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Calcined Cement Clinker Catalyzed Methanolysis of Waste Avacado Fruit Oil and its Engine Emission Analysis

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Abstract:- The adverse environmental impact and rapid depletion of fossil fuel has resulted in the search of environmentally friendly and renewable energy. Among various alternatives for fossil fuel, biodiesel is emerging as a promising choice for compression ignition engine due to its renewable nature and superior emission characteristics. However, the cost of biodiesel is at present relatively higher than that of diesel as the feed stock come principally from edible oils. This research work focused on biodiesel production using low cost oil and catalyst as a means of reduction of biodiesel cost. The waste avocado fruit oil (WAFO) was extracted using solvent extraction method. The oil was characterized based on American Society for Testing and Materials (ASTM) method. The fatty acid profile and the functional group of the oil were determined using gas chromatography mass spectrometry and Fourier Transform infrared spectroscopy respectively. The fuel properties of the waste avocado fruit oil fatty acid methyl ester (WAFOFAME) produced was determined based on ASTM standards. The physiochemical properties of WAFO: free fatty acid, saponification value, iodine value , kinematic viscosity, fire point, flash point, cloud point, pour point, density , moisture content, gave the values 7.15%, 201.4mgKOH/g, 74.8gI$_2$/100g, 38.5mm^{2}s-^{1} @ 40^{0}C, 167^{0}C, 120^{0}C, 13^{0}C, 3^{0}C 919Kg/m^3, 6% respectively. The fatty acid profile of WAFO shows the constituents saturated fatty acids to be lauric acid 12.30%, palmitic acid 24.20%, stearic acid 18.20%, myristic acid 14.54%, while the unsaturated fatty acid constituents are linolenic acd 10.61%,, sapentaenoic acid 12.57%, and linoleic acid 7.55%. The experimentally determined properties of the WAFOFAME: acid value, density, kinematic viscosity, flash point, cetane number, water and sediments, calorific value, iodine value, cloud point and pour point gave the values, 0.45mgg^{-1}, 873Kg/m^3, 4.95mm^{2}s^{-1}, 160^{0}C, 62.69, 34.683MJ/Kg, 34.2gI$_2$/100g, 7^{0}C, 4^{0}C respectively. The X- ray fluorescence analysis showed the chemical composition of the clinker catalyst; CaO , SiO$_2$, Al$_2$O$_3$, Fe$_2$O$_3$, MgO, SO$_2$, K$_2$O, Na$_2$O, P$_2$O$_3$, TiO$_2$ as 66.6%,, 21.9%, 6.38%, 4.10%, o.72%, 0.47%, 0.90%, 0.2%, 0.03%, 0.31% respectively. The engine emission test revealed increase in carbon monoxide (CO) and hydrocarbon emission (HC) emission with engine load. Again, CO and HC emission decreased with increase in biodiesel content of the blend while nitrogen oxides (NOx) increased with increase of engine load as well as increase in biodiesel content of the blends.

***Keywords**:- Calcined cement clinker catalyst, engine emission test, engine load,* ester*ification, transesterification, waste avacado fruit oil biodiesel.*

I. INTRODUCTION

The impact of fossil fuel in the environment coupled with its nonrenewable nature and the spate of its depletion has made the search for alternative environmentally friendly and renewable energy sources inevitable. Among the various options investigated for diesel engine, biodiesel obtained from vegitable oil and other sources has been universally accepted as the foremost contender for reduced exhaust emission [1].Biodiesel is a mono-alkyl ester of long chain fatty acid, that has characteristics similar to diesel with additional advantages of high lubricity, high cetane number, being biodegradable and environmentally friendly [2]. Burning of fossil fuel results in environmental pollution such as emission of green house gases , including sulphur oxides (SOx), nitrogen oxides (NOx) and methane [3]. Biodiesel is produced by the reaction of oil or fat with an alcohol usually in the presence of catalyst which could be a base, acid or an enzyme. Various processes have been adduced for production of biodiesel, including, micro-emulsion with alcohol, catalytic cracking, pyrolysis and transesterification [4] [5] [6] [7]. Among these processes, transesterification has proved to be the most useful means of converting oil or fat into environmentally safe biodiesel [8]. Although, biodiesel is gaining popularity, more than 95% of the renewable resources used for its production are edible oils [9], which will in a long term have serious implications on food availability and the cost of biodiesel as it may be more expensive than petro-diesel. Worldwide, biodiesel production at present is mainly from edible oils such as soybean, sunflower and canola oils etc. Utilization of edible oils as feedstock for biodiesel production poses a lot of concerns as this practice competes with food supply leading to high cost of edible vegetable oil, and consequently results in relative increase in biodiesel production cost.

The global trend towards increased use of renewable energies has led to investigation of non-traditional oil producing crops. Some crops have been discovered in the tropical Sub-Saharan regions of Africa that have potential for use as bio-fuel feed stocks. Oil seeds and feedstock such as jatropha, cotton, palm kernel, soya beans and rice bran has been proposed as potential sources of oil for biodiesel production. In the course of this research, the use of waste avocado fruit oil (WAFO) as a possible feedstock for production of biodiesel of comparable quality as diesel will be considered. Avocado (Persea americana Mill.) of the plant family Lauraceae produce fruit with high oil content [10]. The pulp or mesocarp (fleshy part of the fruit) make up 60 to 75% of the total weight of avocado fruit [10]. Mesocarp is composed of parenchyma cells that surround uniformly distributed specialized oil containing idioblast cells [11]. The endocarp (stony part of the fruit) makes up 13% of the total weight of the fruit. Avocado is a tropical fruit that stands out for its high nutritional value [10]. The oil content is mainly of saturated fatty acid and low amount of polyunsaturated fatty acid [12]. Avocado fruit oil has been used for cooking, cosmetics, and treating diseases, but has not been widely studied as a good source of oil for renewable energy [13].

Therefore, concerted research efforts are geared towards evaluating non-edible oils and waste cooking oil (WCO) or used cooking oil (UCO) as suitable feedstock. The cost of the feed stock will as well be reduced by the use of oil from waste discarded fruits and seeds which abound during the harvesting seasons. Here oil from mashed discarded avocado fruits was utilized. The cost of biodiesel will be further reduced by the use of low cost catalyst. The oil from waste avocado fruit has relatively high free fatty acid, of which biodiesel yield is not favored by alkaline catalysis alone without first of all esterifying the oil with an acid catalyst. This research work, in order to circumvent the two step process of esterification with acid catalyst before transesterification with alkali catalyst, investigated the use of heterogeneous catalyst of cement clinker which major constituent is CaO for transesterification of the WAFO into waste avocado fruit oil fatty acid methyl ester (WAFOFAME). Heterogeneous base catalyst has the advantages of being reusable, tolerant to free fatty acid and water content of the oil feedstock, improved yield and purity of biodiesel, simpler purification process of glycerol [14], [15], [16] . The advantages of use of CaO catalyst for transesterification include low cost, high activity, mild reaction conditions and being reusable. Some researchers [17], [18,] have reported biodiesel yield of 95% and 96.6% respectively from soya bean oil using CaO catalyst.

II. MATERIALS AND METHODS

2.1 Materials

Waste avocado pear fruits, reagents, glasswares, equipments including gas chromatography mass spectrometer (GC-MS), Fourier transform infrared spectroscopy (FTIR), viscometer, magnetic hot plate, soxhlet extractor, 4-stroke Perkin 4:108 diesel engine.

2.2 Experimental Methods

2.2.1 Extraction of oil from the waste avocado pear fruits

The waste or mashed avocado fruits used were collected from a local market in Uga Aguata L.G.A, Anambra state. The seed, seed coat and skin were removed and the pulp was sundried for 7 days followed by oven drying till it was sufficiently dry for application of solvent extraction.. Solvent extraction using ethanol was employed for extraction of oil from the dried avocado pulp. The solvent choice of ethanol for extraction of oil from avocado pulp was based on the study by [19], [20]. Both researchers reported higher yield of oil from avocado pulp using ethanol as compared to extraction with n-hexane.

3kg of the dried, ground pulp was introduced into a plastic container containing 3 liters of ethanol. The mixed content of the container were vigorously shaken after covering the container. The container was made air tight to prevent evaporation of the ethanol and then kept for a day for maceration of the content. Then the dissolved oil in ethanol was decanted and the slurry filtered. The filtrate was then distilled to recover the ethanol at 65^0C (AOAC 1990). The percentage oil yield was calculated as:

$$\%\,oil\ yield\ = wejght\ of\ oil\ obtaind\ \div\ weight\ of\ seed\ sample\ x\ 100 \qquad (1)$$

2.2.2 Characterization of waste avocado pear oil

The physiochemical properties of the oil extracted from mashed avocado fruit was characterized based on American Society for Testing Materials, ASTM 6751 (1973) method. Analytical equipments, GC MS (QP2010 plus Shimadzu, Japan) and FTIR (M530 Bulk scientific FTIR) were used to determine the fatty acid profile and the functional groups of the oil respectively.

2.2.3 Preparation of the clinker catalyst

The clinker used was obtained from DANGOTE Cement Factory in Nigeria. The cement clinker was washed with1% solution of sulphuric acid to remove dirty stains on the surface of the clinker. It was then pulverized and sieved using 80-100 mesh in order to obtain large surface area of the catalyst particles for efficient catalysis. The chemical composition of the clinker was obtained from X-ray florescence with in-built XRD (ARL 8660S which shows the major constituent of clinker as the base CaO responsible for the catalysis of transesterification reaction. The clinker was activated by soaking with methanol in the ratio of 1:1(w/w), followed by calcinations at 700^0C for 7 hours in the furnace. After cooling on a water bath the catalyst was ready for use.

2.2.4 Production of Waste avocado fruit oil fatty acid methyl ester (WAFOFAME)

The biodiesel used in this work was produced using the normal method of laboratory preparation of biodiesel. The amount of oil required for the transesterification was run into a 500 cm^3 three-necked round bottomed flask. Onto the side arms of the three-necked flask used as the reactor,

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were fitted a thermometer and a receiver respectively, and then on the central arm was also fitted a condenser. The amount of oil specified for the reaction was run into the flask and the oil heated to the specified temperature for the reaction.. Then specified quantity of calcined cement clinker catalyst (4% w/w of oil) with methanol were added onto the flask content. The hot plate stirrer was switched on after setting the stirrer speed at the value required for the reaction. Heating was continued and the flask content continuously stirred and refluxed. At the end of transesterification, the flask content was poured into separating funnels, allowed to settle for a day where it separated into upper biodiesel layer and the lower glycerol layer. The two layers were tapped off separately, the glycerol layer first followed by the biodiesel layer. As the biodiesel layer may contain some traces of sodium hydroxide and glycerol, they were removed by wet washing. The washed biodiesel was then dried on a laboratory hot plate at 105^{0}C to remove all traces of moisture remaining in it. The percentage biodiesel yield is given by the expression,

$$\%\ biodiesel\ yield = Volume\ of\ biodiesel\ produced \div volume\ of\ oil\ used\ x\ 100 \quad (2)$$

2.2.5 Determination of fuel properties of WAFOFAME

The fuel properties of the waste avocado fruit oil biodiesel were characterized based on ASTM standards. The property determined include density, viscosity, iodine value, cetane number, acid value, free fatty acid, calorific value, flash point etc.

2.2.6 Engine emission test at constant speed and varying load.

The engine emission test using WAFOFAME was carried out on a Perkins 4:108 diesel engine mounted on a steady state engine test bed as shown in plate 1. The engine is a four cylinder, water-cooled, naturally aspirated, 4-stroke engine. The engine specification is as shown in table 1. The experiment was performed with no. 2 diesel fuel, WAFOFAME and the blends. The

Plate 1: Perkin 4:108 diesel engine mounted on Steady state engine test bed at UNN Nsuka

Table 1: Engine specifications

Components	Values
ENGINE	
Type	Perkins 4:108
Bore	79.735mm
Stroke	88.9mm
Swept volume	1.76litres/cycle
Compression ratio	22:1
Maximum BHP	38
Maximum speed	3000rpm
Number of cylinder head	4
Diameter of exhaust	$1^1/_2{}''$
Length of exhaust pipe	36”31’
DYNAMOMETER	
Capacity	112kw/150hp
Maximum speed	7500rpm
KW	(N_mx rev/min)/9549.305
FUEL GUAGE	
Capacity	50-100 cc
AIR BOX	
Orifice size	58.86mm
Coefficient of discharge	0.6

Source: Department of Mechanical Engineering, University of Nigeria Nsuka

Blends consist of 0%, 20%, 40%, 60% 80% and 100% biodiesel, with diesel making up 100% for each, and are denoted as B0, B20, B40, B60, B80 and B100 respectively. A short test run was conducted with the engine to ensure that all essential accessories are in good working order before the actual test begins.

Here the engine was started after running into the fuel chamber 100cm^3 of the fuel blend under test. The engine was kept at a constant speed of 1900rpm, and loaded 20Kg.The engine torque was taken. The time taken to exhaust the 100cm^3 of the fuel blend was read using a stopwatch. The manometer reading and the exhaust temperature reading were taken.The gas emissions of nitrogen oxides (NOx), carbon monoxide (CO), and hydrocarbons (HC) were measured from the end of the exhaust pipe of the engine using portable digital gas analyzer (Testo XL 450). After taking the readings at 20kg load, the load on the engine was varied using dynamometer loading wheel. The above procedure was then repeated in turn for higher load values of 40kg, 60kg, 80kg and 100kg.

III. RESULTS AND DISCUSSION

3.1 Charateristics of waste avocado fruit oil

3.1.1 Physiochemical properties of WAFO

The summary of the characteristics of waste avocado fruit oil are as shown in table 2. From the table, it could be seen that the acid value and the free fatty acid of mashed avocado pear fruit oil 17.0mg and 8.5% respectively are high. The free fatty acid and moisture content of the oil is each greater than 1%, indicative of the fact that mashed avocado fruit oil will not give appreciable yield of biodiesel via alkali transesterification. Oils of high moisture content are prone to hydrolytic oxidation. Again oils of high free fatty acid and moisture content has the tendency for soap formation during alkali transesterification which inhibits glycerol separation from biodiesel and therefore retards biodiesel production. The oil therefore has to be pretreated or esterified before being transesterified. Alternatively such oils are directly transesterified using heterogeneous catalyst such as calcined cement clinker used in this work. The kinematic viscosity and the density of the oil are higher than that of the biodiesel produced from it and much higher than that of diesel. High density and viscosity make atomization of the oil in internal combustion engine difficult and has been associated with increase in engine deposit, hence they cannot be used directly as biodiesel [21].

Iodine value, a measure of degree of unsaturation of the oil obtained is below 100gI_2/100g oil, indicative of the oil being nondrying and therefore suitable for biodiesel production. High iodine value of oil corresponds to high degree of un-saturation of the fatty acid in the triglyceride, and if heated, such oil is prone to thermal oxidation and polymerization of the triglyceride causing formation of deposits

Table 2: Physiochemical properties of WAFO

Properties	Unit	WAPO
Acid value	mgKOH/g	17.0
Free fatty acid	%	8.5
Saponification value	mgKOH/g	201.4
Iodine value	(gI_2/100g oil)	74.8
Peroxide value	meq/kg	16
Kinematic viscosity	mm^2s^{-1} @ 40^0C	38.5
Fire point	^0C	169
Flash point	^0C	120
Cloud point	^0C	13
Pour point	^0C	3
Refractive index		1.4614
Specific gravity		0.919
Moisture content	%	6
Density	Kg/m^3	919

3.1.2 Characterization of cement clinker catalyst

The chemical composition of the clinker was obtained from X-ray florescence with in-built XRD (ARL 8660S) as shown in table 3. From the table it could be seen that the constituents of clinker are the oxides of the metals and non-metals including; CaO, SiO_2, Al_2O_3, Fe_2O_3, MgO, SO_2, K_2O, Na_2O, P_2O_5, TiO_2 with the basic oxide CaO constituting 66.4% by weight of the catalyst and a major constituent responsible for the catalysis of transesterification reaction.

Table 3: X-ray fluorescence of clinker catalyst

Constituent compounds	Weight %
CaO	66.40
SiO_2	21.59
Al_2O_3	6.01
Fe2O3	3.35
MgO	0.65
SO_2	0.73
K_2O	0.84
Na_2O	0.12
P_2O_5	0.03
TiO_2	0.32

3.1.3 Fatty acid profile of waste avocado fruit oil

The Fatty acid profile of WAFO was determined using GC-MS analysis. The individual peaks of the gas chromatogram were identified as shown in figure 1. The relative per centage of fatty acids were calculated from total ion chromatography by computerized integrator and results are presented in table 4. As shown in the table the saturated fatty acid constituents of the oil were identified as palmitic acid (C16:0) 24.20%, lauric acid (C12:0). 12.30%, myristic acid (C14:0) 14.54% and stearic acid (C18:0) 12.57%.. The di-, tri-, and polyunsaturated fatty acid constituents of the oil are linoleic acid (C18:2) 7.55%, linolenic acid (C18:3) 10.61% and sapentaenoic acid 12.57% respectively.

3.1.4 Fourier transform infrared (FTIR) spectra analysis of waste avacado fruit oil

The Fourier transform infrared spectra of WAFO was analyzed using Fourier transform infrared spectroscopy (M530 Buck scientific FTIR). This analysis was carried out in order to detect the various functional groups contained by the oil. The FTIR spectrum of WAFO is shown in figure 2. The different group assignments of the FTIR spectra of WAFO are summarized in table 5. which shows the presence of mostly alkane, alkynes and hydroxyl groups. The presence of hydroxyl groups are detected at 3853.171, 3539.869, 3149.224, 1390.83 cm^{-1} with O-H stretching. The vibration of C-H bending of alkanes were evident at 775.3272 and 878.8254 cm^{-1}. The C≡C stretching at 2042.03 and 2201.238 cm^{-1} shows the presence of alkynes. While the C-H stretch at 2805.394 and 1852.449cm^{-1} depicts the presence of aldehydes and aromatic compounds respectively. The presence of conjugated alkane was also detected by the C=C stretch at 1622.394 cm^{-1}.

Table 4: Summary of fatty Acid Profile of WAFO

Components Common Name	**Systematic Name**	**Structural Formula**	**Concentration (%)**
Lauric C12	Dodecanoic Acid	$CH_3(CH_2)_{10}COOH$	12.30
Palmitic Acid C16	Hexadecanoic Acid	$CH_3(CH2)_{14}COOH$	24.20
∝ Linolenic Acid C18:3	Octadeca-9, 12,15 Trienoic Acid	$C_{17}H_{29}C0_2H$	10.61
Sapentaenoic Acid C20:5	Icosa-5,8,11,14,17- Pentaenoic Acid	$C_{19}H_{29}C0_2H$	12.57
Stearic Acid C18	Octadecanoic	$CH_3(CH_2)_{16}COOH$	18.20
Linoleic Acid C18:2	Octadeca-9, 12-Dienoic Acid	$C_{17}H_{31}C0_2H$	7.55
Myristic Acid C14	Tetradecanoic Acid	$CH_3(CH_2)_{12}COOH$	14.54

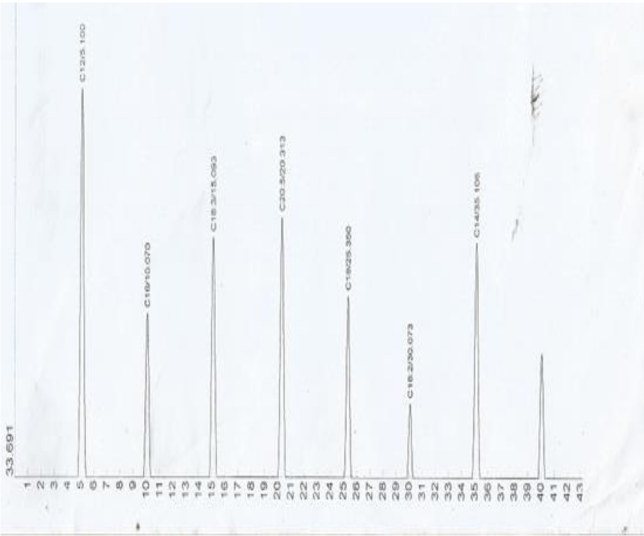

Figure 1: GC-MS plot of waste avocado fruit oil

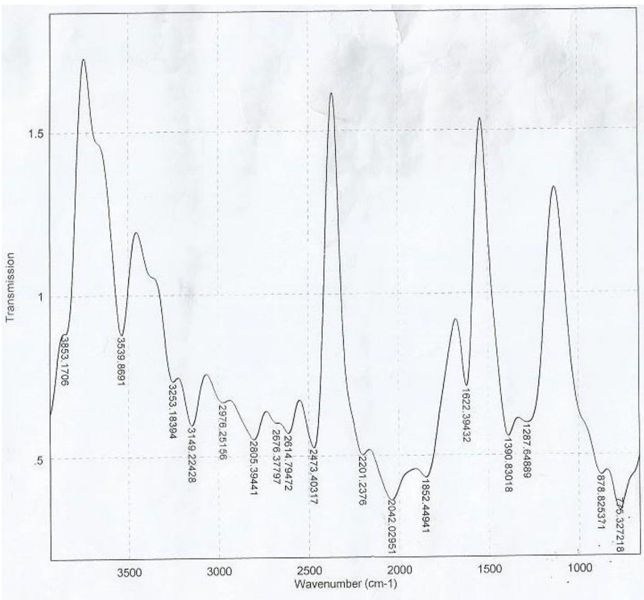

Figure 2: FTIR spectra of waste avocado fruit oil

Table 5: FTIR functional group frequencies of WAFO

Frequency wave number (cm^{-1})	Types of Vibration	Functional Group
775.3272	Bending	C-H (Alkane)
878.8254	Bending	C-H (Alkane)
1287.649	Stretch	C-O (Aromatic)
1390.83	Bending	0-H (Phenol)
1622.394	Stretch	C=C (conjugated alkene)
1852.449	Stretch	C-H (Aromatic Compound)
2042.03	Stretch	C≡C (Alkyne)
2201.238	Stretch	C≡C (Alkyne)
2805.394	Stretch	C-H (aldehyde)
2976.252	Stretch	C-H (alkane)
3149.224	Stretch	0-H (alcohol)
3253.184	Stretch	Normal polymeric O-H
3539.869	Stretch	O-H
3853.171	Stretch	O-H

3.2 Fuel properties of waste avocado fruit oil biodiesel

The fuel properties of APOFAME produced are given in table 6. The density of the biodiesel was evaluated to be 873kg/m^3 which is within the ASTM limit for biodiesel. The biodiesel density is however lower than that of the oil from which it was derived. This underscores the essence of transesterification in reducing the density of oil to a level where it could be properly atomized in the engine in order to exhibit good combustion characteristics.

The kinematic viscosity of the biodiesel produced was evaluated as 4.95mm^2/s and is therefore within the ASTM limit. High kinematic viscosity of biodiesel result in poor atomization and incomplete combustion which give rise to cocking of injector tips and hence engine power loss. This conforms to the findings of [22]. The viscosity of biodiesel is typically higher than that of diesel [23]. On the other hand very low viscosity fuel produces very subtle spray which cannot properly get into the combustion cylinder, thus forming a fuel rich zone that give rise to sooth formation [24], [25] [26].

Flash point measures the degree of flammability of the fuel. The ASTM standard for flash point is ≥ 130^{0}C. However during biodiesel production and purification, some traces of methanol may remain in the fuel making the flash point to be less than 130^{0}C and thus making it flammable and dangerous to handle or store. The flash point of the WAFOFAME is 154^{0}C and thus is within the ASTM standards which make it safe for handling and storage. Cetane number serves as a measure of ignition quality of the fuel. Fuels with low cetane number shows increase of unhealthy gas emission due to incomplete combustion. The higher the cetane number the better the fuel burns in the combustion chamber of the engine. Since biodiesel is composed of long chain hydrocarbon groups with virtually no branching or aromatic structure, it typically has higher cetane number than petro-diesel [23]. The ASTM lower limit for cetane number is 47. The cetane number of the WAFOFAME is 62.69. Thus it is within the ASTM standards and therefore of good ignition quality. Calorific value which is an important property for measuring the energy content of the fuel suggest the suitability of WOFAME as an alternative to petro-diesel as its determined calorific value of 38.2MJ/Kg approximate that of diesels' 44.34MJ/Kg.

Table 6: Fuel properties of APOFAME

Properties	**Unit**	**APOFAME**	**ASTM Standards**	**Test method**
Density	Kgm^{-3}	873	860-900	D93
Kinematic viscosity	mm^{2}s^{-1}	4.95	1.9-6.0	D445
Cetane number		62.69	47min.	D613
Flash point	^{0}C	160	100-170	D93
Cloud point	^{0}C	7	-3-15	
Water &sediment	%	0.5	0.5	D2209
Acid value	mgKOHg^{-1}	0.45		D664
Calorific value	MJKg^{-1}	38.2	42.06	D35
Iodine value	gI$_2$100g^{-1}oil	43.2	42-46	D4067
Pour point	^{0}C	3	+1^{0}Cmin	D97

3.3 Effect of engine load on CO, HC and NOx emission of diesel, WAFOFAME and the blends

3.3.1 Effect of engine load on CO and HC emission of the blends

Figures 3 and 4 showed the effect of engine load on CO and HC emission respectively for diesel, WAFOFAME and the blends. From the figures it could be observed that CO and HC emission increased with increase in engine load. The increase in emission results from decreased air-fuel ratio resulting from increase in engine load which gave rise to incomplete burning of the fuels. From figures 3 and 4 respectively it could be observed that CO and HC emissions decreased with increase in biodiesel fraction in the blend. The researchers (27], [28] have reported a reduction in CO and HC emission when a diesel engine is fueled with biodiesel instead of diesel. This shows that the use of biodiesel lowers the CO and HC emission. This could be explained from the point of view of oxygen content and low carbon to hydrogen ratio of biodiesel. The oxygen content of biodiesel increased the vaporization and atomization of biodiesel and hence the complete combustion leaving low amount of CO and HC in the combustion product as compared to diesel fuel [29]. The low carbon to hydrogen content of biodiesel presents less carbon to be burnt which gave rise to low CO and HC in the combustion product.

3.3.2 Effect of engine load on NOx emission of diesel, WAFOFAME and the blends

Figure 5 shows the effect of engine load on NOx emission for the fuels. From the figure it could be observed that NOx emission increased with increase in engine load. This could be explained by the fact that increase in engine load reduce the air-fuel ratio resulting in incomplete oxidation of the nitrogen components of the biodiesel, thus emitting the oxides of nitrogen or NOx. From the figure, it is also discernible that at specific engine load, NOx emission increases with increase in biodiesel fraction. This is in conformity with the findings of the researcher [27] and [28]].

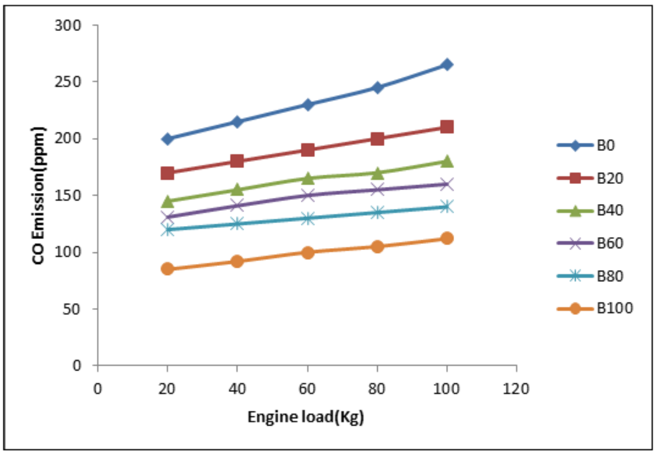

Figure 3: Effect of engine load on CO emission for diesel, WAFOFAME and their blends

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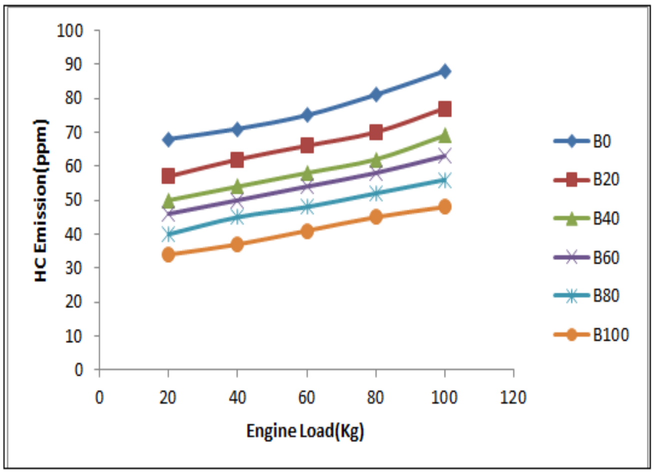

Figure 4: Effect of engine load on HC emission for diesel, WAFOFAME and their blends

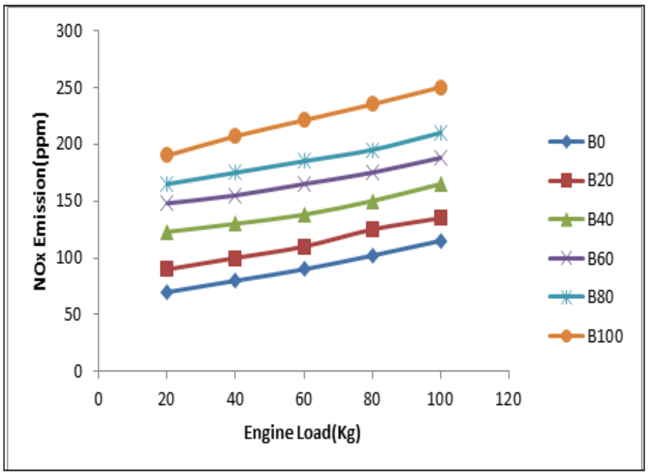

Figure 5:- Effect of engine load on NOx emission for diesel, WAFOFAME and their blends

IV. CONCLUSION

The waste avocado fruit oil biodiesel has properties that are within the ASTM standards and compares favorably with the diesel. The additional advantages of the WAFOFAME over diesel are higher cetane number, higher lubricity, being biodegradable, renewable and environmentally friendly. However the cloud point and pour point values makes it unsuitable for use in cold climates especially during cold weather, but this could be surmounted by the use of pour point and cloud point depressants. The high free fatty acid and moisture content of WAFO makes its transesterification to WAFOFAME a two step process involving esterification before transesterification . The use of calcined cement clinker catalyst enable direct transesterification of the oil to biodiesel and reduce the cumbersome process of the biodiesel purification.

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