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INVESTIGATING THE TRIBOLOGICAL PROPERTIES OF MAHOGANY (*Khaya senegalensis*) SEED OIL

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ABSTRACT

Mineral oil based lubricants are non-renewable, harmful to health and prone to price fluctuations. Thus, vegetable oils are considered as suitable alternatives to mineral oils for lubricant production. Research on the use of non-edible vegetable oils for lubricant development has become necessary. The tribological evaluation of lubricant developed from non-edible vegetable (mahogany) seed oil for industrial applications have been carried out in this study. The oil was characterized, modified for suitability and used to develop lubricants for industrial applications at the petroleum chemistry laboratory American University of Nigeria (AUN) Yola. Commercially available mineral oil based lubricant SAE 20/W50 was used as a control. The mahogany seed oil exhibited a lower coefficient of friction 0.075 in comparison to the mineral oil lubricant 0.115 and also exhibited a wear rate of 0.0068 $mm^3N^{-1}m^{-1}$, which is comparable to the wear rate of the mineral oil 0.0067 $mm^3N^{-1}m^{-1}$.

KEYWORDS

Khaya senegalensis, Tribology, wear rate, coefficient of friction, and bio-lubricant

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INTRODUCTION

Petroleum-based lubricants have long been a staple in various industries due to their effectiveness in reducing friction and wear in machinery and equipment. However, their negative impact on the environment has become increasingly evident. These lubricants are non-degradable, meaning they persist in the environment for extended periods, and their toxicity poses a threat to ecosystems (Zhang *et al.*, 2020). Furthermore, the depletion of mineral oil reserves, a key component in petroleum-based lubricants, has prompted researchers to seek alternative solutions (Srinivas *et al.*, 2020). Mineral oil-based lubricants, while widely used, have their own set of drawbacks. They exhibit poor resistance to oxidation, carbon formation, and corrosion, making them less durable and effective in certain applications (Ahmad, 2021). Additionally, the increasing scarcity of fossil fuel resources has led to rising costs for petroleum-based products, further motivating the search for more sustainable alternatives.

As a result, there is a growing need to develop environmentally friendly lubricants derived from renewable sources. This has led to the exploration of bio-lubricants, which are derived from plant-based oils or synthetic esters (Salih *et al*., 2011). These bio-lubricants are being researched as a suitable replacement for petroleum-based lubricants, as they offer several advantages. They are biodegradable, meaning they break down naturally over time, and they are non-toxic to humans and aquatic life, reducing their impact on the environment (Noreen *et al*., 2021). Bio-lubricants have been shown to have superior physical and chemical characteristics compared to traditional petroleum-based lubricants (Noreen *et al*., 2021). They have higher flash and boiling points, better lubricity, higher biodegradability, higher viscosity index, lower volatility, and are less toxic overall (Noreen *et al*., 2021). This makes them a promising alternative for a wide range of industrial applications.

Research into bio-lubricants has also identified a variety of oils that can be used in their production, including jatropha seed oil, castor seed oil, soybean oil, and sunflower oil, among others (Kumar *et al*., 2021; Cavalcanti *et al*., 2018; & Odetoye *et al*., 2016). These oils offer a renewable and sustainable source for bio-lubricant production, contributing to the overall goal of reducing reliance on non-renewable resources. Therefore, the development of bio-lubricants represents a significant step toward addressing the environmental impact of traditional lubricants. Their biodegradability, non-toxic nature, and improved properties make them a promising and sustainable alternative, driving on-going research and development in this area (Cecilia *et al*., 2020b). However, it's important to note that the use of edible oils for bio-lubricant production is not practical due to the demand for these oils in the human food supply. Using edible oils for lubricant production could lead to ecological damage by diverting land and resources away from food production (Singh *et al*., 2019).

Bahari *et al.* (2017) evaluated the tribological properties of palm oil and soybean oil mixed with ZDDP and boron compound. The soybean oil with ZDDP showed a decrease of 57 percent in wear rate as compared to pure soybean oil (Bahari *et al*., 2017). Boron nitride reduced the wear rate rather than friction in vegetable oil (Bahari *et al*., 2017).

Table 1 represents the review of the research papers done by different investigators

Table 1: Meta-analysis of vegetable oil- based lubricants

Reference	Lubricant Investigated	Contribution
Maleque*et al.,* (2003)	Palm oil	Developed lubricant additive from palm oil methyl ester
Shashidhara *et al.,* (2012)	Pongam and jatropha oils	Developed lubricants from raw and modified non edible vegetable oils
Imran *et al.,* (2013)	Mineral oil and jatropha oil	Evaluated the tribological properties of blended jatropha and mineral oil lubricant
Garba *et al.,* (2013)	Jatropha curcas Seed oil	Degummed jatropha oil meets the ASTM standard for use as transformer oil.
Bilal *et al.,* (2013)	Jatropha curcas Seed Oil	Transesterification of Nigerian Jatropha oil with ethylene glycol improves pour point and gives a lubricant conformable to ISO VG-46
Mohammed, (2015)	Jatropha, moringa,castorand cotton oils	Transesterification of Jatropha, Moringa seed, castor and cotton seed oils with trimethylolpropane improves pour point but degrades rheological properties
Binfa*et al.,* (2015)	castor oil and commercial engine oil	Pure oil from castor bean carry better "lubricity and welding load, than foreign 20W-50 crankc oil found in market
Zulkifli *et al.,* (2015)	Palm oil	Developed bio-lubricant from palm oil and polyols
Kania *et al.,* (2017)	Palm oil	Developed drilling lubricant from palm oil and polyol esters
Menkiti*et al.,* (2015)	Fluted pumpkin seed	Optimised synthesis of bio-lubricant from fluted

The primary function of a lubricant is to minimize wear, friction, and surface damage throughout the intended lifespan of a mechanical system. The tribological assessment of lubricants involves measuring parameters such as frictional forces, friction coefficient, wear rate, and wear scar diameter. Zainal (2015) investigated the physical property of canola oil when blended with ZDDP as an additive. In this study, the sample was prepared with 0 wt%, 2 wt% and 5 wt% concentration by using direct injection method. To determine the concentration of percentage zinc and phosphorus, a rotating disc electrode was used, and the sample was used to determine the kinematic viscosity using heated viscometer (Azhari, 2014).

This study aims to evaluate the tribological properties of mahogany seed oil as bio-lubricant and modify it with additives to assess its potential application in lubrication processes.

MATERIALS AND METHODS

The study utilized locally sourced mahogany *(Khaya senegalensis)* seed oil from Borno State, as well as a commercially available lubricant (SAE 20/W50) obtained from Ammasco International Limited in Yola, for comparison. Distilled water and Potassium methoxide were prepared in the Petroleum Chemistry laboratory at the American University of Nigeria (AUN) in Yola. Various chemical reagents and lubricant additives were also used.

Tribo-meter

The Anton Paar standard tribo-meter TRN version 6.1.19 was used for the tribological evaluation of the oil and lubricant. The TRN model standard tribo-meter is an Austrian design which can be used as a pin-on disc or ball-on-disc tribo-meter. It has an electronic microscope fitted for wear measurements and has several sensors connected to a computer for data acquisition and processing.

Tribological evaluation of mahogany seed oil and developed lubricant

The tribological evaluation of the mahogany seed oil and developed lubricant was achieved in the Metallurgical and Materials Engineering Laboratory of Ahmadu Bello University, Zaria. The evaluation was done using the Anton Paar standard tribo-meter TRN version 6.1.19. Circular 10 mm diameter aluminium (SAE 332) disc was prepared. The disc has a tensile strength of 250

MPa, yield strength of 190MPa and 1% elongation at 240ºC. The composition of the circular disc is shown in Table 2the disc was mounted on the rotating plate holder as shown in Figure1. Next, 2 milliliters of the lubricant was applied to the surface where the disc and ball made contact, and the system was activated. The tribo-meter was turned on for data acquisition; the acquired data was saved for further processing at each experimental interval.

Table 2: Chemical Composition of the SAE 332 Aluminium circular disc

Element	**Cu**	**Mg**	**Al**	**Si**
% composition	3.5	1.0	86.5	9

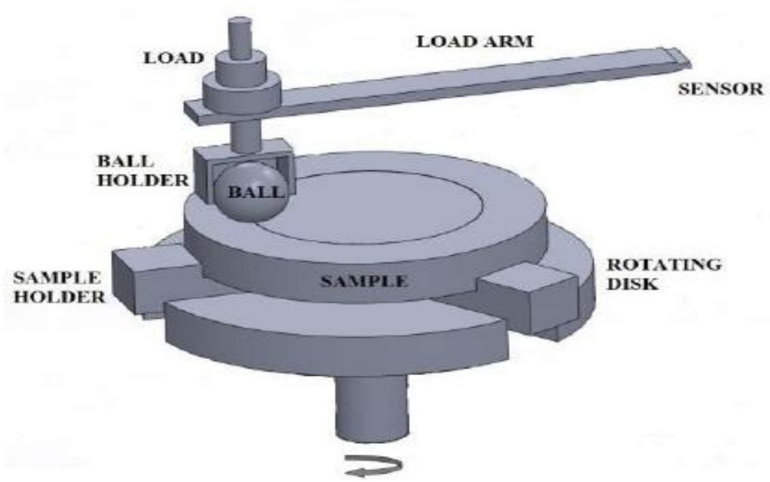

Figure 1: Schematic diagram of ball on a disc Tribo-meter (Alemdag *et al.*, 2015)

The full factorial method was used to determine the influence of control parameters on the coefficient of friction and wear rate. The Minitab 18 computer program was used to select the orthogonal system. The experimental factors and levels used in experimental design are listed in Table 3. Three factor full factorial experimental design method was used.

Table 3: Treatments for the 3^3 Full factorial Design of Experiment

		Factor A		
Factor B	**Factor C**	**0**	**1**	**2**
0	0	000	100	200
0	1	001	101	201
0	2	002	102	202
1	0	010	110	210
1	1	011	111	211
1	2	012	112	212
2	0	020	120	220
2	1	021	121	221
2	2	022	122	222

RESULTS AND DISCUSSIONS

The coefficient of friction of mahogany seed oil compared to a commercial mineral oil-based lubricant is illustrated in Figure 2a. The mahogany seed oil exhibited a lower coefficient of friction (0.075) in comparison to the mineral oil lubricant (0.115). This indicates that the mahogany seed oil has a superior ability to reduce friction compared to SAE 20/W50. Consequently, machines lubricated with mahogany seed oil will experience less energy loss due to friction, leading to lower fuel consumption compared to machines lubricated with SAE 20/W50.

The plot of the wear rate of the mahogany seed oil versus the mineral oil-based lubricant is presented in Figure 2b. The mahogany seed oil exhibited a wear rate of 0.0068 $mm^3N^{-1}m^{-1}$, which is comparable to the wear rate of the mineral oil (0.0067 $mm^3N^{-1}m^{-1}$). This suggests that the mahogany seed oil performs favourably in terms of wear rate when compared to the mineral oil SAE 20/W50.

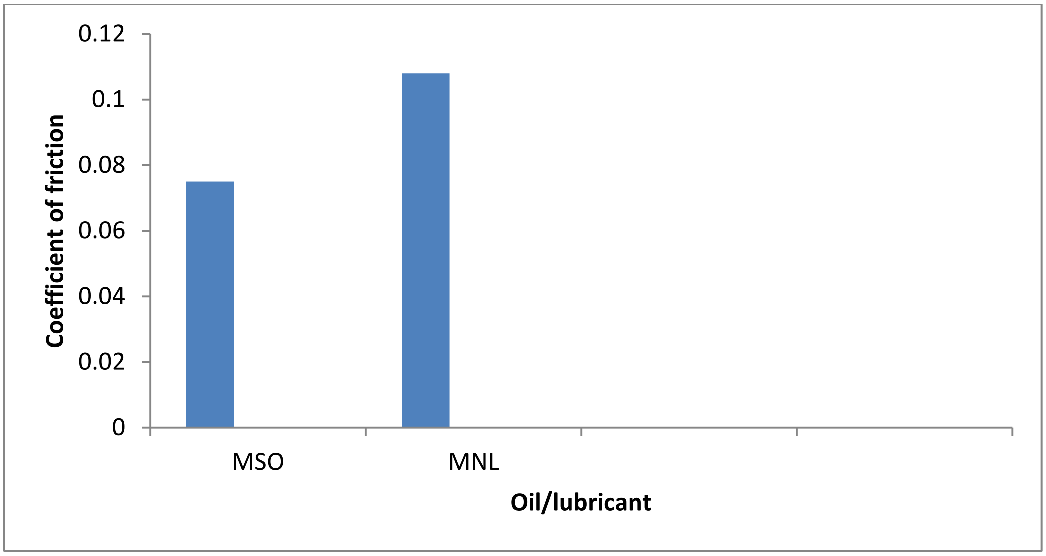

Figure 2a: Friction coefficient of mahogany seed oil

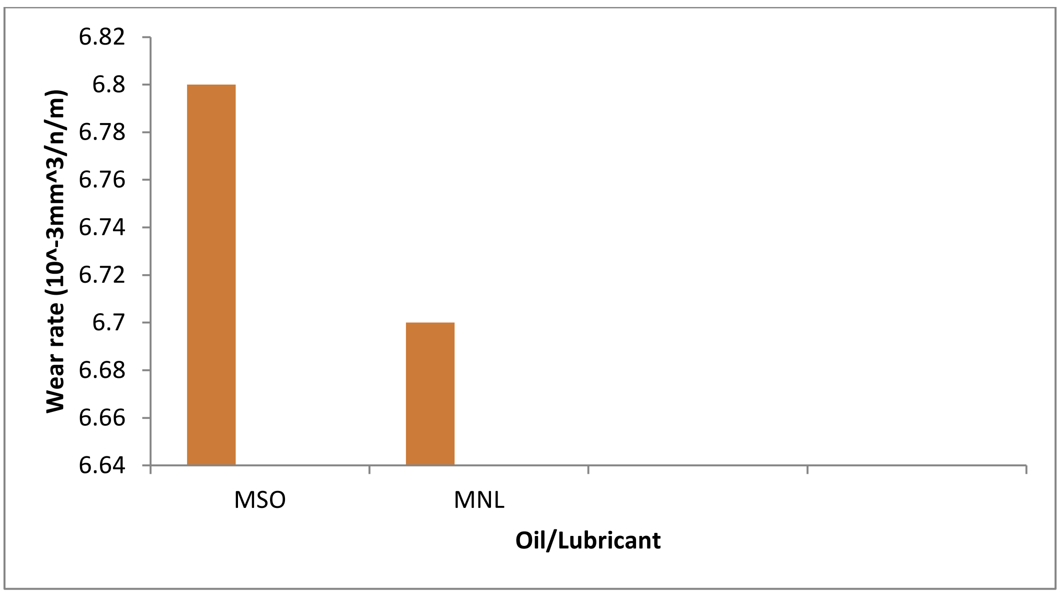

Figure 2b: Wear rate of mahogany seed oil

Tribological properties of the developed mahogany seed oil bio-lubricant

The coefficient of friction of the developed mahogany seed oil bio-lubricants as compared to the mineral oil base lubricant is shown in Figure 3. The chart of the wear rate of the developed mahogany oil bio-lubricant is as shown in Figure 4. The mahogany oil bio-lubricant had lower friction coefficient (0.095) compared to mineral base lubricant (0.115). Mahogany seed oil bio-lubricant friction coefficient is higher than the friction coefficient of the unmodified mahogany seed oil.The vegetable (mahogany) oil-based lubricant had a better friction reduction property than the commercial mineral oil-based lubricant (SAE 20/W50).

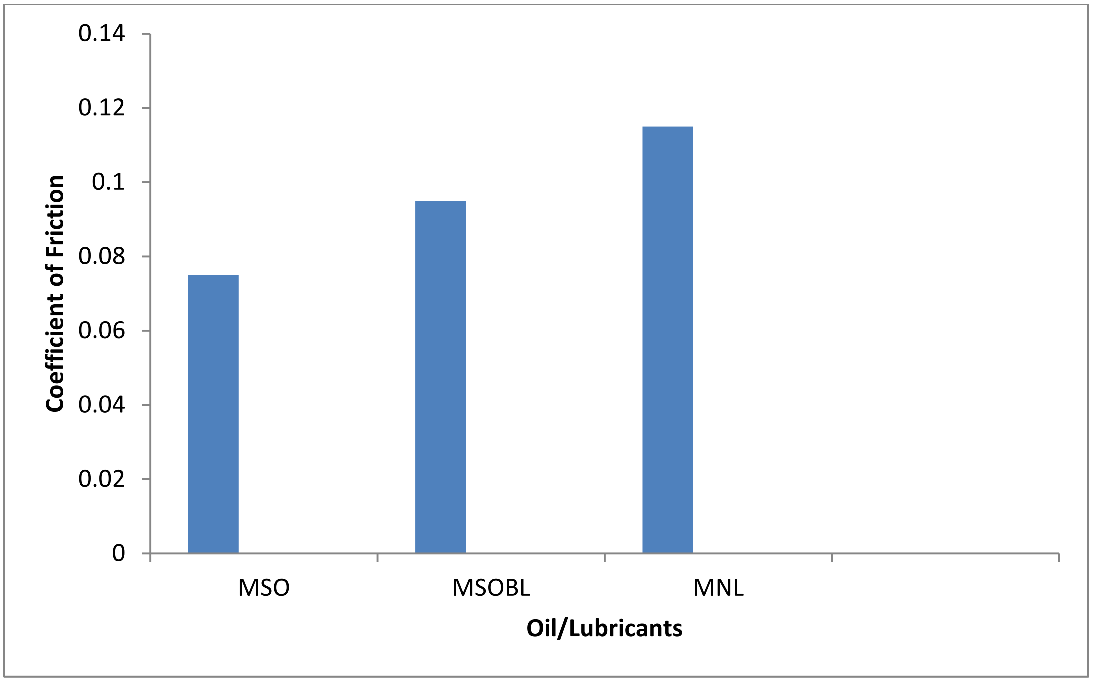

Figure 3: Coefficient of friction of developed mahogany seed oil bio-lubricant and mineral based lubricant

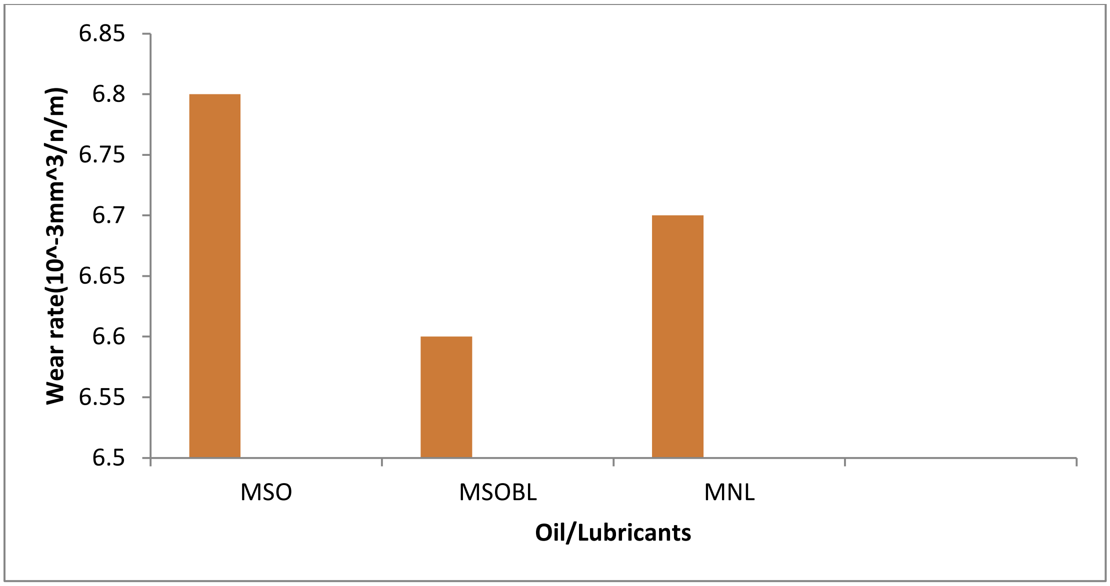

Figure 4: Wear rate of developed mahogany seed oil bio-lubricant and mineral based lubricant

The wear rate of the developed mahogany seed oil bio-lubricant was 0.00660 mm $^{3}N^{-1}m^{-1}$ which is lower than the wear rate of the mineral base oil (0.00670 $mm^3N^{-1}m^{-1}$). The developed mahogany seed oil bio-lubricant performed better in friction and in wear protection than the commercial mineral oil base lubricant (SAE 20/W50). It can be deduced that transesterification of the mahogany seed oil with TMP polyol slightly improved its tribological properties in terms of wear property, but the friction coefficient was increased (Woma, 2021).

The experimental process parameters and the corresponding responses are shown in the tables 4a and 4b respectively.

Table 4a: Coefficient of friction of mahogany bio-lubricant at 0 % of ZDDP

Normal load(N)	**Sliding speed(m/s)**		
	0.1	0.2	0.3
10	0.090	0.096	0.100
20	0.095	0.099	0.103
30	0.098	0.102	0.108

The findings of the coefficient of friction of mahogany seed oil bio-lubricant without ZDDP additive at different levels of sliding speed and normal load is presented in Table 4a. It shows that the coefficient of friction increases with increase in the normal load and increases with the increase in sliding speed.

Table 4b: Wear rate ($10^{-3}mm^3/N/m$) of mahogany bio-lubricant at 0 % of ZDDP

Normal load(N)	**Sliding speed(m/s)**		
	0.1	0.2	0.3
10	6.45	6.56	6.61
20	6.60	6.73	6.80
30	6.71	6.76	6.87

The findings of the wear rate of mahogany seed oil bio-lubricant without ZDDP additive at different levels of sliding speed and normal load is shown in Table 4b. It shows that the wear rate increases with increase in the normal load and increases with the increase in sliding speed.

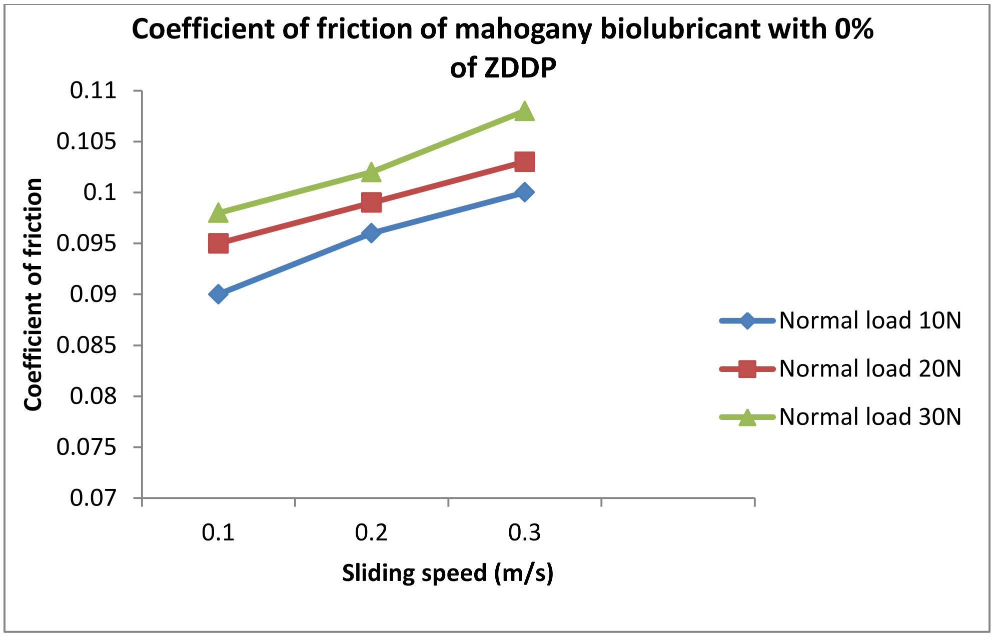

Figure 5: Coefficientof Friction of mahogany bio-lubricant with 0% of ZDDP additive.

Figure 5 illustrates the variation in the coefficient of friction of mahogany seed oil bio-lubricant without ZDDP additive as the normal load and sliding speed are altered. At a normal load of 10N and a sliding speed of 0.1m/s, the coefficient of friction is 0.09. When the sliding speed is increased to 0.2m/s, the coefficient of friction rises to 0.096, and a further increase in sliding speed to 0.3m/s results in a higher coefficient of friction of 0.1. When a load of 20N is applied and the sliding speed is set at 0.1m/s, the coefficient of friction is 0.095. When the sliding speed is increased to 0.2m/s, the coefficient of friction rises to 0.099, and when the speed is further increased to 0.3m/s, the coefficient of friction also increases to 0.103.When a 30N load is applied at a sliding speed of 0.1m/s, the coefficient of friction is 0.098. When the sliding speed is increased to 0.2m/s, the coefficient of friction also increases to 0.102. Further increase of the sliding speed to 0.3m/s results in the coefficient of friction increasing to 0.108.

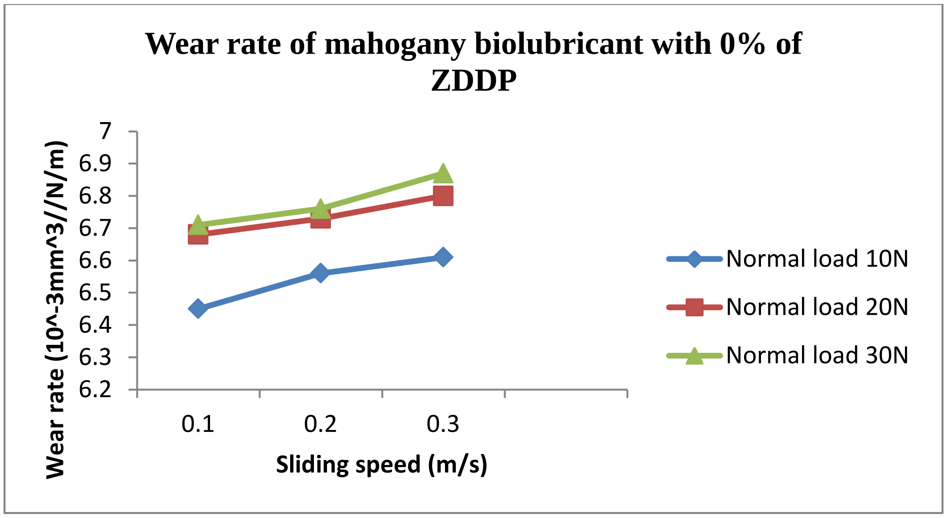

Figure 6: Wear rate of mahogany bio-lubricant with 0% of ZDDP additive

Figure 6 illustrates the variation in the wear rate of mahogany seed oil bio-lubricant without ZDDP additive as the normal load and sliding speed are altered. At a normal load of 10N and a sliding speed of 0.1m/s, the wear rate is 6.45x$10^{-3}$$mm^3$/N/m. When the sliding speed is increased to 0.2m/s, the wear rate rises to 6.56x$10^{-3}$$mm^3$/N/m, and a further increase in sliding speed to 0.3m/s results in a higher wear rate of 6.61x$10^{-3}$$mm^3$/N/m. When a load of 20N is applied and the sliding speed is set at 0.1m/s, the wear rate is 6.68x$10^{-3}$$mm^3$/N/m. When the sliding speed is increased to 0.2m/s, the wear rate rises to 6.73x$10^{-3}$$mm^3$/N/m, and when the speed is further increased to 0.3m/s, the wear rate also increases to 6.8x$10^{-3}$$mm^3$/N/m**.**When a 30N load is applied at a sliding speed of 0.1m/s, the wear rate is 6.71x$10^{-}$$mm^3$/N/m ^{3}. When the sliding speed is increased to 0.2m/s, the wear rate also increases to 6.76x$10^{-3}$$mm^3$/N/m. Further increase of the sliding speed to 0.3m/s results in the wear rate increasing to 6.87x$10^{-3}$$mm^3$/N/m.

CONCLUSION

The tribological evaluation of the lubricant developed from mahogany seed oil for industrial applications was successfully carried out in this study; in the tribological evaluation of the mahogany seed oil-based lubricant, it was found that the oil performed better than SAE 20W/50 in reducing friction, while SAE 20W/50 was better in preventing wear. The modification of mahogany seed oil through acid-catalyzed esterification reduced its friction performance but improved its wear performance. The developed mahogany seed oil biolubricant at 3% of ZDDP was found to have better frictional performance than SAE 20W50 and similar wear performance to SAE 20W/50. The study concluded that the developed mahogany seed oil-based lubricant is a suitable replacement for environmentally harmful mineral-based lubricants in industrial applications.

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CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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