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[1.] K. K. IKPAMBESE, [2]A. A. ONOGU, [3.] H. C. OLISAKWE

EFFECTS OF BIO ADDITIVES ON TRIBOLOGICAL CHARACTERISTICS OF BIO LUBRICANTS FORMULATED FROM SELECTED BIO OILS

[1.]Department of Mechanical Engineering, University of Agriculture, P.M.B. 2373, Makurdi, NIGERIA
[2.]Works and Maintenance Department, Kogi State University Ayingba, Kogi State, NIGERIA
[3.]Department of Mechanical Engineering, Nnamdi Azikiwe University Awka, NIGERIA

Abstract: In this study, the effect of bio additives on the tribological characteristics of bio lubricants formulated from some selected bio oils was carried out. The Bio additives were obtained from Moringa tree bark, Jatropha stem, Yellow oleander latex, Cocoyam stem and African elemi tree bark using ASTM D5369-93. The characterization of the bio additives was also done using using atomic absorption spectroscopy to determine their active elements. The bio lubricants were formulated by mixing each bio based oil with respective bio additives differently in a ratio of 70 % bio base oil with 30 % bio additives. ASTM standards were used to carry out test on the formulated bio lubricants to determine friction and wear performance. The result of characterization of bio additives revealed the presence of active elements such as Iron (Fe), Nickel (Ni), Copper (Cu), Lead (Pb), Magnesium (Mg), Zinc (Zn) and Manganese (Mn) which improved the properties of bio based oils used as lubricants. Coefficient of friction varied from 0.0815 (bio lubricant from Yellow oleander seed oil) to 0.0895 (bio lubricant from Palm kernel oil). The ANOVA confirmed that there was significance difference in the Coefficient of friction with addition of additives as $F = 57.81651 > Fcrit = 2.866081$. It was observed that the wear increased as the pressure applied was increase for all the formulated bio lubricants. The ANOVA at 5 % significant level clearly showed that the bio additives had significant effect on the formulated bio lubricants in terms of wear depth. This research provides information to lubricants producers for replacement of synthetic and mineral based additives with natural plant additives for lubricants production.
Keywords: Bio-additives; bio-lubricants, Coefficient of friction, Wear depth, Bio oils

INTRODUCTION

Due to increased stringent environmental regulations there are efforts by researchers to develop lubricants which are fully or partially biodegradable and do not have toxic effects on the environment. One of these ways is by utilization of bio additives obtained from natural source of plants and animals [1]. Bio additives are bio-based concentrates that can be added to any lubricating oil to improve lubrication performance. Additives in lubricating oils play an important role in the reduction of friction and wear between two mating surfaces [2]. Without additive, even the best base oils are deficient in some features, as performance of a lubricant depends collectively on the base oil, additives and formulation [3]. Mang and Dresel [4] also affirmed that base oils alone are sometimes unable to meet the lubricant requirement of a component so additives are utilized to improve lubrication by modifying their properties, and performance on the metal surfaces.

According to [3] intensive review of previous works show that vegetable oils and natural plants have potential to be used as lubricants and additives to replace conventional lubricants and additives. At present, lubricants derived from natural sources exhibit a promising potential as a new class of eco-friendly lubricants [5, 6]. Balamurugan *et al.* [7] also affirmed that properties of vegetable oils such as high viscosity index, low volatility, higher shear stability, etc make them more suitable for lubrication over mineral oils. However, their applicability in lubrication is partly limited, as they tend to show low oxidative stability and higher melting points. Shahabuddin *et al.* [6] found that chemical modifications through blending with additives can solve these problems.

Recent studies have focused on the development of fully environmentally friendly lubricants by using bio additives in an attempt to provide suitable alternatives to petroleum based lubricants. Shahabuddin *et al.* [6] studied the comparative tribological evaluation of bio-lubricants formulated from jathropha oil. The bio-lubricants were formulated using 10-50 % by volume of Jatropha oil (JO) blended with SAE 40 as the base lubricant. The experimental results showed that the lubrication regime that occurred during the test was boundary lubrication while the main wear mechanisms were abrasive and adhesive wear. During Cygnus wear testing, the lowest wear was found with the addition of 10 % JO, and above 20 % JO the wear rate was increased considerably. The authors concluded that the addition of Jatropha oil in the base lubricant acted as a very good lubricant additive which reduced the friction and wear scar diameter at a maximum of 34 % and 29 % respectively during the tribo-test. Hence, the application of 10 % bio-lubricant in the automotive engine will enhance the mechanical efficiency and contribute in reducing the dependency on petroleum oil as well. Biodegradable additives of palm oil methyl ester (POME) and castor oil (CO) in soya bean oil (SO) based lubricant for diesel engines was studied by Balamurugan *et al.* [7]. These bio-additives were added to soya bean methyl ester to improve wear resistance and oxidation stability. Various soya bean oil formulations were used as lubricants in diesel engines and the sump oil temperature measured compared favorably with SAE 40. The result revealed that the physico-chemical properties of the soya bean oils were similar to those of commercial mineral oil. The engine performance and lube oil temperature were not significantly different for soya bean oil as compared with the manufacturer's recommended oil. Hence the blends of soya bean with POME and CO can be used as a crankcase oils.

The increasing environmental issues regarding biodegradability, renewability, toxicity and health and safety risks have been gaining attention towards the development of bio-based lubricants. Some researchers tend to investigate the potential use of vegetable oils [8] and leave the shortcomings of additive formulations, while others are more interested in chemical modifications of these vegetable oils in order to improve their properties [9]. The lube oil properties include both bulk and surface properties, but it is believed that no single molecule can meet all desired properties. Thus, further formulations using additives are usually required to meet certain application's specific requirements. Bio additives and bio base oils can be obtained from oil bearing crops and according to reports over 350 oil bearing crops are available worldwide [4].

The main focus of this study is to investigate the effects of bio additives on friction and wear produced from locally available oil bearing crops on some selected bio base oils. Extracts of Moringa tree bark *(Moringa oleifera)* (M), Jatropha stem *(Jatropha curcas)* (J), Yellow oleander latex *(Nerium oleander)* (Y), Cocoyam stem *(Colocasia esculenta)* (C) and African elemi tree bark *(Canarium schweinfurthii)* (A), were used as bio additives. While Jatropha seeds oil *(Jatropa curcas)* (J_1), Palm kernel nut seeds oil *(Elacis guineansis)* (P), Soybean seeds *(Glycine soja)* (S), Yellow oleander seeds oil *(Nerium oleander)* (Y_1) and Groundnuts seeds *(Arachis hypogeae)* (G), were used as bio base oil.

MATERIALS AND METHODS

— Preparation of bio base stock & bio additives samples

The raw material for the bio base stock were 5 kg seeds each from the following oil plants, Jatropha, Palm kernel, Soybean, Groundnut and Yellow oleander obtained locally from Kogi State University (KSU) Anyigba, Kogi State, Nigeria. They were properly cleaned to eliminate foreign particles like stones and other impurities. They were dried at room temperature to sufficiently reduce the moisture content, and reduced to smaller sizes using a mortar-pestle and later ground into powder with the aid of a grinding machine to provide a greater surface area for contact with the solvent. Soxhlet extraction process (N-hexane as solvent) in accordance with ASTM D5369-93 was used to extract the oils as bio base stocks

The raw materials for the bio additives were 2 kg dried stems each and 2 litres of latex from the following oil plants stems, Moringa tree barks, Jatropha stems, Yellow oleander latex from fresh stems, Cocoyam stems, and African elemi tree barks obtained from Kogi State University (KSU) Anyigba Kogi State Nigeria. These stems were cut and dried at room temperature to sufficiently reduce their moisture content and properly cleaned to eliminate foreign particles on them. They were pounded in a mortar and ground into powder in a grinding machine as to reduce their sizes and create greater surface area for contact with the solvent. The bio additives were also extracted using Soxhlet extraction method (N-hexane as solvent) in accordance with ASTM D5369-93.

— Characterization of bio additive samples

The bio additives obtained from the plants were characterized using Atomic Absorption Spectrometer Perkin-El-mer model 460 to determine the active elements present in the extracts. A quantity of 2 ml of each of the sample extracts were measured and transferred into beakers and properly coded. The quantity of 10ml each of Nitric acid and HCL were added to each of the beakers and the samples agitated by placing them on a hot plate to raise their temperature to 100 °C for at least one hour. These samples were filtered using a filter to remove all unfiltered soluble within the digested samples after allowing them to cool for 20 minutes. These samples were referred to as digested samples as they were fully ready for atomic absorption spectroscopy (AAS) test. They were one after another introduced into the heating chamber of Perkin-El-mer model 460 atomic absorption spectrometer. Optical and measurement parameters were adjusted for each of the elements detected as to measure the amount of energy absorbed by each of the samples. A detector was used to measure the wavelengths of light transmitted by the sample (the "after" wavelengths) and compared them to the wavelengths which originally passed through the sample (the "before" wavelengths) as each atom has a distinct wavelength. A signal processor then integrates the changes in wavelength, which were readout as peaks of energy on a computer attached to the equipment

— Formulation of the Bio lubricants using Bio additives

The formulation process involved mixing the bio base oils with the bio additives in a required proportion as it done with the convention lubricants. Quantities of bio base oils and the bio additives in pre-determined ratios (as presented in Table 1) were put into a homogenizer and properly blended. Twenty five (25) bio lubricants samples were formulated from the extracted bio base oils after the blending process with the bio additives obtained from the plants been investigated

Table 1: Bio lubricant formulated containing 70 % bio base stocks and 30 % bio additives

Bio additives	Bio Base stock				
	J_1 (70 %)	P (70 %)	S (70 %)	Y_1 (70 %)	G (70 %)
M, (30 %)	J_1M	PM	SM	Y_1M	GM
J, (30 %)	J_1J	PJ	SJ	Y_1J	GJ
Y, (30 %)	J_1Y	PY	SY	Y_1Y	GY
C, (30 %)	J_1C	PC	SC	Y_1C	GC
A, (30 %)	J_1A	PA	SA	Y_1A	GA

BIO ADDITIVES	BIO BASE OILS
M = Moringa tree bark additive	J_1 = Jatropha seed oil
J = Jatropha stem additive	P = Palm kernel nut oil
Y = Yellow oleander latex additive	S = Soybean seed oil
C = Cocoyam stem additive	Y_1 = Yellow oleander seed oil
A = African elemi tree additive	G = Groundnut seed oil

— Evaluation of tribological performance of the formulated bio lubricants

The evaluation of frictional and wear performance of the effects of bio additives on the bio lubricants formulated and reference oils{HDO (SAE 40) and LDO (SAE 30)} was carried out on a Four Balls Rotary tester in accordance with ASTM D 2596 and ASTM G 99(2014) respectively. The Four Balls Rotary tester presented in Figure 1 has the upper holder with one rotating steel ball loaded against three stationary lower steel balls. Prior to conducting the test it was ensured that the surface of the pin and disc were cleaned properly to be free from dirt and debris. All contact areas were submerged in the lubricant and the test, pressures varied from 10 N/mm^2 - 50 N/mm^2 through a hydraulic system in steps of 10 N/mm^2. The ball rotates at 60 rpm through a variable speed drive motor of 2 hp/240 v with a speed range of 60-3000 rpm. The rotation was central along the symmetry axis of both the upper and the lower holders. Piezo electric sensor measured friction force as the rotating disc was heated to 300 ^{0}C, the temperature and rpm were displayed digitally. The applied load was varied from the ranges of 10 N - 50 N, starting with 10 N to obtain the corresponding co-efficient of frictions. While the wear characteristic (wear depth) was measured with high accuracy load cells and values indicated electronically on an indicator as the critical pressures that lead to wear were observed.

Figure 1: Pin-On-Disc Tribotester Set Up

1-LCD; 2-Pin-on-disk assembly; 3-Electric motor; 4-Amplifier/signal processor

RESULTS AND DISCUSION

The results characterization of bio additives obtained from Moringa tree bark (M), Jatropha stem (J), Yellow oleander latex (Y), Cocoyam stem (C) and African elemi tree bark (A) are presented in Table 2. These elements present in the bio additives were similar to those present in conventional additives as reported by Azmi et al. (2016) and Atiya (2013) suggesting that Moringa tree bark, Jatropha stem, Yellow oleander latex, Cocoyam stem and African elemi tree bark extracts can be used as lubricant additives as their functions or actions has the additives qualities of detergent, dispersant, anti- wear, anti-foaming, anti-oxidant, friction modifier, anti-rust, anti-corrosion additives. The authors stated that these elements are usually utilized in engine oils which act as an anti-wear or friction reduction media which formed protective film by physical or chemical absorption to the surface of the metals in contact.

Table 2: Bio additives basic elements obtained by Atomic Absorption Spectroscopy

Elements	Bio additives				
	M	J	Y	C	A
Fe	0.0342	0.0923	0.0581	0.0769	0.1777
Ni	0.0111	0.0222	0.0210	0.0439	0.0034
Cu	0.0015	0.0006	0.0004	0.0046	0.0062
Pb	0.5816	0.4836	0.2230	0.1313	0.5441
Mg	0.0141	0.0408	0.0064	0.0084	0.0157
Zn	0.0004	0.0107	0.0039	0.0439	0.0055
Mn	0.0332	0,0370	0.0248	0.0208	0.0132

— Friction Performance of the Bio Lubricants

Figures 2-6 show the effect of applied load and lubrication condition on the coefficient of friction (COF) at 30 rpm for bio lubricants formulated and reference oils. Coefficient of friction increased steadily with applied load for all the lubricants. Similar results were obtained by [4] while investigating the effect of load on COF of lubricating oils. Light duty oil (LDO) presented the highest COF while heavy duty oil (HDO) presented the lowest COF in all loads. At lower loads the trend of COFs of the formulated bio lubricants (Jathropha seed oil (J_1 as base oil) were (HDO) < (J_1M) < (J_1J) < (J_1Y) = (J_1C) = (J_1A) < (LDO), while at higher loads were (HDO) < (J_1Y) = (J_1A) < (J_1J) < (J_1M) = (LDO) < (J1C). It implies that at lower load bio lubricant J_1M gave a lower value of COF, while at high load the bio lubricant J_1Y gave higher value of COF. Higher value of COF indicates high friction resistance which can probably lead to more wear. In Figure 3 the bio base oil (P) blended with bio additives and reference oils at lower loads exhibited COF as (HDO) < (PM) = (PJ) = (PY) = (PA) < (PC) < (LDO) while at higher loads were (HDO) < (PM) < (PC) < (PY) = (PA) < (PJ) = (LDO). The similar trend was observed for bio lubricants produced from bio base oil and reference oils as (Figure 4) (HDO) = (SC) < (SY) = (SA) < (SJ) = (SM) < (LDO) and at higher loads were (HDO) < (SM) = (SC) < (SY) = (SA) = (LDO) < (SJ).

The COFs for the bio lubricant formulated from bio base oil Y_1 and reference oil (Figure 5) were (HDO) = (Y_1A) < (Y_1J) = (Y_1C) < (Y_1Y) < (Y_1M) < (LDO) while at higher loads were (HDO) < (Y_1J) < (Y_1C) < (Y_1Y) < (LDO) < (Y_1A) < (Y_1M). The trend of COFs (Figure 6) were (HDO) < (GC) < (GA) < (GY) < (GJ) < (GM) < (LDO) and (HDO) < (GA) < (LDO) < (GC) < (GY) = (GJ) = (GM). at lower and higher respectively, for the bio lubricants formulated from bio base oil G. The coefficient of friction of the formulated bio base oils ranged from 0.0815 - 0.09. These values were within established standard range of 0.07 - 0.09 for lubricating oil.

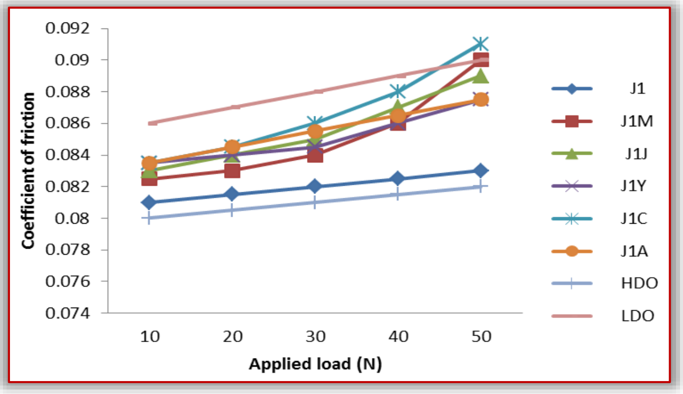

Figure 2: Effect of Applied Load and Lubrication Condition on the Coefficient of Friction at 30 rpm for blended (J_1) oil, pure (J_1) oil and reference oils.

J_1 = Bio base oil from Jatropha seed; J_1M = Mixture of Jatropha seed oil and Moringa tree additives J_1J = Mixture of Jatropha seed oil and Jatropha stem additives J_1Y = Mixture of Jatropha seed oil and Yellow Oleander latex additives; J_1C = Mixture of Jatropha seed oil and Cocoyam stem additives; J_1A =Mixture of Jatropha seed oil African elemi tree additives; HDO = Heavy duty oil; LDO = Light duty oil.

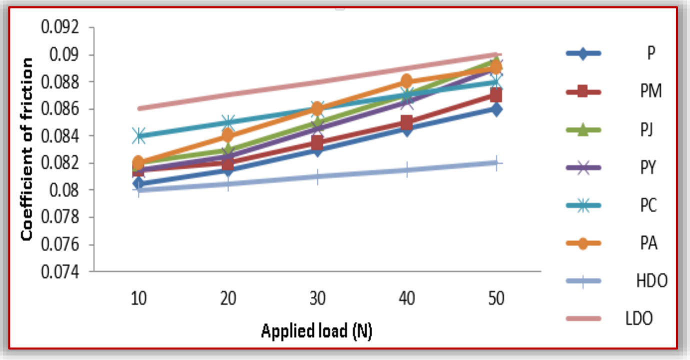

Figure 3: Effect of Applied Load and Lubrication Condition on the Coefficient of Friction at 30 rpm for blended (P) oil, pure (P) oil and reference oils.

P = Bio base oil from Palm kernel nut; PM = Mixture of Palm kernel nut oil and Moringa tree additives; PJ = Mixture of Palm kernel nut oil and Jatropha stem additives; PY =Mixture of Palm kernel nut oil and Yellow Oleander latex additives; PC = Mixture of Palm kernel nut oil and Cocoyam stem additives, PA = Mixture of Palm kernel nut oil African elemi tree additives; HDO = Heavy duty oil; LDO = Light duty oil

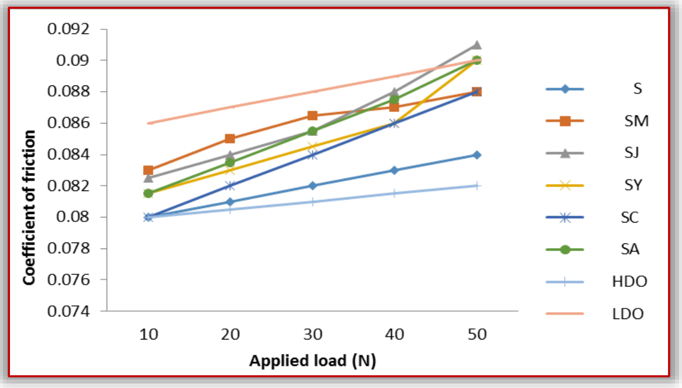

Figure 4: Effect of Applied Load and Lubrication Condition on the Coefficient of Friction at 30 rpm for blended (S) oil, pure (S) oil and reference oils.

S = Bio base oil from Soybean seed; SM = Mixture of Soybean oil and Moringa tree additives; SJ = Mixture of Soybean oil and Jatropha stem additives; SY= Mixture of Soybean oil and Yellow Oleander latex additives; SC= Mixture of Soybean oil and Cocoyam stem additives; SA = Mixture of Soybean oil African elemi tree additives; HDO = Heavy duty oil; LDO = Light duty oil

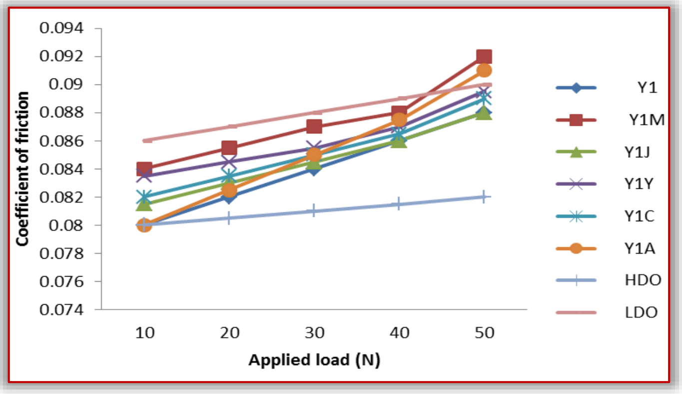

Figure 5: Effect of Applied Load and Lubrication Condition on the Coefficient of Friction at 30 rpm for blended (Y_1) oil, pure (Y_1) oil and reference oils.

Y_1 = Bio base oil from Yellow oleander seed; Y_1M = Mixture of Yellow oleander seed oil and Moringa tree additives; Y_1J = Mixture of Yellow oleander seed oil and Jatropha stem additives; Y_1Y = Mixture of Yellow oleander seed oil and Yellow oleander latex additives; Y_1C = Mixture of Yellow oleander seed oil and Cocoyam stem additives; Y_1A = Mixture of Yellow oleander seed oil and African elemi tree additives; HDO = Heavy duty oil; LDO = Light duty oil

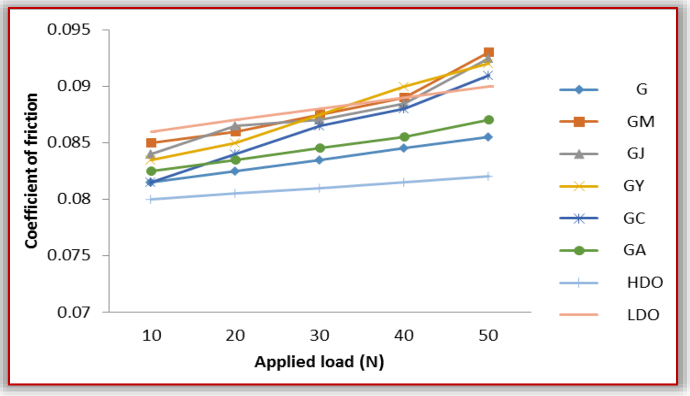

Figure 6: Effect of Applied Load and Lubrication Condition on the Coefficient of Friction at 30 rpm for blended (G) oil, pure (G) oil and reference oils.

G = Bio base oil from Groundnut seed; GM = Mixture of Groundnut oil and Moringa tree additives; GJ = Mixture of Groundnut oil and Jatropha stem additives; GY = Mixture of Groundnut oil and Yellow oleander latex additives; GC = Mixture of Groundnut oil and Cocoyam stem additives; GA = Mixture of Groundnut oil and African elemi tree additives; HDO = Heavy duty oil; LDO = Light duty oil

These results depict that the lubrication regime that existed during the experiment was boundary lubrication, with COF less than 0.1, as the COF for boundary lubrication normally within the range of 0.001 to 0.2 [6]. Generally LDO presented the highest COF at most loads due to its lower viscosity while HDO had lowest COF as it is the most viscous. These trends were similar to those results from earlier researchers which are at lower loads friction on contact area are reduced while at higher loads the friction increased. Lower resistance to wear also presents higher COF [3].

The analysis of variance for coefficient of friction of formulated bio base oils indicated that there was significant difference on the effect of bio addition of bio additives on the formulated bio lubricant at 5 % significant level. The hypothesis (Ho) was that if F ≤ Fcrit then there is no change in the coefficient of friction of the formulated bio lubricant. The other hypothesis (Ha) was that if F> Fcrit then there is significant change in coefficient of friction of the formulated bio base oils with the addition of additives into each of the bio base oils. It is obvious that there was significance difference in the coefficient of friction with the bio addition to the bio additive to the base oils as F =57.81651 > Fcrit = 2.866081.

— Wear Performance of the Bio Lubricants

Figures 7-11 show the effect of applied pressure and lubrication condition on wear depth at 60 rpm with varied pressure of 10 – 50 N/m^2 for the formulated bio lubricants and reference oils. It was observed that the wear depth increased with increase in applied pressure for all the formulated bio base oils and reference oils. Wear depth data were different for the different formulations due to the concentration of the elements present in the bio additives in the formulated bio lubricants. For Jathropha oil (J_1) blended with bio additives at lower pressures using speed of 60 rpm, the wear depth (Figure 7) trends were (HDO) < (J_1M) = (J_1J) = (J_1Y) = (LDO) < (J_1C) < (J_1A). While at higher pressures were depth trends were (HDO) = (J_1M) < (J_1J) = (J_1Y) = (J_1C) = (J_1A) < (LDO). Similar trends of wear depths were observed for bio lubricants formulated using bio base oils from Palm kernel (P), Soya beans (S), Yellow oleander (Y) and Groundnut oil (G). At lower pressure the wear depth (Figure 7-11) trends were (HDO) < (LDO) = (PM) = (PJ) = (PY) < (PC) = (PA), (HDO) < (SM) = (SJ) = (SY) < (LDO) = (SC) < (SA), (HDO) < (Y_1M) < (Y_1J) = (Y_1Y) = (LDO) < (Y_1C) < (Y1A), and (HDO) < (GM) < (GJ) = (GY) < (GC) < (GA) < (LDO) for Palm kernel (P), Soya beans (S), Yellow oleander (Y) and Groundnut oil (G)base oils respectively. While the wear depths trends at higher pressure (HDO) < (PA) = (PC) < (PY) = (PJ) = (PM) < (LDO), (HDO) < (SM) < (SJ) = (SY) < (SC) = (SA) < (LDO), (HDO) < (Y_1Y) < (Y_1C) < (Y_1A) = (Y_1J) < (Y_1M) < (LDO) and (HDO) < (GM) = (GJ) = (GY) = (GC) < (GA) < (LDO).

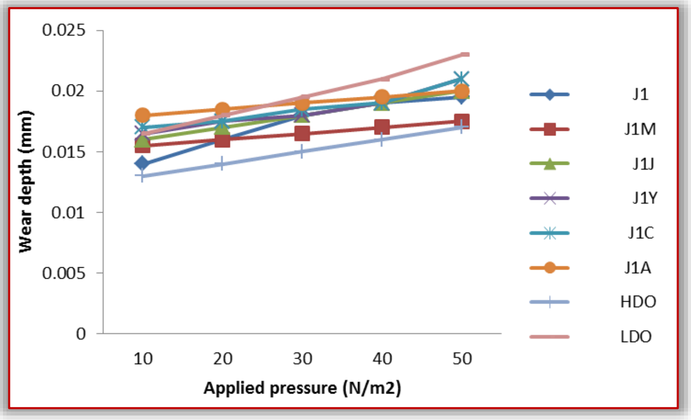

Figure 7: Effect of Applied Pressure and Lubrication Condition on Wear Depth at 60 rpm for blended (J_1) oil, pure (J_1) oil and reference oils.

J_1 = Bio base oil from Jatropha seed; J_1M = Mixture of Jatropha seed oil and Moringa tree additives; J_1J = Mixture of Jatropha seed oil and Jatropha stem additives; J_1Y = Mixture of Jatropha seed oil and Yellow Oleander latex additives; J_1C = Mixture of Jatropha seed oil and Cocoyam stem additives; J_1A = Mixture of Jatropha seed oil African elemi tree additives; HDO = Heavy duty oil; LDO = Light duty oil

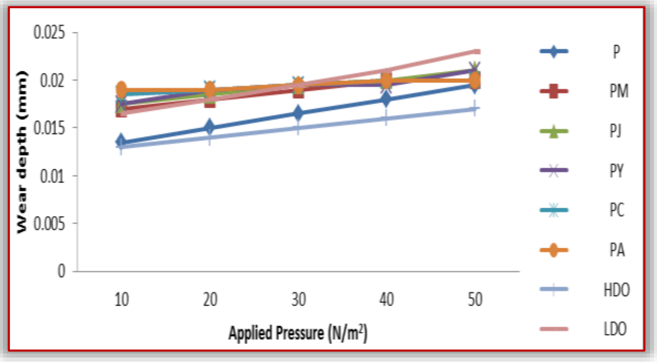

Figure 8: Effect of Applied Pressure and Lubrication Condition on Wear Depth at 60 rpm for blended (P) oil, pure (P) oil and reference oils

P = Bio base oil from Palm kernel nut; PM = Mixture of Palm kernel nut oil and Moringa tree additives; PJ = Mixture of Palm kernel nut oil and Jatropha stem additives; PY = Mixture of Palm kernel nut oil and Yellow Oleander latex additives; PC = Mixture of Palm kernel nut oil and Cocoyam stem additives; PA = Mixture of Palm kernel nut oil African elemi tree additives; HDO = Heavy duty oil; LDO = Light duty oil

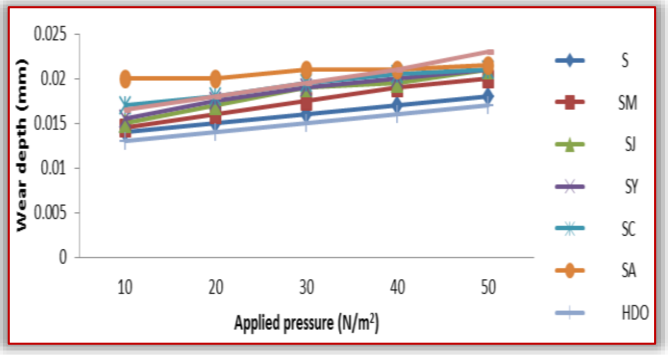

Figure 9: Effect of Applied Pressure and Lubrication Condition on Wear Depth at 60 rpm for blended S oil, pure (S) oil and reference oils.

S = Bio base oil from Soybean seed; SM = Mixture of Soybean oil and Moringa tree additives; SJ = Mixture of Soybean oil and Jatropha stem additives; SY = Mixture of Soybean oil and Yellow Oleander latex additives; SC = Mixture of Soybean oil and Cocoyam stem additives; SA = Mixture of Soybean oil African elemi tree additives; HDO = Heavy duty oil; LDO = Light duty oil

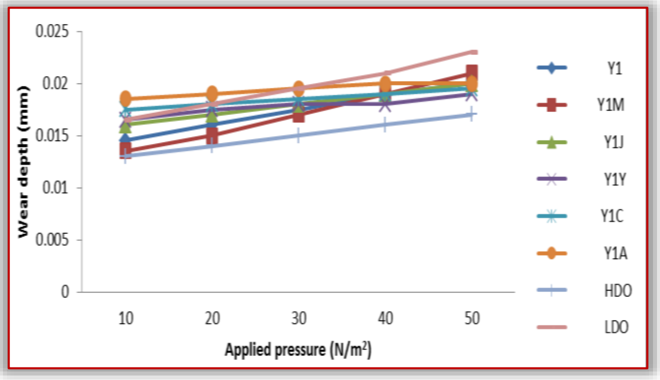

Figure 10: Effect of Applied Pressure and Lubrication Condition on Wear Depth at 60 rpm for blended Y_1 oil, pure (Y_1) oil and reference oils.

Y_1 = Bio base oil from Yellow oleander seed; Y_1M = Mixture of Yellow oleander seed oil and Moringa tree additives; Y_1J = Mixture of Yellow oleander seed oil and Jatropha stem additives; Y_1Y = Mixture of Yellow oleander seed oil and Yellow oleander latex additives; Y_1C = Mixture of Yellow oleander seed oil and Cocoyam stem additives; Y_1A = Mixture of Yellow oleander seed oil and African elemi tree additives; HDO = Heavy duty oil; LDO = Light duty oil

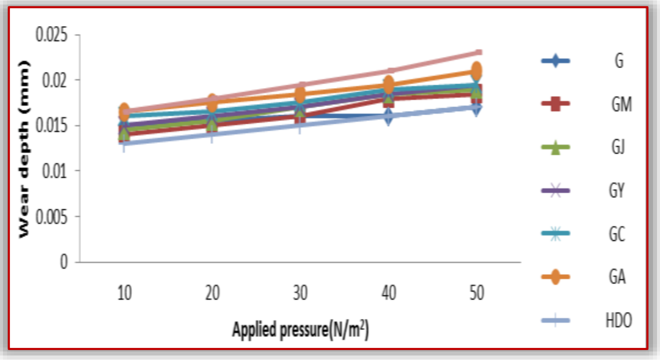

Figure 11: Effect of Applied Pressure and Lubrication Condition on Wear Depth at 60 rpm for blended G oil, pure (G) oil and reference oils.
G = Bio base oil from Groundnut seed; GM = Lubricant mixture of Groundnut oil and Moringa tree additives; GJ = Mixture of Groundnut oil and Jatropha stem additives; GY = Mixture of Groundnut oil and Yellow oleander latex additives; GC = Mixture of Groundnut oil and Cocoyam stem additives; GA = Mixture of Groundnut oil and African elemi tree additives; HDO = Heavy duty oil; LDO = Light duty oil

The wear decreases with increase in viscosity as HDO been more viscous gave the lowest wear depth in the trend. All other oils with lesser viscosity showed increase in wear depth. In the trends the wear depth varied in the formulated bio lubricant. This was confirmed by the analysis of variance that there was a significant effect on wear depth for the formulated bio lubricant with the addition of the bio additives at 5% significant level. The F calculated (7.3268) was greater than F critical (2.689628) which clearly shows that the bio additives have significant effect on the formulated bio base oils. Pressure increase led to increase in contact pressure between the disc and the test sample, thus increased wear depth. The wear depth values for formulated bio base oils ranged from 0.0135 - 0.0210 mm and. these values were within those of the two reference oils (0.0165 - 0.023) mm for light duty (LDO) and 0.013 - 0.017 mm for heavy duty (HDO) used. Lesser wear depths were exhibited in the formulated bio lubricants when compared with light duty (LDO) reference oil and the values of 0.02 - 0.05 mm reported by [6] for Jatropha seed oil. The anti-wear elements such as Cu, Pb, and Zinc which were present in the extract of the selected bio additives has contributed to the reduction of wear in the test carried out. However, the values of wear depth obtained were higher than the wear depth for heavy duty oil (HDO). This implies that the bio lubricants are not suitable for heavy duty vehicles except further treatment are provided for that purpose. The additive in a lubricant is a minimum of one but when present as a package it would consist of many additives serving different functions. Our formulated bio lubricants as a package has many lubricant enhancement properties which were notably viscosity index improvers, friction modifiers, anti -wear agents, rust and corrosion inhibitors, foam inhibitors, detergents, extreme pressure and anti-oxidation additives.

CONCLUSIONS

The following conclusions were drawn

- These bio additives obtained from Moringa tree bark, Jatropha stem, Yellow oleander latex, Cocoyam stem and African elemi tree contain Iron (Fe), Nikel (Ni), Copper (Cu), Lead (Pb), Magnesium (Mg), Zinc (Zn) and Manganese (Mn) as active elements which are also found in conventional lubricant additives.
- The bio-additives were found to improve coefficient for bio lubricants formulated from groundnut oil, yellow oleander seed oil and Jatropha oil.
- The wear depths in the evaluation of the formulated bio lubricants were different and increased as the applied loads were increased. Moreover, the wear depth for the formulated bio base oils using groundnut oil, yellow oleander seed oil and Jatropha oil were better than the reference oils.

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