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EXPERIMENTAL INVESTIGATION OF THE NEAT RUBBER SEED OIL AS A HYDRAULIC FLUID USING FOUR-BALL TRIBOTESTER

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Abstract

Malaysia, Indonesia and other South East Asia countries are known to be the producers of natural rubber that involves huge rubber plantation. Rubber latex is the main product from the cultivation of rubber plantation exists in the market for the manufacturing of rubber products. Besides the rubber products, an investigation was done on the seeds of the rubber trees for the purposes of bio- hydraulic. Oil from the rubber seeds were extracted using Soxhlet extractor. The oil extraction rate and the solid to the solvent ratio for the extraction process were obtained. The four-ball tribotester was used for the determination of lubricant properties for the neat rubber oil. In this paper, the characteristics of the rubber seeds oil as a neat bio-hydraulic was investigated and compared with the results of the mineral hydraulic under different normal loads. All investigational tests were identical to the American Society for Testing and Materials D4172-B. The outcomes demonstrated that the rubber seeds oil has a lower value of friction coefficient under different loads, lower wear scar diameter and high value of flash temperature parameter under low loads compared to commercial hydraulic oil. As a conclusion, the wear scar observation showed that the rubber seeds oil was capable to reduce wear at low loads but the wear condition becomes worse when the load increased, and the rubber seeds oil has high ability to work as a hydraulic fluid.

Keywords: Applied normal load, Coefficient of friction, Hydraulic fluid, Rubber seeds oil, Wear scar diameter.

1. Introduction

Bio-hydraulic fluid or the bio-based lubricants are oils that extracted from a set of edible or non-edible tree oils like, rapeseed, rubber seeds, sunflower, palm, coconut, jatropha and jojoba oil. Because of some poisonous components in most of the non-edible oils like the rubber seeds oil, these oils are not appropriate for the human uses. The usage of bio- hydraulic fluid or lubricants from non-edible oils can overcome the problems of food verse fuels, hydraulic fluid or lubricants, environmental and economic issues related to edible vegetable. For many years, Malaysia is known as one of the producers of natural rubber that involves large cultivation of rubber plantation. Besides producing many types of rubber products such as tyres, sandals, gloves and others, its rubber seeds oil could be used to turn into useful products [1]. In the last years, the hydraulic fluid especially that produced from the fruits, seeds or shells of the vegetable and plants are becoming a very important and suitable alternative source to the petroleum oils. However, using the non-edible oils as a bio-hydraulic fluid requires extensive characterisation works [2].

The usefulness of choosing the plant fluids compared to the lubricants or hydraulic fluid that extracted from the other sources are the fact that these fluids are natural, renewable, biodegradable and are non-toxic when compared to mineral-based oil. Also, they are simple to produce.

Hassan and Syahrullail [3] evaluated the characteristics of the behaviour for the two moving metals lubricated with vegetable oil and compared with the characteristics for the moving metals when used the mineral oil, the results showed that the biodegradable vegetable oils have a better anti-friction ability compared to the petroleum or synthetic fluids, that is because of the high contain of the unsaturated fatty acid and polar ester groups components that have positive affected on the features of the reciprocating sliding. In another study, Golshokouh et al. [4] investigated the chemical attack features, which appear on the surface of the ball that tested by using the four ball-tester because of the fatty acids that present in the vegetable oil, researchers detected that the chemical attack accord, because the thin film of the metallic soap was rubbed away during the sliding motion, and creating the non-reactive cleaners, which increases wear.

In a lot of studies, Bari et al. [5], Jabal et al. [6] and Ahmed et al. [7] have examined several types of plant oil for engineering and industrial applications, these studies included; the plant oils as a renewable biofuel in the internal combustion engines, Nik et al. [8-10] on the plant oils as a fluid work and hydraulic on the tribological features of the neat palm oil as a metal forming oil. In addition, Syahrullail et al. [11, 12], Ing et al. [13], Masjuki and Maleque [14], Hassan et al. [15] and Jabal et al. [16] tested the behaviour features of the neat and blends of vegetable oil with mineral oil and different additives.

Most of the researchers detected that the plant (vegetable) oils presented satisfactory behaviour characteristics, and has a strong ability to become bio-renewable hydraulic fluid or lubricant can be used in several industrial applications. However, some obstacles like the oxidation level of the plant oils at the high temperatures must be resolved. In current work, behaviour characteristics of the rubber seeds oil as a neat bio-hydraulic fluid was investigated (experimentally) under various normal loads (kg), utilizing the four-ball tribotester.

2. Methodology

Raw rubber seeds were collected from rubber plantation and were manually de-hulled to separate the kernels from the shells. After cleaning the rubber seed kernels, it was ground to smaller particles and was placed on a tray. It was dried in the oven at 105 °C for 4 hours. After the drying process, the rubber seed particles were placed in the airtight container for the extraction process.

2.1. Oil extraction apparatus

The extraction of rubber seeds oil from the rubber seed kernel particles was done using Soxhlet extractor. An amount of rubber seed particles was placed into the paper thimble, which was placed in the Soxhlet extractor. N-hexane as the solvent is poured into the round bottom flask.

The Soxhlet extractor was heated to temperatures of 70 °C, which is above the boiling temperature of n-hexane. The vapours of n-hexane evaporate from the round bottom flask and flow into the Soxhlet chamber where it was condensed by the cooling temperature of the condenser. The condensed n-hexane liquid was dropped into rubber seed particles and extracts the rubber seeds oil and flow back into a round bottom flask with the rubber seeds oil.

After the extraction process of rubber seeds oil has been done, the separation of n-hexane from the rubber seeds oil need to be separated. The rotary evaporator was used to separate the n-hexane from the rubber seeds oil. Rubber seed oil contained the following fatty acids as shown in Table 1.

Table 1. Fatty acids types in rubber seeds oil.

Type	Ratio%
Palmitic	0.2%
Stearic	8.7%
Oleic	24.6%
Linoleic	39.6%
Linolenic	16.3%

2.2. Apparatus

A four-ball wear tester (shown in Fig. 1) is an instrument provides several standards of testing the characteristics of the fluids under different testing conditions. The four-ball tester utilizes four new balls made from the chrome alloy steel. Three from the four balls was fixed in the bottom and the last ball placed in the top.

The first three balls, which is fixed in the bottom are caught firmly in a pot, which including 10 ml of the fluid or lubricant, which being experimented, the three balls are pressed against the ball, which is fixed in the top. By utilizing a steel collet, a top single ball is fixed in case ensures able it to rotate in the required standard speed and in the same time, the three bottom bearing balls are pushed against the top ball.

Other necessary parts are attached with the four-ball machine like the loads in (kg) and the oil cup assembly [17-24]. By using acetone, all surfaces for the parts used for completed the experiments must be cleaned before the start of each test.

In current work, behaviour characteristics investigation tests were executed under different normal loads 40, 50, 60, 70 and 80 kg, also the rotational speed of the top ball was specified in 1200 rpm and 75 °C as a temperature of the oil sample. The time for each experiment was set in one hour.

Fig. 1. Photograph of a four-ball tester machine.

2.3. Ball materials

The four balls that employing for each experiment in current work was standardized and manufactured from (AISI E-52100) chrome steel alloy. Balls specifications are shown in Table 2.

Table 2. Balls specifications.

Ball diameter	12.7 mm
Extra polish (EP) grade	25
Hardness (Rockwell C hardness)	64-66 HRC

2.4. Fluids

Two types of fluids were utilized for experiments in this study; the first type was the neat rubber seeds oil (Rubber 100) and the second type was the petroleum hydraulic (Hydraulic 100), which was used as a reference for the comparative process. For each experiment, 10 ml of the oil sample must be available.

2.5. Test procedures

By using the four-ball tribometer, all experiments in the current research were done according to the American Standard (ASTM D4172-B). Base on the principle of this standard, a three chrome steel balls are installed together in the clean balls pot assembly, by utilizing the torque wrench the balls assembly was tightened to curb the moving through the test. The top, spinning ball was locked inside the collet and tightened onto the rotational spindle, 10 ml of the test fluid was introduced into the balls pot assembly. The performance characteristics were investigated under the specific conditions, which illustrating in Table 3.

Table 3. Specific conditions of the experiments.

Normal load (kg)	40, 50, 60, 70 and 80
Rotational speed of spindle (rpm)	1200
Oil sample temperature (°C)	75

2.5.1. Wear scar diameter (WSD)

For each one of the three balls that was used in the experiment, the diameter of the wear area (WSD) was determined from the photomicrograph, which captured by using the SEM microscope, which connected to the personal computer by the specific data acquisition software. This procedure must be repeated for three balls, and then the average of the three values of wear diameter will be calculated and depended in the next steps of the other results that must be determined.

2.5.2. Frictional torque and coefficient of friction

The friction parameter (frictional torque and coefficient of friction) is an important factor in evaluating the performance characteristics of fluids. The values of the friction torque are obtained straight from the four-ball machine in the two forms; graphically or as an axial sheet, but the values are adopted after about 5 to 10 minutes from starting the test because of this period necessary for the stability of the friction values [20]. In addition, friction values are necessary because they are used to calculate the coefficient of friction (μ) according to (IP-239) by employing Eq. (1):

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

where *T* is frictional torque (kg.mm), *W* is Applied load (kg), and r is the rotation radius (3.67 mm).

2.6. Flash temperature parameter (FTP)

The flash temperature parameter is a single number without units that expresses the critical flash temperature and at which, the fluid thin film begins to collapse. Alternatively, it expresses the less possibility of the thin oil layer to fail [21]. This parameter is very important because it predetermines the appropriate working conditions for the fluid in which, the oil can operate successfully; this means that the high value of this parameter indicates better fluid performance. The value of the flash temperature parameter is calculated by using the mathematical equation described below:

$$FTP = \frac{W}{(WSD)^{1.4}} \tag{2}$$

where *W* indicates the load value applied in unit kg; *WSD* indicates the value of the diameter of the scar, which measured in unit mm.

3. Result and Discussions

3.1. Rubber seeds oil yield

The weight of rubber seed particles and the oil yield was recorded to obtain the oil extraction rate of the rubber seed oil. The weight of rubber seeds particles use for the extraction is 20 g and the weight of rubber seeds oil that was obtained from the extraction is 10.6 g giving the oil yield extraction rate of 53%. The solid to the solvent ratio for the extraction process is 1:7.5.

3.2. Lubrication characteristics

The behaviour characteristics (anti-wear and anti-friction) of the rubber seeds oil (Rubber 100) under different loads have been studied and analysed. The results gave a better understanding of the nature rubber seed oil behaviour characteristics by adopting a set of parameters like the wear scar diameter, friction torque, coefficient of friction and flash temperature parameter. The values of these parameters are then compared with those of the mineral hydraulic fluid (Hydraulic 100).

3.2.1. Wear scar diameter

After finish the test time (one hour for each sample), the scar diameter of the three bottom balls was measured using the electron microscope (SEM) and then the average of these three diameters was calculated to find the final scar diameter, then these values were collected and plotted and presented in Figs. 2 and 3. Depending on the results in this figure, it can be concluded that the wear scar diameter for both oil samples (neat rubber oil also hydraulic oil) was increased with higher loading values. The neat rubber seeds oil (Rubber 100) gave a smaller rate of wear scar diameter compared with the mineral hydraulic under the low value of load (484.4 μm under 40 kg) as compared with 546.4 μm under same normal load for the hydraulic oil. At higher loads, the rubber seeds oil has shown high values of wear scar diameter (864.7 μm under 80 kg) than the value of 721.1 μm under 80 kg using hydraulic oil. This behaviour occurs as a result of the chemical attack of fatty acids on the surface of the ball that lubricated with rubber seeds oil and the metallic soap film was remove and scrub away during the sliding motion under high load, leading to the production of the non-reactive detergents that increased the wear.

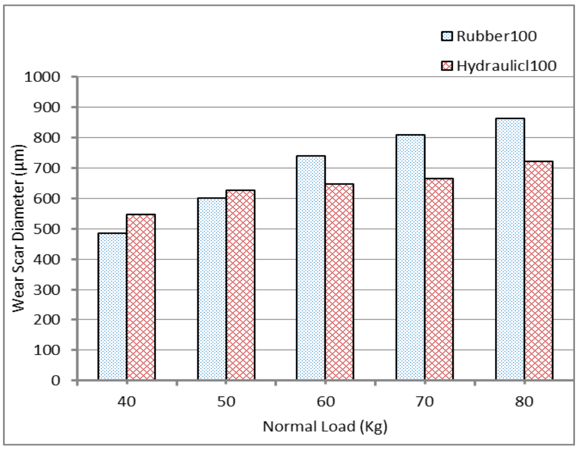

Fig. 2. Wear scar diameter (WSD) for fluid specimens under various loads.

3.2.2. Friction torque (FT)

In studying the performance features of the rubber seeds oil under various normal load (40-80 kg), all experiments were conducted at a rotational speed installed at 1200 rpm, and also the oil temperature was raised to 75 ^{o}C, and the test time was set at 60 minutes for each experiment. All test results for the anti-friction characteristics were rearranged, drawn, and displayed in Fig. 3. The results that were presented in Fig. 3, which shows that there is a slight increase in the values of friction torques when increasing the applied normal load for both oil samples (neat rubber seeds oil and hydraulic engine oil). In addition, it could be seen from Fig. 4 that the rubber seeds oil has lower values of friction torque compared with mineral hydraulic oil under different loads.

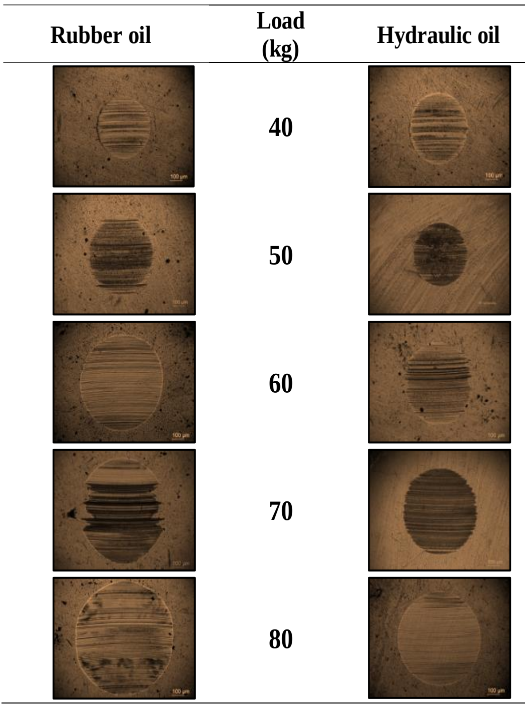

Fig. 3. SEM image for fluid specimens under various loads.

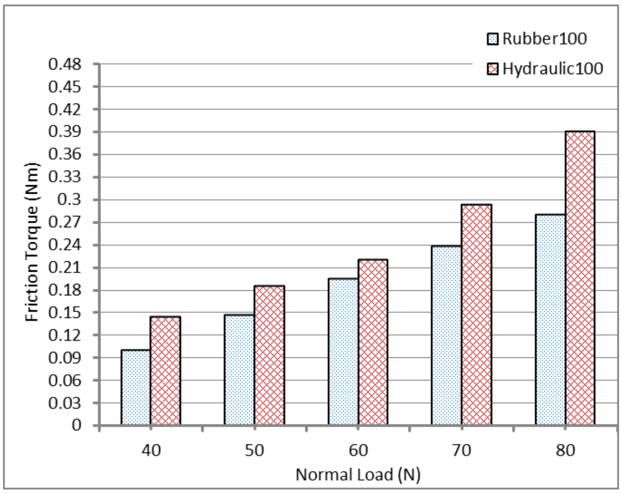

Fig. 4. Friction torque values for fluid specimens under various loads.

3.2.3. Coefficient of friction

The friction coefficients values for each sample of oils (neat rubber seeds oil and mineral hydraulic) were calculated using Eq. (1) under different test conditions, which were determined according to the (ASTM D4172-B) standard and then the results were scheduled, rearranged and graphically presented in Fig. 5.

The rubber oil sample was given a lower value for the friction coefficient than the friction coefficient for the mineral hydraulic sample, this behaviour occurs because the fatty acids in the vegetable oil (rubbed oil) help the lubricant molecules to stick on the surface of the steel ball strongly and maintain the lubricant layer [19].

Results of the friction coefficient in Fig. 5 shows also, the increased load led to the increase in the friction coefficient value for both oil samples [6]. The lower value for the coefficient of friction was obtained of the rubber seeds oil at 0.0563 under 40 kg as compared with 0.0815 under the same load for the mineral hydraulic oil.

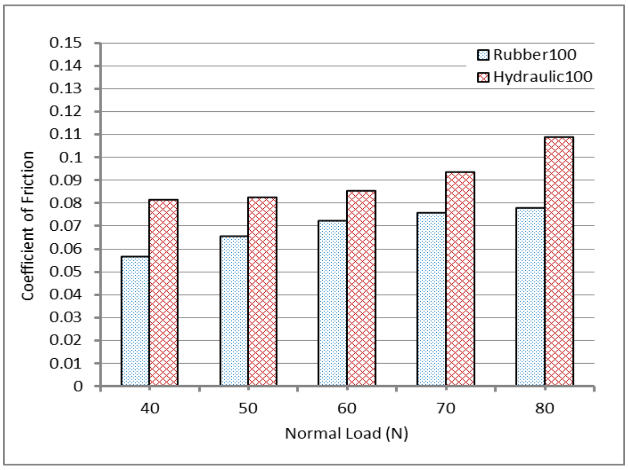

Fig. 5. Coefficient of friction for fluid specimens under various loads.

3.2.4. Flash temperature parameter

Flash Temperature Parameter (FTP) is calculated and tabulated using Eq. (2) for rubber seeds oil and mineral hydraulic under different normal loads as shown in Fig. 6. For the rubber seeds oil, the highest FTP value occurred under 40 kg was 110.35 as compared with 93.21 for the mineral hydraulic fluid under the same normal load.

Figure 6 shows, under low loads, the rubber seeds oil give a higher value of the FTP and under the high value of loads, the rubber seeds oil show lower value of FTP as compared with the FTP values of mineral hydraulic oil [6]. The reason is that, under the lower value of loads, the rubber seeds oil caused a reduction in the possibility for lubricant thin film to breakdown and increases the lubricity efficiency as compared to the mineral hydraulic oil.

The higher value of flash temperature parameter was obtained of the mineral oil 126.44 under 80 kg as compared with 98.06 under the same load of the rubber seeds oil.

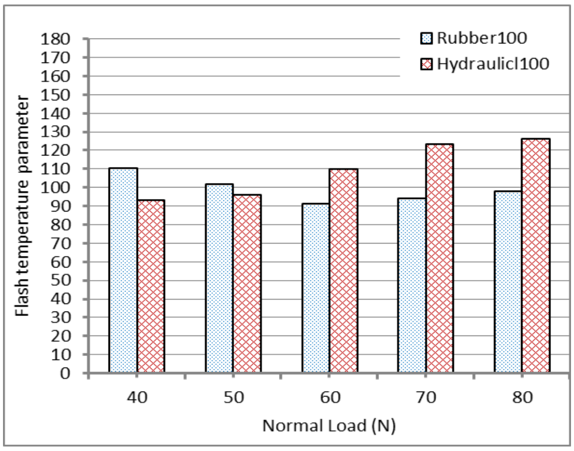

Fig. 6. Flash temperature parameter for fluid specimens under various loads.

4. Conclusions

The performance behaviour characteristics of the rubber seeds oil were assessed using a four-ball tribotester instrument under varies normal loads. The results of the neat rubber oil were compared with the outcomes of the petroleum hydraulic fluid. The results of the tests can be summarized and presented in the following points:

- The friction coefficient obtained from the rubber seeds oil was the lowest compared to mineral hydraulic fluid, for both low and high normal load conditions. The friction coefficient for both l oils increased as the applied load was increased.
- The wear resulted from those lubricated with rubber seeds oil showed a better result under lower normal load. In contrast, at the higher normal load, the wear dominated by those lubricated with rubber seeds oil was higher compared to mineral hydraulic oil.
- Could be concluded that rubber seeds oil shows better performance characteristics compared to petroleum hydraulic in term of the coefficient of friction and wear under low load. Therefore, rubber seeds oil has a possibility to be used as a hydraulic fluid in the machine, which works under low load.

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