Effect of garlic oil as lubricant additive into coconut and palm oils on the physical and tribological properties

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Abstract. Palm and coconut oils have been used as an alternative source of biolubricant that is environment-friendly and biodegradable lubrication to replace petroleum oil. Due to the lack of physical and tribological properties of biolubricant, the addition of environmentally friendly additive can increase their lubricant properties. Effect of addition of garlic oil as an additive in coconut and palm oils on the physical and tribological properties was investigated and discussed. Oil treatment (OT) was used as a comparison which is known as conventional additive contained ZDDP. The results obtained from physical tribological test showed that the addition of garlic oil into coconut and palm oils had changed physical properties of these oils. Pin on disc test and ball bearing wear apparatus were conducted to study tribological properties of lubricant additives into coconut and palm oils. The addition with 5 wt % of garlic oil into palm oil showed significant improvement in both wear and coefficient of friction. The lubricant was worked very well on mixed lubrication regime stated by the smooth surface texture of inner race of bearings. Even though the results were not as good as OT; garlic oil could be an alternative as an environment-friendly additive.

1. Introduction

The concept of green tribology has been defined as the science and technology of the tribology aspects of ecological balance and environmental and biological impacts [1]. This includes lubrication technology that is expected to be environment-friendly by using biolubricant. The sources of biolubricants are come from vegetable oils and animals. These oils have been used in the past as a source of lubricants. Nowadays, biolubricant from the vegetable oils has been investigated several researchers as a good source of biolubricant due to fatty acid contained [2]. Vegetable oils are tri-esters of straight-chained, mostly unsaturated fatty acids with glycerol and have high levels of biodegradability and low toxicity. Also, vegetable oils have some advantages such as very low volatility, good high lubricity, and high viscosity energy, as well as lower cost than synthetic oils [2,3,4]. So, vegetable oils as bio-based lubricant are demanded green industrial activity [5].

In tropical countries such as Indonesia, coconut and palm oils as a major corp product can be used as a source of biolubricants. Palm and coconut oils are vegetable oil, which could fulfill the demand for vegetable-based lubricant in the future. These oils have excellent lubricating properties and can act
as anti-wear additives and friction modifiers due to strong interactions with the lubricating surface [6]. For these reasons, biolubricants can be used in various industrial and maintenance applications. Some applications are as follows: industrial oils, automotive oils, and special oils such as process oils and instrumental oils [7].

Research of the coconut and palm oils as biolubricants have been investigated by some investigators [8,9,10]. Some research of these oils as biolubricant have been applied not only in the ball bearings [9] but also in the engines [10]. The results show that these oils have some drawbacks. To increase the performance of these oils, the additives are required. Additives are widely used to impart specific properties to the based lubricant. The amount of additives used varies from a few hundredths of a percent to 30 %. The introduction of environmentally friendly additives can alter the properties required in the lubricant application. The four-ball test was performed by Weimin et al., 2014 [11] to investigate the effect of addition natural garlic oil (NGO) into base fluids. The incorporation of 1 wt % NGO into the base fluids improved the weld point of the base fluids [11] significantly. In this paper, to increase of physical and tribological properties of coconut and palm oils, garlic oil was added 5 wt % into coconut and palm oils. As a comparison, oil treatment (OT) was used as conventional additive contained zink dialkyldithiophosphates (ZZDP) its potential as effective anti-wear (AW) [12].

2. Methodology

2.1. Lubricant and material
Vegetable oils used in this study were coconut and palm oils. The coconut oil was extracted from dry processing. Both oils were purchased directly from the local market around the city of Padang. Garlic oil was supplied by CV. Griya Annur, Jakarta and OT was supplied by STP product Company, USA. OT is a commercial product for oil treatment for engine contained ZZDP. Garlic oil and OT were introduced into coconut and palm oils as additives. In this study, the effect of addition with 5 wt % of garlic oil was investigated. The additives were mixed by coconut and palm oils using hot plate stirrer at temperature 50°C for 20 minutes with stirrer speed, 600 rpm.

2.2. Physical properties test
Analysis of physical properties of coconut and palm oils consists of viscosity, viscosity index, density, flash point, and pour point. The viscosity of the oil sample was determined at temperatures of 40°C and 100°C. The viscosities at 40°C and 100°C have been measured according to ASTM D445-14 using Capillary Viscometer 200-629A and Capillary Viscometer 100-S2X, respectively. The viscosity index (VI) was calculated from kinematic viscosity data following the ASTM D2270-04 procedure. The density of the oil sample was measured by density meter at 15°C according to ASTM D4052-11. Flashpoint and pour point were measured according to ASTM D92-12.

2.3. Pin on disc test
Pin on disc test is used to investigate tribological properties (wear and coefficient of friction) of biolubricants. The pins were 5 mm in diameter, and the discs were 100 mm in diameter and 0.4 mm thick. The flat faces of the disc were ground to a surface finish of about 0.946 Ra. The surface hardness of the pin was about 660.5 BHN and that of the discs about 202 BHN. The disc was prepared from AISI 1018, and stainless steel 440C used to prepare the pin. Table 1 shows the chemical composition of pin and disc. The same size and shape of discs were used to present uniformity in measurements. Before the conduct of the test, it was ensured that the surfaces of the specimens are cleaned properly with alcohol to free the surfaces from dirt and debris. During testing, the disc was rotated at 1200 rpm with load 30 N.
### Table 1. Chemical compositions of disc and pin materials

| Remarks | Fe (%) | C (%)  | Si (%) | Mn (%) | Cr (%) |
|---------|--------|--------|--------|--------|--------|
| Disc   | 99.5   | 0.0995 | 0.0028 | 0.311  | 0.0062 |
| Pin    | 95.05  | 3.7    | 0.24   | -      | 1.63   |

2.4. **Ball bearing wear apparatus test**  
To investigate wear on ball bearings, the ball bearing wear apparatus test was used. A self-aligning ball bearing with 62 mm outer diameter and 30 mm inner diameter was used in this study. It was mounted on the ball bearing wear apparatus. This apparatus consists of a rotating shaft of 30 mm in diameter, supported by two deep-groove ball bearings and a self-aligning ball bearing. As shown in figure 1, the two deep-groove ball bearings were fitted to at the ends of the shaft and fixed into rigid housings. A radial load, 300N, was applied on the self-aligning ball bearing. The shaft was rotated by a 1.5 kW electric motor. The tests were conducted for 6 hours at 2840 rpm and 34 hours at 500 rpm which are equal to one million rotations of the ball bearings. Biolubricant oils were injected onto the self-aligning ball bearing by using a pump to circulate the oil. The wear occurred on the inner race, outer race, and ball bearings were examined using an optical microscope.

![Figure 1. Photo (a) and schematic diagram (b) of ball bearing wear apparatus test](image)

3. **Results and Discussion**

3.1. **Physical properties**  
Tables 2 and 3 show the results of measuring the physical properties added with 5 wt % of garlic oil and OT into coconut and palm oils. Physical properties measured were viscosity index, flash point, pour point, density, and the viscosity at 40°C and 100°C. The viscosity and viscosity index of coconut oil added with 5 wt % of garlic oil and OT were increased, while their density and flash point was decreased. Moreover, the viscosity and viscosity index of palm oil added OT were increased. However the addition garlic oil was decreased the viscosity and viscosity index. This is due to the viscosity of garlic oil is lower than that of the palm oil. Flashpoint increased after introducing garlic oil and OT in both oils. Whereas pour point decreased in coconut oil after adding garlic oil, but in palm oil, it was
increased. The addition of garlic oil and OT into coconut and palm oils could change the physical properties of biolubricants.

Table 2. Comparison of physical properties between pure palm oil and 5 wt % of additives

| Remarks             | Pure Palm oil [9] | 5 wt % OT | 5 wt % Garlic oil |
|---------------------|-------------------|-----------|-------------------|
| Viscosity 40ºc, (cSt) | 40.01             | 40.83     | 39.35             |
| Viscosity 100ºc, (cSt) | 8.931             | 9.478     | 8.319             |
| Viscosity Index     | 213.13            | 226.672   | 194.468           |
| Density 15ºc, Kg/L  | 0.9154            | 0.912     | 0.9156            |
| Flash Point, ºc     | 305.5             | 310       | 330               |
| Pour Point, ºc      | +6                | +6        | +9                |

Table 3. Comparison of physical properties between pure coconut oil and 5 wt % of additives

| Remarks             | Pure Coconut oil [9] | 5 wt % OT | 5 wt % Garlic oil |
|---------------------|----------------------|-----------|-------------------|
| Viscosity 40ºc, (cSt) | 26.58               | 27.49     | 27.18             |
| Viscosity 100ºc, (cSt) | 5.76               | 6.078     | 5.903             |
| Viscosity Index     | 167.59              | 178.33    | 170.68            |
| Density 15ºc, Kg/L  | 0.9256              | 0.9221    | 0.9254            |
| Flash Point, ºc     | 303.5               | 294       | 306               |
| Pour Point, ºc      | +21                 | +21       | +12               |

Figure 2. Wear mass of the disc lubricated by coconut and palm oils added with 5 wt % of garlic oil and OT

3.2. Tribological properties of the pin on disc test
The investigation of the tribological behavior of coconut and palm oils added with 5 wt % of garlic oil and OT was completely obtained using a pin on disc test. The operating condition was 1200 rpm and 30 N of speed and load, respectively. The abrasive wear on the discs has been investigated at different additives into coconut and palm oils. Wear mass of the disc lubricated by coconut and palm oils added
with garlic oil and OT is shown in figure 2. It is revealed that wear mass of the disc lubricated by coconut and palm oils added with OT was lower than that of the pure coconut and palm oils. Whereas, the wear mass of the discs lubricated by palm oil added with garlic oil was lower than that of the pure coconut oil. However, wear mass of the discs lubricated by coconut oil added with garlic oil was higher than that of the pure coconut oil. The additive in OT contained zinc dialkyl dithiophosphates (ZDDP) serves as the antiwear [4,10].

![Figure 3. Wear scar widths of the disc lubricated by coconut and palm oils added with 5 wt % of garlic oil and OT at 1200 rpm with load 30 N](image_url)

Figures 3 and 4 show wear scar widths of the disc and pin lubricated by coconut and palm oils added garlic oil and OT. Figure 3 reveals that there was no difference between wear scar width of the disc lubricated by both oils with the addition of garlic oil and OT, except those lubricated with palm oil added OT. The test of the coefficient of friction for both oils was measured after a running-in period (30 minutes after wear test) and conducted on dynamic condition. Figures 5 and 6 show the comparison of the coefficient of friction of coconut and palm oils added garlic oil and OT with 30 N loads. The coefficient of friction of both oils by adding garlic oil and OT was lower than that of both pure oils. The addition of additives into palm oils was better than that of coconut oil. Effect of garlic oil and OT in coconut and palm oils could decrease the coefficient of friction. Garlic oil as an additive has the ability to generate tribofilms composed with iron oxides, iron sulfates, and iron sulfide, so it provided superior load-carrying ability [11].
Figure 4. Wear scar widths of the pin lubricated by coconut and palm oils added with 5 wt % of garlic oil and OT at 1200 rpm with load 30 N

Figure 5. CoF of coconut oil added with 5 wt % of garlic oil and OT at 1200 rpm with load 30 N
3.3. Surface wear form of an inner and outer race of bearings

The ball bearing wear apparatus was used to observe the form of wear that appeared on the bearing under load, 300 N, with different rotations (at 500 and 2840 rpm). The tests were conducted for 6 hours at 2840 rpm and 34 hours at 500 rpm or equal to one million rotations of ball bearings. The wear on the bearing was investigated on the inner and outer race. A stereo optical microscope was used to examine the wear on the inner and outer race. During testing, the inner and outer race was in contact with the spinning steel ball, so that the path pattern appeared along the inner and outer race surface due to loading as shown in figure 7. The path pattern of the inner race surface was uniform in width positioned in the center and extended around the entire circumference of the raceway because the inner ring was rotating and the outer ring was fixed. Whereas the path pattern of the outer race was widest in the load direction and tapered off towards the ends, with normal fits and normal internal clearance, the pattern extends around slightly less than half the circumference of the raceway. The wear form of the outer race was rougher compared to the inner race because the outer race was a standstill.

Figure 6. CoF of palm oil added with 5 wt % of garlic oil and OT at 1200 rpm with load 30 N

Figure 7. Wear area of (a) inner and (b) outer race
| Remarks  | Bearing rotation at 2840 rpm | Bearing rotation at 500 rpm |
|---------|------------------------------|----------------------------|
|         | Coconut-based oil | Palm-based oil | Coconut-based oil | Palm-based oil |
| Pure oil | ![Image](image1) | ![Image](image2) | ![Image](image3) | ![Image](image4) |
| Garlic oil | ![Image](image5) | ![Image](image6) | ![Image](image7) | ![Image](image8) |
| OT | ![Image](image9) | ![Image](image10) | ![Image](image11) | ![Image](image12) |

**Figure 8.** Surface textures of the inner race between coconut and palm-based oils at 500 and 2840 rpm with load 300 N

| Remarks  | Bearing rotation at 2840 rpm | Bearing rotation at 500 rpm |
|---------|------------------------------|----------------------------|
|         | Coconut-based oil | Palm-based oil | Coconut-based oil | Palm-based oil |
| Pure oil | ![Image](image13) | ![Image](image14) | ![Image](image15) | ![Image](image16) |
| Garlic oil | ![Image](image17) | ![Image](image18) | ![Image](image19) | ![Image](image20) |
| OT | ![Image](image21) | ![Image](image22) | ![Image](image23) | ![Image](image24) |

**Figure 9.** Surface textures of the outer race between coconut and palm-based oils at 500 and 2840 rpm with load 300 N

To investigate the effect of rotation speeds on wear surface of inner and outer race, tests were conducted at two speeds (2840 and 500 rpm). Based on the Striebeck curve, the value of the coefficient
of friction is changed from boundary lubrication to elastohydrodynamic lubrication as the rotation speed of bearing increases. Gasmi and Rahmat [13] modeled a Stribeck curve by approaching mixed lubrication model on ball bearings. The results show that the speed of bearing at 500 rpm occurred at mixed lubrication regime and the speed at 2840 rpm was elastohydrodynamic lubrication regime — figures 8 and 9 show comparison of surface textures of the inner and outer race between coconut and palm-based oils at 2840 and 500 rpm after introducing garlic oil and OT as additives. The wear mechanism occurred in contact between the ball, and the inner and outer race was abrasive wear marked with path pattern on the surface of the inner and outer race.

The surface textures of the inner race after introducing of garlic oil into based oils at 2840 and 500 rpm are shown in figures 8c and 8d. By the addition of garlic oil, the flakes occurred on the surface textures of the inner race could be reduced compared to those of based oils (figures 8a and 8b). The qualities of surface textures when were introduced OT were smoother than the addition of garlic oil. At 500 rpm, the smoothest of surface textures of the inner race after introduce of OT was palm oil. The flakes were not found on the inner race surface (figures 8e and 8f). The surface textures lubricated these oils at 2840 rpm were tend to rougher than at low speed. The flakes were found on the surface textures even if based oils were added by garlic oil and OT.

The same case with the surface textures of outer race (figure 9), the based oils added with garlic oil and OT were better surface textures than those of based oil. Surface textures of the palm oils added with additives were smoother than those of based oil, especially at 500 rpm. In contrast with the inner race after introducing of additives, the surface textures of the outer race were rougher than the inner race due to radial load where the bottom of the outer race is a standstill.

The addition of garlic oil and OT as additives in the coconut and palm oil could be reduced scratch and flakes on the surface of the inner and outer race. The OT is contained ZDDP which is effective as anti-wear (AW) and extreme pressure additive [14, 15]. Even though garlic oil was not as effective as OT in reducing scratch and flakes on the surfaces of the inner and outer race; the garlic oil could be used as extreme pressure (EP) additive [11]. The EP additive would form layer through tribochemical reactions. It was shown that at a speed of bearings 500 rpm or mixed lubrication regime, the additives worked very well compared to at a speed of bearings 2840 rpm or elastohydrodynamic lubrication regime.

3.4. Effect of scar width of the inner and the outer race of bearings at 2840 and 500 rpm

The average of scar widths on the inner surface was performed because the wear in the circumference of the inner race was not uniform. Whereas, On the outer race, the scar widths were measured on the bottom of the bearings, because the wider scar width occurred on the bottom. Figures 10 and 11 show the comparison of scar widths of the inner and the outer race of bearing with different speeds and biolubricants. The scar width of the inner race was larger than that of the outer race. It was caused that the outer race was fixed, whereas the inner race was flexible. On the inner race (figure 10), scar width at low speed (500 rpm) was lower than that of at high speed (2840 rpm) for both oils added additives. The garlic oil as an additive in coconut oil gave the lowest scar width for both speeds. In the outer race, the scar width at high speed with the addition of garlic oil into coconut oil was lower than that of low speed, in contrast with the addition of garlic oil into palm oil at low speed was lower than that of high speed.

The surface textures and scar widths occurred on the surface of the inner and outer race which were lubricated by biolubricants were not match. There was no linear correlation between smooth surface texture and small scar width. Even though the addition of garlic oil into palm oil on the surface of the
inner race gave a good quality of surface texture at bearing speed 500 rpm; the scar width was bigger than that of coconut oil.

**Figure 10.** Comparison between wear scar widths of the inner race at 2840 rpm and 500 rpm

**Figure 11.** Comparison between wear scar widths of the outer race at 2840 rpm and 500 rpm

4. Conclusions
The measurement of physical properties has been done on coconut and palm oils by adding with 5 wt % of garlic oil and OT as additives. The tests were conducted to measure viscosity, density, flash point and pour point. The results show that the addition of garlic oil and OT as additives in coconut and
palm oil could change physical properties of pure coconut and palm oils. By adding 5 wt % of garlic oil, the viscosity increased on coconut oil but decreased on palm oil. On the other hand, the pour point increased on palm oil and decreased on coconut oil. The flash point increased for both coconut and palm oils. The tribological test was performed by using a pin on the disc to measure wear and coefficient of friction. The wear was investigated by measuring the mass of wear and scar width. The addition with 5 wt % of garlic oil and OT into coconut and palm oils would increase the tribological properties of palm and coconut oils. In term of the coefficient of friction, the addition garlic oil and OT into palm oil was better than that of coconut oil. From the ball bearing wear apparatus test, ball bearings worked very well at mixed lubrication regime (500 rpm) when they were lubricated by adding garlic oil as an additive into coconut and palm oils. It was shown that the surface textures of the inner and outer race of bearings were smooth. Even though tribological properties of addition garlic into coconut and palm oil were not as good as addition OT into both oils, the addition of garlic oil into palm and coconut oils could be an alternative to replace OT as an environment-friendly additive in the future.

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