3.7 mm at 150 kg). While the largest WSD of 3.80 mm was obtained in PKO at 90 kg. This happened because of PKO provided less stiffness of lubrication film which led the metallic soap film to easily rub away and subsequently produces non-reactive detergents that triggered formation of wear [16-18]. The addition of nanoparticles has successfully protected the metal surfaces from getting into contact when subjected to the extreme pressure condition.

Figure 9 illustrated surface roughness (Ra) of all tested lubricants as a function of load. The increment in Ra values with increasing load was similar to trend observed in COF and WSD results. As PKO demonstrated the poorest friction and wear performances, it was expected that the palm oil-based lubricant to have the highest Ra value as observed in the figure below. When the WSD value equal to 4 mm, the least Ra value of 0.513 µm was obtained in SAE15W-50, followed by SAE-40 (0.6 µm) and PKO-CuO (0.678 µm). From the results it can be inferred that the performance of PKO-CuO was comparable with mineral oil-based lubricant of SAE-40, thus has a potential to be used as alternative lubricant in a future.

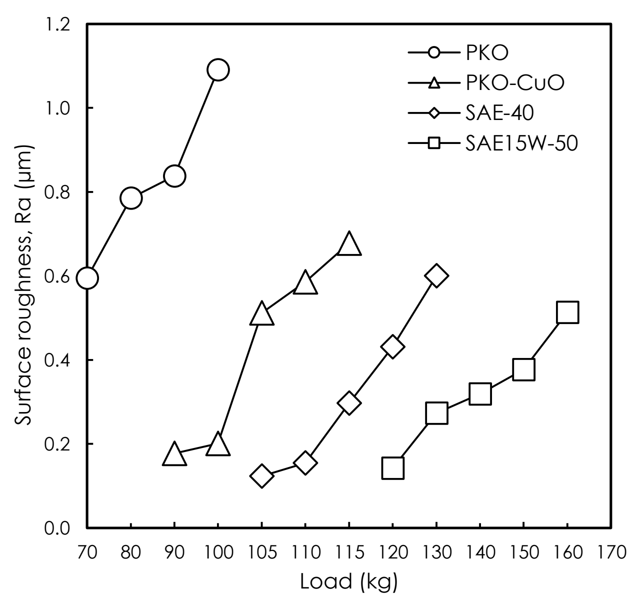


Figure 9 Surface roughness of steel ball using different lubricants under extreme pressure test

4.0 CONCLUSION

In this research, copper oxide nanoparticle was blended with natural palm kernel oil to produce nanolubricant. The tribological performance of PKO-CuO nanolubricant is evaluated by conducting standard test and extreme pressure test. Form the experimental results, it can be concluded that the presence of nanoparticle in palm kernel oil was found to slightly improve the friction behaviour of the natural palm kernel oil under both standard and extreme pressure conditions. However, COF value of nanolubricant was higher than mineral oil and synthetic oil, demonstrated that performance of nanolubricant as friction reduction is not comparable with the commercial lubricant. Besides that, wear scar diameter and surface roughness values of PKO-CuO were slightly lowered than that of PKO only. And this trend of nanolubricant also had been observed in surface morphology analysis. Therefore, it can be inferred that the application of nanoparticle is successfully improved tribological performance of natural palm kernel oil in term of wear and friction reduction, though it did not good as the performance of commercial lubricant.

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