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Modification of RBD Palm Kernel and RBD Palm Stearin Oil with ZDDP Additive Addition

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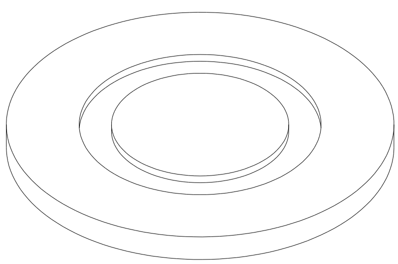
Graphical abstract



Disk with lubricant groove

Abstract

Vegetable oils have gained worldwide concern due to environmental issues since it is biodegradable, renewable and environmental-friendly. However, the limitations of vegetable oils such as having low oxidation stability and poor low temperature properties need to be solved. The purpose of this paper is to evaluate the tribological behavior of refined, bleached and deodorized (RBD) palm kernel and RBD palm stearin by using a modified pin-on-disc tester. The influence of an anti-wear/extreme pressure (AW/EP) additive on the anti-friction and anti-wear characteristics was also evaluated. The experiment was carried out by varying zinc-dialkyl-dithiophosphate (ZDDP) additive concentration of 1wt%, 3wt% and 5wt%; load of 1kg, sliding speed of 2.5 m/s, test duration of 60 minutes and at room temperature. The findings have revealed that without an additive, RBD palm kernel and RBD palm stearin have high friction coefficient and wear as compared with synthetic oils. The addition of additives helps in the improvement of tribological performance of tested vegetable oils. It can be concluded that vegetable oils have a great potential to be used as a petroleum-based substitute.

Keywords: Alternative lubricants, AW/EP additive, ZDDP, pin-on-disc, tribological properties

Abstrak

Minyak sayuran telah mendapat perhatian di seluruh dunia disebabkan oleh isu-isu alam sekitar kerana minyak sayuran boleh diurai, boleh diperbaharui dan mesra alam. Walau bagaimanapun, kelemahan minyak sayuran adalah tahap kestabilan pengoksidaan yang rendah dan sifat suhu rendah perlu diselesaikan. Tujuan kertas ini adalah untuk menilai prestasi tribological daripada ditapis, diluntur dan dinyahbau (RBD) isirong sawit dan RBD stearin sawit dengan menggunakan penguji *pin-on-disc* yang telah diubahsuai. Pengaruh anti-haus/tekanan yang melampau (AW/EP) tambahan kepada ciri-ciri anti-geseran dan anti-memakai juga dinilai. Eksperimen ini dijalankan dengan mengubah kepekatan tambahan zink-dialkyl-dithiophosphate (ZDDP) daripada 1wt%, 3wt% dan 5wt%; beban 1kg, kelajuan 2.5 m/s, tempoh ujian selama 60 minit dan pada suhu bilik. Hasil kajian telah menunjukkan bahawa tanpa bahan tambah, RBD isirong sawit dan stearin sawit RBD mempunyai pekali geseran yang tinggi dan memakai berbanding dengan minyak sintetik. Penambahan bahan tambahan membantu dalam peningkatan prestasi tribological minyak sayuran diuji. Kesimpulannya, minyak sayuran mempunyai potensi yang besar untuk digunakan sebagai pengganti minyak berasaskan petroleum.

Kata kunci: Pelincir alternatif, AW/EP tambahan, ZDDP, *pin-on-disc*, hartanah tribological

1.0 INTRODUCTION

In automotive fields and industries, failures of machinery components or engine parts usually occur due to friction and wear between two mating components. This problem can be solved with the application of lubricants since the main function of lubricants is to reduce friction and wear between two moving surfaces [1]. Since lubricants play a vital role in the industrial world, about 38 million metric tons of lubricants per year have been utilized globally in the last decade, where mostly are petroleum-based [2-3]. Environmental problems have opened up the world into seeking for alternative lubricants and at the same time, fulfill the global demands of lubricants.

Vegetable oils are preferred as a substitute for petroleum-based lubricants due to their environmental-friendly nature, renewability, non-toxicity, biodegradability and economically efficient [4-6]. Vegetable oils have numerous advantages including high lubricity and viscosity, lower volatility, higher shear stability, good contact lubrication, high viscosity index and high flash point [7-8]. Those advantages are generally due to the triglyceride structure of vegetable oils, where it contains up to three hydroxyl groups and long chain unsaturated free fatty acids attached at the hydroxyl group via ester linkages [6]. However, low resistance to oxidative degradation and poor low temperature properties are the limitations of vegetable oils. These limitations are due to the rapid reactions of unsaturated double bonds in the fatty acids and strong intermolecular reactions to form a lubricant film [9-10]. There are a few ways to improve the oxidation stability of the vegetable oil; this includes (i) oil formulation by reducing the level of unsaturated fatty acids [11], (ii) chemical modification of the base oil through epoxidation, hydroxylation and esterification processes [12-13], and (iii) addition of additive packages into the oil [14].

This paper focuses on the addition of additive packages into the lubricants since it will improve lubricant properties and performances such as an improved flow, modified friction and resistance to oxidation hence prolonging useful life. Several types of additives can be used including antioxidants, viscosity modifiers, pour point depressants, detergents and dispersants, antifoam agents, demulsifiers and emulsifiers, dyes, anti-wear/extreme pressure (AW/EP) additives, friction modifiers and corrosion inhibitors [15].

In the present work, the improvement of tribological performance of refined, bleached and deodorized (RBD) palm kernel and RBD palm stearin is evaluated with the addition of an anti-wear/extreme pressure (AW/EP) additive into the tested vegetable oils. Zinc-dialkyl-dithiophosphate (ZDDP) additives will be added into both RBD palm kernel and RBD palm stearin at different concentrations (1wt%, 3wt% and 5wt%).

The tribological behavior of RBD palm kernel and RBD palm stearin will be evaluated by using a modified pin-on-disc tester, in accordance to the ASTM G99 standard. The materials used for both pin and disc are pure aluminium A1100 and tool steel SKD11, respectively. Coefficient of friction and wear scar diameter of the pin are studied to get a better understanding on the lubrication performance.

2.0 METHODOLOGY

2.1 Test Materials

Pure aluminium A1100 hemispherical pin (with density 2.71 g/cm3) and tool steel SKD11 (with density 7.85 g/cm3) grooved disc were used in this study. The surface of the disc needs to be scrubbed by using sandpaper so that the surface finish of the disc is within required specifications (a ground surface roughness of 0.8 μm arithmetic average). Acetone was used to clean and dry the specimens in order to ensure that there were no particles or debris trapped between the pin and disc.

2.2 Test Lubricants

The tested lubricants used in this study are commercial synthetic oil (SAE 15W-50) and two types of vegetable oils i.e. refined, bleached and deodorized (RBD) palm kernel and RBD palm stearin. Some physical properties of the tested lubricants can be found in Table 1. An AW/EP additive ZDDP was added to both RBD palm kernel and RBD palm stearin to improve the tribological performance of the vegetable oils. The additive was added into the vegetable oil with different concentrations (1wt%, 3wt% and 5wt%) at room temperature. For each experiment, 2.5 ml of lubricants was used.

Table 1 Physical properties of the base oils

	Density (g/cm³)	Kinematic viscosity at 50℃ (mm²/s)	Kinematic viscosity at 100℃ (mm²/s)
Synthetic oil (SO)	0.83	64.3	17.4
RBD palm kernel (PK)	0.89	22.0	10.0
RBD palm stearin (PS)	0.88	49.0	18.4

2.3 Test Conditions

Figure 1 shows the modified disc that was used in this work. The function of the groove is to make sure that the lubricant does not flow out during the rotation of the disc. The test conditions applied in this experiment are:

i. Pin – Diameter: 6 mm; Length: 30 mm
   Disc – Width: 10 mm; Depth: 1 mm; Diameter: 160 mm; Wear track diameter: 40 mm
ii. Load: 1 kg
iii. Sliding speed: 1.5 m/s, 2.5 m/s and 3.5 m/s
iv. Temperature: room temperature (25 ± 2℃)
v. Test duration: 60 minutes

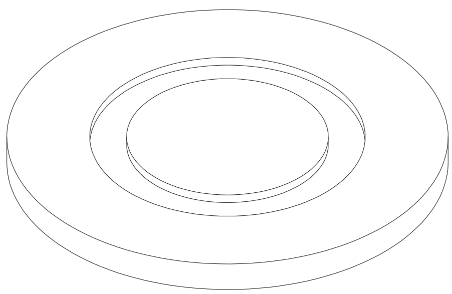


Figure 1 Modified grooved disc

2.4 Friction and Wear Tests

A pin-on-disc machine was used to evaluate the anti-wear and anti-friction properties of the tested lubricants—in accordance to American Standard Testing Material, ASTM G99. The frictional force was measured by a load cell connected to the pin-holding lever arm, so that the coefficient of friction can be obtained by dividing the friction force by the normal force (see Equation 1) [16]. The width of the wear track on the pin was also measured using an optical microscope to get a better understanding of the anti-wear properties of the tested lubricants. The wear scar diameter was reported in unit millimeters.

$$\mu = F_f/F_n \quad (1)$$

where; F_f = frictional force due to two contacting bodies in motion, N
F_n = normal force pressing the same two bodies together, N

2.5 Surface Analysis

The worn surface of the pin was analyzed using optical micrograph. Acetone was used to clean the pin surface before taking the pin image to make sure there is no debris on the surfaces.

3.0 RESULTS AND DISCUSSION

3.1 Friction Tests

Coefficient of friction of RBD palm kernel and RBD palm stearin was measured using a pin-on-disc tester. An aluminium A1100 pin specimen, 6 x 30 mm was tested. To study the antifriction performance with additive concentration, the experiments were conducted by varying the concentrations in the range of 1wt%, 3wt% and 5wt% under a load of 1kg, sliding velocity of 2.5 m/s, test duration of 60 minutes and at room temperature of 25 ± 2℃. Figure 2 plots the friction coefficient over the additive concentrations of RBD palm kernel and RBD palm stearin. Commercial synthetic oil (SO) was used as a reference. SO exhibits good tribological behavior since lubricant manufacturers have focused on adding more additives in the formulation of SO.

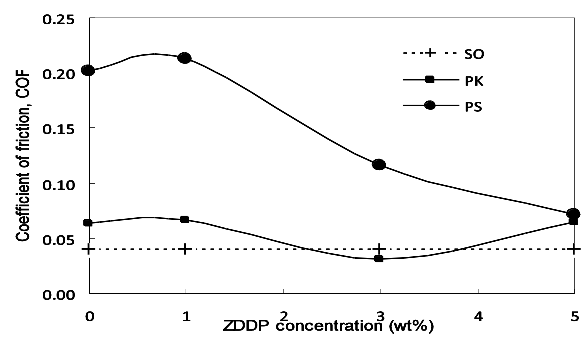


Figure 2 Effect of ZDDP additive concentration on anti-friction performance of RBD palm kernel and RBD palm stearin

Coefficient of friction of RBD palm kernel was found decreasing with increasing additive concentration up to 3wt%. After that, the coefficient of friction increases again. Up to a particular limit (PK + 3wt% ZDDP), the formation of hydrodynamic lubricant film significantly reduced the friction coefficient between two contact surfaces. After the limit, it changed from hydrodynamic to boundary lubricant film due to excess zinc absorption on the contact surfaces that affected the friction coefficient by increasing it [17]. Meanwhile, RBD palm stearin showed slight increase of friction coefficient when the additive concentration was less than 1wt%. However, the friction coefficient reduced significantly with an increase of ZDDP additive concentrations above 1wt% of ZDDP, where the best anti-friction performance was at 5wt%. This might have occurred because of the additive functions effectively such that it reacts with the oxide layer that causes it to form a protective film on the aluminium surface [18].

Figures 3 and 4 show the effect of sliding speed on the anti-friction performance of RBD palm kernel oil at ZDDP concentration of 3wt% and RBD palm stearin at ZDDP concentration of 5wt%. The anti-friction performance was evaluated at sliding speeds of 1.5, 2.5 and 3.5 m/s, constant load of 1 kg, 60 minutes of test duration and room temperature of 25 ± 2℃. Both pure RBD palm kernel and RBD palm stearin exhibited poor anti-friction performance than synthetic oil and the tested modified vegetable oils. For non-additive RBD palm kernel oil, the maximum friction coefficient was 3.5 m/s. Whereas, for non-additive RBD palm stearin, the friction coefficient were unchanged with the increase in sliding speed. This happened because vegetable oils contain long and polar fatty acid chains, which help in the formation of a monolayer film on the sliding surface that prevents direct metal-to-metal contact [19].

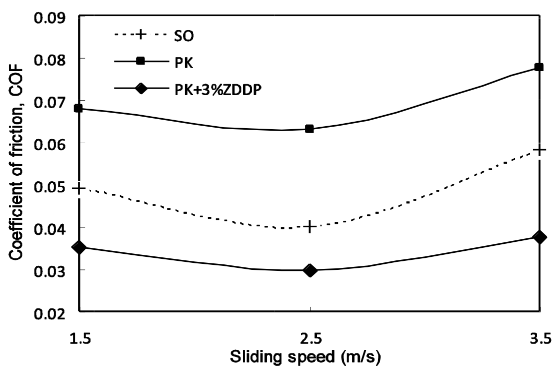


Figure 3 Effect of sliding speed on anti-friction performance of RBD palm kernel oil at ZDDP concentration of 3wt%

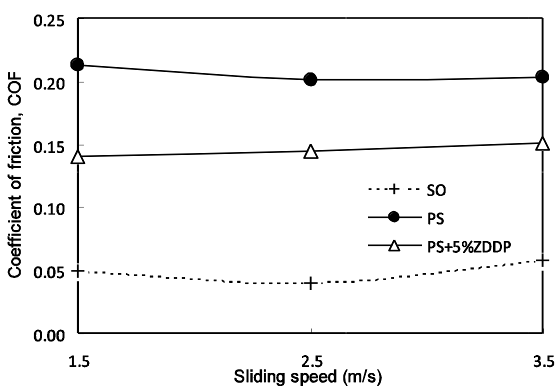


Figure 4 Effect of sliding speed on anti-friction performance of RBD palm stearin oil at ZDDP concentration of 5wt%

The existence of AW/EP additive improved both RBD palm kernel and RBD palm stearin friction performance, where the minimum friction coefficient was at sliding speed of 2.5 m/s. The anti-friction performance was improved because ZDDP additives have the ability to form protective lubricating films at the contact surfaces. This also occurred because the ZDDP additive penetrates through the surface cracks on the pin surface and forms a thin lubricating film that affected the secondary bonds between atomic layers under shear loading, resulting in a reduction of friction coefficient [20]. In addition, RBD palm kernel with ZDDP mixture has the best anti-friction performance as compared to the other tested lubricants.

3.2 Wear Tests

The anti-wear performance with additive concentrations were also investigated with the test conditions of 1kg load, 2.5 m/s sliding speed, 60 minutes test duration, at room temperature and varying additive concentrations of 1wt%, 3wt% and 5wt%. The result is illustrated in Figure 5, which shows the relationship between wear scar diameter against ZDDP additive concentration of RBD palm kernel and RBD palm stearin. Both RBD palm kernel and RBD palm stearin show a similar trend in which the wear rate was highest at 1wt% of ZDDP concentration and then continuously reduced with the increment of additive concentration. This phenomenon occurred because the additive overwhelmed the base oil in the formation of the thin film on the surface contact and hence reduced wear [21].

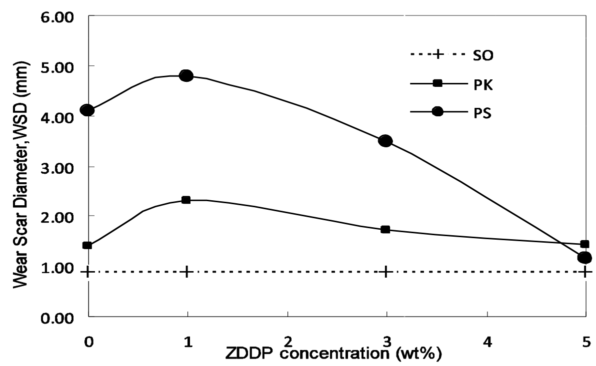
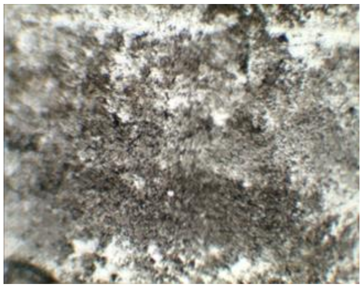


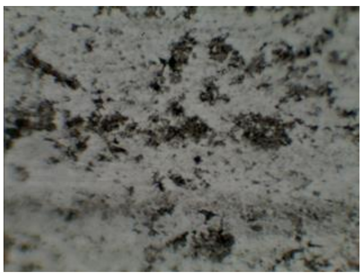
Figure 5 Effect of ZDDP additive concentration on anti-wear performance of RBD palm kernel and RBD palm stearin

3.3 Surface Morphology

Optical micrograph was used to analyze the worn surface of the pin specimens after each test with 500x magnification in order to understand the reaction of additives in both RBD palm kernel and RBD palm stearin oils. Morphological images of the pin surfaces under a sliding speed of 2.5 m/s and normal load of 1 kg are shown in Figure 6. Figure 6 shows that the commercial synthetic oil performs well and produces smooth surfaces compared to the other tested lubricants. Figure 6(b) shows that adhesive wear occurred on the pin surface that was lubricated by RBD palm kernel oil. Adhesive wear are composed of deformed asperities and craters arising from the removal of welded asperities. Meanwhile, abrasive wear occurred on the RBD palm stearin lubricated surfaces; the abrasive wear consists of wear tracks, formed by abrasives as they slide over the surface [22]. It was also found that the wear decreases when AW/EP additive was added into the tested vegetable oils. This means that ZDDP bonds to the lubricated metal surfaces to form a protective layer against wear [23].

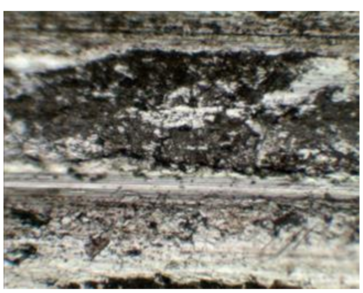


(a) Commercial synthetic oil



(b) RBD palm kernel (PK)

(c) PK + 3wt% of ZDDP



(d) RBD palm stearin (PS)

(e) PS + 5wt% of ZDDP

Figure 6 Worn surfaces of the pin surfaces

4.0 CONCLUSION

The tribological performances of RBD palm kernel and RBD palm stearin have been evaluated using a modified pin-on-disc tester. Commercial synthetic oil (SAE 15W-50) was used as the reference lubricant. The following points emerged from the present investigations:

1. Commercial synthetic oil exhibits good lubrication properties when compared with non-additive RBD palm kernel and RBD palm stearin.
2. The existence of AW/EP additive (ZDDP) in the RBD palm kernel and RBD palm stearin has improved both anti-friction and anti-wear characteristics.
3. The analysis of the worn surfaces by optical micrograph shows that the wear protection of the pin surface has been improved when both RBD palm kernel and RBD palm stearin were mixed with ZDDP additive.
4. Vegetable oils have the potential to be used as a substitution for petroleum-based oil.

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