Rubber Seed Oil Fatty Acid Methyl Esther Synthesis, Engine Performance Evaluation and Emission Analysis

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ABSTRACT
The shortfalls of fossil fuel, rapid depletion of reserves, nonrenewable, non-biodegradable, low lubricity, emissions of poisonous gases have resulted in the search for alternative energy source to fill the gap. This research work focused on synthesis, engine performance evaluation and exhaust gas emission analysis of rubber seed oil biodiesel. The rubber seed oil was solvent extracted using n-hexane and the physiochemical properties of the oil were characterized based on ASTM methods. The oil was esterified and then transesterified using sodium hydroxide catalyst. The fuel properties of the bio-diesel produced were characterized based on ASTM standards. The engine performance and emission tests were carried out using Perkins 4.108 diesel engine. The oil yield of rubber seed was obtained as 36.2%. The physiochemical properties of rubber seed oil were obtained as acid value 28.72mgKOH/g, free fatty acid 14.36%, saponification value 185.66mgKOH/g, iodine value 120.4gI_2/100goil, peroxide value 14.62meq/Kg, kinematic viscosity 60.08mm^2/s @40^{O}C, fire point 180^{O}C, flash point132^{O}C, cloud point 6^{O}C, pour point 2^{O}C, refractive index 1.428, specific gravity 0.92, moisture content 7%, density 920Kg/m^3. The fuel properties of RSOFAME were determined as density 880Kg/m^3, kinematic viscosity 4.25mm^2/s, cetane number 58.2, flash point 164^{O}C, cloud point 4^{O}C, water content o.44%, acid value 0.32mgKOH/g, iodine value 72gI_2/100goil, pour point 2^{O}C. The engine test shows that the engine performance characteristics, torque (T), brake thermal efficiency (BTH), and brake power (BP) RSOFAME are lower than that of the diesel, while the brake specific fuel consumption (BSFC) is higher. However, the lower the biodiesel fraction in the blend, the more the engine performance characteristics approximates that of diesel. Engine exhaust gas emission analysis revealed reduction of CO and HC emission and increase in NOx emission from the use of RSOFAME compared to diesel.

Keywords: Engine Load, Engine Performance Characteristics, Engine Performance Test, Exhaust Gas Emissions Test, Transesterification.

I.0 INTRODUCTION
Biodiesel is fast gaining grounds as the foremost bio-fuel to replace fossil fuels owing to its numerous advantages over the later. The numerous disadvantages of fossil fuel, rapid depletion of the reserves, non-renewable, non-biodegradable, low lubricity, emission of poisonous gases has resulted in the search of alternative energy source to fill the gap. Biodiesel is a mono-alkyl ester of long chain fatty acid that has properties that approximate that of diesel with added advantages of higher cetane number, higher lubricity, being biodegradable , environmentally friendly and renewable. The use of fossil fuel results in environmental pollution from emitted greenhouse gases, including sulphur oxides (SOx), nitrogen oxides (NOx), carbon monoxide (CO), hydrocarbon (HC), and methane [1]. Presently, bio-diesel, bio-ethanol and biogas are considered as the most promising alternatives in energy generation that can compete with the fossil fuel [2, 3] and this global trend towards increased use of renewable energies has led to the investigation of non-traditional oil producing crops such as jatropher and cotton seed. The production of biodiesel as at present is mainly based on the use of edible vegetable oil as the feed stock. The researcher [4] has reported that 95% of renewable resources used for biodiesel production come from edible vegetable oil, and this has been envisaged to have serious implication on food availability and the cost of biodiesel. This has resulted in concerted effort being geared towards the production of biodiesel from non-edible oil and used cooking oils (UCO) feed stock. Used cooking oils have many disposal problems like water and soil pollution, human health concern, and disturbance to aquatic ecosystem [5]. Rather than its disposal that is harmful to the environment, it can be used as cost –effective feedstock for production of biodiesel. Notable researchers [6-9] have given the methods of producing biodiesel as micro-emulsion with alcohol, catalytic cracking, pyrolysis and transesterification. Among the various production processes, transesterification has been shown to be the most useful means of converting oil or fat into environmentally safe biodiesel [10, 11].
The compression ignition engine performance evaluation and emission analysis of biodiesel derived from different sources have been investigated by different researchers [12-18]. This research work is focused on production, engine

performance evaluation and emission analysis of rubber seed oil biodiesel. The rubber seed oil (RSO) was solvent extracted with n-hexane and pretreated to reduce the free fatty acid content below 1% which is the normal free fatty acid content of triglyceride to be transesterified with alkali. The pretreated oil was then transesterified to rubber seed oil fatty acid methyl ester (RSOFAME) or biodiesel. The engine performance evaluation was carried out using Peking 4:108 diesel engine, while the exhaust gas emission of the engine was characterized using portable digital gas analyzer (TEXTO XL 450). The qualities of biodiesel include oxygenation, sulphur and aromatic hydrocarbon-free, biodegradable, nontoxic and environmentally friendly. It shows less emission of SOx, CO, HC and particulate matter as a result of oxygen present in the molecule, constituting 10-12% by weight. However, biodiesel is known to emit more NOx during combustion, has lower heating value, more viscous and denser than diesel with the attendant poor atomization in the engine. The engine performance of rubber seed oil biodiesel was evaluated by comparing the plots of engine performance evaluation characteristics, torque (T), brake thermal efficiency (BTE), brake specific fuel consumption (BSFC) and brake power (BP) against engine speed and against engine load for the biodiesel and the blends with that of diesel. The engine emission analysis was investigated by comparing the effect of engine load on the gases emitted , carbon monoxide (CO), nitrogen oxides (NOx) and hydrocarbon (HC) using the biodiesel, diesel and the blends.

2.0 MATERIALS AND METHOD

2.1 Materials

Rubber seeds, reagents, glassware, viscometer, magnetic hot plate, soxhlet extractor, water bath, engine test bed, gas analyzer.

2.2 Experimental Methods

2.2.1 Extraction of rubber seed oil

The rubber seeds used in this work was purchased from Sapele in Delta state, Nigeria. It was de-shelled and the inner seed coat was removed by winnowing. The kernel was then dried in an oven at 50^0C for five hours to reduce the water content. It was then grind with mechanical grinder in order to expose more surface area of the seed for faster and maximum oil extraction. In order to determine the oil content of the seeds, the oil was solvent extracted with n-hexane using soxhlet extractor. The bulk of oil used in this research work was also obtained by solvent extraction by placing 3kg of the dried, ground seed in a plastic container containing 3 liters of n-hexane. The mixture was well shaken after covering the container. The container was made air tight to prevent evaporation of the solvent and then macerated for a day. Then the dissolved oil in n-hexane was decanted and the slurry filtered. The filtrate was then distilled to recover the methanol at 65^0C [19]. The percentage oil yield was calculated as:

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

2.2.2 Characterization of rubber seed oil

The physiochemical properties of the oil extracted from rubber seeds was characterized based on American Society for Testing Materials, ASTM 6751 (1973) method.

2.2.3 Synthesis of RSOFAME

In order to obtain high biodiesel yield, the rubber seed oil which contain high free fatty acid (14.36%) was pretreated or esterified to reduce the free fatty acid below 1%. During esterification, the oil was heated to a temperature of 110^OC for 10 minutes to drive off most of the water present in the oil. After cooling, the pretreated oil was introduced into a 500ml three-necked round bottomed flask fitted with a condenser and a thermometer at the middle and side arm respectively. Then methanol of 60%w/w of oil mixed with concentrated sulphuric acid of 7% w/w of oil was added into the flask content. The set up was heated to 60^OC for 60 minutes with a magnetic heating mantle and the agitation speed set at 400rpm. After cooling, the reaction mixture was transferred into 250ml separating funnels where it settled and separate into water, pre-treated oil and methanol layers. The pre-treated oil after being tapped off was wet-washed and oven dried at 105^OC for complete evaporation of water. The pre-treated oil was then transesterified using methanol and sodium hydroxide catalyst. A specified quantity of the pre-treated oil was run into a 500ml three-necked round bottomed flask fitted with a condenser, a thermometer and a receiver on the middle and the side arms respectively. Then a known amount of mixture of sodium hydroxide catalyst in methanol was added into the flask. The stirrer was switched on to a specified speed and the reaction mixture was heated and refluxed for the required reaction time The reaction mixture was made to stand for a day in separating funnels where it separated into the upper

biodiesel layer and the lower glycerol layer. The remnants of sodium hydroxide, methanol and glycerol in the biodiesel were removed by wet-washing.
The methyl ester or biodiesel layer was gently washed with hot distilled water in the ratio of 3:1 water to methyl ester in order to prevent its loss due to formation of emulsion that results in complete phase separation [19].

The washed biodiesel was then oven dried at 105^{O}C until all the residual water was removed. The percentage biodiesel yield is given by the expression of equation (1)

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

2.2.4 Determination of fuel properties of RSOFAME

The fuel properties of the rubber seed oil biodiesel were characterized based on ASTM standards. The properties determined include density, viscosity, iodine value, cetane number, acid value, free fatty acid, calorific value, flash point, cloud point.

2.2.5 Engine performance evaluation test

The engine performance evaluation test of the RSOFAME was carried out on a Perkins 4:108 diesel engines mounted on a steady state engine test bed as shown in plate1. The engine is a four cylinder, water-cooled, naturally aspirated, 4-stroke CI engine. The engine specification is as given in Table 1. The experiment was conducted with no. 2 diesel fuel, RSOFAME and their blends. The blends by volumes are, 0% biodiesel (B0), 20% biodiesel (B20), 40% biodiesel (B40), 60% biodiesel (B60), 80% biodiesel (B80), and 100% biodiesel (B100). B0 and B100 are neat diesel and biodiesel respectively. A short test run was done in order to ensure that all essential accessories were in working order before the actual test.

2.2.5.1 Engine test at varying speed

In carrying out this test, the engine was started after running into the fuel chamber 100cm^3 of the fuel blend under test and the engine kept at maximum load of 100Kg. The engine speed in rpm was measured using tachometer attached with the dynamometer and kept at a relatively low speed of 1000rpm and then the value of the torque was taken and recorded. The time taken for a used volume of the fuel to be consumed at this speed was noted using stop watch. The manometer reading was taken, as well as the reading of exhaust gas temperature. The above procedure was repeated for higher speed values of 1300 rpm, 1600 rpm, 1900 rpm and 2200rpm.

2.2.5.2 Engine emission test at varying load

For this test, the engine was started after running in into the fuel chamber 100cm^3 of the fuel blend tested and the engine kept at a constant speed of 1900 rpm, and loaded 20kg. The exhaust gases, NOx, CO, and HC were measured with a portable digital gas analyzer (Testo XL 450). The data of exhaust emissions were taken from the end of the exhaust pipe of the engine. After taking the necessary readings including exhaust gas temperature (EGT) at this specified speed, the load on the engine was varied using the dynamometer loading wheel. The procedure was repeated for higher loads 40kg, 60kg, 80kg and 100kg.

Plate 1: Biodiesel production by transesterification of oil

Plate 2: Perkin 4:108 diesel engine mounted on Steady state engine test bed at UNN Nsukka

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

3.0 RESULTS AND DISCUSSION

3.1 Extraction of rubber seed oil

Solvent extraction using n-hexane in soxhlet extractor was used to determine the oil content of the rubber seed.It has been reported by [20] that n-hexane gave the highest oil yield for rubbers seed when compared with other solvents and hence its use for the oil extraction. The result from the extraction process showed rubber seed to contain 34.2% of oil.

3.2 The physiochemical properties of rubber seed oil

Figure 2 depicts the physical and chemical properties of the extracted rubber seed oil. The determined acid value of rubber seed oil is (28.72mgKOH/g). This high acid value can react with excess alkali to yield soap which retards the separation of the biodiesel from the glycerol [21] and thereby reduce the amount of biodiesel produced. The oil therefore needs to be pretreated to reduce the free fatty acid below 1% for high biodiesel yield. The saponification value of the oil 185.66mgKOH/g shows rubber seed oil is probably more suitable for production of biodiesel than for soap as it is only moderately high. The iodine value of the rubber seed oil, 120.4mg I2/100g, shows the oil to be a semidrying type and therefore susceptible to oxidative rancidity. Peroxide value which indicates the degree of saturation and susceptibility of the oil to rancidity was obtained as 14.62meq/kg in this work. The high peroxide value is indicative of the fact that the oil is susceptible to spoilage by oxidation during storage and handling [22]. The experimentally determined kinematic viscosity and density of the oil 60.08mm2/s and 920kg/m3 respectively are high and make its atomization in internal combustion engine difficult as this has been associated with increase in engine deposits [23] and hence cannot be used directly as biodiesel. The determined flash point of rubber seed oil 132OCis moderately high. Oils of high flash point are safe for handling and storage.

Table 2: Physiochemical properties of RSO

Properties	**Unit**	**RSO**
Acid value	mgKOH/g	28.72
Free fatty acid	%	14.36
Saponification value	mgKOH/g	185.66
Iodine value	(gI_2/100g oil)	120.4
Peroxide value	meq/kg	14.62
Kinematic viscosity	mm^2s^{-1} @ 40^OC	60.08
Fire point	^OC	180
Flash point	^OC	132

Cloud point	^{O}C	6
Pour point	^{O}C	2
Refractive index		1.428
Specific gravity		0.92
Moisture content	%	7
Density	Kg/m^3	920

3.3 Fuel properties of the RSOFAME

The quality of any good biodiesel depends on its various properties such as density, viscosity, cetane number flash point, calorific value etc. The physicochemical properties of the produced RSOFAME are as given in table 3. The determined density of the RSOFAME is $880kg/m^3$ while the kinematic viscosity is $4.25mm^2/s$. These values are within the ASTM limits and also in agreement with the findings in literature [24,25]. High viscosity and density of fuel results in poor atomization in compression ignition engine which give rise to carbon deposits, plugging of fuel filter, and injector coking [26] and therefore reduction of the engine power output..

Acid value indicates the degree of acidity of the biodiesel and therefore the corrosive tendency of the fuel to the machine parts. This was obtained as 0.32mgKOH/g. This is sufficiently low as not to have adverse effects on handling and on the machine parts. Cetane number indicates the ignition quality of the fuel. Biodiesel generally have higher cetane number than diesel [27]. Fuels of low cetane number show increase in emission due to incomplete combustion. The cetane number of the produced biodiesel is 58.2 which is within the ASTM standard limit and indicative of its good ignition response. Flash point indicates the degree of flammability of the material. Based on ASTM, a standard biodiesel should have flash point of $\geq 130^{O}C$ for it to be classified as “nonflammable”. The determined flash point of the RSOFAME, $164^{O}C$ is within the range of ASTM standard, indicative of the fact the rubber seed oil biodiesel is safe for handling and storage.

The cloud point and the pour point of RSOFAME was determined as $4^{O}C$ and $2^{O}C$ respectively. Calorific value is an important property indicating the energy content of the fuel and indicates its suitability as alternative petroleum diesel. The calorific value of the RSOFAME was measured as 38.5MJ/Kg as against 44.0MJ/kg for diesel. The lower calorific value of the biodiesel is attributed to the presence of oxygen in its molecule.

Table 3: Fuel properties of RSOFAME

Properties	Unit	RSOFAME	ASTM Standards	Test method
Density	Kgm^{-3}	880	860-900	D93
Kinematic viscosity	mm^2s^{-1}	4.25	1.9-6.0	D445
Cetane number		58.2	47min.	D613
Flash point	^{O}C	164	100-170	D93
Cloud point	^{O}C	4	-3-15	
Water &sediment	%	0.44	0.5	D2209
Acid value	$mgKOHg^{-1}$	0.32		D664
Calorific value	$MJKg^{-1}$	38.5	42.06	D35
Iodine value	$gI_2/100g$ oil	72	42-166	
Pour point	^{O}C	2	$+1^{0}C$min	D97

3.4 Engine performance evaluation of diesel, RSOFAME and the blends

The engine performance evaluation characteristics namely, torque (T), brake specific fuel consumption (BSFC), brake thermal efficiency (BTE) and brake power (BP) were computed using the formulae shown below.. The engine performance evaluation characteristics were plotted against engine speed for the biodiesel, diesel and the blends. The plots for the biodiesel and the blends against engine speed were compared with that of the diesel against speed in order to evaluate the performance and suitability of the biodiesel and the blends as a suitable compression ignition engine fuel.

3.4.1 Calculations of engine performance evaluation characteristics

Volume flow rate of fuel, $V_f(m^3/s) = V/t$

Where V= volume of fuel (m^3) and t = time(s)

(i) Mass flow rate of fuel M_f,$(kg/s) = \rho_f V_f$

(ii) Brake power, BP (KW) = TxN/9549.30
Where T=torque (Nm), N =engine speed (rpm), ρ_f = density of fuel (Kg/m^3)
(iii) Brake thermal efficiency, BTE (n_{BT}) (%) = BP/M_f x44200
(iv) Brake specific fuel consumption, BSFC (Kg/KWh) = 3600M_f/BP

3.4.2 Effect of engine speed on Torque for diesel, RSOFAME and the blends

Figure 1 shows the plot of variation of engine torque against speed for diesel, RSOFAME and their blends at full load. The engine torque increased as the engine speed increase and attain maximum value at the an engine optimal speed of 1600rpm for diesel, and 1900rpm for RSOFAME and blends and then started decreasing with increase in speed. The decrease in torque observed on exceeding the optimal engine speed of 1600rpm or 1900rpm as the case may be could be as a result of increase in the fuel temperature that occasioned reduction of the fuel's viscosity and lubricity. The torque produced by diesel is greater than that of the biodiesel and the blends as a result of lower energy content, higher density and viscosity of biodiesel compared to diesel. Attainment of maximum torque by the diesel and the RSOFAME and blends at different temperatures of 1600rpm and 1900rpm respectively is indicative of the differences in their energy content. Again, at a specific engine speed, torque increased with decrease of biodiesel fraction in the blend. This is in conformity with the findings of [28-32], who studied the effect of diesel and biodiesel on engine power and reported that with biodiesel, engine torque will drop due to its loss of heating value.

3.4.3 Effect of engine speed on brake specific fuel consumption (BSFC) for diesel, RSOFAME and the blends

RSOFAME and the blends

An engine of low BSFC uses less amount of fuel to produce equal amount of work as one rated higher and as such low BSFC is preferred to higher one. The effect of engine speed on BSFC is shown in Figure 2. From the Figure, it could be observed that BSFC decreased with increase in engine speed and attained minimum value at an engine speed of 1600rpm for B0 and B20 and 1900rpm for B40-B100 and then started increasing with increase in speed. The decrease of BSFC with engine speed could be attributed to the fact that initially, the engine speed was relatively low and therefore the engine and fuel temperatures as well were low and as such the viscosity and lubricity were stably high resulting to high torque and thermal efficiency of the engine. The later increase in BSFC with engine speed stems from the fact that at higher speed, the engine and fuel temperature soared resulting in the reduction of the viscosity and lubricity of the fuel. Consequently, the torque and thermal efficiency of the engine decreases resting in higher BSFC. Again from Figure 1, it could be observed that at specific engine speed, the BSFC increases with increase in biodiesel fraction in the blend. This agrees with the findings of [33-38] who reported that fuel consumption of an engine fueled with biodiesel is higher as more of the fuel is required to compensate for the low heating value of biodiesel. It could then be seen that B100 is of highest BSFC value while B0 has the least value. The B0 and B20 BSFC approximate each other because of their equivalent heating values.

3.4.4 Effect of engine speed on brake thermal efficiency for diesel, RSOFAME and blends

Figure 3 shows the effect of engine speed on brake thermal efficiency of a diesel engine fueled with diesel, RSOFAME and the blends. From the Figure it could be seen that BTE increased with increase in engine speed at full load and peaked at optimum speed of 1600rpm for B0 and 20 and 1900rpm for B40-B100 and then decreased with increase in speed. BTE increased with engine speed initially because increase in speed resulted to increased torque and hence the thermal efficiency of the engine. At higher speed in excess of the optimum 1600rpm or 1900rpm as the case may be more amount of fuel is injected into the combustion cylinder per cycle. As a result of the high engine speed, the fuel will not have sufficient time for complete combustion resulting to reduction of the engine efficiency [39]. Figure 3 also revealed that the thermal efficiency of B0 and B20 are very close. This could be as a result of closeness of their heating values. Again, at specific engine speed, brake thermal efficiency decreased with increase in biodiesel fraction in the blends ostensibly as a result of low calorific value of biodiesel compared to diesel. It is also discernible here that B0 has the highest BTH while B100 has the least value.

3.4.5 Effect of engine speed on brake power for diesel, RSOFAME and blends

The variation of brake power with engine speed for RSOFAME, biodiesel and the blends are as shown in figure 4. It could be seen from the Figure that the BP of diesel, RSOFAME and the blends increased with increase in engine speed and attained maximum value at an optimum speed of 1600rpm for B0-B100 from where it then decreased with increase in engine speed. The increase in BP with engine speed initially observed before peaking at 1600rpm optimum speed resulted because at the relatively lower speed the lubricity of the fuel is nigh coupled with high torque resulting from higher speed. At higher speed in excess of 1600rpm, the torque as well as the lubricity of the fuel reduced with increase in speed resulting in the reduction of engine BP. This is in agreement with the findings of [40-45] who reported that engine power decreased with increase in biodiesel fraction in the blend.

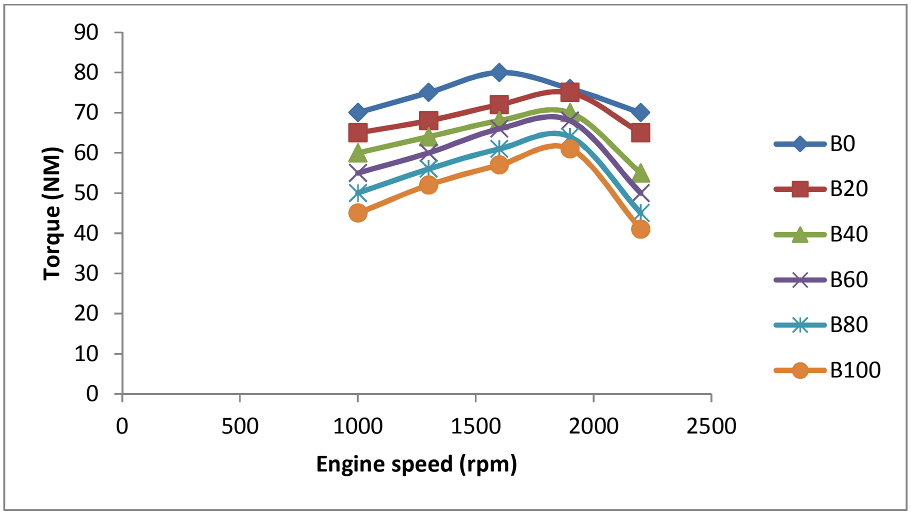

Figure 1: Effect of engine speed on torque for diesel, RSOFAME and blends

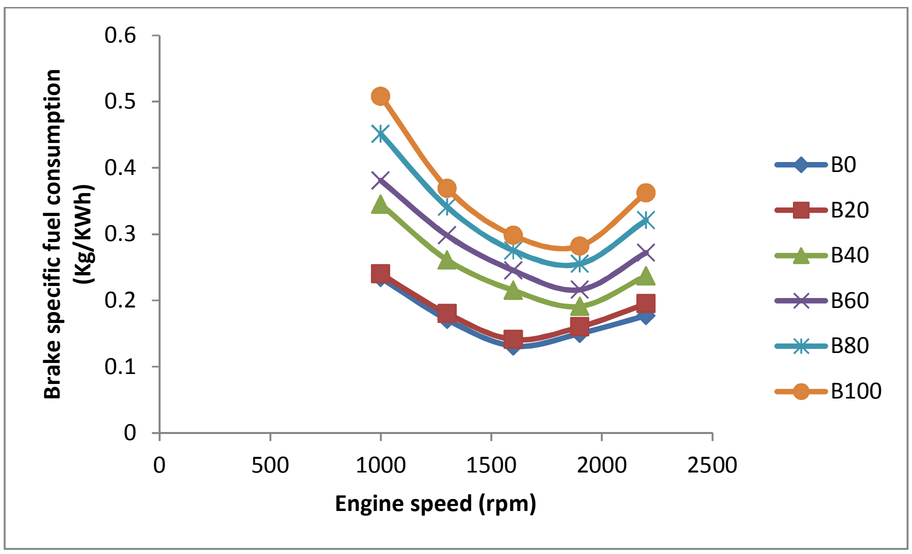

Figure 2: Effect of engine load on brake specific consumption for diesel, RSOFAME and blends

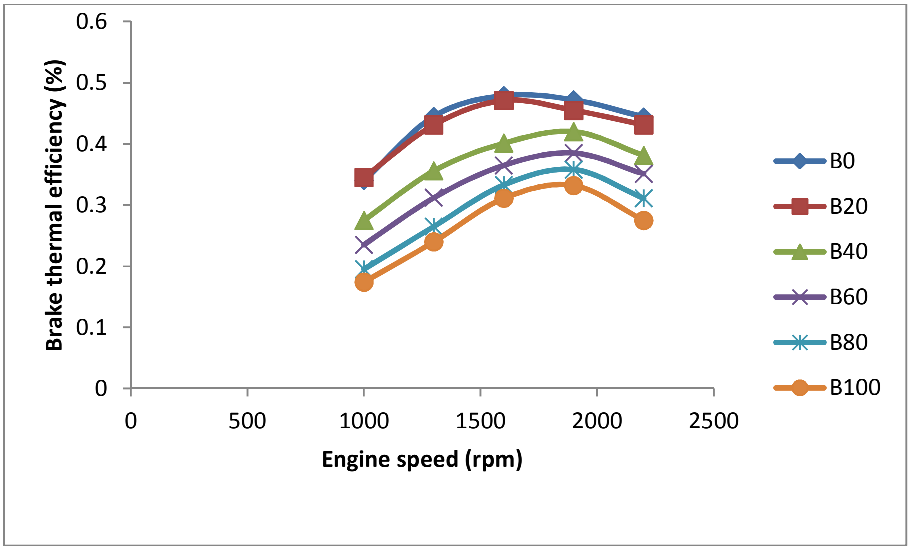

Figure 3: Effect of engine speed on brake thermal efficiency for diesel, RSOFAME and blends

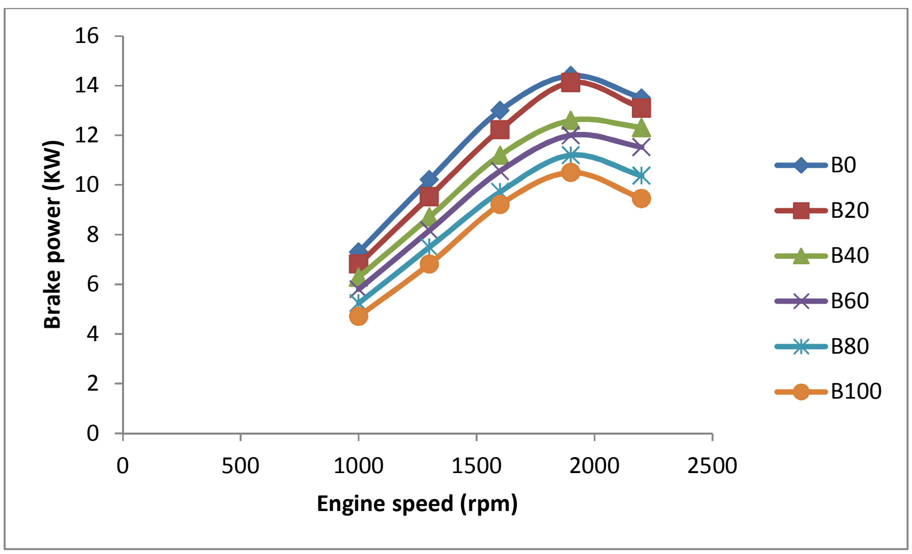

Figure 4: Effect of engine speed on brake power for diesel, RSOFAME and blends

3.5 Engine emission analysis for diesel, RSOFAME and blends

3.5.1 Effect of engine load on exhaust gas temperature

Exhaust gas temperature, EGT, indicate the rate of heat released during combustion of a fuel. The effect of heat load on EGT is as shown in Figure 5. From the figure it could be observed that increase in load result in increase of EGT. The oxygen content of biodiesel results in the improvement of its combustion which give rise to its enhanced temperature. This finding conformed with those of [46,47] who reported increase of EGT with increase in load in diesel engine for mahua and jatropher biodiesels respectively. Again from the figure it is discernible that at a specific load, EGT decreases with increase of biodiesel fraction in the blend.

3.5.2 Effect of engine load on CO, HC and NOx emission for diesel, RSOFAME and blends

3.5.2.1 Effect of engine load on CO and HC emission of diesel, RSOFAME and the blends

Figures 6 and 7 showed the effect of engine load on CO and HC emission respectively for diesel, RSOFAME 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 as a result of increase in load could be explained from decreased air-fuel ratio resulting from increase in load which gave rise to incomplete burning of the fuels. From figures 6 and 7 respectively it could be observed that CO and HC emissions decreased with increase in biodiesel fraction in the blend. The researchers (48,49]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 enhances its complete combustion leaving low amount of CO and HC in the combustion product as compared to diesel fuel [50]. The low carbon to hydrogen content of biodiesel presents less carbon to be burnt which translates to low CO and HC in the combustion product.

3.5.2.2 Effect of engine load on NOx emission of diesel, RSOFAME and the blends

Figure 8 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 combustion 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 [48, 49].

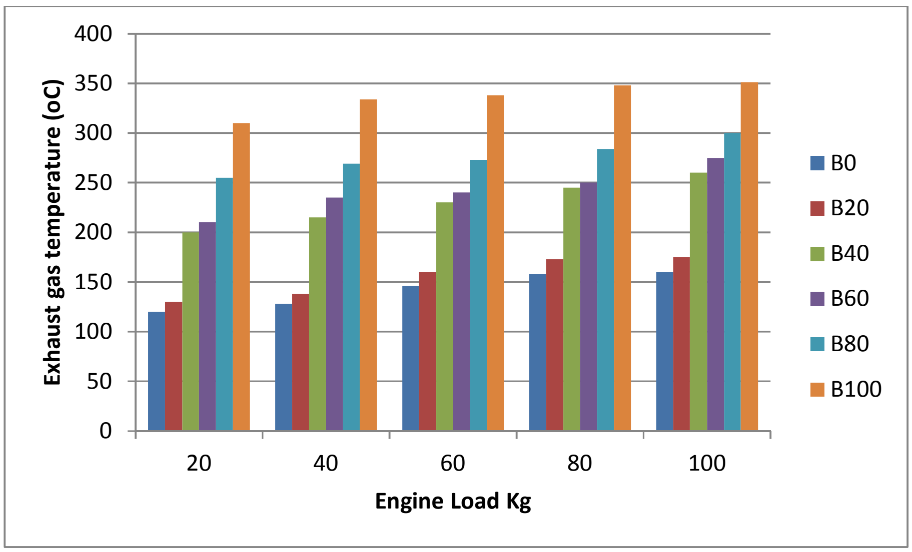

Figure 5: Effect of engine load on exhaust gas emission for diesel, RSOFAME and blends

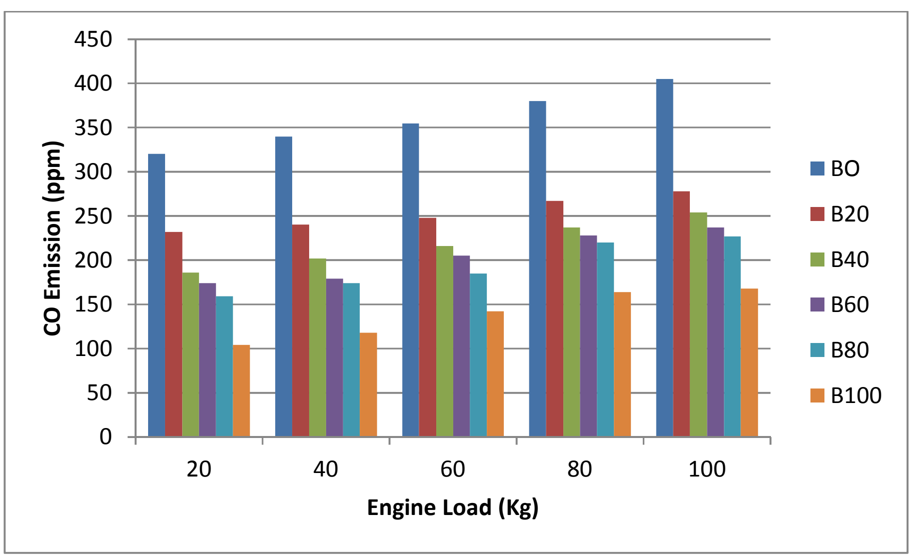

Figure 6: Effect of engine load on CO emission for diesel, RSOFAME and blends

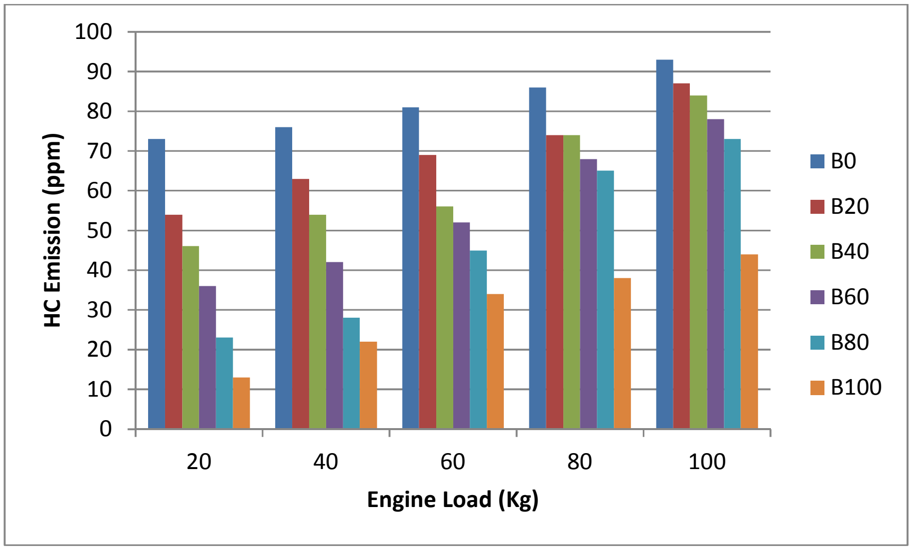

Figure 7: Effect of engine load on HC emission foe diesel, RSOFAME and blends

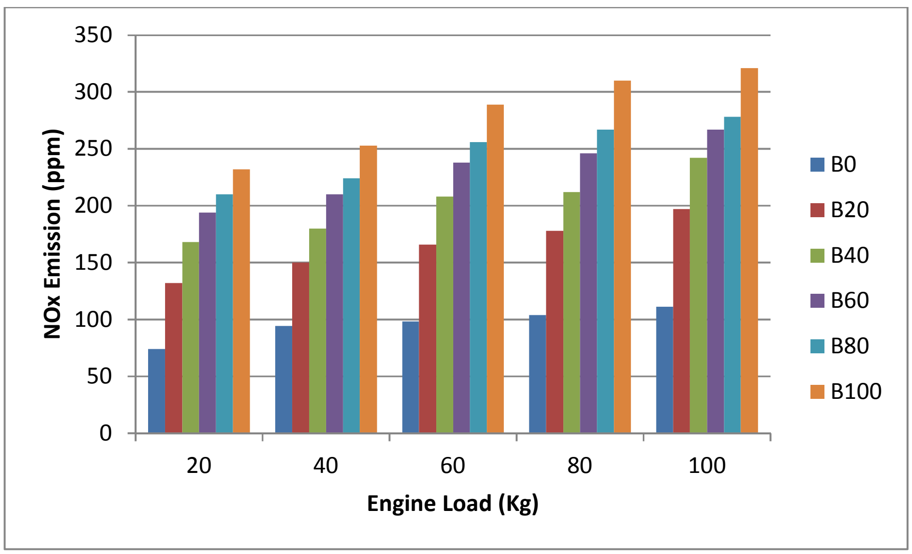

Figure 8: Effect of engine load on NOx emission for diesel, RSOFAME and blends

CONCLUSION

Esterification followed by transesterification of rubber seed oil, gave a high yield of biodiesel with physiochemical properties within the ASTM limit. Rubber seed oil is therefore suitable for bio-diesel synthesis and as such should be employed for this purpose instead of discarding the seeds as a waste as is the practice in most part of Nigeria where the focus is mainly on the rubber latex. The engine test shows that RSOFAME torque, brake thermal efficiency and brake power are lower than that of diesel while the brake specific fuel consumption is higher. Engine exhaust gas emission analysis reveals reduction of CO and HC emission and increase in NOx emission from the use of RSOFAME compared to diesel.

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