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Comparative Analysis of the Friction Characteristics of Graphite enhanced Biolubricants and SAE20W40 Engine Oil

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Abstract: *Biolubricants are increasingly becoming attractive to researchers due to environmental concerns associated with most conventional lubricants. In this study, the effect of graphite nanoparticles on the friction characteristics of Vegetable oil (V), Palm oil (P) and SAE20W40 engine oil(S) using G.U.N.T. TM 260.01 rolling/sliding disc module is presented. The main parameters considered were graphite concentration in the lubricant, rotational speed of the contact surfaces and applied load. The volume of each lubricant was 50ml and all the investigations were carried out at room temperature for 10 minutes. The results show that friction force decreased with increase in rotational speed for all the lubricants. The coefficient of friction (COF) also decreased with both rotational speed and increasing particle concentration in the lubricants. However, friction force increased with increasing load. The effect of graphite nanoparticles addition into each of the lubricants was more significant for vegetable oil than palm oil and SAE20W40. Lowest friction forces and coefficients of friction were observed at a particle concentration of 2g. In all cases, addition of graphite nanoparticles into the lubricant improved the frictional characteristics of the lubricant, though at different magnitudes*

Keywords: Vegetable oil, palm oil, graphite; SAE20W40; biolubricant; friction

1. INTRODUCTION

Effective lubrication remains an important factor that determines the lifespan of machine elements and components. Conventional lubricants commonly used are often mineral based. The primary function of these lubricants is to control friction, transmit energy, protect against corrosion and wear, remove heat, disperse wear debris, eliminate foreign contaminants, and act as a sealant [1]. However, due to strict environmental regulations imposed on them because of their potential hazards to humans and the environment [2], the increasing price of crude oil and the depletion of crude oil reserves in the world, there is a renewed interest in sourcing for viable alternatives [3] that are both effective as lubricants and biodegradable. One direction where the searchlight has been beamed on is on the use of bio-lubricants made from plant oils such as rapeseed, palm, soybean, sunflower, coconut, and groundnut [4]. Biolubricant is a renewable lubricant that is biodegradable, non-toxic, and emits net zero green house gases [3,5]. The advantages of using biolubricants include; low toxicity, good lubricating properties, high ignition temperature, increased equipment service life, high load carrying abilities, good anti-wear characteristics, excellent coefficient of friction, natural multi-grade properties, low evaporation rates, low emission into the atmosphere and rapid biodegradability [1,5]. Recently, numerous research works [2,5,7,8] has been carried out on biolubricant with most of them being recommended as viable alternatives to conventional lubricants for specific engineering applications. However, biolubricants such as vegetable oils in their natural form lack sufficient oxidative stability for lubrication application. Low oxidative stability indicates that oil will oxidize rapidly during use if untreated, becoming thick and polymerizing to a plastic-like consistency [3]. There are also thermal issues associated with vegetable oils with many other inferior characteristics when compared with petroleum based lubricants [5]. This has necessitated the need for further research to improve their tribological properties. The use of nanoparticles to improve the tribological properties of lubricants has been widely reported [2,5,6,7,9,10,11]. Some of these nanoparticles include, Cu, CuO, Fe, Ni, TiO_2, Al_2O_3, fullerenes, nano diamonds, ultra dispersed boric acid, PTFE [5] and graphite [6]. Infact, grapheme exhibit unique properties that render them as suitable contact finish treatments that can reduce friction, while still providing the potential benefit of stability in harsh environments such as high temperatures or vacuum when compared to liquid based lubricants [7]. Although, the use of graphite based nanoparticles as additives to lubricants has been reported [6], there are few works on the comparison of the friction characteristics of graphite enhanced biolubricants with SAE20W40 engine oil using G.U.N.T. 260.01 rolling/sliding disc experimental module. This study therefore seeks to compare the friction characteristics of vegetable oil, palm oil and SAE20W40 engine oil mixed with graphite nanoparticles.

2. MATERIALS AND METHODS

The friction characteristics of Vegetable oil, Palm oil and SAE20W40 oil were investigated using TM 260.01 Rolling/Sliding Disc Tribometer produced by G.U.N.T Hamburg [12]. Figures 1 and 2 show the pictorial views of the tribometer and its control unit respectively. This unit comprises two friction wheels, pairing aluminum and rubber at the contact points. As a result of the two friction wheels rolling on each other, rolling friction occurs between the two

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wheels in contact. This friction is a combination of rolling and dynamic friction and is necessary for the characterization of the friction reduction property of the lubricants. Due to the clear representation of the rolling friction and an analysis of the frictional forces [12], the tribological system in TM 260.01 was chosen to conduct these investigations. Each experiment was carried out for 10 minutes.

Fig 1: TM 260.01 Rolling and Sliding Disc Tribometer [12].

This Tribometer consists of two friction disc that are in contact, driven by a gearbox unit clamped with a motor. A lubricant tank that contains the nanolubricant is placed directly below the friction discs and a load mechanism is used to vary the load applied on the friction. The rolling and sliding disc Tribometer is used with a control unit having a motor connected to its rear socket. The control unit is used to regulate the speed of the motor clamped to the gearbox unit and display the friction force in the contact between the two discs.

Fig 2. TM 260 Control Unit/Motor [12].

To set up the Tribometer, the motor was connected to the control unit. This was done by inserting the plug on the motor cable into the socket on the rear of the control unit.

The rolling/sliding disc module was then connected to the control unit and the motor clamped to the gear unit of the module. Thereafter, the control unit was plugged to a 220 V power supply.

2.1 Preparation of lubricant samples

Sets of lubricant samples of all three oils with and without graphite nanoparticles were prepared. Each set of lubricant was stirred thoroughly for even dispersion of the nanoparticles in the lubricant. The graphite nanoparticles were added in varying quantities ranging from 0g, 1g and 2g in 50 ml for each of the oils to produce the nanolubricants. The particles size was < 100nm with purity of approximately 99.9% graphite. The oils were locally sourced from the market with no additional treatment carried out but were utilized as-received. Digital weighing balance was used to determine the weight of the graphite nanoparticles for each experiments.

Each sample was poured into the lubricant tank and placed directly below the lower friction disc of the rolling/sliding disc module as shown in Figure 1 such that it had contact with the lubricant in the tank. Having set up the tribometer and prepared the lubricant samples, the control unit was powered, and both the motor and rolling/sliding disc module sensor switches on the control unit were turned on. For each sample, the following investigations were carried out; (1) Friction Force as a function of rotational speed (2) Frictional Force as a function of load. The results obtained were then used to determine the Coefficient of Friction. All investigations were carried out with 50ml of each lubricant and at room temperature. For a constant load, the rotational speed of the motor was increased in order of 10, 50, 100 and 200 rpm. The friction force was read from the display on the control unit for each load condition in an increasing order of 5, 10, 20 and 40N for each lubricant sample.

2.3 Determination of Coefficient of Friction

Having obtained the friction force for each load at different rotational speeds, the coefficient of friction between the interacting surfaces was calculated using the formula:

$$COF = \frac{\text{Measured Friction Force}}{\text{Load}}, \mu \qquad (1)$$

3. RESULTS AND DISCUSSION

3.1. Effect of rotational speed and load on the friction force.

Fig 3 (a-d) shows the effect of rotational speed for loads of 5N,10N,20N and 40N respectively on the friction force exacted on the interacting surfaces in contact for vegetable oil (V), palm oil (P), and SAE20W40 (S) engine oil with and without graphite nanoparticles.

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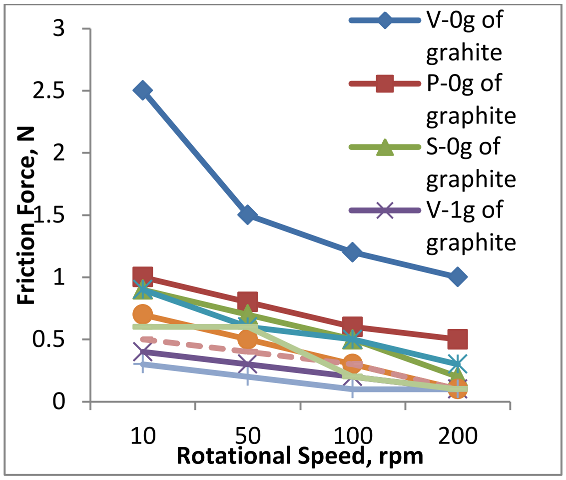
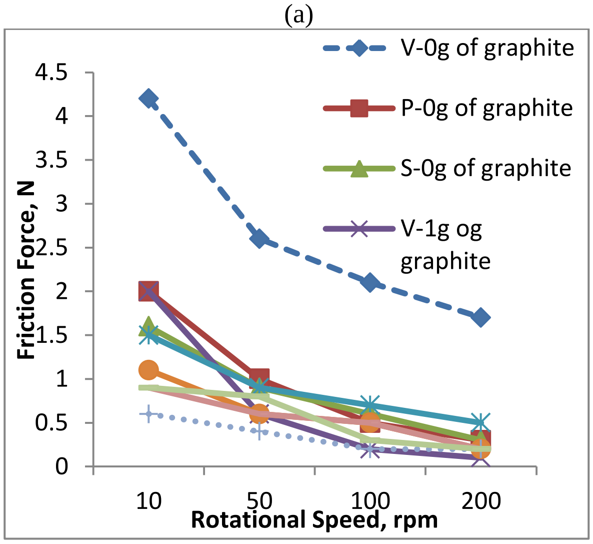
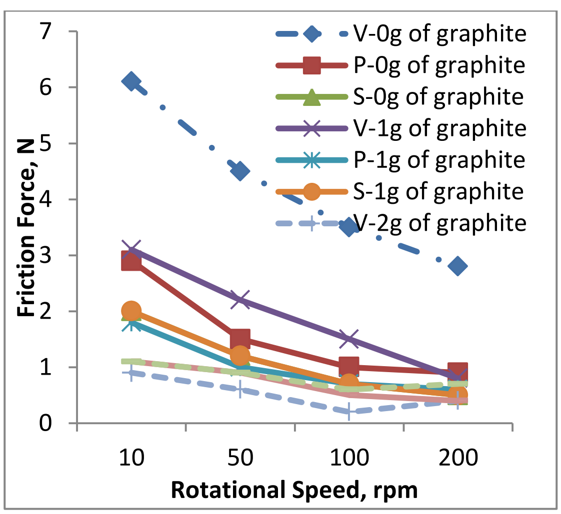


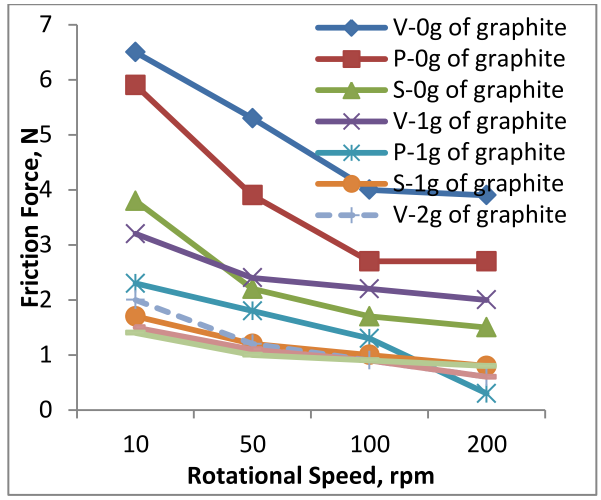
(a)



(b)



(C)



(d)

Fig 3 (a-d) Friction force as a function of rotational speed for loads of (a) 5N (b) 10N (c) 20N (d) 40N

The results show a consistent decrease in friction force with increase in rotational speed for the loads investigated. Also, it is evident from fig3 (a-d) that friction force increased with increase in load. Furthermore, it is evident from fig 3(a-d) that the highest values of friction forces were observed for a load of 40N in fig 3(d), while the lowest values were observed for a load of 5N in fig 3(a). Indicating, an increase in friction force with increase in load. Although, friction force increased with increase in load, for each of the four loads investigated, friction forces consistently decreased when nanographite particles were added to the individual oils. This is an indication that when graphite nanoparticles were added to the oils, load bearing capacity improved for each of the loads. It has been reported [5] that load bearing capacity of journal bearings increased when TiO_2 nanoparticles were added as lubricant additive when compared to plain oils without particle additives.

3.2 Effect of particles concentration on the friction force

As evident from fig.3(a-d), particle concentration in the lubricants had significant influence on the friction force of the contact surfaces. In each case, friction force decreased with the addition of graphite nanoparticles into the lubricants. As can be seen, friction force was consistently higher for the samples without graphite nanoparticles and evidently decreased with further increase in particle content of the lubricant. The friction force for all the lubricants under investigation reduced with increasing amount of nanographite particles. That is, friction force of V-0g >V-1g >V-2g of graphite for vegetable oil. Similar were the trends for both palm oil and SAE20W40 engine oil. This implies that for the present study, friction force is inversely proportional to graphite concentration in each of the lubricants even though optimum concentration of the graphite particles was not determined at this stage. However, the magnitude of dcrease was not same for all the lubricants. Evidently, the effect of graphite nanoparticles was more significant for the case of vegetable oils. As evident from each of the figs in fig 3(a-d), vegetable oil without graphite nanoparticles (V-0g) exhibited the highest friction forces and lowest friction forces with 2g of graphite nanopartices (V-2g). This is an indication that graphite nanoparticles improves the friction characteristics of vegetable oil [6]. Particles of 'nano' size have been shown to exhibit enhanced and novel properties [5]. Although, not in same order, similar improvements are also evident for both palm oil and SAE20W40 engine oil as shown in fig 3(a-d). In addition, fig 4 shows the effect of graphite nanoparticles on the friction force for vegetable oil with increasing load. The results show an increase in friction force with increase in load while the friction force decreased with increase in graphite nanoparticles in vegetable oil for each load investigated.

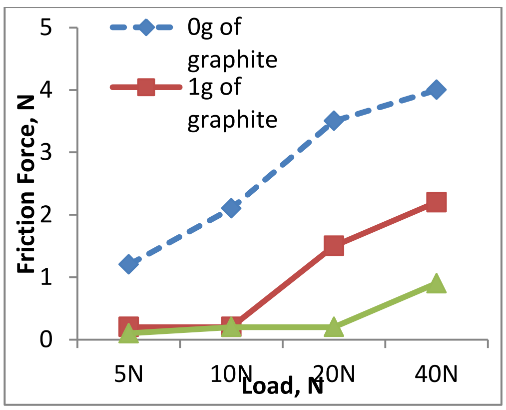


Fig. 4. Effect of load and particle concentration on the friction force for vegetable oil at 100rpm.

Although, viscocity measurements were not carried out in the present work, the consistent decrease in friction force may be associated with changes in viscocity with increase in particle content of the oils. Viscosity variations due to addition of TiO_2 in oil were responsible for the increase in load carrying capacity of bearings operating on nano particles dispersions as compared to plain oil [5]. Also, the improvement in friction reducing and antiwear properties of pure oil are attributed to the presence of spherical particles, which prevent direct contact between frictional surfaces [6]. Frictional surfaces have concave and convex portions, such that when the nanoparticles are added into the lubricant, the particles penetrate into the concave of the friction surface and mend the damaged position effectively. On the other hand the nanoparticles might be deposited on the robbing surface, which separates the contacting surfaces.[6]. Solid lubricants, usually in the form of bonded dry films are used where the temperatures are too high or too low for oil or grease, or where leakages cannot be tolerated, or where the gears must be operated in a vacuum [5].

3.3 Effect of rotational speed and applied load on the coefficient of friction

Fig 5 shows the effect of rotational speed and concentration of graphite nanoparticles on the coefficient of friction at a load of 20N

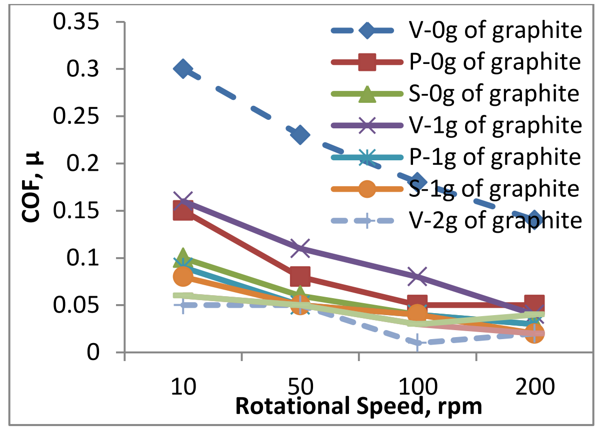


Fig 5: Effect rotational speed and concentration of graphite nanoparticles on the coefficient of friction. Load 20N.

From Fig 5, it is evident that for both increase in rpm or graphite nanoparticles in the lubricants, coefficient of friction decreases. That is, either way the coefficient of friction decreases. Although, optimum rpm for minimal coefficient of friction was not determined in the present work, the decrease in coefficient of friction tends to drop towards a steady state. It has been reported [6] that for vegetable based oil and vegetable based oil with graphite nanoparticles, the friction coefficient gradually decreased and then got to steady state. Furthermore, friction coefficient under the condition of vegetable based oil and vegetable based oil with graphite nanoparticles were lower under dry friction conditions especially for the vegetable oil with graphite. An indication that graphite nanoparticles played an important role in reducing the friction coefficient [6].

Furthermore, the effect of graphite concentration and increasing load for all three lubricants on the coefficient of friction at 100rpm is shown in Fig 6. The results show that, coefficient of friction was lower for all the lubricants with graphite nanoparticles. The coefficient of friction decreased in an increasing order of nanoparticles. This is consistent with findings of other researchers [5,6] on the effect of nanoparticles in lubricants. Increase in volume fraction of graphite nanoparticles resulted in the reduction in the average friction coefficient regardless of particle size and normal force [6], It is reported [5] that nano-oil mixed with copper nanoparticles has a lower friction and less wear on the friction surface indicating an improvement of the lubrication properties of the raw oil. Palm oil TMP ester has shown remarkable lubricant effects on metal surface, through the formation of a protective boundary film which results in increased wear resistance of the mating surfaces [13]. Infact vegetable cooking oil could serve as a good and better lubricant than mineral and synthetic oils due to their long chain fatty acids [7]. The improvement in friction-reducing and antiwear properties of pure oil was attributed to the presence of spherical nanoparticles, which prevent direct contact between frictional surfaces [6].

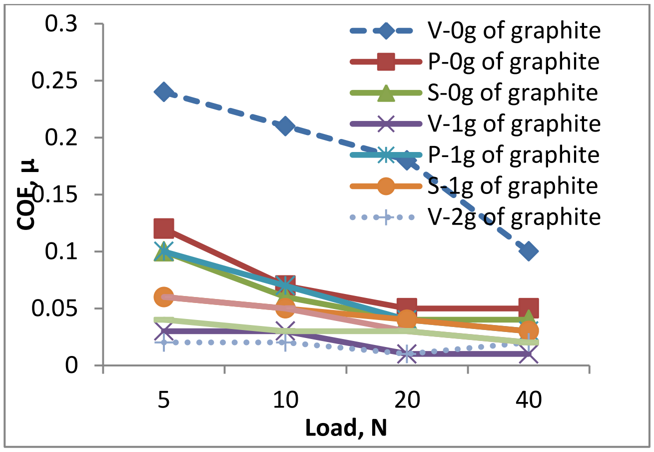


Figure 6: Effect of load and graphite nanoparticle concentration on the coefficient of friction. Rotational speed 100rpm.

In addition, the coefficient of friction continued to decrease with increasing amount of graphite nanoparticles for all three lubricants. It has been reported [11] that carbon nanoparticles tend to develop a thin film thickness that act as a separation from asperites which in turn produce lower coefficients of friction [11]. Majority of the COFs investigated in the present work decreased as the graphite content in the oils increased from 0 to 2g. Moreover, the material design for solid lubrication must display desirable coefficients of friction (0.001 to 0.3) [5]. The coefficients of friction for all the nanolubricant samples investigated were within this range. Meaning that graphite as a solid lubricant when mixed in the right proportions with vegetable oil, palm oil and SAE20W40 oil could serve as a good nanolubricant blends for specific applications [14]. Quite significantly, it is evident from all the figures that the friction forces and coefficients of friction were higher for vegetable oil. However, when the concentration of graphite nanoparticles were increased to 2g in all the lubricants, both the friction forces and coefficients of friction became lower than those of palm oil and SAE20W40 oil. The reasons for this are not very clear. It could be related to changes in viscosity or it could be that at 2g of graphite nanoparticles concentration in the vegetable oil, graphite nanoparticles became deposited as a thin layer of graphite on the frictional surfaces further improving the frictional characteristics of vegetable oil as compared to those of palm oil and SAE20W40 engine oil.

4. CONCLUSION

In conclusion, the results from this study reveal that;

- Graphite nanoparticles improved the frictional characteristics of vegetable oil, palm oil and SAE20W40 engine oil.
- Friction forces and coefficients of friction consistently decreased with increase in graphite concentration in the individual oils.
- Friction forces and coefficients of friction for vegetable oil without graphite nanoparticles were significantly higher than the others for almost all the conditions investigated.
- However, friction forces and coefficients of friction for vegetable oil with 2g of graphite nanoparticles was lower than all other investigations carried out in this study. This sudden improvement of frictional characteristics of vegetable oil may be associated with possible formation of a thin layer of graphite nanoparticles as a solid lubricant on the interacting surfaces or due to viscocity changes at that concentration.

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