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Effect of boric acid nanoparticles on the tribological characteristics of vegetable oil

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ABSTRACT: *A combination effective lubrication and eco-friendliness is a major requirement for modern lubricants. In this study, the effectiveness of Boric acid (H_3BO_3) nanoparticles as an additive to vegetable oil was investigated. Varying concentrations of the nanoparticles ranging from 0 to 2g were added to 50ml of the oil to form a nanolubricant. Viscosities studies were carried out using Ostwald Viscometer at 40 ^oC. Frictional force was determined using a Rolling/Sliding Disc tribometer model TM 260.1. Parameters investigated include; effect of load, speed and concentration of nanoparticles in the oil. The results show that H_3BO_3 nanoparticles in vegetable oil improved the tribological properties of the oil. Both frictional forces and coefficient of friction decreased in the presence of the H_3BO_3 nanoparticles as compared with the oil without the nanoparticles. Although, the range of nanoparticle concentrations in the oil investigated was small, viscosity changes were insignificant with a general tendency of an increase to a maximum and then a decrease.*

KEYWORDS: *Boric acid, friction force, nanoparticle, vegetable oil, tribometer*

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I. INTRODUCTION

The lifespan of engineering components in moving parts of machines is largely a function of effective lubrication. As such every mechanical machine needs oil between its moving parts, not only to reduce friction and wear, but also to remove frictional heat. Most lubricants used in the industry are mineral-based. However, mineral-based lubricants can be very dangerous to the workers and the environment as they are known to cause dermatitis and cancer. In terms of the environment, mineral-based lubricants are not biodegradable and discharges toxic products when it degrades in soil [1]. Also, the risk of machine oils being discharged into waterways by a marine vessel is significant [2]. This could negatively impact marine ecosystems. Recently, there has been increasing demand for environmentally benign lubricants due to stricter regulations imposed on the use of conventional lubricants made from mineral oils [3]. This has caused lubricant manufacturers to produce lubricants that are inherently biodegradable, minimally harmful to marine life, yet able to maintain anti-corrosive as well as lubricating properties [2] The use of biolubricants for lubrication has been widely reported [4,5]. However, a major challenge with the use of these biolubricants has been their oxidative instability, low temperature properties etc. [6]. Despite the great potential of vegetable oils as biolubricants, they are not widely commercialized due to their high heterogeneity and other undesirable physical properties related to poor oxidation stability, poor low temperature properties, and poor viscosity indexes, among others [7] The challenges of poor oxidation, low temperature properties, and other tribological properties of pure oils and base oils can be improved by the addition of nanoparticles such as MoS_2, H-BN, WS_2, IF-MoS_2, H_3BO_3, $PbCl_2$ and other solid lubricants as additives to a large extent [8,9,10]. These nanoparticles mixed with lubricating oil exhibits better friction and wear properties [8,11]. According to Pisal and Chavan [11] addition of CuO nanoparticles into of SAE 20W40 engine oil improved its tribological properties. Similarly, Charoo et al [9] reported that addition of IF-MoS_2 into SAE20W40 oil reduced the friction coefficient and increased the wear resistance when utilized as a lubricant on cylinder liner and piston ring turbo-pair . Lovell et al [12] also carried out an experiment on the influence of Boric acid additive size on green lubricant performance in other to study the relative tribological performance of different sized boric acid powder additives in a green lubricant liquid carrier (Canola oil). However, few research works have been carried out on the effect of Boric acid in liquid lubricants. This research work therefore, focuses on investigating the effect of Boric acid nanoparticles on the tribological properties of vegetable oil using TM 260 Rolling Disc Tribometer.

II. MATERIALS AND METHOD

The experiments were conducted in the Chemical Science Laboratory and the Mechanical Engineering Laboratory, Niger Delta University to investigate the effect Boric Acid nanoparticles on the lubrication characteristics of vegetable oil. The tribological properties investigated were Kinematic Viscosities of the various samples, frictional force as a function of load and rotational speed, coefficient of friction of each sample with and without boric acid as a function of load and rotational speed. Digital weighing balance was utilized to measure the required amount of nanoparticles for each of the investigations. Ostwald Viscometer was utilized to determine the kinematic viscosities of the vegetable oil and nanolubricants.TM 260.01 series Rolling/sliding Disc Tribometer produced by G.U.N.T Hamburg [13] was utilized to determine the frictional force and coefficient of friction between the contact surfaces. Figure 3.1 shows a pictorial view 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 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 [13]. Each experiment was carried out for 10 minutes. The Tribometer consists of two friction discs 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.

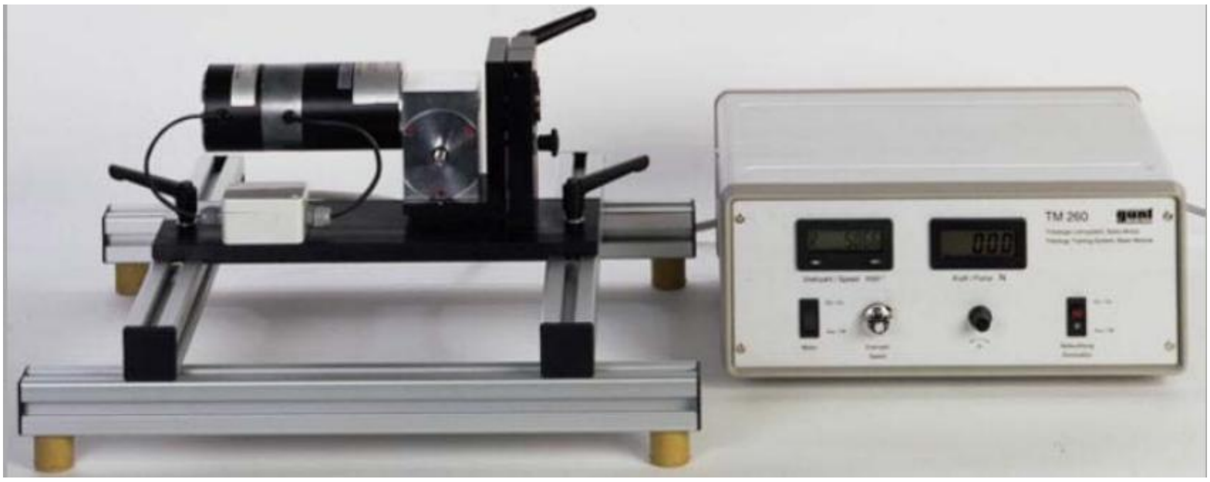

Fig 3.1: TM 260.01 Rolling and Sliding Disc Tribometer [13].

Having obtained the friction force for the different loads at different rotational speeds, the coefficient of friction **μ** was calculated using the following relationship:

$$\textit{Coefficient of Friction, } \mu = \frac{\textit{Measured Friction Force}}{\textit{Load}}$$

2.1 Viscosity studies

A transparent bucket was filled with water with the Ostwald Viscometer, ring boiler and a thermometer suspended to enable the pipette filler drag out the required oil. The experiment was carried out at a temperature of 40°C.

III. RESULTS AND DISCUSSION

3.1 Kinematic viscosity of the lubricants

Tab 3.1 shows the kinematic viscosity of vegetable with and without H_3BO_3 nanoparticles. It is evident from the table that the vegetable oil sample without nanaoparticles exhibited the least value of kinematic viscosity. In other words, kinematic viscosity of the nanolubricants was higher than the base oil [14] being vegetable oil

TABLE 3.1: Kinematic Viscosity

Lubricant (g/50ml)	Kinematic viscosity (centristoke)
Veg. oil + 0g of H_3BO_3	9.18
Veg. oil + 0.5 g of H_3BO_3	9.36
Veg. oil + 1 g of H_3BO_3	9.28
Veg. oil + 2 g of H_3BO_3	9.25

Also, there is a general tendency of the kinematic viscosity to increase with increase in particle content of the H_3BO_3 nanoparticles in the vegetable oil. Initially to a maximum value of 9.28 at a particle concentration of 1g/50ml of vegetable oil and then a decrease with further increase in the amount of nanoparticles.

3.2 Effect rotational speed and load on the frictional force

Figs 3.1-3.4 show the relationship between the frictional force, rotational speed and applied load for 0g, 0.5g, 1g and 2g of H_3BO_3 per 50 ml of vegetable oil respectively. For all the particle concentrations, a consistent decrease in friction force with increasing rotational speed was observed. A similar trend is also evident for the vegetable oil without nanoparticles.

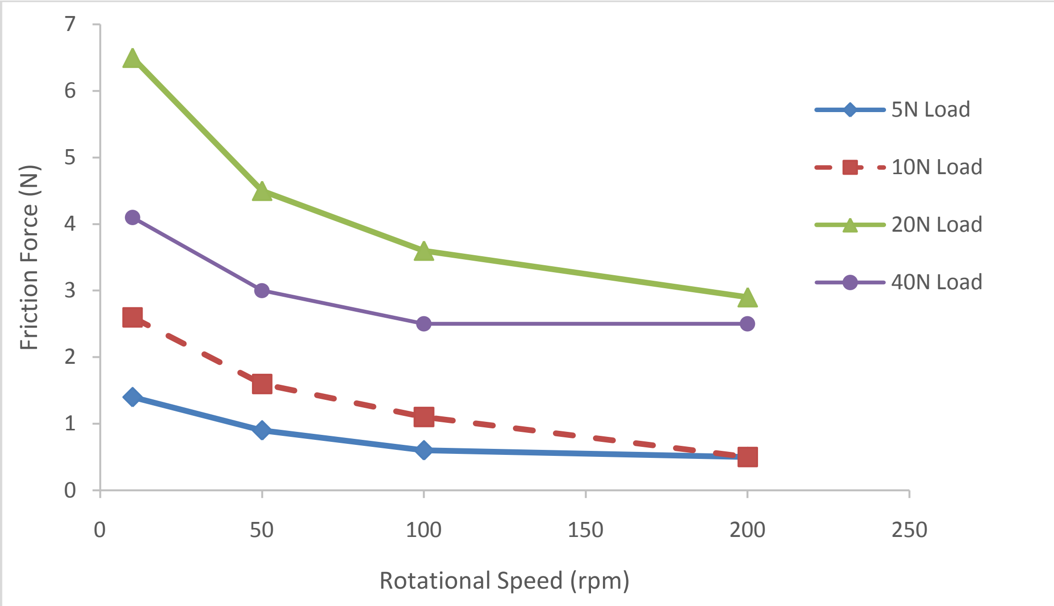

Fig. 3.1: Effect of rotational speed and load on friction force for vegetable oil without nanoparticles

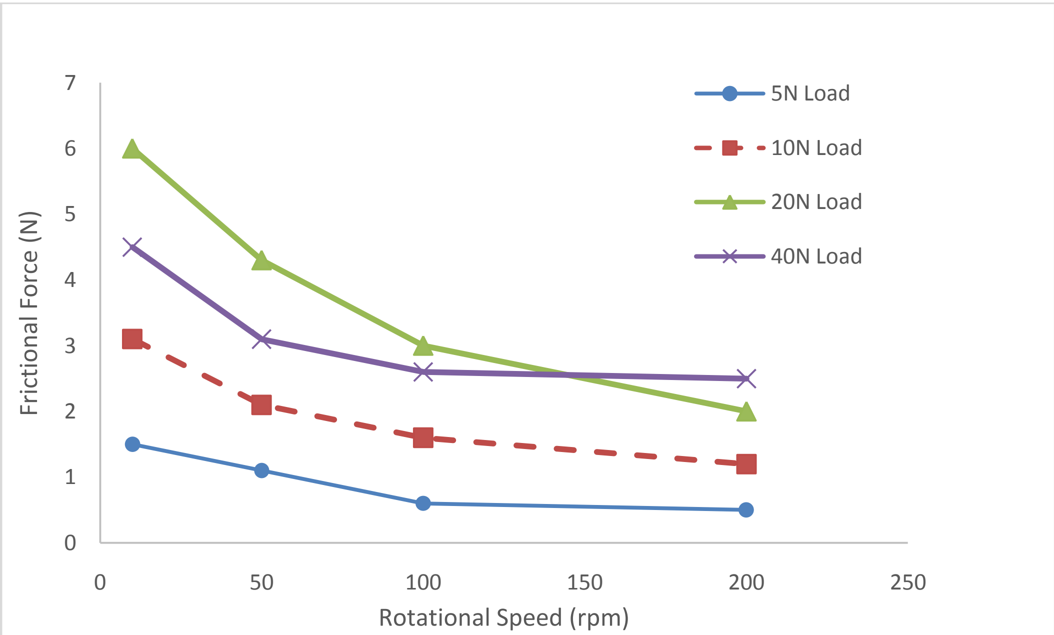

Fig. 3.2: Effect of rotational speed and load on friction force for vegetable oil with 0.5 g Boric acid.

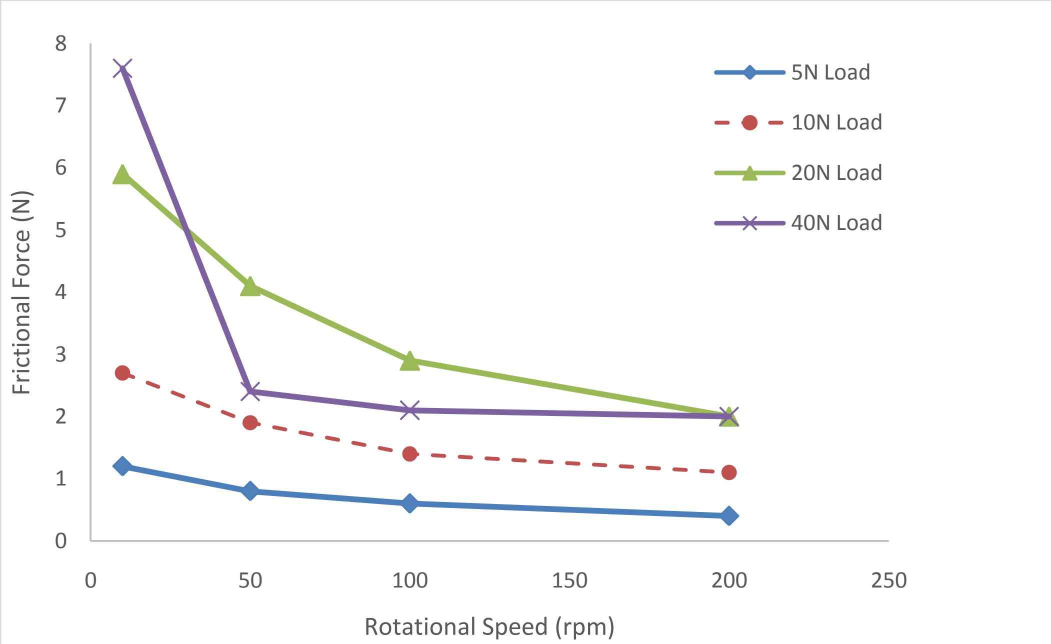

Fig. 3.3: Effect of rotational speed and load on friction force for vegetable oil with 1g of Boric acid

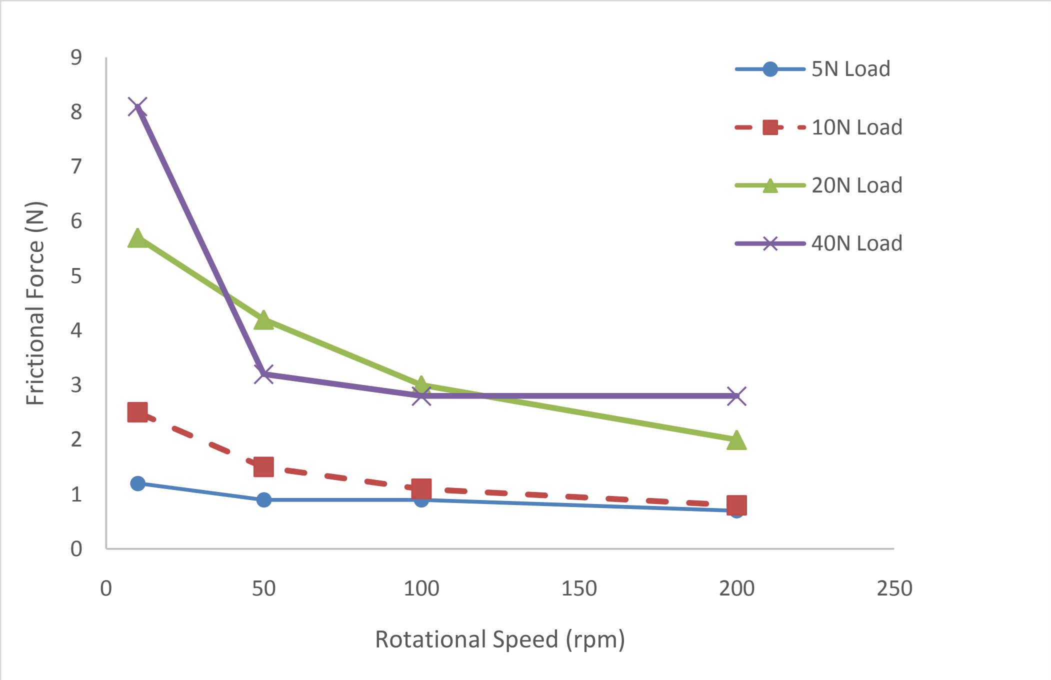

Fig. 3.4 Effect of rotational speed and load on friction force for vegetable oil with 2 g of Boric acid

The general trend is that of a decrease in friction force with increase in rotational speed. This decrease in frictional force may be attributed to the mechanical entrapment theory. It is possible that the nanoparticles may have penetrated the contact area, created an additional protective layer as a thin lubricating film thereby enhancing in a complimentary manner the lubrication characteristics of the vegetable oil. Also, the changes in tribological behaviour may have been due to three possible mechanisms. The nanoparticles probably became molten and got welded onto the shearing surface; or they may have reacted with the specimen to form a protective layer, or tribo-sintered on the surface. In general, majority of studies agree that nanoparticles improve tribological properties of lubricants by being deposited at the contact areas and creating a protective layer [15].

3.3 Frictional force as a function of load

Figs 3.5 – 3.8 show the effects of load and rotational speed on the friction force on the contact surfaces. In terms of friction force as a function of load, the general trend is that of an increase in friction force with increase in load up to 20N and then a decrease. This trend was evident for all the rotational speeds investigated. Furthermore, for each load, the friction force decreased with increasing rotational speed with the magnitude of decrease being larger for 20N compared to others. Also, it can be seen that CoF increased as the load increased. Increasing load could produce higher stress concentration in localized regions leading to localized plastic deformation, initiation and abrupt propagation of crack which in turn, could resultant in spall formation

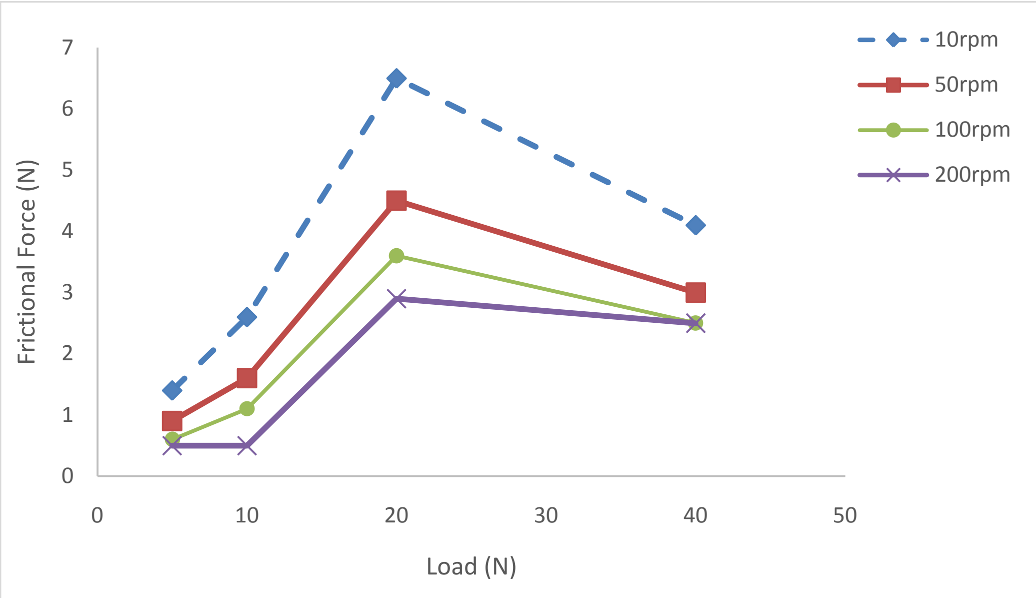

Fig. 3. 5: Effect of load on Frictional force for vegetable oil without nanoparticles

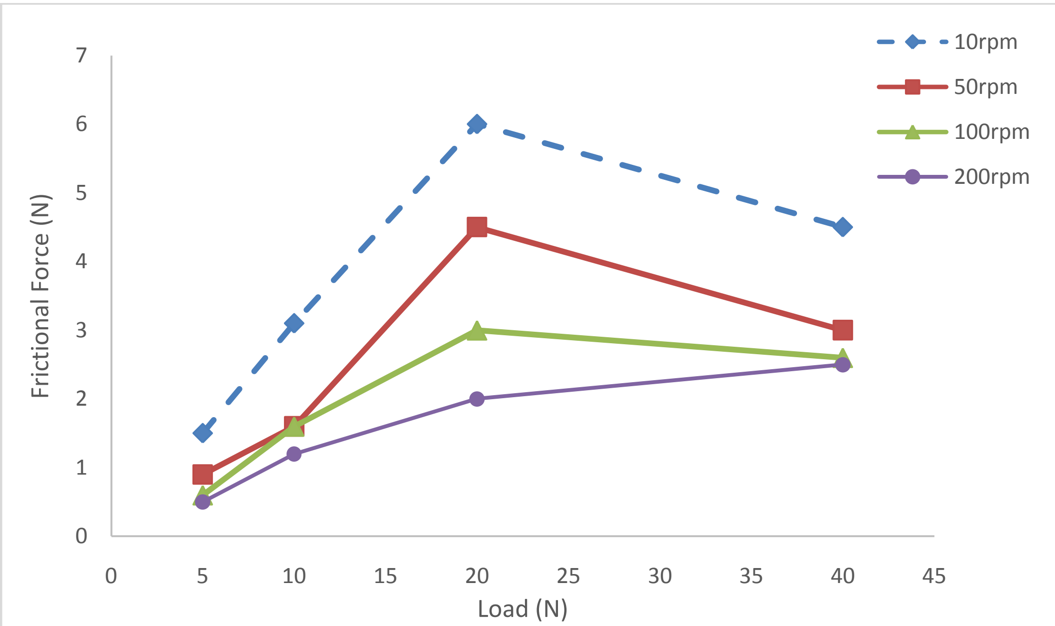

Fig. 3.6: Effect of load on Frictional force for vegetable oil with 0.5g of Boric acid

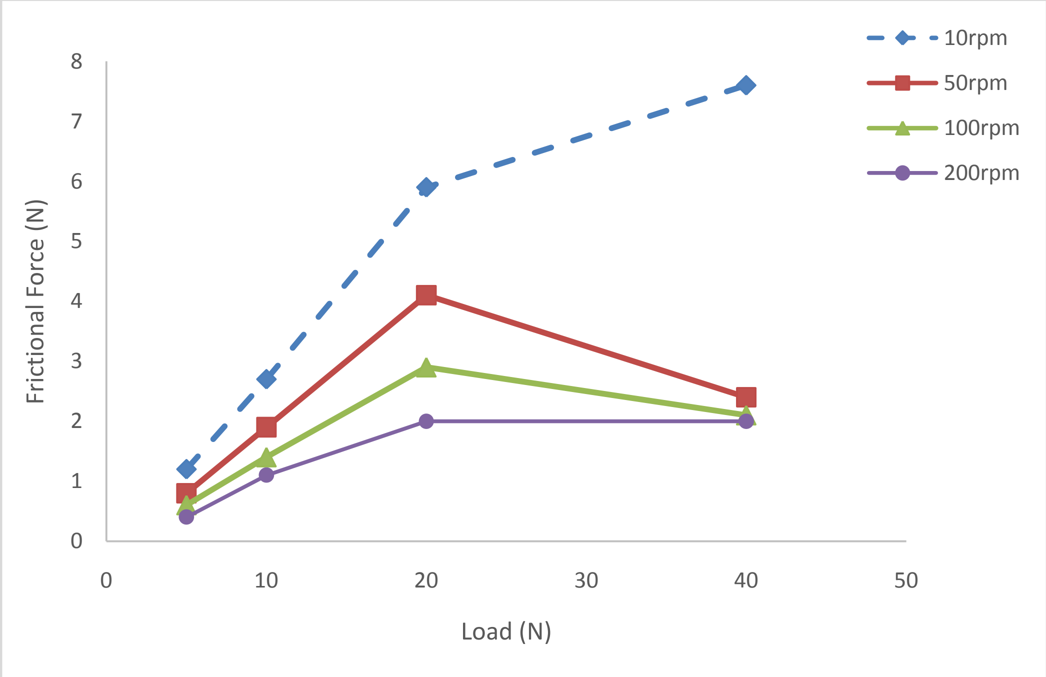

Fig. 3.7: Effect of load on Frictional force for vegetable oil with 1g of Boric acid

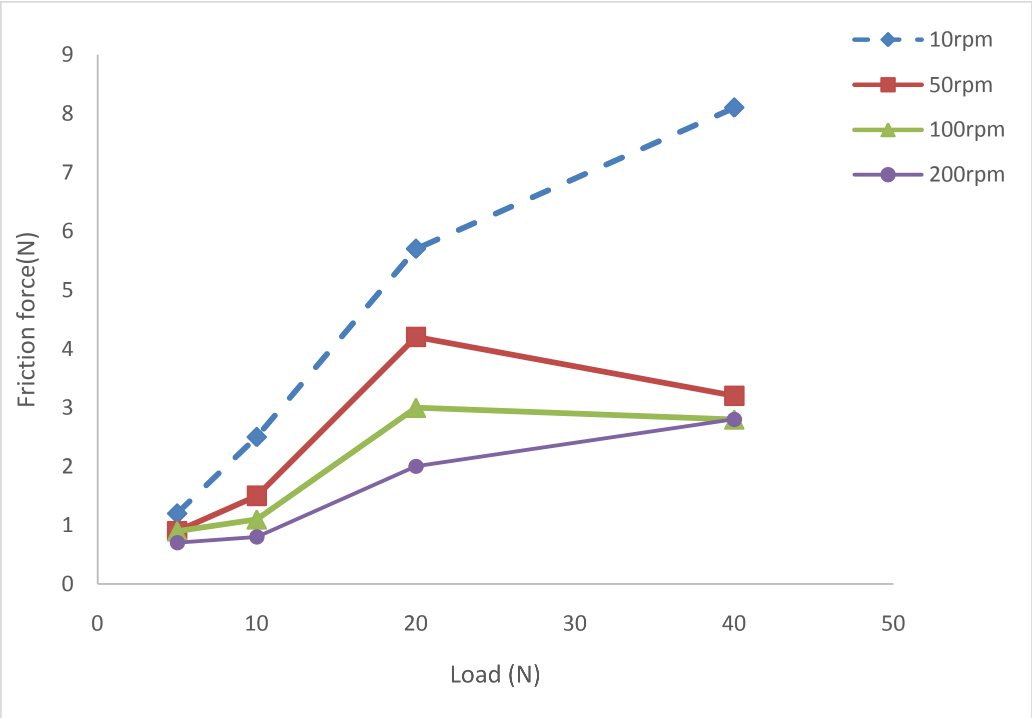

Fig.3. 8: Effect of load on Frictional force for vegetable oil with 2g of Boric acid

3.4. Effect of nanoparticle concentration on the coefficient of friction.

Fig 3.9 shows the effect of rotational speed and nanoparticle concentration in the vegetable oil on the coefficient of friction for a load of 20N

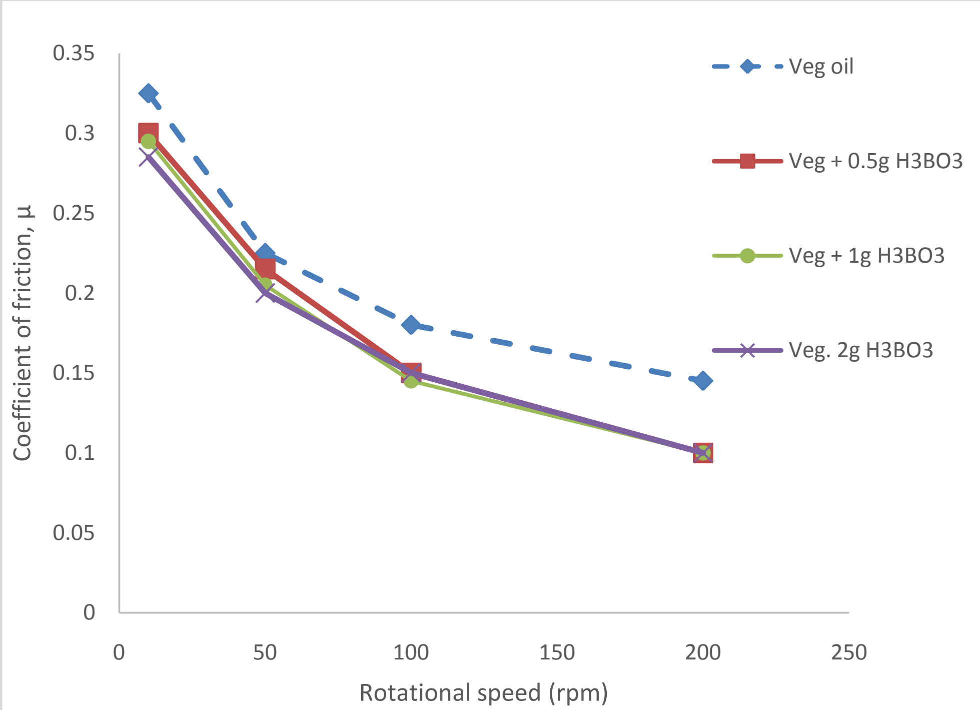

Fig. 3.9: Effect of rotational speed and particle concentration on the Coefficient of friction for the nanolubricants. Load 20N

Although, changes are evidently insignificant, the trend is that of a decrease in coefficient of friction with increase in particle concentration in the vegetable oil. Also, it is evident that for all the rotational speeds investigated, vegetable oil without nanoparticles exhibited higher coefficients of friction. This is an indication that presence of nanoparticles in the vegetable oil improved its tribological properties.

From Fig. 3.9, it is evident that for both increase in rpm or concentration of H_3BO_3 nanoparticles in the vegetable oil, coefficient of friction decreases.

Generally, the results show that coefficient of friction was lower for vegetable oil mixture with H_3BO_3 nanoparticles and evidently decreased with increase in H_3BO_3 nanoparticles. It has been reported [16] that presence of nanoparticles in lubricants improves their tribological characteristics. For instance, 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 [16]. These improvements are attributable to the formation of a protective boundary film which results in increased wear resistance of the mating surfaces. Infact, vegetable cooking oil could serve as a good and better lubricant than mineral and synthetic oils due to their long chain fatty acids [17].

IV. Conclusion

The effectiveness of Boric acid (H_3BO_3) nanoparticles as an additive to vegetable oil was investigated. The results show that H_3BO_3 nanoparticles in vegetable oil improved the tribological properties of the oil. Both frictional forces and coefficient of friction decreased in the presence of the H_3BO_3 nanoparticles as compared with the oil without nanoparticles. Generally, it was observed that nanoparticles of Boric Acid (H_3BO_3) proved to have an excellent effect in improving the lubrication characteristics of vegetable oil in terms of friction force and coefficient of reduction reduction under selected operating conditions. It was also evident that increasing the concentration of the nanoparticles in the oil decreases its coefficient of friction. Although, changes in viscosity index were insignificant, the trend tends to follow that of an increase to a maximum and then a decrease. The insignificant changes may have been due to the investigations carried out only at a constant temperature of 40^{o}C.

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