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Friction Characteristic of Mineral Oil Containing Palm Fatty Acid Distillate using Four Ball Tribo-tester

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Abstract

Vegetable oil was one of the main sources of lubricating oil before the discovery of petroleum. Nowadays, due to vegetable oil's poor performance at high temperatures and oxidation, it has not been widely used in the industrial sector. However, the fatty acids contained in vegetable oils may significantly reduce the frictional coefficient. To optimize lubrication, vegetable oil can be mixed with mineral oil. In this paper, palm fatty acid distillate (PFAD) was mixed in mineral oil and it lubricating properties were tested. Palm oil is one of the major vegetable oils produced in the world, and PFAD is one of the by-products of the palm oil refinery process. It is classified as a non-edible oil, and therefore, the increased use of this product for mechanical lubrication would not affect the production of cooking oil, the food chain or increase food prices. The mixing percentage (PFAD to mineral oil) varies from 5% to 25% of the total mass. Testing was conducted using a four-ball tribotester accordance with the American Society for Testing and Materials (ASTM) standard 4172. The results show that by mixing a 20 % total mass of palm oil in the mineral oil, the coefficient of friction reached its lowest value. The wear scars on the ball bearings lubricated with this mix of oil also showed acceptable diameter values when compared to other conditions. From these results, it can be concluded that the performance of the mineral oil could be enhanced by mixing it with vegetable oil (instead of mineral oil). However, the percentages should be determined properly.

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Keywords: Palm oil, mineral oil, friction coefficient, wear scar diameter.

Nomenclature

μ	coefficient of friction
T	friction torque (kg.mm)
W	applied load (kg)
r	distance from the center of the contact surface on lower ball bearing to the axis of the rotation (mm)

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1. Introduction

Nowadays, the demand for mineral lubricants in industry is growing faster each year. In addition, the oil price has become expensive. Therefore, a modification of mineral oil by adding a non-edible of vegetable oil can minimize the use of mineral oil as a lubricant.

It is well known that vegetable oil is a potentially good lubricant due to several factors. One reason is that vegetable oil has a high viscosity index, high lubricity, low vitality, low toxicity and high biodegradability. Therefore, the modification of existing mineral oil by adding vegetable oil can increase the performance of both lubricants in terms of the coefficient of friction and wear performance.

The use of vegetable oil as a lubricant is not a new idea in industries such as the food industry, and this type of industry must make sure that their products are uncontaminated by the dangerous chemicals that exist in the base oil. Because of this, there are already vegetable oil products available, and global environmental awareness encourages researchers to produce these environmentally friendly lubricants [1]. Due to its environmental benefits, the use of vegetable oil as an alternative in industry is quite desirable. Vegetable oil is a renewable resource, and most vegetable oil has contains methyl ester, monoglycerides, diglycerides, free fatty acids, and triglycerides that can improve its lubricating properties.

From the research that has been done by Jianbo et al. [2], methyl esters and monoglycerides are the main components that determine the lubricity of biodiesel and meet the international standards. Free fatty acids and diglycerides also affect the lubricity of biodiesel, but not as much as monoglycerides. Additionally, the triglyceride structure of vegetable oils provides qualities that are important in lubrication since long polar fatty acid chains provide high strength lubricant films that interact strongly with metallic surfaces. As a result, this film can reduce the friction and wear. The strong intermolecular structure in the vegetable oil is able to withstand changes in temperature, enough to make sure it maintains a stable viscosity [3, 4].

Vegetable oil also has a high degree of biodegradability and nontoxicity. Biodegradability and nontoxicity are the major issues when oil comes in contact with soil, crops and water [5]. Vegetable oil also has a lot of technical advantages over fossil fuels, such as lower overall exhaust emissions and toxicity, negligible sulphur content and a superior flash point. In terms of economics, vegetable oil is more cost-effective when compared with mineral oil, however, the drawbacks of vegetable oils include poor oxidation, hydrolytic stability and low temperature properties.

Researchers work tirelessly to develop a vegetable-based oil lubricant, and due to different climatic conditions, many countries have been looking for various types of vegetable oils that could possibly be used in lubricant production. In Malaysia, palm oil is the focus of development as an industrial oil. Palm oil is unique in that it can be refined into many different types of oil. Refined, bleached and deodorized (RBD) palm olein is the most important product of palm oil and is used as a cooking oil. Other by-products that are often used in the development of vegetable-based industrial oils are palm fatty acid distillate (PFAD), palm stearin and palm kernel oil. Other than these, typical vegetable oils that have the potential to create lubricants are jatropha and coconut oil.

For this paper, PFAD was mixed into commercial metal forming oil, and tests were conducted using a Fourball Tribotester, following the ASTM standard D4172. Similar experiments were conducted using pure PFAD and commercial metal forming oil as benchmarks. The analyses were focused on the coefficient of friction and wear scar diameter, and the results showed that a mixture of 20% (mass) of palm fatty acid distillate into commercial metal forming oil could reduce the coefficient of friction. However, the wear scars on the ball bearings that were lubricated by these mixtures were slightly increased when compared to those lubricated by pure commercial metal forming oil.

2. Material and method

2.1. Test Standard

Tests were conducted using the Fourball Tribotester and conformed with the ASTM standard D4172. This standard of procedure was used to determine the properties of the lubricant at the standard temperature, speed and load. The results that can be gained from this type of test are the coefficient of friction, wear scar diameter and type of wear that occurs on the bearings by using a specified type of oil. In general, three 12.7 mm diameter steel balls were clamped together and covered with the lubricant to be evaluated. A fourth steel ball, referred to as the top ball, was pressed with a force of 392 N [40 kgf] into the cavity formed by the three clamped balls for a three-point contact. The temperature of the test lubricant was regulated at 75 °C and then the top ball was rotated at 1200 rpm for 60 min. The lubricants were compared by using the average size of the scar diameters worn on the three lower clamped balls. The details for the Fourball Tribotester and ASTM standard 4172 can be found in previous publications [6].

2.2. Test lubricants

In this paper, palm fatty acid distillate (PFAD) was mixed into the commercial metal forming oil (CMFO). Five mixing test lubricant which had PFAD mass percentages of 5%, 10%, 15%, 20% and 25% were prepared. At the same time, pure PFAD and commercial metal forming oil were tested to compare the performances. The test lubricants were labelled from S1 to S7, as shown Table 1.

Table 1. Test lubricants' label and details.

Label	Mass %
S1	CMFO 100%
S2	CMFO 95% + PFAD 5%
S3	CMFO 90% + PFAD 10%
S4	CMFO 85% + PFAD 15%
S5	CMFO 80% + PFAD 20%
S6	CMFO 75% + PFAD 25%
S7	PFAD 100%

3. Results and discussion

3.1. Coefficient of friction (COF)

For these experiments, the frictional torque from a fourball tribotester was recorded. From the frictional torque values, the coefficients of friction of the lubricants were determined by using Equation 1.

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

where μ is the coefficient of friction, T is the frictional torque in kg/mm, W the applied load in kg and r the distance from the centre of the contact surface on the lower balls to the axis of rotation, which is 3.67 mm [6]. The value of the coefficient of friction (COF) for all test lubricants is shown in Figure 1.

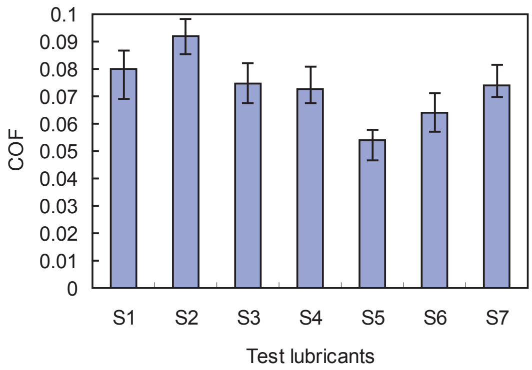

Fig.1. Coefficient of friction at steady state condition for all type of test lubricants.

From the figure, it was found that the highest value of the coefficient of friction was given for the test lubricant S2, which was 5% PFAD in the CMFO. The coefficient of friction value was 0.09. However, the lowest value of the coefficient of friction was for the test lubricant S5 (CMFO 80% + PFAD 20%), which was 0.054. The coefficient of friction of pure PFAD is lower when compared to pure CMFO (which represents mineral oil). The compositional structure of PFAD has a fatty acid structure that acts as a film layer on the surface of the material. The triglyceride structure of the PFAD 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. Strong intermolecular structures in the vegetable oil withstand changes in temperature, enough to assure its more stable viscosity [7,8].

3.2. Wear scar diameter (WSD)

In Figure 2, the wear scar diameter is shown as increasing when the percentage of palm fatty acid distillate (PFAD) increases in the commercial metal forming oil (CMFO). The smallest wear scar diameter was found on the ball bearing lubricated with S1 (539.13 microns), however, the largest wear scar diameter was found on those ball bearings lubricated with S7, which was pure PFAD (895.26 microns). In this paper, there are no correlation between the coefficient of friction and wear scar diameter. The wear scar diameter was a reflection of the oxidation rate that occurred during the experiment. As can be seen in Figure 2, the wear scar diameter for 100% palm fatty acid distillate (S7) was the largest. This is because the palm fatty acid distillate had 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.

For the ball bearings lubricated with 100% commercial metal forming oil (S1), the wear scar diameter was the smallest. With the mineral oil, there was no oxygen element that could trigger oxidation, however, the commercial metal forming oil used in this experiment was mixed with anti-wear additives. As the percentage of palm fatty acid distillate increased in the commercial metal forming oil, the wear scar diameter increased, due to the increment of oxygen in the test lubricant.

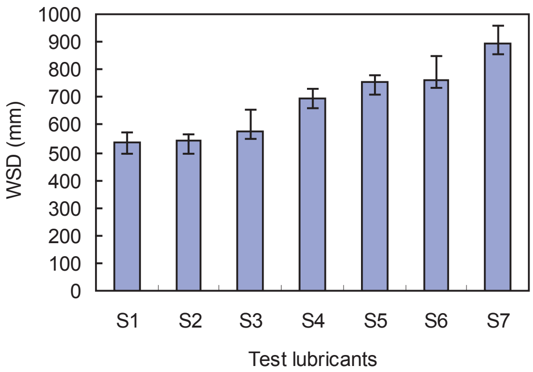

Fig.2. Wear scar diameter on ball bearing lubricated with test lubricants.

4. Conclusion

In conclusion, by mixing palm fatty acid distillate (PFAD) into commercial metal forming oil (CMFO), the coefficient of friction has been decreased from 0.08 to 0.054 (20% PFAD). This shows that the PFAD has the potential of acting as a performance enhancer (additive) in the lubricant. However, from the results of the wear scar diameter tests, the addition of palm fatty acid distillate into commercial metal forming oil increases the diameter of the wear scar when compared to pure CMFO. These consequences can be overcome by using anti-wear additives in future tests.

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