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Production of Eco-Friendly Bio-Lubricant from Sandbox (Hura Crepitans) Oil

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ABSTRACT
The demand for renewable, biodegradable and environmentally friendly lubricant as well as the international concerns about environmental pollution associated with the use and disposal of mineral oil based lubricants is increasing daily due to the threats posed by the mineral lubricants. This work aimed at replacing mineral based and edible vegetable oil based lubricants with non-edible vegetable oil based lubricant as a step towards sustainable development of bio-lubricant. Bio-lubricant was produced from sandbox (Hura crepitans) oil, a highly neglected non-edible oil, in two stage processes. Methyl ester of the oil was produced by esterification in the first stage of the process, while in the second stage the methyl ester was transesterifed with ethylene glycol using sodium hydroxide catalyst to produce the bio-lubricant. The bio-lubricant was analyzed for major lubricating properties such as viscosities at 40^{o}C and 100^{o}C, viscosity index, pour point, cloud point, flash point as well as fire point and found to have values of 55.9 cSt, 13.5 cSt, 169.31, -3^{o}C, 4^{o}C, 302^{o}C and 306^{o}C respectively. These values indicate that this bio-lubricant can be used under wide range temperatures and is comparable with the mineral based standards of lubricant (SAE 40).

KEYWORDS: Renewable, biodegradable, bio-lubricant, chemo-physical, sandbox.

I. INTRODUCTION

The growing international concerns about environmental pollution associated with the use and disposal of mineral oil based lubricants has inspired research on alternative lubricants with focus on the formulation and development of biodegradable, renewable and eco-friendly lubricants. Lubricants are usually incorporated between tribo-pairs for lower friction and reduced wear. They separate the interacting surfaces to reduce friction as well as wear; and to cool the mechanical system of the engine by absorbing part of the generated heat in the contacts. [1] reported that lubricants have ability to remove contaminants and heat from tribo-contacts in addition to the ability to reduce wear and friction. Also, they clean and protect contacting surfaces from corrosion as well as neutralizing acids formed during combustion in internal combustion engine. Lubricants according to [2] and [3] perform critical functions such as lubrication, suspending, cooling, cleaning and protecting metal surfaces in order to increase equipment lifetime as well as provide protection from corrosion, dissipation of heat, exclusion of contaminants, and flushing away of wear products. Lubricants also have capacity to transport protective chemical to the contacts where they are needed and transport wear particles generated away from where they are generated [4].

Bio-lubricants are becoming an important alternative to mineral oil based lubricants due to improvement in awareness of environmental pollution. They are mostly produced through esterification and transesterification reactions [5] [6]. The aim of esterification of triglyceride is to reduce the fatty acid of the feedstock. Esterification in bio-lubricant production is a pre-treatment process that involves the reaction of alcohol, acid and triglycerides to form ester and glycerol. This pre-treatment is important to reduce formation of soap throughout the reaction and make easy the extensive handling for separation of glycerol and biodesel together with removal of catalyst and alkaline wastewater. Transesterification results in production of methyl ester of fatty acid and subsequently purification. In the transesterification process, enzymes and alkalis are used independently.

Bio-lubricants, according to [7] possess better properties like renewability, environmental friendliness, biodegradability, non-toxicity, excellent lubricity, high fire point and flash point, high viscosity index, low volatility and low vapour emissions. They are also free of sulphur-containing compounds and chemicals harmful to human skin and health. Vegetable oils are nowadays considered as viable bio-resource and promising

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candidates for the development of bio-based lubricants because they have some basic chemo-physical properties which make them suitable to be used as lubricants. Vegetable oils, because of their non-toxic and readily biodegradable nature, are good and viable alternative resources for lubricants**.** [1] and [8] reported that vegetable oils can be used as an alternative to mineral oil or petroleum based lubricant as they provide important environmental benefits with excellent performance in many applications and possess several advantages which include biodegradability, lower toxicity, lower volatility, higher lubricity, higher flash point and viscosity index.

The use of vegetable oil as lubricant was experimented over a century ago, using oil from the agricultural industry [9]. [10] reported that more than 95% of world bio-lubricant is produced from edible oils such as rapeseed oil, soyabean oil, canola oil, palm oil and palm kernel oil. But considering the daily rise in human population, this has brought high price of base oil and serious competition between food and lubricants arising from the extensive use of these edible oils for lubricants. It is also believed that the large-scale production of bio-lubricant from edible oil may bring global imbalance to food supply and demand market. In order to overcome this devastating phenomenon, researches have shifted focus to non-edible oils which are very economical comparable to edible oils and potentially offer greatest opportunities in the longer term for effective lubricant production.

There are many studies on the use of many non-edible oils such as pongamia oil [8], jatropha oil [6][11][12], neem oil [11][13], mahua oil [14], linseed [15][16] and castor oil [17][18] for bio-lubricant production. The strong pressures to avoid the use of edible oils as base oils for lubricant has led to the need to search for more non-edible oilseeds which can be used as raw materials for lubricant production to replace industrial oil based seeds and which can establish a new pathway from prospective oilseeds. This increasing need to search for more non-edible oils from vegetable sources to complement others has led to employing sandbox seed oil as alternative raw material for lubricant production.

[9] described sandbox has an evergreen tree of the spurge family (Euphorbaiceae) usually planted in the cities and villages of Nigeria mostly for shade. The tree, according to [10], have large ovate leaves which grow to 2 ft wide with many dark and pointed spines, smooth brown bark and spreading branches. The tree produced pumpkin shaped seed pods which are green when fresh and brown when dried. The seeds which have been reported to contain oil are enclosed in a hard protective coat which usually and suddenly splashes open and scatters when the seeds are riped and well dried. Sandbox seed oil is highly neglected non-edible oil available at little or no cost of purchase. It was reported by [19] that it has no specific use and no commercial value presently, as the seeds are discarded as waste.

Sandbox oil is a promising alternative oil because it is environmentally friendly, renewable, cheap, and easily manageable [10]. Table 1 shows some of the properties of the oil. The oil contains high content of unsaturated fatty acid such as oleic acid. Oleic acid has been proved as the most ideal monounsaturated fatty acid for bio-lubricant. This makes the oil suitable for bio-lubricant production because of presence of double bond will lower the melting point, which would enhance the low temperature performance of the bio-lubricant. The fatty acid contained in some vegetable oils tends to cling to metal surfaces effectively and therefore provide improved lubricity according to [20]. Selection of vegetable oils for lubrication relies upon the oils having relatively low cost, acceptable low temperature properties, good miscibility and acceptable oxidative and thermal stabilities.

The major benefits of bio-lubricant according to [21] are its renewability, low environmental toxicity and biodegradability as well as its high viscosity index, which makes its viscosity to be virtually stable at constant temperature unlike mineral oil. This makes it to be more preferable than mineral oil based lubricant. [22] reported that bio-lubricants are easy to produce and have better lubricating ability due to a huge amount of unsaturated and polar ester groups components they contained which favourably affected the status during reciprocating sliding. Vegetable oil based lubricant according to [8] is becoming more attractive everyday due to its environmental benefits. [23] reported that vegetable oils have a capability to contribute towards the goal of controlling environmental pollution, security and energy independence since they are biodegradable and nontoxic. [24] reported that composition of vegetable oil, which consists of a mixture fatty acid esters derived from glycerol is used to determine its efficacy. According to the report, vegetable oils with high concentration of mono-unsaturated fatty acid and oleic acid (18:1) are considered as the best oil for potential bio-lubricants. The natural base oils should have more mono-unsaturated fatty acids than poly-unsaturated ones. In addition to fatty

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acid, triacylglycerol (TAG) is the key component in plant oils ideally used for bio-lubricants. [25] described triacylglycerols as the long chain fatty acid tri-esters of glycerol that is structurally similar to mineral base oils. The sand box oil is a triglyceride which is ester of glycerol with long - chain acids, commonly called fatty acids.

[26] reported that usage of crude vegetable oils directly as lubricants is not suitable for long time use in engines due to their low thermal and oxidation stability. The thermal oxidative stability and low oxidative stability of the vegetable oil causes a setback to its use as lubricant; however, this can be overcome by chemical modification of the vegetable oil by transesterification, epoxidation, and hydroxylation. [27] reported that out of all the available chemical modification techniques, vegetable oil transesterification has been a more probable option for lubricant production with better appreciable fluidity and temperature performance. The properties of lubricating oils can be classified as physical, thermal, temperature and chemical. The lubricants physical properties are used to determine where lubricants can be applied, compare the lubricants and their service life. [1] listed some fundamental properties of lubricants to include: viscosity, shear stability, foaming characteristics, element content, ash, density, colour, corrosiveness, elastomer compatibility and homogeneity, water tolerance and miscibility. There are two important thermal properties for thermodynamic effect in lubrication assessment, like temperature and cooling of contacted tribological surfaces. These properties are thermal conductivity and specific heat. This research work investigates the lubrication potential of sandbox oil so as to complement other oilseeds used as raw materials for lubricant production.

Table 1: Properties of Sandbox (Hura crepitans) Oil

Properties	**Hura crepitans Oil**
Specific gravity (30^{o}C)	0.9369
Refractive index (30^{o}C)	1.4683
Density	0.9194 (g/cm^{3})
Moisture content (%)	0.38
Viscosity (28^{o}C)	35.00 (cSt)
Viscosity (40^{o}C)	27.40 (cSt)
Viscosity (100^{o}C)	6.30 (cSt)
Viscosity index	172.96
Acid Value	2.81 ± 2.30 (mg KOH/g)
Peroxide Value	3.83 ± 0.15 (mgKOH/g)
Iodine Value	177.66 ± 0.03 (giodine/100g)
Free Fatty Acid	14.03 (mgKOH/g)
Ester value	210.5 (mgKOH/g)
Saponification value	245.98 ± 1.43 (mgKOH/g)
Cloud Point	11.00 (^{o}C)
Flash Point	249.00 (^{o}C)
Fire point	252 (^{o}C)
Pour Point	- 3.00 (^{o}C)

II. MATERIALS AND METHODS

Materials

The materials and reagents used in this research included: sandbox (Hura crepitans) oil, methanol, n-hexane, potassium hydroxide, sodium hydroxide, hydrochloric acid, glacial acetic, potassium iodide, Wij's solution, carbon-tetrachloride, phenolphthalein, isopropyl alcohol, trimethylolpropane (TMP), oleic acid (OA) and conventional lubricant SAE 40.

Methods

The bio-lubricant was formulated using sandbox oil as feedstock in accordance with ISO 5509 method described by [6]. The formulation involves a double trans-esterification process; methyl ester synthesis and bio-lubricant synthesis. During the first trans-esterification, an intermediate product, methyl ester of the oil was produced by mixing the oil sample with methanol using potassium hydroxide as catalyst in the ratio 3:1. Potassium hydroxide of 0.5 wt.% of the oil was used as a catalyst. Bio-lubricant synthesis was achieved during the second trans-esterification by

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adding trimethylolpropane (TMP) to the sandbox methyl ester in the ratio 3.5:1 to produce the desired product, a polyol ester (bio-lubricant) in accordance with [28]. The reaction was conducted at a temperature of 120°C for two and half hours (2½ hrs) as prescribed by [29]. After the reaction was completed, vacuum filtration was used to separate potassium hydroxide from the product mixture. Thereafter un-reacted methyl esters were removed from the final product by vacuum distillation.

Characterization of the Bio-lubricant

Standard methods were used to determine the chemo-physical properties of the produced bio-lubricant, functional groups and chemical compounds present in the bio-lubricant. Some of the properties of the lubricant that are important to lubricity according to [30] are: viscosities at 40°C and 100°C, viscosity index, pour point, cloud point, acid value, density, iodine value, specific gravity and saponification value.

Fourier transform infrared (FTIR) analysis

The FITR analysis was performed on the bio-lubricant to determine the functional groups present in the bio-lubricant and analyze its degradation in accordance with the method adopted by [31] and [32] using PerkinElmer Spectrum 400 FTIR spectroscopy instrument with a data acquisition system. The bio-lubricant sample was placed between the infrared source and detector. These infrared radiations are required to pass through the lubricant sample to be transmitted and provide corresponding spectra. The transmittance spectra for bio-lubricant samples were analyzed for functional groups and related peaks were determined. A background spectrum was obtained as reference before FTIR measurements was conducted. The crystal surface was cleaned and properly installed before obtaining the background spectrum. The spectra were obtained over a spectral range of 650 - 4000 cm^{-1} at 8 cm^{-1} spectral resolution. The transmittance spectra mode was chosen for data analysis.

Determination of density and specific gravity

The density and specific gravity were determined in accordance with ASTM D1298-17 method. Bio-lubricant of 5 ml was poured into a weighed beaker and weighed. The density was determined from the sample weight by using the ratio of weight of the bio-lubricant to the known volume (5 ml) as well as specific gravity using equations (1) and (2) respectively.

$$Density = \frac{m}{v} \quad (1)$$

$$Specific\ gravity = \frac{A}{B} \quad (2)$$

Where

$m = sample\ mass\ (g)$

$v = sample\ volume\ (cm^3)$

$A = Weight\ of\ a\ unit\ volume\ of\ the\ oil\ (kg)$

$B = Weight\ of\ equal\ volume\ of\ water\ (kg)$

Determination of cold flow properties (pour point and cloud point)

Pour point and cloud point were determined in accordance with ASTM D97-05 method. The bio-lubricant was poured into a test tube and placed in a refrigerator to solidify. It was then removed after it solidifies and the temperature at which the solidified oil starts to melt and flow was measured using thermometer. The lowest temperature at which movement was observed is the pour point. The temperature at which a cloud of crystals first appear when the bio-lubricant is cooled is the cloud point.

Determination of kinematic viscosity and viscosity index

The kinematic viscosity was measured in accordance with ASTM D445-15a method. This method covers the determination of kinematic viscosity using Smart series rotational viscometer TSML 21105. The viscosity was measured at three different temperatures 28°C, 40°C and 100°C. At a start a proper viscometer spindle (3) was chosen. The samples were transferred to a beaker large enough to hold the viscometer spindle. The beaker was placed on a heating mantle set to a desired temperature, while the temperature of the samples was raised to the desired level by heating the oil with constant stirring. The viscosity was read at the desired temperature.

The viscosity of the bio-lubricant was determined using equation (3) reported by [33]:

$$Viscosity = reading\ obtained\ x\ \frac{factor\ for\ the\ spindle}{speed} \quad (3)$$

The viscosity index was determined in accordance with ASTM D2270-04 method. Viscosity index is used to measure change in the viscosity with variation in temperature. The viscosity index of an oil may be determined if its viscosity at any two temperatures is known. This method provides the lubricant's kinematic viscosities at 40°C and 100°C. Equation (4) was

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used for the calculation of viscosity index values for the bio-lubricant.

$$Viscosity\ Index = \frac{L-U}{L-H}\ x\ 100 \qquad (4)$$

Where:

U = Oil's kinematic viscosity at 40°C

L = Values of kinematic viscosity at 40°C for oils of lowest viscosity index (0)

H = Values of kinematic viscosity at 100°C for oils of high viscosity index (100)

Determination of flash and fire points

The flash and fire points measurement of the bio-lubricant were done in accordance with ASTM D93-02a method. The bio-lubricant was poured into a metal container and heated at 5°C interval with a flame being passed over the surface of the sample. The temperature at which an instantaneous flash occur was taken immediately and recorded as a flash point.

The fire point is that temperature at which the vapour of the bio-lubricant burns constantly for 5 seconds when flame is brought near. It is always flash point plus 5°C up to 400°C.

Determination of iodine and peroxide values

The iodine and peroxide values of the bio-lubricant were analyzed using AOAC (2000) methods by dissolving 0.1g of oil in 15ml of carbon tetrachloride and stirring. The solution was mixed with 25ml Wij's solution and stayed in the dark at room temperature for 30 minutes. Distilled water of 100ml and 20ml of 10% (w/v) of potassium iodide were then added to the mixture. It was then titrated with 0.1ml sodium thiosulphate using 10% (w/v) starch indicator. The titration continued until light blue colour was observed. The iodine value and peroxide value were then calculated using equations (5) and (6) respectively.

$$Iodine\ value = \frac{12.69(B-S)N}{W} \qquad (5)$$

$$Peroxide\ value = \frac{0.1(S-B)N}{W} \qquad (6)$$

Where

$B =$ $Titre\ value\ of\ sodium\ thiosulphate\ used\ for\ blank$

$S =$ $Titre\ value\ of\ sodium\ thiosulphate\ used\ for\ sample$

$N =$ $Normality\ of\ sodium\ thiosulphate$

$W = Sample\ weight$

Determination of free fatty acid (FFA)

Free fatty acid is the value of specified fatty acid in oil. The value was measured in accordance with AOAC (2000) method. Bio-lubricant of 5g was weighed into 100 ml of hot neutralized ethanol and 3 drops phenolphthalein indicator was added and titrated with 0.1M sodium hydroxide. Free fatty acid was calculated using equation (7).

$$FFA\ value = \frac{28.05\ VN}{W} \qquad (7)$$

Where

$V =$ $Titre\ value\ of\ sodium\ hydroxide\ used\ (cm^3)$

$N = Normality\ of\ sodium\ hydroxide$

$W = Sample\ weight\ (kg)$

Determination of acid value

Acid value was determined in accordance with ASTM D 664-18 method. Bio-lubricant of 1g was weighed into 25ml of isopropyl alcohol in a 250ml conical flask. The solution was titrated using 0.1M potassium hydroxide (KOH) and 3 drops of phenolphthalein was added with constant stirring until a persistent colour appeared. The titre value obtained was used to calculate the acid value using the equation (8) given by [6]:

$$Acid\ value = \frac{56.1\ VN}{W} \qquad (8)$$

Where

V = Titre value of potassium hydroxide used (cm^3)

N = Normality of potassium hydroxide

W = Sample weight (kg)

Determination of saponification value

Saponification value of the bio-lubricant was determined in accordance with ASTM D5558-95 method. Bio-lubricant of 10g was weighed into 250ml conical flask. Potassium hydroxide solution of 25 ml was added using pipette. The flask content was thoroughly stirred and then connected to reflux condenser to boil for one hour for complete saponification. The cooled content was titrated with hydrochloric acid of 0.5M using phenolphthalein indicator. The value was calculated using:

$$\text{SAP value} = \frac{56.1\ (B-S)N}{W} \qquad (9)$$

Where

B = Titre value of hydrochloric acid used for the blank (cm^3)

S = Titre value ofhydrochloric acid used for the sample (cm^3)

N = Normality of hydrochloric acid

W = Sample weight (kg)

Determination of ester value

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The ester value of the bio-lubricant was obtained as a difference between the saponification value and the acid value in accordance with AOAC (2000) method.

$$\text{Ester value} = \text{SAP value} - \text{AV}$$

Where

$$\text{SAP value} = \text{Saponification value}$$
$$\text{AV} = \text{Acid value}$$

Determination of moisture content

Moisture content of the bio-lubricant was determined in accordance with ASTM D2974-93 by weighing 10g of the bio-lubricant into an empty crucible. The crucible and bio-lubricant were weighed. The crucible with the content was placed in an oven at 105°C for 5 hours. It was removed after 5 hours and reweighed after cooling to room temperature. The heating and cooling process was done repeatedly until the weight became constant. The moisture content was obtained using equation (10).

$$\text{Moisture content (\%)} = \frac{m_1 - m_2}{m_1} \times 100 \quad (10)$$

Where

m_1 = mass of the test specimen before drying (kg)

m_2 = mass of the oven dried specimen (kg)

Determination of refractive index

Refractive index of the bio-lubricant which is the degree of refraction of a beam of light that occurs when it passes from one transparent medium to another was determined in accordance with ASTM D1218-01. Digital Abbe's refractometer Model DRA-1 was used for the measurement of the bio-lubricant's refractive index. The bio-lubricant was smeared on the lower position of the refractometer, after some adjustment, the refractive index was read directly at room temperature (25°C).

III. RESULTS AND DISCUSSION

In Figure 1, there are two interesting spectral regions in a complete characterization of the vibrational activity of lubricant as reported by [32]. The first region is a region at 1500 - 700 cm^{-1} where there are observations of vibrational activity in the conjugated bond and bending vibration of aliphatic compounds, while the second region is at 3800 - 2800 cm^{-1} where the activity of fatty acid stretching vibration and hydroxide are observed. The range of wavelength of various functional groups as reported by [31] is presented in Table 2. The presence of vibration absorption band observed at 1744.4 cm^{-1} similar to carboxyl (C=O) indicating the presence of fats which makes the oil to have good lubricating ability, while a weak band at 3008 cm^{-1} similar to the unsaturation C-H stretching indicating the presence of carbohydrate; 1159.2 cm^{-1} corresponding to the vibration of the C-O, indicating the presence of ester which helps the oil to have high affinity towards metal surfaces to form protective films on the contacting surfaces and its shoulders at 1105 cm^{-1} and 1235 cm^{-1}; and 3500 cm^{-1} corresponding to stretching of the hydroxyl group (O-H), indicating the presence of phenol and water which help in emulsion formation. These values were similar to the previous studies by [30] and [34] for bio-lubricants from jatropha seed oil and sesame seed oil respectively.

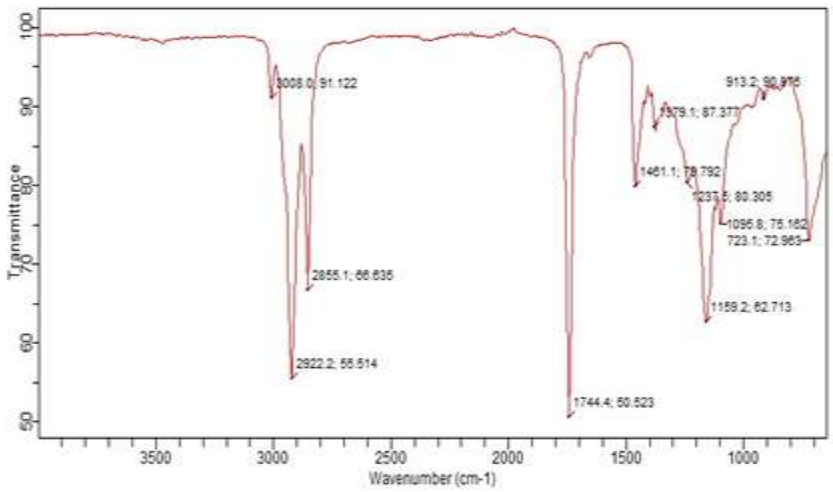

Figure 1: FTIR spectrum of the bio-lubricant

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Table 1: Range of wavenumber (cm^{-1}) of various functional groups in FTIR

Wavenumber range (cm^{-1})	Functional group
3200 – 3550	O-H stretch
3300 – 3500	N-H stretch
3000 – 3500	O=C-N-H stretch
3010 – 3100	=C-H stretch
2500 – 3000	Carboxylic O-H
2850 – 2950	C-H stretch
2220 – 2260	Nitrile (CN)
1735 – 1750	Ester C=O
1710 – 1780	Carboxylic acid C=O
1690 – 1740	Aldehyde C=O
1680 – 1750	Ketone C=O
1630 – 1690	Amide C=O
1620 – 1680	C=C stretch

Source: Khan et al, 2019

Density

Density plays a critical role in the functioning of a lubricant and the performance of moving parts of a machine. The density of the bio-lubricant was 0.90 g/cm^3 which mean that it is less dense than water. Hence, in case of contamination with water, water will settle below the bio-lubricant and will be subsequently drained off. The obtained value is in line with 0.89 g/cm^3 obtained for conventional lubricant SAE 40 and 0.86 g/cm^3 reported by [35] and [36] for lubricant SAE 40, as well as 0.92 g/cm^3 reported by [33] and [6] for jatropha bio-lubricant.

Specific gravity

Specific gravity of the bio-lubricant was 0.95, while that of conventional lubricant SAE 40 was 0.89. The value is within the range acceptable for lubricant and is comparable to [37]. The specific gravity of the bio-lubricant was observed to increase compared to that of crude sandbox oil sample. This may be as a result of series of modification the oil undergoes through trans-esterification processes. It can be inferred from these data that the bio-lubricant is more likely to mix well with water since the specific gravity is close to that of water.

Pour point

Pour point of the sandbox oil improved from -3^oC to -4.50^oC for the bio-lubricant as shown in Figure 2. The pour point of the bio-lubricant competes favourably with that of conventional lubricant SAE 40 which had a pour point of 3^oC. The reason for high pour point value obtained for SAE 40 is due to its higher viscosity compared to the bio-lubricant. This value is consistent with the pour point values of other bio-lubricants as reported by [6] [30] and [38] from previous studies. In their work, [30] reported an improvement in the pour point of crude jatropha oil from -7^oC to -12^oC for jatropha oil based bio-lubricant. [6]) reported improved pour points of jatropha oil from 5^oC to -7^oC for its bio-lubricant. [11] reported pour points of 1.30^oC for neem based bio-lubricant, 0.20^oC for jatropha based bio-lubricant and -3^oC for mineral oil SAE 50.

Cloud point

The cloud point of the crude sandbox oil improved from 11^oC to 0.50^oC as shown in Figure 2. This improvement was due to the trans-esterification reaction. These might be as a result of the presence of polyol group and the absence of beta-hydrogen in the bio-lubricant produced when the methyl ester reacted with trimethylolpropane (TMP) as reported by [30]. The value is consistent with the cloud point values of other bio-lubricants as reported by [6] [30] and [38] from previous studies. Low temperature fluidity according to [38] is the most essential property for lubricants to perform in environments that are extremely cold. [39] also reported cloud point of -20^oC for mineral oil SAE 40.

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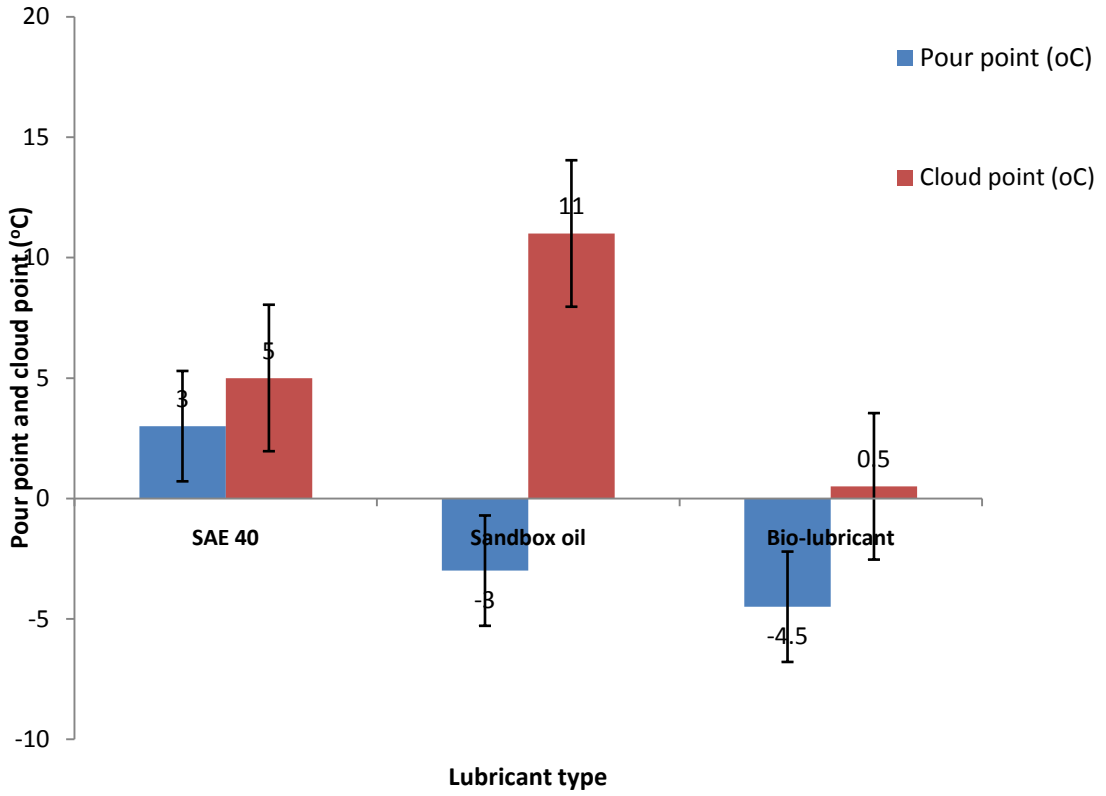

Figure 2: Pour and cloud points of the bio-lubricant

Viscosity

Viscosity which is one of the critical properties of a lubricant is usually determined at 40°C and 100°C for lubricants. The reference temperature of 40°C represents the operating temperature in engine. Viscosity of the bio-lubricant is higher in comparison with that of sandbox oil but lower than that of conventional lubricant SAE 40 as shown in Figure 3. The viscosities of the crude sandbox oil were 27.40 cSt and 6.30 cSt at 40°C and 100°C respectively while that of conventional lubricant SAE 40 were 59.00 cSt and 7.70 cSt at 40°C and 100°C respectively. The viscosities of the bio-lubricant at 40°C and 100°C were 55.90 cSt and 13.50 cSt respectively. The bio-lubricant conform to the ISO VG32 specifications of greater than (>) 28.80 cSt at 40°C and 4.10 cSt at 100°C according to ISO viscosity classification recommended for automobiles applications as reported by [11] and [15]. In earlier works, [40] reported viscosities of 92.45 cSt at 40°C and 12.32 cSt at 100°C for conventional lubricant SAE 40. [41] reported 42.85 cSt at 40°C and 10.00 cSt at 100°C respectively for conventional lubricant SAE 30. [20] also reported viscosity of 42.8 cSt at 40°C for SAE 30. [30] reported viscosities in the range of 39.1 – 54.1 cSt for palm and palm kernel oils based bio-lubricants and 43.9 cSt for jatropha oil based bio-lubricant at 40°C as well as in the range of 7.7 – 9.8 cSt and 8.7 cSt at 100°C. [6] reported viscosities of 55.17 cSt and 10.96 cSt for jatropha oil based bio-lubricant at 40°C and 100°C respectively. [38] reported viscosities of 40.5 cSt at 40°C and 7.80 cSt at 100°C for canola oil based bio-lubricant. These reports show a good comparison between sandbox oil based lubricant and other seed oil based lubricants.

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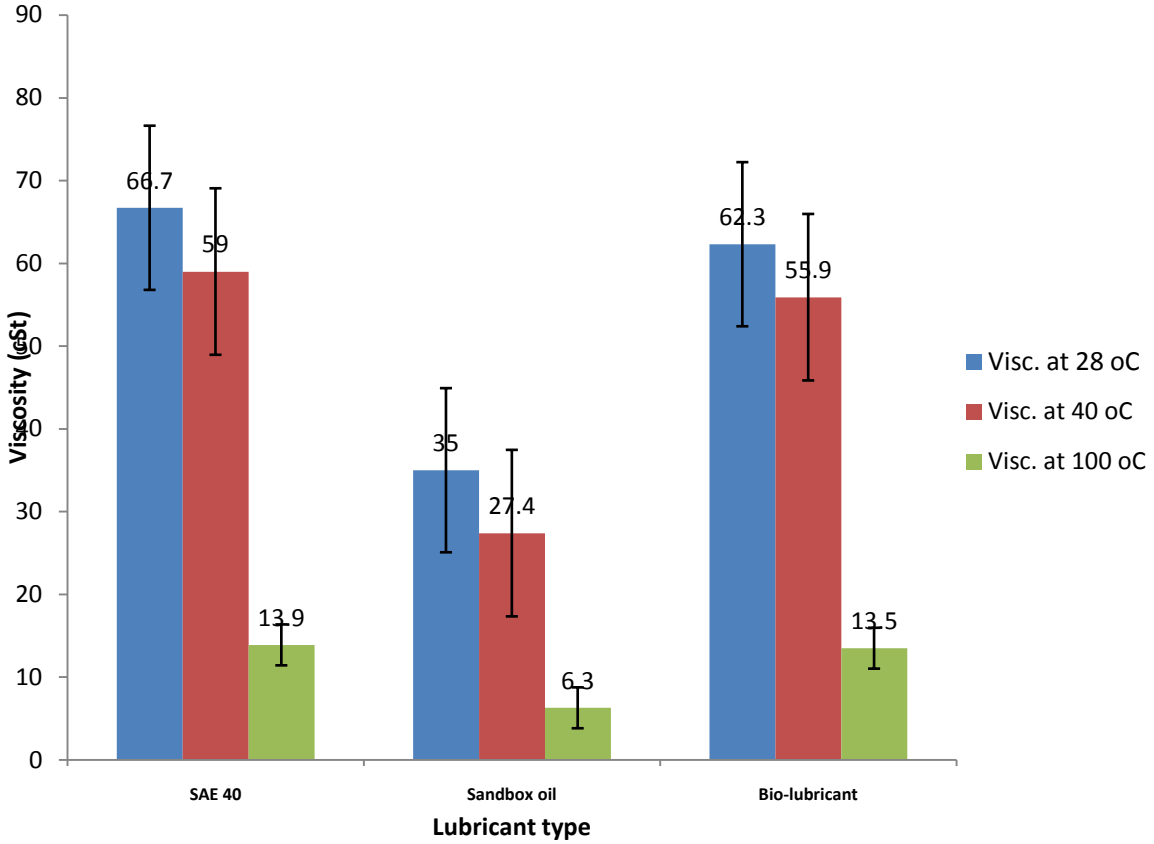

Figure 3: Viscosities of the bio-lubricant

Viscosity index

A good multipurpose lubricant maintains a constant viscosity throughout temperature changes. The standard viscosity index required for lubricants according to [42] can vary from 30 to 240 for automobiles. The conventional lubricant SAE 40 has the viscosity index of 161.22, crude sandbox oil has 172.96 while the viscosity index of the bio-lubricant was 169.31 as shown in Figure 4. This high viscosity index will allow the lubricants to keep their lubrication properties at higher temperatures as reported by [42] and could meet the requirement of the ISO VG46 lubricant since it is within the ISO viscosity range 46 standard.

In comparable with other research works, [33] and [43] [44] reported viscosity index of 125, 162 and 110 respectively for conventional lubricant SAE 40. [6], [23] {30},and [38] and reported viscosity indexes of 180.00, 187.00, 167.00, 204.00 and 170.00 for jatropha oil, palm oil, palm kernel, canola oil and soybean oil based lubricants respectively.

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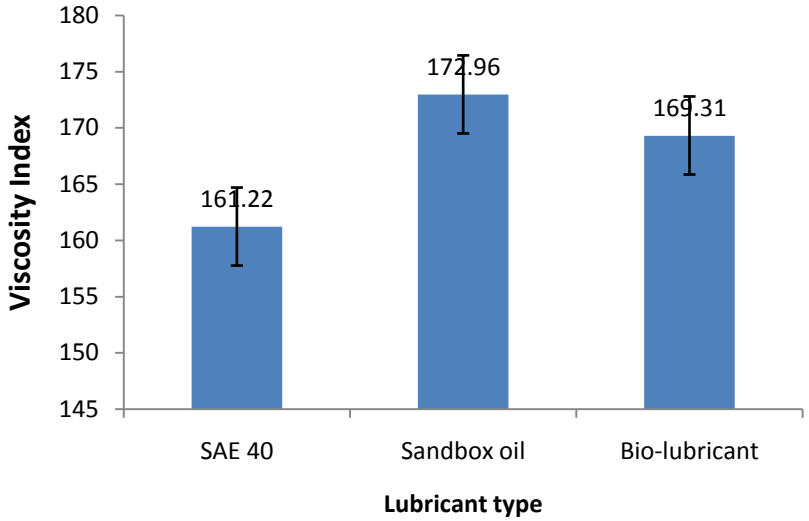

Figure 4: Viscosity index of the bio-lubricant

Flash and fire points

The flash and fire points of the bio-lubricant were found to be relatively higher than that of crude sandbox oil due to the trans-esterification process. The flash point of the crude sandbox oil and bio-lubricant were 249^{o}C and 302^{o}C respectively, while the fire points of the sandbox oil and bio-lubricant were 252^{o}C and 306^{o}C as presented in Figure 5. It is clear from the results obtained that sandbox bio-lubricant has very good flash and fire points as they can be compared with conventional lubricant SAE 40. The value indicates that the bio-lubricant can be used in both humid and temperate regions and transported safely with minimum risks of explosion. These values are similar to the values of previous work by [45] and are in agreement with them. [23] reported flash point of 256^{o}C for soybean oil based bio-lubricant. [44] reported flash point of 200^{o}C for mineral oil SAE 40. [29] also reported flash point of 204^{o}C and fire point of 209^{o}C for mineral oil SAE 40. Aji et al. (2015) reported flash points of 262^{o}C for neem based bio-lubricant, 274^{o}C for jatropha based bio-lubricant and 234^{o}C for mineral oil SAE 50.

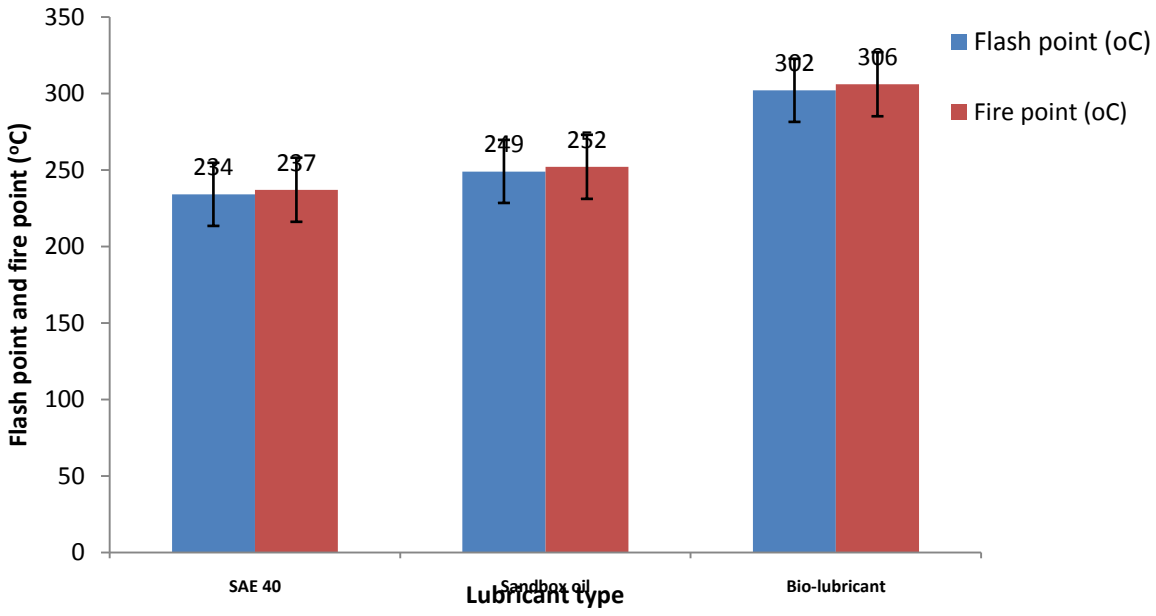

Figure 5: Flash and fire points of the bio-lubricant

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Iodine value

Iodine value is the measurement of fats and oils unsaturation. High iodine value means high degree of unsaturation fats and oils. The higher the iodine value, the less stable, softer, more reactive and susceptible to oxidation the oil will be. Oils with high iodine value according to [46] have lower melting point and performs better in cold weather.

Iodine value of conventional lubricant SAE 40 was 102 $gI_2/100g$ while that of sandbox bio-lubricant was 148.96 $gI_2/100g$ as shown in Figure 6. This shows that there is decrease in the iodine value of the bio-lubricant compared to that of crude sandbox oil (177.66 $gI_2/100g$) .The iodine value of sandbox oil was high, owing to the fact that the oil contains unsaturated glycerides, which have the ability to absorb a definite amount of iodine. This value is comparable to the iodine value of 174.9 $gI_2/100g$ for jatropha bio-lubricant and 185.6 $gI_2/100g$ for moringa bio-lubricant reported by [33] in a previous research work and 102 $gI_2/100g$ obtained for conventional lubricant SAE 40.

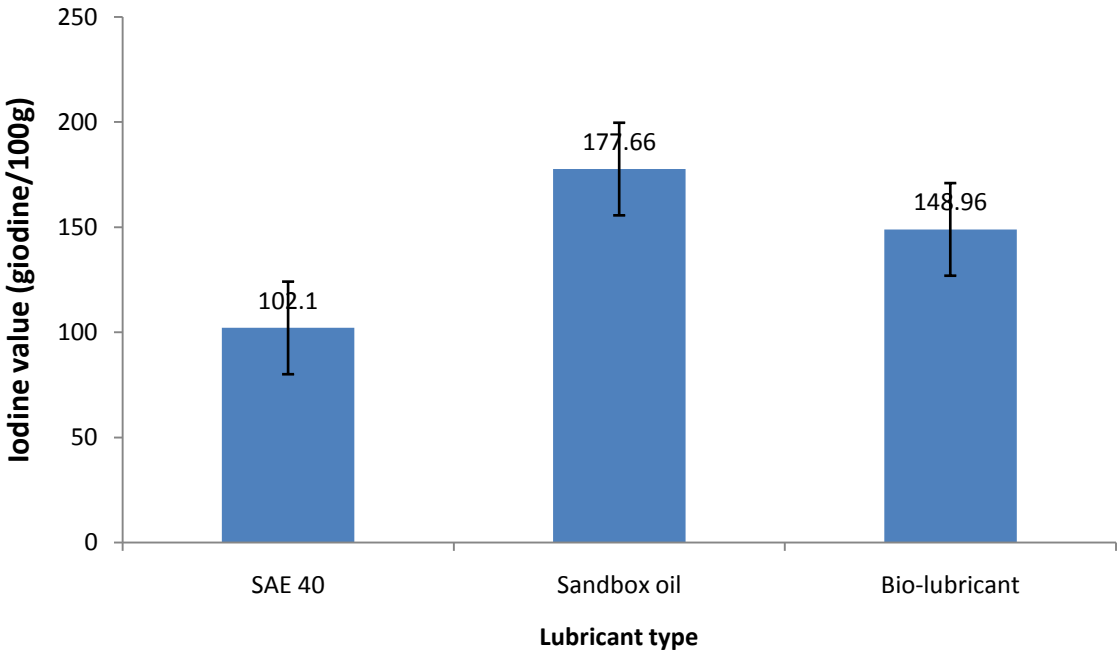

Figure 6: iodine value of the bio-lubricant

Free fatty acid values

Free fatty acid values for the crude sandbox oil and bio-lubricant were 14.03 mgKOH/g and 8.42 mgKOH/g respectively as shown in Figure 7. The free fatty acid content of the oil reduced from 14.03 mgKOH/g to 8.42 mgKOH/g as a result of series of modification the oil undergoes through trans-esterification processes. [6] recommended that oil used in trans-esterification reaction should contain not more than 1% free fatty acid. The values obtained are in-line with previous work by [26] and [33] where the free fatty contents of the crude jatropha oil, moringa oil, castor oil and cotton oil reduced due to esterification of the oil with methanol.

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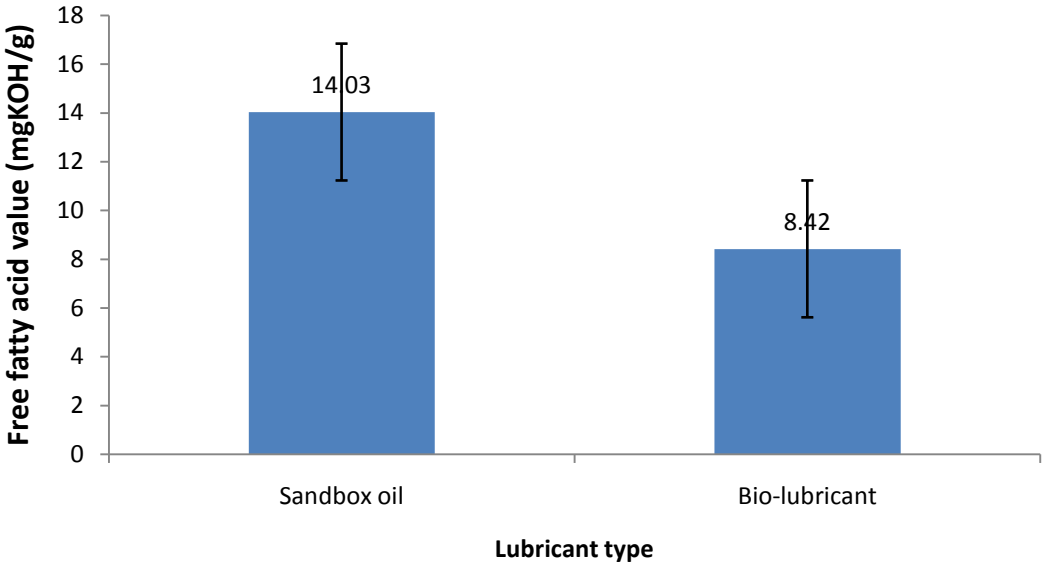

Figure 7: Free fatty acid of the bio-lubricant

Acid value

Acid values of the crude sandbox oil and bio-lubricant which is the number of grams of potassium hydroxide required to neutralize one gram of oil were 2.81mgKOH/g and 1.68 mgKOH/g as presented in Figure 8, while the acid value for conventional lubricant SAE 40 was 4.40 mgKOH/g. In comparison with the conventional lubricant SAE 40, the bio-lubricant has lower acid values which make it of higher quality. This is very good because the lower the acid value of the oil, the higher the quality. A high acid value is not recommended for bio-lubricant due to oxidation which can accelerate wear and rust formation as well as corrosion. The results obtained are in agreement with the findings of [11] where acid values of 1.60 mgKOH/g for neem oil bio-lubricant and 3.90 mgKOH/g for jatropha oil bio-lubricant were reported. The acid value of all the bio-lubricant was above 0.50 mgKOH/g set as lower value for bio-lubricant in both European (EN 14214) and American standards (ASTM D6751) as reported by [46]

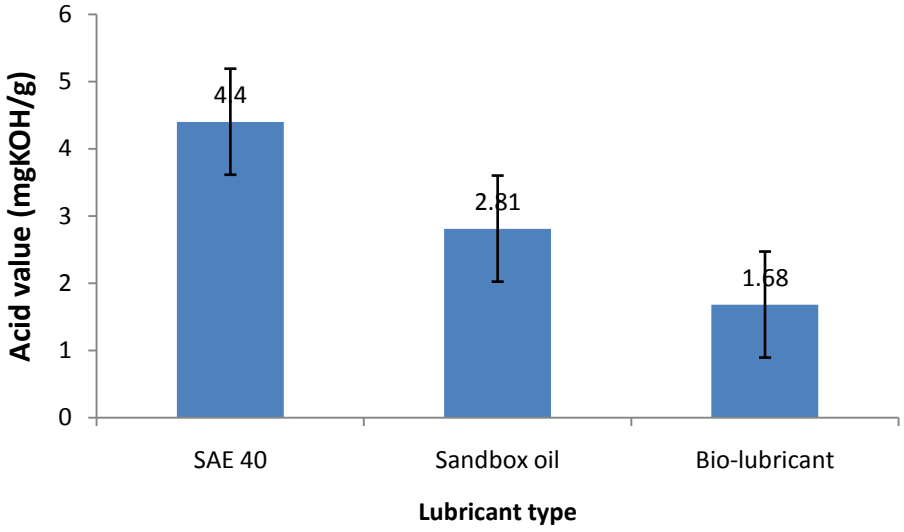

Figure 8: Acid value of the bio-lubricant

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Saponification value

Saponification values of sandbox oil and bio-lubricant were 245.98 mg KOH/g and 179.52 mg KOH/g, while that of conventional lubricant SAE 40 was 213.18 mg KOH/g as presented in Figure 9. This shows 27% reduction in the saponification value of the crude sandbox oil compared to that of the bio-lubricant due to the esterification reaction for the free fatty acid reduction using methanol. The reason being that saponification value is said to have strong positive correlation with free fatty acids content. According to [46], the higher the free fatty acids, the higher the saponification value and vice versa. The high saponification values indicate the presence of high percentage of free fatty acids which might lead to foam formation. The obtained values are comparable to 198.76 mg KOH/g reported by [33] for crude jatropha oil, 193.04 mg KOH/g for moringa oil, 196.35 mg KOH/g for castor oil and 194.75 mg KOH/g for cotton oil which reduced to 193.15 mg KOH/g, 186.11 mg KOH/g, 182.75 mg KOH/g and 191.20 mg KOH/g for jatropha, moringa, castor and cotton bio-lubricants respectively. The values also align with 198.76 mg KOH/g reported by [6] for crude jatropha oil.

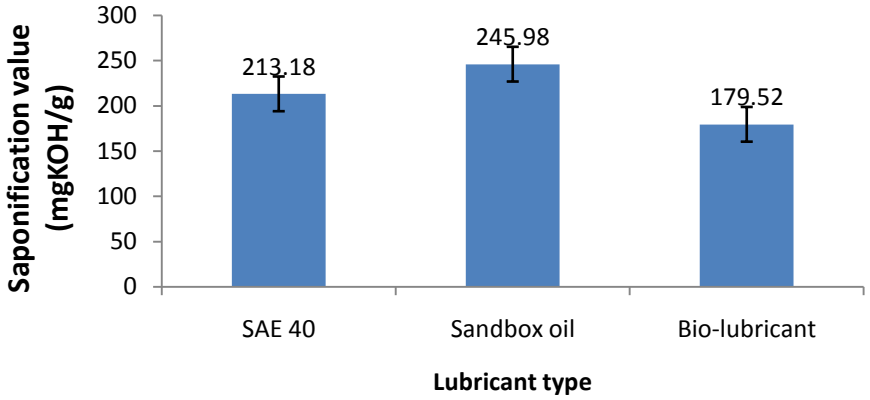

Figure 9: Saponification value of the bio-lubricant

Moisture contents

Moisture content of the bio-lubricant ranged was 0.40%, which is within allowable limit of 0.1% - 0.5% for lubricants [37]. [36] reported that water present in oil had a direct negative effect on machines, increased the oxidation progress and resulted in premature oil aging. Low moisture content in lubricant is a requirement for long storage life and indicates corrosion and rust prevention. The lubricant with low moisture content is expected to be more stable during storage than oils with high values [37]

Refractive index

Refractive indexes of the sandbox oil and bio-lubricant were1.4665 and 1.4706, while the refractive index of SAE 40 was 1.4815. This shows that the bio-lubricant is more saturated than crude sandbox oil. Refractive index, according to [46], increases with increase in saturation and length of fatty acid. This value is satisfactory as it lies within the standard range of 1.3000 – 1.7000 as reported by [11] and comparable to that of conventional lubricant SAE 40 which is 1.4815 in the previous works of [11]) and [37]

IV. CONCLUSION

Sandbox oil is a potential vegetable oil that can be used as alternative lubricant feedstock in lubricant production. Besides the advantages of vegetable oil like renewability, biodegrability, and non-toxic, it has shown positive response to both friction and wear resistance as well competing favourably well with conventional lubricant SAE 40. The bio-lubricant developed conformed to the International Standards Organization (ISO) grade and exhibited good chemo-physical and lubricity properties and could be favourably used in automobile application as engine lubricant.

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