Assessment of quality parameters of ecofriendly biolubricant from waste cooking palm oil

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ABSTRACT (ARIAL, BOLD, 11 FONT, LEFT ALIGNED, CAPS)

The use of vegetable oils as renewable source for the production of ecofriendly biolubricant is gaining attention of the renewable energy researchers and lubricating oil producers. This study evaluates the quality assessment parameters of ecofriendly biolubricant from waste cooking palm oil (WCPO). The crude WCPO was filtered, centrifuged at 500 rpm, and dried over Na_2SO_4 crystals overnight. The quality assessment parameters of the pretreated WCPO (PWCPO) were determined to authenticate its potential for the production of multigrade lubricating oils. Kinematic viscosities at 100°C (8.26±0.03 cSt) and 40°C (36.98±0.01 cSt) were determined according to ASTMD-446 method, while the viscosity index (208±0.11) was determined according to ASTMD-2270 method. A design of experiment (Mixture Design Method using Minitab 17) was used to determine the proportion of PWCPO (68.75%), SN 500 (23.75%), and additives (7.50%) that gave the ~~optimum~~ mixture with the ~~best~~ optimum quality parameters of the produced biolubricant. The produced biolubricant ~~has~~ had kinematic viscosities at 100°C (10.72±0.13 cSt) and 40°C (59.32±0.20 cSt) respectively, viscosity index of 173±0.10, flash point of 234±1.13°C, pour point of -31±0.10°C, acid value of 21.04±1.21 mg KOH g^{-1}, and iodine value of 1.28±1.40 mg I_2 g^{-1}. The produced biolubricant has quality parameters that are comparable to available ecofriendly lubricating oil and was also found within standards for engine oils.

Keywords: Ecofriendly; biolubricant; palm oil; production.

1. INTRODUCTION

Current developments in human lifestyle and significant population growth have gradually led to increased ~~in the~~ consumption of fossil fuels. Excessive consumption of non-renewable fuels also means depletion of fossil oil reserves. Depletion of the world's energy reserves, increase in petroleum prices, increase in environmental awareness, growing regulations ~~over~~

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of environmental pollution and contaminations resulting from emission of greenhouse gases (GHG) (such as carbon monoxide, and carbon dioxide), heavy metals, volatile organic matters, and polyaromatic hydrocarbons have accelerated the development of renewable and biodegradable energy sources [1-7].

Accidental and deliberate lubricant losses to the environment by leakages, spills and evaporation, are major concerns regarding environmental health and pollution. Anjana and Preeti [8] reported that about 10 million tonnes of petroleum products enter the environment annually through urban runoff, refinery processes, spills, industrial and municipal wastes, and condensation from marine engine exhaust. It is therefore mandatory on the producers of lubricants, for certain applications, to enforce strict specifications on toxicity, occupational health and safety, biodegradibility, and emissions.

Fats and oils have been found useful in biolubricating processes to produce tailor-made products [9-11]. Biolubricants act as anti-friction which ease working while reducing the risks associated with machine failure~~s~~ and maitaining optimum machine operation~~s~~. They are essential for heat transfer, power transmission, lubrication, and corrosion inhibition in machinery [12].

The main purposes of lubrication are to protect the surfaces from corrosion, reduce oxidation, reduce wear due to contact, prevent heat loss from the surfaces in contact, act as insulator in transformer applications, act as sealing agents against dust, dirt and water and improve efficiency of machines [13,14].

According to Amit and Amit [12], the main characteristic of any lubricant is viscosity, which is responsible for preventing friction between two surfaces in contact. Other important qualities used for selecting lubricants include temperature stabiliy, environmental friendliness, toxicity, chemical stability, corrosiveness, flammability, and compatibility (15).

Lubricating oil is composed of base stock and additives formulated to enhance the performance of the oil. A lubricant is primarily base oil (75-90%) and additive formulated to improve its performance properties such as pour point, viscosity index and oxidative stability [8,15].

The fried palm oil which remains after food processing is called waste cooking palm oil (WCPO). Waste cooking palm oils are generated from eateries, food industries and restaurants around the world [6,16,17] and their main use is in the production of animal feed~~s~~, ~~manufacture of~~ biolubricants, pharmaceuticals and cosmetics ~~industries~~, and ~~manufacture of~~ soaps [18,19]. Waste cooking palm oils are less expensive than fresh palm oils, they are renewable and non-toxic, and therefore, they are promising feedstocks for the production of biolubricants [6,20-23,16,7,15].

Waste cooking palm oil essentially consists of triglycerides, unsaturated fatty acids, with glycerol [6,23,17,24], water, and other impurities. Water is responsible for degradation of oils and additives via hydrolysis, and ester-based lubricanting oils are susceptible to attack by water resulting in the production of acids and alcohol.

This research focuses on the assessment of quality parameters of ecofriendly biolubricant from waste cooking palm oil as renewable base stock.

2. MATERIAL AND METHODS

~~The material and methods used for this research are discussed below.~~

2.1 Sample Collection and Treatment

The waste cooking palm oil was obtained from Owuna Catering & Restaurant Services, Ikor-Ochekwu, Apa Local Government Area, Benue State, Nigeria.

The crude WCPO was filtered to remove suspended particles and other residues. The oil, which contained water and other impurities, was centrifuged at 500 rpm, and dried over sodium sulphate (Na_2SO_4) crystals overnight. Sodium sulphate (Na_2SO_4) forms clumps when it absorbs water, and the crystals were removed by decantation. Then the pretreated WCPO

(PWCPO) was mixed with n-hexane (1:3 oil/hexane, volume ratio) to remove the remaining impurities [17].

2.2 Production of biolubricant

The pretreated WCPO (PWCPO) has poor thermal and oxidative stability in its raw form and thus, is not suitable for the production of biolubricants [25]. Therefore, the PWCPO oil was mixed with mineral-based oil and additives (Appendix I) to produce the biolubricant. In order to determine the best proportion of variables (PWCPO, SN 500, and additives) that gave the ~~optimum~~ biolubricant with the ~~best~~ optimum quality parameters, ~~a design of~~ an experiment was designed (Mixture Design method of Minitab 17) and ~~was~~ carried out in two different levels and two replicates. The mixture was done in a conical flask at a temperature of 45°C, agitation speed of and stirred at 600 rpm for 15 minutes. A heating mantle equipped with magnetic stirrer was used to attain a homogeneous mixture of the base oil~~s~~ and additives [26,27].

~~The optimum mixture that gave the best quality assessment parameters for the produced biolubricant was obtained as PWCPO (68.75% wt), SN 500 (23.75% wt), and additives (7.50%wt) as presented in Table 3.1. The quality assessment parameters for the produced biolubricants were replicated three (3) times, and average values for all the quality parameters were recorded in Table 3.2.~~

2.3 Quality assessment parameters of the PWCPO and the biolubricant

The quality assessment parameters of the PWCPO and the produced biolubricants were determined as follows.

The density of the oil was determined according to ASTMD-4052. The oil was poured into a clean measuring cylinder and accompanying air bubbles were allowed to settle. The oil was stirred continuously with a thermometer and the temperature was recorded to the nearest 0.25°C immediately the oil stabilised. Once the thermometer was removed, the hydrometer was lowered by about two scale divisions into the oil and released ~~when~~ in a position of equilibrium. ~~A time of~~ 10 minutes was allowed for the hydrometer to remain stationery in the oil and at this point, the hydrometer reading was taken [26]. The density (at 15°C) was calculated using equation 2.1.

$$Density = [(Temp.(°C) - 15)\ x\ 6.20x10^{-4}] + Specific\ Gravity \quad .... \quad 2.1$$

where ?

The kinematic viscosity (KV) of the oil was determined according to ASTMD-445. The oil was poured into a viscometer ~~and the viscometer was~~ mounted upright in the viscometric bath maintained at 40 ~~and~~ or 100°C ~~respectively~~. The oil in the tube was allowed to stabilise for 15 minutes. When the equilibrium temperature was attained, the oil level was adjusted, using a suction pump, to 7 mm above the upper mark of the viscometer tube. ~~A stop watch was started when the meniscus of the oil was at the upper mark, and stopped when the meniscus got to the lower mark.~~ The time taken for ~~a given volume of~~ oil meniscus to move from the upper mark to the lower mark of the viscometer tube was recorded [26]. The kinematic viscosity (KV) was calculated using equation 2.2.

$$KV\ (cSt) = c\ (cSt\ s^{-1})\ x\ t\ (s) \quad ....2.2$$

where ?

The viscosity index (VI) of the oil was obtained using values of kinematic viscosity obtained at 40 and 100°C with standard measurement table as determined by ASTMD-2270 method. The pour point test was conducted according to the method described in ASTMD-97 in pour point tester with accuracy of ±3°C ~~with the pour point tester~~. The tester has a minimun temperature of -68°C with methanol as cooling agent. 45 cm^3 of oil was poured into a test jar to the leveled mark. Then the tester was cooled to -37°C. While cooling the tester, the oil jar was heated to 45°C using a water bath. The oil jar was cooled with another water bath to a temperature of 27°C. When the pour point tester had reached -36°C, the oil jar was placed in a horizontal position in the hole at the top of the tester and the pour point temperature was taken ~~after~~ 5 seconds ~~when~~ after the oil showed no movement.

The flash point was determined by heating a cup containing the oil while presenting a flame on the surface of the oil at regular ~~temperature~~ intervals, starting ~~with a temperature of~~ 28°C below the expected flash point of the oil. ~~The bulb of the thermoneter was immersed in the oil.~~ A flash occured in the cup containing the oil when the temperature of the ~~tested~~ oil had reached (or exceeded) the flash point. This test conforms to ASTMD-92 (28,17).

The acid value of the oil was determined following a method described by Akpan *et al.* [29] and Kyari [30]. The oil (2.00 g) was placed in a dry 250 cm^3-conical flask. 50 cm^3 of ethanol and a few drops ~~(2-3)~~ of phenolphthalein indicator were added. The mixture was heated at 60°C in a water bath for 10 minutes and then cooled. The mixture was titrated with 0.1 M KOH to the end point with consistent shaking, a dark pink colour was observed and the volume of KOH used to reach the end point was recorded as the titre value. The acid value was calculated using equation 2.3.

$$Acid\ value\ \left(\frac{mgKOH}{g\,sample}\right) = \frac{Volume\ KOH(cm^3)\,x\,N\ KOH(mmol/cm^3)\,x\ 56.1\,(mg/mmol)}{sample\ weight\ (g)} \qquad \text{..........2.3}$$

where …?

The iodine value of the oil was determined following a method described by Akpan *et al.* [29] and Kyari [30]. The oil (2.00 g) was placed in a dry 250 cm^3-conical flask and 25 cm^3 of carbon tetrachloride (CCl_4) was added to dissolve the oil. Then 25 cm^3 of Wijs' reagent was added (in the fume chamber) to the mixture using a safety pipette. The flask was stoppered and the content of the flask was vigorously shaken. The flask was placed in the dark for 1 hour. Then, 20 cm^3 of 10.00% aqueous potassium iodide (KI) and 125 cm^3 of water were added using a measuring cylinder. The solution was titrated with 0.1 M sodium thiosulphate ($Na_2S_2O_3$) solution~~s~~ until the yellow color almost disappeared. A few drops of 1.00% starch solution indicator were added and the titration continued by adding sodium thiosulphate drop-wise until the blue coloration disappeared after vigorous shaking. The same procedure was used for blank test. The iodine value (I.V) was determined by using equation 2.4:

$$I.V = \frac{12.69\ x\ 0.1M\ Na_2S_2O_3\ \ (Blank\ cm^3\ Na_2S_2O_3 - Sample\ \ cm^3\ Na_2S_2O_3)}{Wt\ of\ Sampl\ \ (g)} \qquad \text{..........2.4}$$

where …?

2.4 Fourier Transform Infrared Spectroscopy Analyses of the Oils

The oil was placed on sodium chloride (NaCl) plate (sample holder) forming a thin layer of the sample. A second sodium chloride layer was mounted on the first sodium chloride plate. All the analyses were carried with wave number set at a range of 4000 ~~cm^{-1}~~ to 650 cm^{-1} [31].

2.5 Gas Chromatography Mass Spectroscopy Analyses of the Oils

The oil was analysed by a gas chromatograph equipped with mass spectrometer. The GC-MS system was equiped with an Econo-Cap EC-WAX capillary column (30.0 m in length x 250 µm in diameter x 0.25 µm in film thickness). The oven temperature was set initially at 50°C for 3 minutes, ~~and then~~ increased at 10°C/minute to 210°C and held at 210°C for another 9 minutes. The temperature for front inlet (splitless mode) was set at 255°C. Helium was used as carrier gas with a flow rate of 12 cm^3 min^{-1}. The split ratio was set at 1:1 and 1.0 µL of the sample was injected into the GC system. The analysis of the chemical composition~~s~~ of the oil was carried out ~~by injecting~~ on 1.0 µL of the oil solution (blend of the oil with a prepared internal standard of GC i.e. methyl heptadecanoate) [18]. The percentage composition by weight of the oil was determined using equation 2.5:

$$Weight\ percent\ (\%) = [\frac{\Sigma(A_i - A_R)}{A_R}]\frac{C_R V_R}{w} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.5$$

where A_i is the peak area calculated from the chromatogram ~~of sample,~~ A_R the peak area from chromatogram of the internal standard, C_R the concentration of the internal standard, V_R the volume of the internal standard and W the total weight of the oil sample.

3. RESULTS AND DISCUSSION

The optimum mixture that gave the best quality assessment parameters for the produced biolubricant was obtained as PWCPO (68.75% wt), SN 500 (23.75% wt), and additives (7.50%wt) as presented in Table 3.1. The quality assessment parameters for the produced biolubricants were replicated three (3) times, and average values for all the quality parameters were recorded in Table 3.2.

The viscosity index of PWCPO (206±0.11), as presented in Table 3.2, is a good test of its potential to be used for the production of multigrade lubricating oil, even though the PWCPO could not be used in its raw form for the production of biolubricant due to its poor thermal and oxidative stability [25]. The flash point of the PWCPO was found to be 153±0.10°C which is lower ~~compared to~~ than the flash point of ecofriendly Mobil 1 5W-30 (172°C). This shows that there is higher risk of flammability for transporting and storing PWCPO than Mobil 1 5W-30. The pour point of the PWCPO was found to be -9±0.00°C and is lower ~~compared to~~ than the pour point of ecofriendly Mobil 1 5W-30 lubricating oil (-40°C). The quality assessment parameters of the PWCPO showed kinematic viscosities at 40°C (36.98±0.01 cSt) and 100°C (8.26±0.03 cSt) (Table 3.2) respectively, while the viscosity index was found to be 206±0.11. This high viscosity index shows that the PWCPO could be used for the production of multigrade ~~motor car~~ engine oils (Appendix II)~~ due to its high viscosity index~~.

According to Gobinda *et al*. [15], good lubricating oil should have high~~er~~ flash point, viscosity index, shear stability, and thermo-oxidative stability, and have low~~er~~ cloud point and pour point. In order to produce biolubricant that could compete with available ecofriendly oil, the PWCPO was mixed with mineral based SN 500 oil [26], and additives. The produced biolubricant (run no. 6 of Table 3.1) showed improved kinematic viscosity, higher flash point, lower pour point, lower acid value, and lower iodine value compared to ~~the~~ PWCPO (Table 3.2).

The kinematic viscosity of produced biolubricant was found to be 59.32±0.20 cSt at 40°C and 10.72±0.13 cSt at 100°C (Table 3.2). Similar results were found for palm oil TMP lubricating oil as 50.33 cSt at 40°C and 10.87 cSt at 100°C [32], palm kernel TMP ester as 34.90 at 40°C and 7.80 cSt at 100°C [33], and waste cooking oil as 36.7 cSt at 40°C and 8.50 cSt at 100°C [6]. This indicates that the produced biolubricant has higher internal resistance to flow compared to palm kernel TMP ester [33] and waste cooking oil [6], and lower internal resistance to flow compared to palm oil TMP lubricating oil [32].

The viscosity index of the produced biolubricant was found to be 173±0.10 (Table 3.2), which is lower compared to viscosity index of palm oil TMP ester, 214 [32], palm kernel TMP ester, 210 [33], and waste cooking lube oil, 220 [6]. This shows that the produced biolubricant will experience greater changes in its viscosity with change in temperature~~s~~ compared to palm oil TMP, palm kernel TMP ester, and waste cooking lube oil.

The flash point of the produced biolubricant was found to be 234±1.13°C (Table 3.2). In similar reviews, the flash point of palm kernel TMP ester was found to be 322°C [33], while that of palm oil TMP ester was found to be 253°C [32]. This shows that palm kernel TMP ester and palm oil TMP ester have more carbon atoms in their molecular structures compared to the produced biolubricant. The produced biolubricant could be used in vehicles without engine failure owing to its conformity with standard [34,35].

The pour point of the produced biolubricant was found to be -31±0.10^{o}C (Table 3.2). In similar reviews, the pour point of palm oil TMP ester was found to be 5^{o}C [32], that of palm kernel TMP ester was found to be -15^{o}C [33], while that of WCO was found to be -2^{o}C [6]. The large differences in the pour points of those lubricants reviewed compared to that of the produced biolubricant could be as a result of ~~none formulation~~ non-incorporation of additives (pour point depressants) ~~incorporated in the production of the biolubricant which were absent~~ in those reviewed. This shows that ~~formulation~~ incorporation of pour point depressants (PPDs) in vegetable oils could boost their usefulness for various applications at very low temperatures.

The acid value of the produced biolubricant was found to be 21.04±1.21 mg KOH g^{-1} (Table 3.2). The acid value is higher than that ~~compared to acid value (0.05 mg KOH g^{-1})~~ of palm kernel TMP ester (0.05 mg KOH g^{-1}) reported by Robiah *et al*. [33], acid value (1.56 mg KOH g^{-1}) of WCO lube oil reported by Weimin and Xiaobo [6]. Though the acid value of the produced biolubricant is within standard range (0.20 – 50.00 mg KOH g^{-1}) for engine oils [34,35], calculated amounts of anti-corrosion and anti-oxidants are required as additives in order to enhance the usefulness of the produced biolubricant for any particular application. These additives will inhibit the negative effects of corrosion and oxidation.

The iodine value of the produced biolubricant was found to be 1.28±1.40 mg I_2 g^{-1} (Table 3.2), ~~and it is~~ higher compared to that of palm kernel TMP ester (89.60 mg I_2 g^{-1}) as reported by Robiah *et al*. [33]. This shows that the produced biolubricant has more methylene-interrupted double bonds [15] and it is more susceptible to oxidation reactions [36] than palm kernel TMP ester.

The absorption bands for C-H and –CH_2 for the PWCPO and the produced biolubricant occurred at wavenumbers 2922 cm^{-1} and 2855 cm^{-1} (Table 3.3) respectively. This is an indication of alkane functional group in the oils. The alkane functional group was found for biodiesel within the range of 3000-2855 cm^{-1} as reported by Ebtism *et al.* [32]. The methyl group, -CH_3 bending occurs at wavenumber of 1375 cm^{-1} for both PWCPO and the produced biolubricant. Alkene out-of-plane, =C-H bending was observed at 969 cm^{-1} for the produced biolubricant and at 961 cm^{-1} for PWCPO. The alkene functional group is an indication of unsaturation of the PWCPO and the produced biolubricant. The carbonyl functional group, C=O was observed at 1744 cm^{-1} for both oils. The C-O stretching vibration, occurring at 1159 cm^{-1} for both oils, is an indication that the carbonyl group, C=O is ~~for~~ that of ester since there is no visible O-H band for both oils. In similar reviews, the ester group was reported at 1744 cm^{-1} for palm oil-based TMP ester [32], and 1745 cm^{-1} for waste cooking oil [37]. The wavenumber at 1710 cm^{-1} observed in both oils suggests a C=O stretching vibration. This is ~~a possible~~ an indication of the possible presence of carboxylic acid functional group in both oils even though ~~their~~ its corresponding O-H functional group was not observed.~~, and the~~ The high acid values observed in both oils (Table 3.2) attest to this claim. A unique peak, ~~was~~ observed at 1975 cm^{-1} for the produced biolube,~~. This unique peak which occurred~~ within the range of 2270-1950 cm^{-1}, suggests the presence of X=C=Y bond in alkenes, isocyanates, or isothiocyanates. Details of the infrared spectra of PWCPO and the produced biolubricant are found in Figures 3.1 and ~~Figure~~ 3.2 respectively.

The chemical composition~~s~~ of the PWCPO ~~were~~ was determined by GC-MS. Unsaturated fatty acids of carbon chain length C_{18} (oleic acid, linoleic acid, and linolenic acid) were ~~found~~ more in the PWCPO (50.96%) ~~compared to~~ than saturated fatty acids (palmitic acid, and stearic acid) of carbon chain length C_{16}-C_{18} (27.25%). In order reviews, palm oil was found to contain 53.87 and 43.60% unsaturated and saturated fatty acids respectively, as reported by Ebtisam *et al*. [32], and waste cooking oil was found to contain 58.55 and 29.84% unsaturated and saturated fatty acids respectively, as reported by Hassani *et al*. [17]. This shows that the PWCPO is susceptible to oxidation reactions due to the high degree of unsaturation of the carbon atoms.~~, therefore~~ Therefore, an anti-oxidant was used in the production of the biolubricant ~~because of the high concentration of unsaturation in the molecules of the oil~~ [38].

Table 3.1. Optimisation mixture for the biolubricant production

Run Order	PWCPO	SN 500	Additive	KV @ 100 ^{0}C	KV @ 40 ^{0}C	VI	FP	PP	AV	IV
1	90.00	10.00	0.00	8.70	50.10	159	169	-22	33.94	1.50
2	68.75	23.75	7.50	10.70	59.50	174	233	-31	22.00	1.28
3	23.75	68.75	7.50	11.50	63.20	178	238	-29	10.55	1.01
4	28.75	68.75	2.50	8.20	44.10	164	230	-25	11.13	1.02
5	0.00	90.00	10.00	9.01	99.03	114	203	-15	2.33	0.91
6	68.75	23.75	7.50	10.72	59.32	173	234	-31	21.04	1.28
7	28.75	68.75	2.50	8.20	43.40	163	231	-27	11.85	1.02
8	47.50	47.50	5.00	10.50	63.90	152	247	-32	12.11	1.09
9	23.75	68.75	7.50	11.50	62.00	180	238	-28	10.23	1.00
10	68.75	28.75	2.50	9.50	81.00	93	173	-25	22.79	1.25
11	90.00	0.00	10.00	8.60	40.11	195	156	-17	36.20	1.56
12	0.00	90.00	10.00	9.01	98.23	112	203	-14	2.10	0.90
13	10.00	90.00	0.00	10.60	60.40	167	216	-19	2.84	0.98
14	47.50	47.50	5.00	10.10	63.90	154	249	-30	12.44	1.00
15	68.75	28.75	2.50	9.50	82.00	95	172	-25	22.66	1.52
16	90.00	10.00	0.00	8.70	50.18	160	167	-22	34.09	1.51
17	10.00	90.00	0.00	11.00	62.10	169	216	-20	2.10	0.98
18	90.00	0.00	10.00	8.60	40.91	195	158	-16	36.70	1.56

Key: ***PWCPO*** *= Pretreated Waste Cooking Palm Oil;* ***KV*** *= Kinematic Viscosity* (cSt)*;* ***VI*** *= Viscosity Index;* ***FP*** *= Flash Point* (^{o}C)*;* ***PP*** *= Pour Point* (^{o}C); ***AV*** *= Acid Value* (mg KOH g^{-1})*;* ***IV*** *= Iodine Value* (mg I g^{-1})

Table 3.2: Quality assessment parameters of the PWCPO and the biolubricant

Oils	KV @100°C	KV @40°C (cSt)	VI	D@15°C (g cm^{-3})	FP (°C)	PP (°C)	AV (mg KOH g^{-1})	IV (mg I_2 g^{-1})
Crude WCPO	8.26±0.03	36.98±0.01	206±0.11	0.91±0.02	153±0.10	-9±0.00	39.91±1.04	1.35±1.20
WCPO Biolube	10.72±0.13	59.32±0.20	173±0.10	-	234±1.13	-31±0.10	21.04±1.21	1.28±1.40

*Key: **KV** = Kinematic Viscosity; **VI** = Viscosity Index; **D** = Density; **FP** = Flash Point; **PP** = Pour Point; **AV** = Acid Value; **IV** = Iodine Value; (**-**) = Not Applicable; (**±**) = Mean Value Plus or Minus Standard Deviation (n = 3)*

Table 3.3: FTIR Analyses of the PWCPO and the biolubricant

Bonds	Wave Number (cm^{-1})	Bond Description	Functional Group	Samples
C-H	2922	Alkane stretch	Alkane	PWCPO, biolube
$-CH_2-$	2855	Alkane stretch	Alkane	PWCPO, biolube
$-CH_2-$	1461	Alkane bend	Alkane	PWCPO, biolube
$-CH_3$	1375	Methyl bend	Alkane	PWCPO, biolube
$-(CH_2)4-$	723	4 or more –CH2- (chain)	Alkane	PWCPO, biolube
C=O	1710	Carbonyl stretch	Carboxylic acid	PWCPO, biolube
C-O	1159	Stretching vibration	Esters	PWCPO, biolube
X=C=Y	1975	Stretching vibration	Alkenes, Isocyanates, Isothiocyanates	biolube

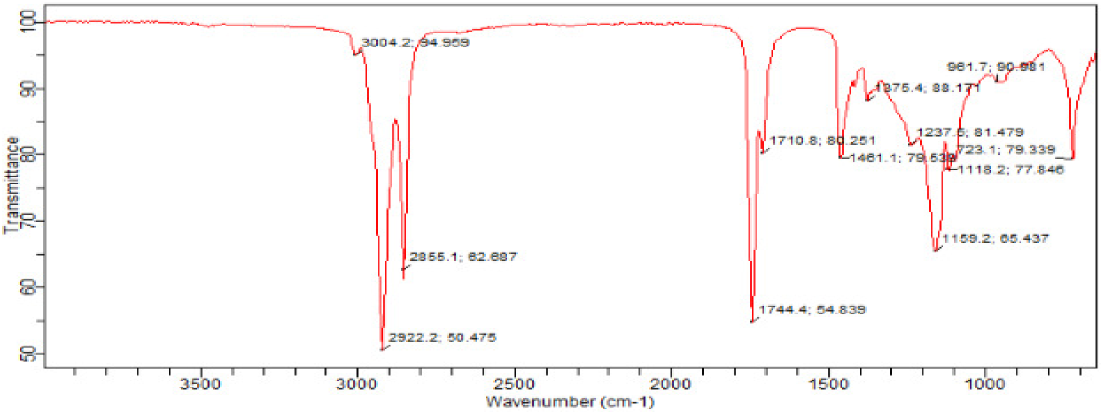

Fig. 3.1: FTIR spectrum of the PWCPO

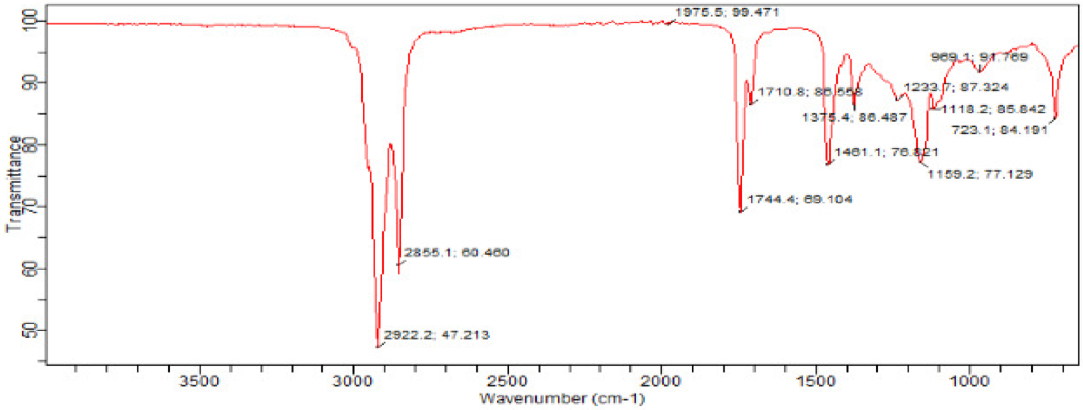

Fig. 3.2: FTIR spectrum of the biolubricant

4. CONCLUSION

Analyses of the PWCPO confirmed its potential to be used for the production of multigrade lubricating oil. Mixing the PWCPO with mineral-based oil (SN 500) and additives, gave biolubricant with improved quality parameters that are comparable to ~~that~~ those of ecofriendly lubricating oil (Mobil 1 5W-30) and are within standards for engine oils. FTIR analyses of the produced biolubricant confirmed the presence of the ester functional group: ~~esters~~ Esthers are good starting materials for the formulation of lubricating oil because of their good lubricity.~~, while~~ GC-MS revealed ~~both~~ the presence of both saturated and unsaturated fatty acids in the oil. The biolubricant produced from watse PWCPO is renewable, biodegradable and ~~is~~ ecofriendly.

ACKNOWLEDGEMENTS

This research is self-sponsored and was carried out using facilities provided by OHV Energies and Marketing, Kaduna, Nigeria, and authors highly appreciate OVH for this gesture.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

AUTHORS' CONTRIBUTIONS

This work was carried out in collaboration ~~among~~ by the authors. Author MUD supervised the work. Author~~s~~ FJO carried out the analyses. Authors MAS and ALA interpreted the results and compiled the write up. All authors read and approved the final manuscript.

CONSENT (WHERE EVER APPLICABLE)

Not applicable

ETHICAL APPROVAL (WHERE EVER APPLICABLE)

Not applicable

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DEFINITIONS

API = American Petroleum Institute
CCS Vis = Cold Cranking Simulator Viscosity
CSO = Calabash Seed Oil
FTIR = Fourier Transform Infra-red Spectroscopy
GC-MS = Gas Chromatography Mass Spectroscopy
Ibs/gal = Density (pounds per gallon in US)
MRV-TP1 = Mini-Rotary Viscometer Temperature Profile 1

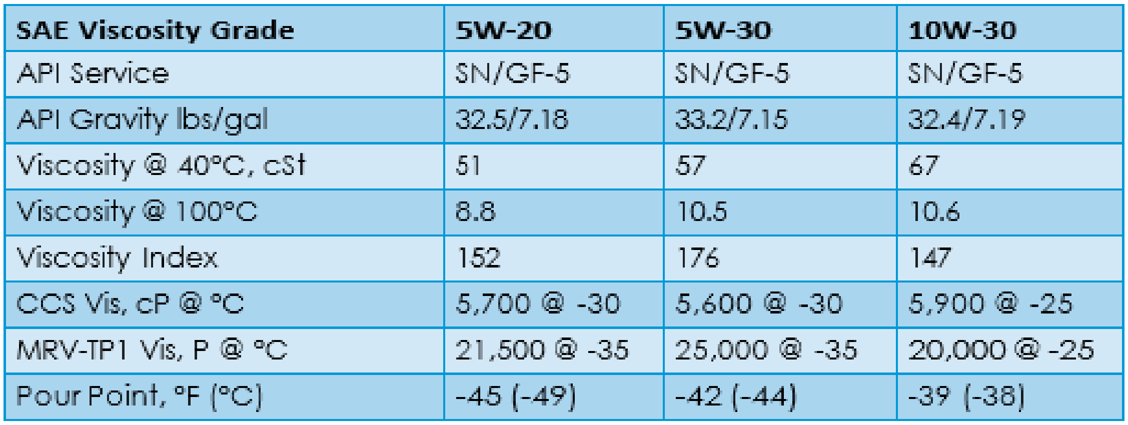
PWCPO = Pretreated Waste Cooking Palm Oil
TMP = Trimethylol Propane
WCO = Waste Cooking Oil
SEA = Society of Automotive Engineers
SN/GF-5 = API/ILSAC (International Lubricant Standardization and Approval Committee) engine oil standard

APPENDIX

Appendix I: Additives used for WCPO biolubricant production

The additives used for the production of the biolubricant are equal amount of triethylenetetramine (TETA – used as dispersant and anti-oxidant), zinc dialkyldithiophosphate (ZDDP - used as viscosity index improver, pour point depressant and anti-foam), and poly alkylmethacrylate (PAMA - used as anti-oxidant, anti-wear and detergent).

Appendix II: Multigrade engine oil specification



SAE Viscosity Grade	5W-20	5W-30	10W-30
API Service	SN/GF-5	SN/GF-5	SN/GF-5
API Gravity lbs/gal	32.5/7.18	33.2/7.15	32.4/7.19
Viscosity @ 40°C, cSt	51	57	67
Viscosity @ 100°C	8.8	10.5	10.6
Viscosity Index	152	176	147
CCS Vis, cP @ °C	5,700 @ -30	5,600 @ -30	5,900 @ -25
MRV-TP1 Vis, P @ °C	21,500 @ -35	25,000 @ -35	20,000 @ -25
Pour Point, °F (°C)	-45 (-49)	-42 (-44)	-39 (-38)