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EVALUATING THE TRIBOLOGICAL PERFORMANCE OF GREEN LIQUID LUBRICANTS AND POWDER ADDITIVES BASED GREEN LIQUID LUBRICANTS

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ABSTRACT

In the present investigation, experiments were conducted using a pin-on-disk apparatus to study the tribological performance of various green liquid lubricants. More specifically, various green liquid lubricants, such as: avocado, canola (rapeseed), corn, olive, peanut, safflower, sesame, and vegetable oil are considered. In addition, tribological performance was also investigated by the addition of various sizes and combinations of green solid powder additives in the green liquid lubricants. It was found that the avocado oil showed the best friction and wear performance when compared to other green lubricants. Further, the nano sized additives in green liquid lubricants showed the best tribological performance when compared to micron, sub-micron sized, and their combinations in green liquid lubricants. The possible mechanisms governing low friction and wear are summarized.

INTRODUCTION

Pure natural oils have for a long time been known to be good lubricants in lowering friction and preventing wear. Since the beginning of the 20th century investigations into the properties of natural oils have received much attention [1]. More recently in an effort to curb the use of petroleum-based lubricants due to concerns of protecting the environment, depletion of oil reserves, and increases in oil price, natural oils have witnessed a resurgence. Furthermore the emphasis placed on pure natural oils is a result of the increase in demand for environmentally friendly lubricants that are less toxic to the environment, renewable, and provide feasible and economical alternatives to traditional lubricants [2]. The attraction to natural oils is due to their composition of triacylglycerol made up of esters derived from glycerol and long chains of polar fatty acids that are desirable in boundary lubrication for

their ability to adhere to metallic surfaces, remain closely packed, and create a monolayer that is effective at reducing friction and wear [1, 3]. Much of the work with natural oils has concentrated on understanding the fundamentals of saturated and unsaturated fatty acids with the bulk of the attention focusing on their use as neat lubricants, additives in mineral oils, and most recently carrier fluids for particle additives [1, 3, 4]. When compared to mineral and synthetic oils, natural plant oils have a higher lubricity, lower volatility, higher shear stability, higher viscosity index, higher load carrying capacity, and superior detergency and dispersancy [3, 4]. Therefore natural oils are a good alternative to petroleum-based oils. Green lamellar powders such as boric acid (H_3BO_3) and hexagonal boron nitride (hBN) are well-known solid lubricants for their low interlayer friction, ability to form a protective boundary layer, and accommodate relative surface velocities [4, 5]. These powders are effective in a broad range of applications to lower friction and minimize wear. Furthermore they are environmentally-benign and inert to most chemicals making them an attractive performance enhancing additive to natural oils [4].

EXPERIMENTAL DETAILS

Pin-on-disk tests at ambient conditions are conducted to characterize the tribological properties of eight natural oils: avocado, canola (rapeseed), corn, olive, peanut, safflower, sesame, and vegetable oil, as neat lubricants. Additionally an investigation into the size effect of boron nitride particles in canola oil during sliding contact is evaluated. During these tests, hexagonal boron nitride particles having sizes of 5 μm , 1.5 μm , 0.5 μm , and 70 nm and their combinations were combined with the canola oil forming a colloidal solution. During this study copper pins were used with a hemispherical shaped tip

having dimensions of 6.35 mm in diameter and 50 mm in length. The disks were composed of aluminum and stainless steel with dimensions of 70 mm in diameter and 6.35 mm in thickness. They were polished to a surface roughness, R_a , of $0.3 \pm 0.05 \mu\text{m}$. Scanning electron microscopy (SEM) and optical profilometry were used to study the damage formed on the pin surface during sliding under the presence of green lubricants.

RESULTS AND DISCUSSIONS

The test results indicate that the avocado, olive, and corn oil had the lowest coefficient of friction (COF), while safflower, sesame, and vegetable oil had the highest COF as shown in Fig. 1. The avocado, safflower, and olive oil have the lowest wear rates and the vegetable, corn, and canola oil have the highest wear rates. Analyzing the fatty acid concentration in Fig. 2, it can be seen that as the pin wear volume increases the monounsaturated fat, oleic acid (C18:1) decreases. The trend is reversed in terms of the polyunsaturated fat, linoleic acid (C18:2).

the linoleic acid [3]. Therefore when the wear volume is low, the protective layer would be more densely packed due to the higher percentage of Oleic acid. At a higher wear volume, the Oleic acid percentage is low and thus, the linoleic acid content dominates. This corresponds to a weak protective layer on account of the presence of the double bonds. This is in accordance with known results as high oleic content natural oils have improved lubricity and oxidative stability, that in some cases can even surpass Group I petroleum-based oils [4]. These improved properties allow the vegetable oil to be subjected to higher temperatures prior to thermal degradation.

Attempts were also made to study the influence of green additives in green lubricants on friction and wear performance. Hence, in this study, the canola oil was selected because it is readily available and inexpensive. Moreover, canola oil exhibits a surface tension and viscosity index similar to transmission fluids and lubricants used in sheet metal stamping processes. The size effect of the boron nitride

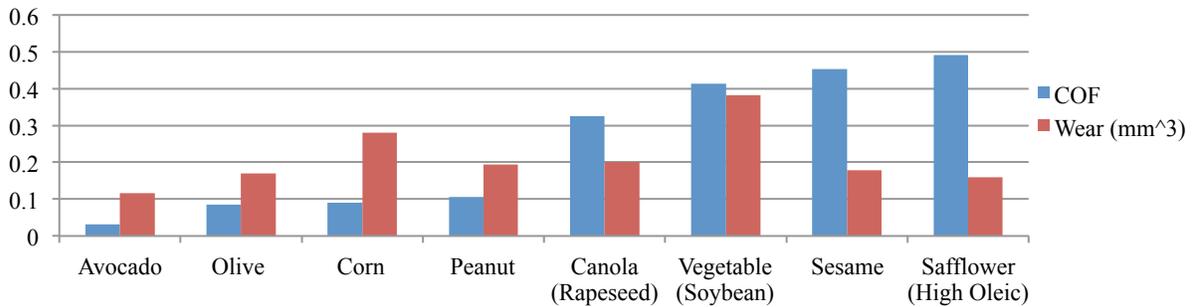


Figure 1: Coefficient of Friction and Pin Volumetric Wear Rate for Vegetable Oils

It is also shown that the pin wear volume increases with increasing linoleic acid percentage. The presence of the double bonds in the unsaturated fatty acids (linoleic acid) prevent the carbon chains from forming tight packs, thus weakening the protective layer [1]. Hence, the pin wear volume increases with increasing linoleic acid content. Oleic acid has only one double bond as opposed to two in

particles in canola oil are shown in Fig. 3, where the coefficient of friction and the pin wear volume are plotted for each hBN combination. It can be generally stated that small nanoparticles outperform large micron particles. The results reveal that the hBN additives that are larger than the magnitude of the disk's initial surface roughness decrease the friction when compared to neat canola oil by carrying a

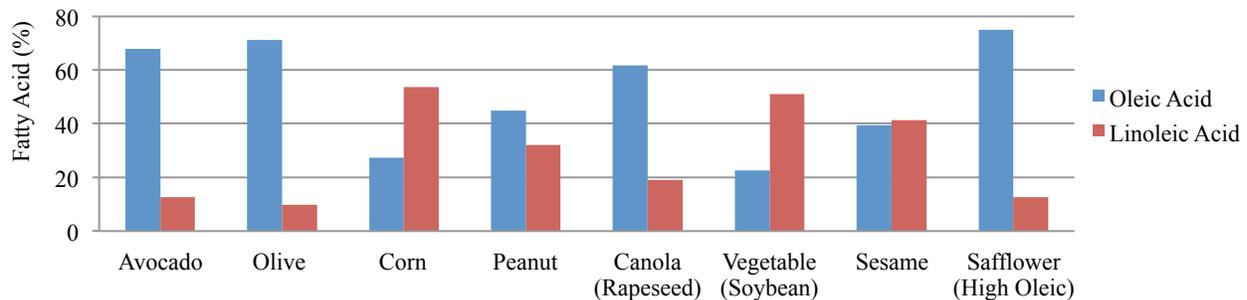


Figure 2: Fatty Acid Concentration in Various Vegetable Oils

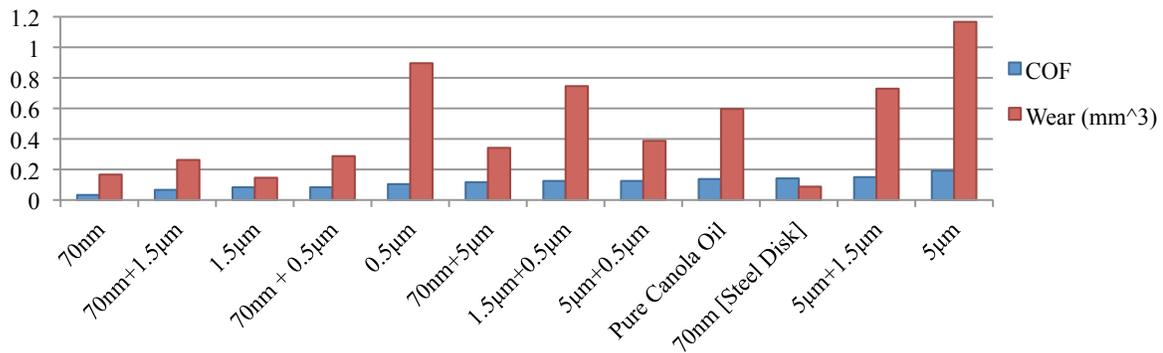


Figure 3: Coefficient of Friction and Pin Volumetric Wear Rate for Lubricant Mixtures

portion of the load between the contacting asperities. It was further shown with SEM that the pin damage for large micron sized particles was more than the nano-sized particles. The optical profilometry studies are in agreement with the SEM results, showing that the pin worn surfaces were rougher for micron-sized particles and smoother for nano size particles. The 5 µm particles create a rougher surface when compared to the 70 nm particles. These results reveal that larger particles act as an abrasive unit, resulting in higher wear rates. Particles smaller than the asperity size coalesce in the asperity valleys establishing a thin, smooth, solid lamellar film between the contacting surfaces, decreasing the friction coefficient and wear rate. Nano-particles in canola oil provide the optimum friction and wear performance because their ability to fill surface asperities is more important than the larger micron sized particles ability to carry contact loads between the surfaces.

CONCLUSIONS

- Avocado, peanut, and vegetable oil have the lowest coefficient of friction of the natural oils. In contrast, avocado, olive, and safflower oil have the lowest wear rates. Of the natural oils avocado oil has the best tribological performance.
- Natural oils with high percentages of monounsaturated fatty acids particularly oleic acid, present in avocado oil develop tightly packed carbon chains that better protect the pin-disk interface, resulting in lower friction and wear.
- The nano particles showed the best tribological performance in green lubricants when compared to micron-sized particles in green lubricant.
- The hBN additives that are larger than the asperities carry a portion of the load between the contacting asperities, resulting in a decrease of friction, however these larger particles are also more abrasive causing higher wear rates.
- Nano sized particles in canola oil coalesce in the asperity valleys creating a superior protective film between the contacting surfaces that thwarts friction and wear.

FUTURE WORK

This research provides a basis for determining what characteristics of green lubricants provide the optical tribological properties. Avocado oil is revealed to be the best overall natural oil for consistently minimizing friction and wear along with having a high value of oleic acid, and the highest smoke temperature, providing it with the highest thermal stability. Moreover, future tests will investigate using avocado oil in the presence of boron nitride powder additives, which is speculated to greatly minimize friction and wear.

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