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Comparative Performance Assessment of Vegetable Oils as Suitable Lubricants under Extreme Temperature and Pressure Conditions

Charles Onyinegbaliwene Amgbari[1,*]

Department of Mechanical Engineering, Federal Polytechnic Ekowe, Bayelsa State, Nigeria; wilson.okon@akwaibompoly.edu.ng.

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Abstract

The environmental pollution caused by mineral oil (petroleum-based) lubricants, coupled with the depletion of petroleum reserves, has encouraged the sourcing of more biodegradable and environmentally friendly lubricants. To this end, vegetable oils have been promoted as suitable replacements for these petroleum-based lubricants. It is chiefly because of their biodegradable nature and abundance in the environment. One major limitation in the use of vegetable oils as lubricants is their seemingly poor performance when exposed to extreme temperature and pressure scenarios. It is due to the fact that they undergo oxidation at high temperature operations, which causes an alteration of their physical and chemical nature. Upon this degradation, the released oxygen bond becomes harmful to metals as it sponsors oxidation on the metal's surface, which leads to structural weakness, evident in the near future as rust. This paper tested the high-temperature and high-pressure performance of vegetable oils using a four-ball tribometer according to ASTM D2783. The lubricants used for this comparative test were commercial hydraulic oil, RBD palm olein, Palm Fatty Acid Distillate (PFAD), jatropha oil, and commercial stamping oil. The end performance evaluation showed that jatropha oil, a vegetable-based oil, has a higher Coefficient of Friction (COF) in comparison to the other oils, which were mineral (petroleum-based) oils. The study also exposed that the wear scars on the metal surface when machined with the vegetable oil are lower than those when the mineral oils were used. Hence, the vegetable oils are very suitable for use as lubricants under extremely high temperature and pressure regimes.

Keywords: Performance, Lubricants, Friction, Pollution.

1 | Introduction

Petroleum is in high demand right now because of rising industrialization, modernization, and development. From 1990 to 2008, Nigeria's overall energy consumption grew at an average yearly rate of 7.2% of which petroleum sources accounted for more than 80% of this. According to reports, the European Union uses

Corresponding Author: wilson.okon@akwaibompoly.edu.ng

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about 320,000 tonnes of petroleum annually. Some of this petroleum is used as a coolant for high-quality manufacturing processes and as a lubricant for metal cutting and shaping procedures in mineral oil-based fluids for metalworking applications, where it can boost productivity. This oil is really helpful, but it also poses a threat to the environment because at least two-thirds of the used oil needs to be disposed of in special means, as they are not biodegradable. Research has exposed that skin contact with cutting fluids causes nearly 80% of all occupational illnesses affecting machine operators [1]. For instance, out of a million workers in the USA, almost 700,000 are exposed to fluids used in metalworking. These liquids have intricate chemical makeup and a high concentration of microbial toxins, which irritate or trigger allergic reactions in the human skin [2]. Scientists have been looking for alternatives that are economically viable, clean, renewable, and dependable as a result of this issue. The introduction of biodiesel as a more environmentally friendly renewable fuel that may take the place of diesel fuel in the transportation industry was one of the best discoveries [3]. Vegetable oil has therefore been tried out and seems to have the ability to take the place of mineral oil-based fluids.

High viscosity index, high lubricity, low volatility, and advanced traits that can be compared to mineral oil, such as low toxicity and high biodegradability, are only a few of the qualities that are necessary in a lubricant that are present in vegetable oils [4]. Triglycerides, which are glycerol molecules with three long-chain fatty acids connected at the hydroxyl group via ester bonds, make up the majority of vegetable oils. Natural vegetable oils contain a variety of fatty acids, each with a unique chain length and amount of double bonds. The ratio and placement of carbon-carbon double bonds define the fatty acid makeup. Oleic, linoleic, and linolenic fatty acid constituents, respectively, have one, two, or three double bonds holding them together. The majority of fatty acids found in plant-based oils range from four to twelve. Boundary lubrication benefits from the glyceride structure. They can produce high-strength lubricant coatings that interact aggressively with metallic surfaces thanks to their long and polar fatty acid chains [5]. They also possess a high viscosity coefficient, which results from the strong intermolecular interactions, making the viscosity more stable and resistant to temperature variations. Strong molecular connections like these provide a long-lasting lubricating layer. Vegetable oil lubricants are biodegradable and have low levels of toxicity during their entire life. Based on the advantages and drawbacks of vegetable oils, lubricant formulations are being created. Vegetable oils outperformed mineral-based oils in terms of fatigue resistance, scuffing load capacity, and Anti-Wear (AW) and friction [6]. It is why even while vegetable oil exhibits worse thermal and oxidative stability, it generates a low friction coefficient, similar scuffing load capacity, and greater pitting resistance. Under heavy weights, vegetable oil also loses effectiveness. Given the high polarity of the entire base oil for robust interactions with lubricated surfaces, this suggests that vegetable oils are particularly useful as boundary lubricants [6]. Sunflower oil, coconut oil, and palm oil are a few of the vegetable oils that have undergone testing. Based on earlier research, coconut oil has been used in metal-cutting machining applications.

Regarding cutting speed, depth of cut, and feed rate, it performed superbly. In addition, the specimen's surface was smoother than that of mineral oil. It has been demonstrated that palm oil produces smoother surfaces when used in milling than mineral oil, and it also increases tool life. When sunflower oil was tested in drilling equipment, the outcomes were the same [7]. Vegetable oils should be able to be used for hydraulic or stamping applications despite the fact that prior studies have shown that they are less effective than mineral oil for severe loads. Seven different oils, these being commercial hydraulic oil, commercial stamping oil, jatropha oil, PFAD, RBD palm olein oil, palm kernel oil, and soybean oil, were examined in this experiment.

2 | Material and Method

2.1 | Four-Ball Tribometer

The four-ball tribometer is used to gauge the Extreme Pressure (EP) and AW capabilities of lubricating oil and grease. A typical ball bearing with a diameter of 12.7 mm was used for the test. Under a specific load, the lubricant was submerged in a revolving ball bearing with a point of contact interface against three stationary ball bearings. The machine's specifications, such as the typical load, rotational speed, and temperature, were set in accordance with ASTM regulations. Different methods are used to analyze the four-ball tribometer test's qualities, including evaluating the wear scar diameter where welding occurs and the normal load under high pressure. For lubrication oil and grease, the standards employed for these trials are ASTM D 2783 and ASTM D 2596, respectively. Under varying load conditions, the top bearing rotates at 1770 ± 60 rpm in opposition to three stationary ball bearings.

For a period of 10 seconds, the lubricating fluid has a temperature of around 27 °C ± 8 °C. Up until welding, the experiment was run with increasing loads. The sole objective of this test was to establish the characteristics of the lubricating oil and grease at low, medium, and high pressure levels. This methodology was not used in the determination of anti-ware behaviour. It was made to test lubricant properties under more demanding conditions and larger loads in order to identify failure areas.

2.2 | Tested Lubricants

In this paper, three types of vegetable oils were used as test lubricants: jatropha oil (JAT), RBD Palm Olein (PO), and Palm Fatty Acid Distillate (PFAD). Their performances were compared with commercial stamping oil (STP) and hydraulic oil (HYD). The viscosity for all the test lubricants was almost the same at 40ºC, which was between 37 and 70 mm /s.

3 | Results and Discussion

3.1 | Coefficient of Friction

The four-ball tribotester's friction torque was measured during the experiments. The equation below has been used to calculate the lubricant's Coefficient Of Friction (COF) from the friction torque value. The friction torque of the four-ball tribotester was recorded during the experiments. The lubricant's COF was then calculated from the measured torque using *Eq. (2)*.

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

where μ is the distance in mm (3.67) from the center of the contact surface on lower balls to the axis of rotation, T is the frictional torque in kg.mm, W is the applied weight in kg, and is the COF [8]. *Fig. 1.* displays the COF values for all test lubricants. Vegetable oils clearly exhibit a high COF while working under high-pressure settings with a typical load of 126 kg, as shown in *Fig. 1*. The distillate of palm fatty acids (PFAD) demonstrated the highest COF. It is due to the fact that at room temperature, it is semi-solid. The semi-solid form of PFAD makes it difficult to flow.

Under a high normal load, the PFAD lubricant film easily degrades. The amount of metal-to-metal contact and friction increased COF. At room temperature, both jatropha and RBD palm olein are still liquid and can sustain the lubricating film. The COF was low for the mineral oil representatives (commercial stamping oil). It is because the mixture contains an AW ingredient.

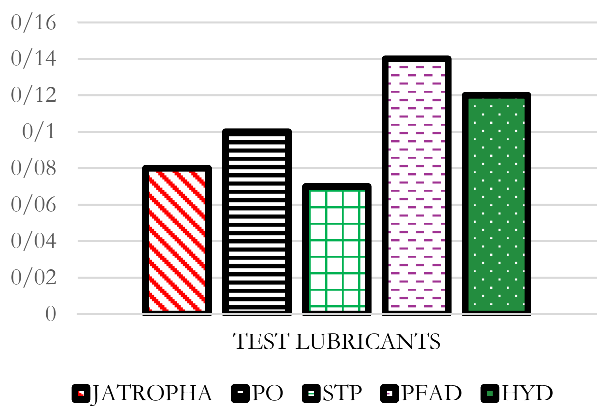


Fig. 1. Coefficient of friction at steady state conditions for all types of test lubricants.

3.2 | Wear Scar Diameter

The distribution of the wear scar diameter for each test lubricant is shown in *Fig. 2*. The wear scar diameter is smallest while using commercial stamping oil (STP). It is so that the oil's AW ingredients can aid in slowing down the rate of wear. Although hydraulic oil (HYD) also contains additives, it is not used to resist movement like the four-ball tribometer; rather, hydraulic oil is utilized to transfer energy in the hydraulic system. The ball bearing lubricated with jatropha oil had the least wear scar diameter when compared to the other vegetable oils, which were palm olein and PFAD [9]. The chemical chain of PFAD had the most oxygen double bonds. The oxygen double bond tends to react with another element, most likely the ball bearing's substance, when a ball bearing rotates under high pressure, [10]. The ball bearing's substance oxidizes and weakens as a result. A third body abrasion mechanism would cause a significant wear rate in the material. The frictional resistance would rise due to the metal-to-metal contact between the top and bottom ball bearings. As a result, as previously seen in *Fig. 1,* the COF rises.

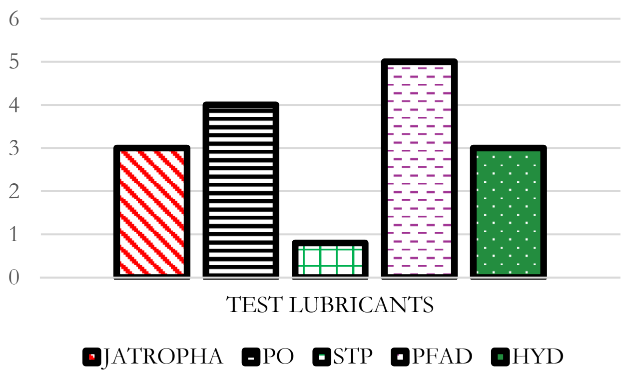


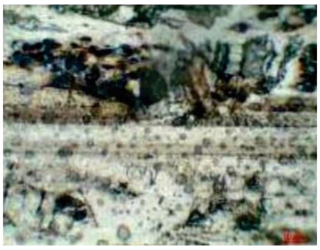
Fig. 2. Wear scar diameter on ball bearing lubricated with test lubricants.

3.3 | Worn Scar Observation

It is extremely clear how much wear scar is developed between oils. Some of the oils failed to operate as a lubricant in cases when a bearing's wear scar diameter was greater than 4 mm or all four ball bearings were welded together, using a standard load of 126 kg as a point of comparison. Due to the 5.25 mm diameter ball bearing wear that PFAD oil in this experiment induced, as depicted in *Fig. 2*, it can be said to have failed.

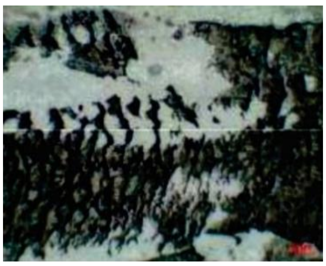
Commercial stamping oil operates admirably under this load and creates wear scars with a 0.62mm diameter. Despite producing significant wear scars, the remaining oils tested (aside from PFAD) showed low friction coefficients, comparable to commercial stamping oils. This experiment produced fascinating wear scar surfaces, including smooth surfaces, metal burns, shear surfaces, and wedge-shaped metal formations. *Fig. 3*, demonstrates that the only stamping lubricant that provided a flat surface was commercial stamping oil. A portion of the commercial hydraulic oil wear scar revealed burnt metal along with adhesive wear [11]. This charred metal demonstrates that the presence of oxygen must have caused the temperature in that location to rise.

a.



b.

c.



d.

e.

Fig. 3. CCD pictures of worn surface on the ball bearing: a. Commercial stamping oil, b. Hydraulic oil, c. Jatropha oil, d. RBD Palm olein, e. Palm fatty acid distillate.

Commercial oil's oxidation stability deteriorates under this load, resulting in abrasive wear. These microscopic cutting forms are indicative of the surface hardness and are found in ductile materials. Jatropha oil and RBD palm olein oil both have worn scar surfaces that are similar in that they have a lot of shear surface in the middle and wedge cutting on the edge [11]. The wedge cutting is caused by abrasive wear of the brittle surface, whereas the shear surface is caused by adhesive wear. The extra oxygen present during the experiment must have caused the wear scar's edge to become brittle [4].

4 | Conclusion

Based on the results of these tests, it can be said that vegetable oil has the potential to become a useful industrial lubricant.

Even though the steel ball wear scar diameters and friction coefficient values were slightly bigger than those obtained using commercial stamping oil, this issue could be resolved by using the right additives.

The investigation of acceptable additives for vegetable oil will be covered in the upcoming experimental efforts, as it is outside the purview of this study.

Conflict of Interest

The authors declare no conflict of interest.

Data Availability

All data are included in the text.

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