Impact Of Used Soya Oil Biodiesel On The Performance And Emission Of Diesel Engine

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***Abstract*—The adverse environmental impact and fast depletion of petroleum, has necessitated the search for renewable, sustainable and alternative fuel for compression ignition engines. As an alternative to and perhaps a replacement for diesel, biodiesel has been increasingly fueled to study its effect on engine performance and emission. This research work focused on diesel engine performance evaluation and emission using used soya oil fatty acid methyl ester (USOFAME) or biodiesel. USOFAME was synthesized using methanol and sodium hydroxide (NaOH) catalyst. The fuel properties if USOFAME were determined based on American standards for Testing and Materials (ASTM). The engine performance evaluation was carried out on Perkin 4:108 diesel engine using diesel, USOFAME and their blends at constant engine load. The engine speed was varied between 1000-2200rpm using the blends consisting of 0%, 20%, 40%, 60%, 80%, and 100% USOFAME by volume, denoted by B0, B20, B40, B60, B80 and B100 respectively. The engine emission test was carried out at constant speed of 1900rpm using diesel, USOFAME and their blends at varying loads of 20,40,60,80, and 100Kg. The fuel properties of USOFAME which is within the ASTM standards were determined as density 863Kgm^3, kinematic viscosity @ 40^{0}C 4.60mm^{2}s^{-1}, fire point 171^{0}C. flash point 162^{0}C, cloud point 7^{0}C, cetane number 61.00, calorific value 40MJ/Kg. pour point 4^{0}C iodine value 30.60gl$_2$100g^{-1} Engine performance evaluation revealed that torque (T), brake thermal efficiency (BTE) and brake power (BP) increased with increase in engine speed until they attain maximum value at 1600rpm, when they start decreasing. The brake specific fuel consumption (BSFC) decreased with increase in engine speed until it reached the minimum value at 1600rpm when it starts to increase. At a specific speed, T, BTE and BP decreased with increase in biodiesel fraction in the blends while BSFC increased with increase in biodiesel fraction in the blends. As B20 and blends with less biodiesel fraction have equivalent calorific value with diesel, T, BTE, BP and BSFC approximate that of diesel. The engine emission test revealed that CO and HC emission increased with increase in engine load. At a specific load, CO and HC emission decreased with increase in biodiesel fraction. NOx emission increased with increase in load and as well increased with increase of biodiesel fraction.**

Keywords—Biodiesel, brake power, emission test, torque, trasesterification

1. INTRODUCTION

Fossil fuels from petroleum, coal and natural gas has been the major sources of world energy needs. However the fast depletion, nonrenewable nature and environmental impact of the fossil fuels have drawn the world attention to the need for search of energy resources to fill these gaps. Among the various options investigated, biodiesel produced from vegitable oil and other sources has been universally recognized as the foremost contender for exhaust emission reduction [1]. Burning of fossil fuel results in environmental pollution from emitted green house gases, including sulphur oxides (SOx), nitrogen oxides (NOx), carbon monoxide (CO), hydrocarbon (CO), and methane [2]. Biodiesel is a mono-alkyl ester of long chain fatty acid that posses characteristics similar to diesel with additional advantages of high lubricity, high cetane number, being biodegradable and environmentally friendly [3]. The production of biodiesel as at present is mainly based on the use of edible vegitable oil as the feed stock. The researchers [4] have reported that 95% of renewable resources used for biodiesel production come from edible vegitable 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.

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. A monohydric alcohol, for example methanol will react with a fatty acid, to produce biodiesel [6]. Various processes have been adduced for production of biodiesel, including, micro-emulsion with alcohol, catalytic cracking, pyrolysis and transesterification [7]-[10]. Among these processes, transesterification has proved to be the most useful means of converting oil or fat into environmentally safe biodiesel [11], [12]. 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.

The main drawback of used cooking oil is that its previous exposure to high temperature, during cooking of food, increases the moisture, free fatty acid and particulate material contents in the oil. The high free fatty acid leads to soap formation with alkali catalyst and retard the dispersion and mixing efficiency of the reaction mixture and thus reduce the formation of biodiesel. The particulate matter in the oil persist in the formed biodiesel and may result in carbon deposit, plugging of fuel lines, fouling piston heads and sticking of the rings. The moisture contained in the oil can react with base catalyst to give emulsion [13]. thus favoring the reverse reaction. Used cooing oil polymerizes on heating and storage and thus exhibit increase in molecular weight and viscosity [14], [15].This research work focused on diesel engine property evaluation and emission characteristics using used soya oil biodiesel. In other to carry out the research work purely with used soya oil, the used soya oil was prepared by frying foods (yam, potato plantain etc) in virgin soya oil for a total of 72 hours [16]. The resulting used soya oil was synthesized to biodiesel, characterized and the compression ignition engine performance evaluation and emission characteristics of the biodiesel analyzed. The engine performance was evaluated using the correlation between the engine performance characteristics- torque (T), brake specific fuel consumption (BSFC), brake thermal efficiency (BTE) and brake power (BP) with engine speed.

11 Materials and Methods

A Materials

Used soya oil (USO), reagents, glass wares, viscometer, magnetic hot plate, water bath, soxhlet extractor, engine test bed, gas analyzer etc

B Preparation of used soya oil

20 liter of pure soy oil was purchased from Ogboete main market Enugu. 10 liters of the oil was introduced into a 20 liter steel pot. Heating was done using gas cooker. The oil was used for frying food for a period of 72 hours (8 hours a day for 9 days) to make waste cooking oil [16]. The acid value test of the used soy oil showed much increase form 0.22mg/g oil before frying to 4.20mg/g oil after frying.

C Production of USO biodiesel by transesterification

The production of used soya oil biodiesel or used soya oil fatty acid methyl ester (USOFAME) involves, first, pretreatment or esterification of the USO to reduce the excess free fatty acid below 1%. The oil was pretreated or esterified by heating a measured quantity of the oil with methanol of 60%w/w of oil mixed with concentrated sulphuric acid of 7% w/w of oil. The pretreated oil was then transesterified using methanol and sodium hydroxide catalyst. A 500ml three-necked round bottomed flask fitted with a condenser on the middle arm, a thermometer and sample outlet on the side arms respectively served as the reactor. The heating system consists of an electromagnetic hot plate which heats the reactor and rotates the metal knob in the reactor through an electromagnetic field. Specified quantity of the oil sample was introduced into the flask and the flask content heated to the temperature established for the reaction. Then methanol and the sodium hydroxide catalyst mixture was added in the amount established for the reaction, and the stirrer switched on at a specified speed, taking this moment as zero time of the reaction. The reaction mixture was vigorously stirred and refluxed for the required reaction time. At the end of methanolysis, the transesterfied product was made to stand for a day in separating funnels where it separates into the upper biodiesel layer and the lower glycerol layer. The lower glycerol layer was tapped off first followed by the upper biodiesel layer.

D Biodiesel purification by wet washing

After transesterification, the upper ester layer may contain traces of methanol and glycerol. The remaining un-reacted methanol has safety risk as it could corrode the engine parts, and the remaining glycerin in the biodiesel will lessen the fuel lubricity and cause injector coking and other deposits [17]. Such trace of methanol is soluble in water and is therefore 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. The methyl ester was gently washed to prevent its loss due to formation of emulsion that results in complete phase separation [18]. The washed biodiesel was dried by heating at 105^{0}C on a laboratory hot plate until all residual water molecules evaporated. This conforms to the findings of [19]. The percentage biodiesel yield is given by the expression of equation (1)

$$\begin{aligned}&\%\ biodiesel\ yield\\ &= Volume\ of\ biodiesel\ produced\\ &\div volume\ of\ oil\ used\ x\ 100 \quad (1)\end{aligned}$$

E Determination of the fuel properties of used soya oil biodiesel produced

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

F Engine performance evaluation test

The engine performance evaluation test of the USOFAME was carried out on a Perkins 4:108 diesel engines mounted on a steady state engine test bed as 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, biodiesel and the blends. The blends 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.

(a) Engine test at varying speed (constant load).

In carrying out this test, the engine was started and kept at maximum load. 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 given volume ($100cm^3$) 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 temperature. The above procedure was repeated for higher speed values of 1300 rpm, 1600 rpm, 1900 rpm and 2200rpm.

(b) Engine emission test at constant speed (varying load)

For this test, the engine was started and 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 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: Perkin 4:108 diesel engine mounted on Steady state engine test bed at UNN Nsuka

Table 3.3: 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

III RESULTS AND DISCUSSION

A. Fuel properties of used soya oil produced

Table 1 gives the summary of the fuel properties of the USOFAME produced. Biodiesel generally has a higher density than petro-diesel. This has a significant impact on fuel consumption as fuel introduced into the combustion chamber is determined volumetrically. The density was evaluated as 863 kg/m^3 for used soya oil biodiesel and this is within the ASTM limits for biodiesel. The biodiesel has lower density compared to the density of used soya oil (962 kg/m^3). The value of kinematic viscosity obtained for the biodiesel produced from used soya oil is 4.6mm^2/s as shown in table 1, and it could be observed that it is within the standard range of ASTM limit. The increase in viscosity resulted in poor atomization and incomplete combustion which leads to coking of injector tips and engine power loss. Low-viscosity fuel result to very subtle spray which cannot properly get into the combustion cylinder, and thus form a fuel rich zone which lead to the formation of soot [20], [21]. From the result it could be inferred that FAME from used soya oil has a good injection and atomization performance. Furthermore it will offer superior lubrication and protection for the moving parts of engine than diesel.

The flash point is a determinant for flammability classification of materials. The typical flash point of pure methyl ester is ≥130^{0}C, classifying them as “non-flammable”. However, during production and purification of biodiesel, not all the methanol may be removed, making the fuel flammable and dangerous to handle and store if the flash point falls below 130^{0}C. The flash point is 156^{0}C for used soya oil fatty acid methyl ester. This is within the ASTM standard as shown in Table 1, indicative of the safety of USOFAME in handling and storage.

Table 1: Fuel properties of USOFAME

Properties	**Unit**	**USOFAME**	**ASTM Standards**
Acid value	mgKOH/g	0.400	o.50
Density	Kg/m^3	863	860-900
Kinematic viscosity@ 40^{0}C	mm^2/s	4.60	1.9-6.0
FIre point	^{0}C	171	197
Flash point	^{0}C	162	100-170
Cloud point	^{0}C	7	-3-15
Cetane number		61.00	48-65
Refractive index		1.4710	1.38
Specific gravity	Kg/m^3	0.873	0.860-0.900
Calorific value	MJ/Kg	40.28	42.06
Pour point	^{0}C	4	0.5
Iodine vlue	gI$_2$/100g	30.60	42.46

Cetane number serves as a measure of ignition quality of the fuel. This is the most pronounced change from vegetable oil to the transesterified product. Fuels with low cetane number show an increase in emission due to incomplete combustion.

The lower limit for cetane number by ASTM and EN standards are 47 and 51 respectively. The values obtained for used soya oil biodiesel is 61.00. Thus the obtained result which are within the acceptable ASTM limits indicates that the produced biodiesel possess good ignition response. The cloud point of used soya oil biodiesel which is the lowest temperature at which wax like material is formed was determined as 7^{0}C. The pour point which is the lowest temperature at which the fuel will still pour was determined as 4^{0}C for used soya oil biodiesel. Most properties of the biodiesel produced are within the ASTM standard limit for biodiesel, as shown in Table 1. However the cloud and pour points might give rise to cold flow problems in cold season. This problem however could be overcome by addition of suitable cloud and pour point depressants or by blending the biodiesel with diesel oil [22].

B. Engine Performance Evaluation of USOFAME

Correlation of the engine performance evaluation characteristics (torque(T), brake specific fuel consumption (BSFC), Brake thermal efficiency (BTE) and brake power (BP)) with engine speed for diesel, biodiesel and their blends and comparison between these correlations with diesels', relates the suitability and efficiency of biodiesel as a compression ignition engine fuel. Therefore the engine performance evaluation characteristics obtained for diesel, biodiesel and their blends were plotted against the speed in other to evaluate the performance of the used soya oil biodiesel as a diesel fuel.

From the data generated from the engine test and characteristics of the USOFAME, the engine performance characteristics namely, BSFC, BTE and BP were calculated using the calculations for engine performance test given below.

(a)Calculations on engine performance test

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

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

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

(iii) Brake power, BP (KW) = $T x N/9549.30$

Where T=torque (Nm), N =engine speed (rpm), ρ_f = density of fuel

(iv) Brake thermal efficiency n_{BT}(%) = BP/M_f x44200

(v) Brake specific fuel consumption, BSFC (Kg/KWh) = $3600M_f/BP$

(b) Variation of torque with engine speed for diesel, USOFAME and their blends

Figure 1 shows the plot of variation of engine torque against speed for diesel, USOFAME and their blends at full load. The engine torque increases as the engine speed increases and attain maximum value at the engine speed of 1600rpm for diesel, USOFAME and their blends and then started decreasing. The decrease in torque observed at the stipulated engine speed could be as a result of increase in the fuel temperature that occasioned reduction of the fuel's viscosity and lubricity. From the graph it could be observed that the engine torque developed by B0 and B20 closely approximate each other, showing the closeness of the energy content between the two fuels. However, the torque developed by diesel is greater than that of the biodiesel as shown by B40-B100, indicative of lower energy content of biodiesel and blends compared to diesel. This is attributable to lower calorific value, higher viscosity and higher density of biodiesel compared to diesel. It was also observed that the diesel fuel, USOFAME and blends attained maximum torque at the same speed of 1600rpm, indicating the closeness of their energy contents. Again, at a specific engine speed, torque decreases with biodiesel fraction in the blend. This is in conformity with the findings of [23]-[27], who studied the effect of pure diesel on engine power and reported that with biodiesel engine power will drop due to loss of heating value of biodiesel.

(c) Variation of break specific fuel consumption (BSFC) with engine speed for diesel, USOFAME and their blends.

Fuels of low brake specific fuel consumption generate the same amount of power as that rated higher and therefore low BSFC is preferred to higher one. Break specific fuel consumption is a measure of efficiency of the engine in using the fuel supplied to produce useful work. An engine is described as having low brake specific fuel consumption if it used less amount of fuel to produce the same amount of work obtained from higher fuel quantity. Figure 2 shows that brake specific fuel consumption of diesel, USOFAME and their blends decrease with increase in engine speed till the minimum value was attained at 1600 rpm when BSFC starts to increase again with the engine speed. A similar trend was also reported by Azad et al (2016) with minimum BSFC found at 1600 rpm for all blends and then started to increase with speed using biodiesel from macadamia oil. The initial decrease of BSFC before attaining the minimum value may be explained by the fact that at lower speed the engine temperature was relatively low and thus the viscosity and lubricity of the fuels were intact, resulting to higher torque and thermal efficiency of the engine. The BSFC increase after attaining the minimum value could be attributed to the fact that at higher speed, the engine and fuel temperature increased resulting in the reduction of fuel viscosity and lubricity and consequently decrease of torque and thermal efficiency of the engine and hence higher specific fuel consumption. From figure 2 it could be observed that at specific speed the BSFC of the blends increased with increase in biodiesel fraction, This agrees with the findings of [23], [26], [28]-[30],who reported that the fuel consumption of an engine fuelled with biodiesel becomes higher because it is needed to compensate for the heating loss of heating value of biodiesel. Thus B20 and B100 have the lowest and highest BSFC respectively. Again the BSFC of B0 and B20 closely approximate each other with B20 BSFC slightly lower than that of B0 and therefore the best of the blends.

(d) Variation of break thermal efficiency (BTE) with engine speed for diesel, USOFAME and their blends

Figure 3 shows the variation of brake thermal efficiency with engine speed for diesel, USOFAME and Their blends. It was observed that the brake thermal efficiency of an engine fueled with USOFAME, diesel and their blends increases with increase in engine speed at full load until it attained a maximum value at 1600 rpm when it starts decreasing. This is due to the fact that, initially with the increase in engine speed, the torque produced by the engine increased, hence efficiency increases. But at higher rpm (>1600 rpm) for diesel, FAME and its blends more amount of fuel is injected into the engine cylinder per cycle and due to higher engine speed the fuel does not have sufficient time to burn completely which resulted in the reduction of the engine efficiency (Labeckas and Slavenskas 2016). In addition, it was seen that B20 and standard diesel have comparatively very close thermal efficiency. This may be attributed to their similar heating values and other thermal properties (Labeckas and Slavinskas 2016). B20 combined higher engine lubricity from the biodiesel fraction and higher energy value of the diesel fraction to exhibit a little higher and better BTE compared to diesel. From figure 3, it is also discernible that at a specific engine speed, brake thermal efficiency decreases with increase in biodiesel fraction. This is attributable to the lower calorific value, of biodiesel.

(e) Variation of break power (BP) with engine speed for diesel, USOFAME and their blends

From figure 4 it is shown that the brake power increased with increase of engine speed at full load till it attained maximum value at the engine speed of 1600 rpm and then started decreasing with increase in speed. This can be explained by the fact that initially before attaining maximum brake power, as the engine speed increased, the torque increased and also there was adequate lubricity. However after attaining maximum brake power at the high speed of 1600 rpm, the torque as well as the engine lubricity reduced and thus resulted in the reduction of the brake power. From figure 4 it could be seen that at specific engine speed, brake power decreased with increase of biodiesel fraction. This agrees with the findings of the researchers [31]-[35], who reported that engine power will drop due to loss of heating value of biodiesel. Thus B100 and B0 have the least and the most BP respectively. This is attributed to the higher calorific value as well as the higher torque developed from diesel as compared to biodiesel and the blends.

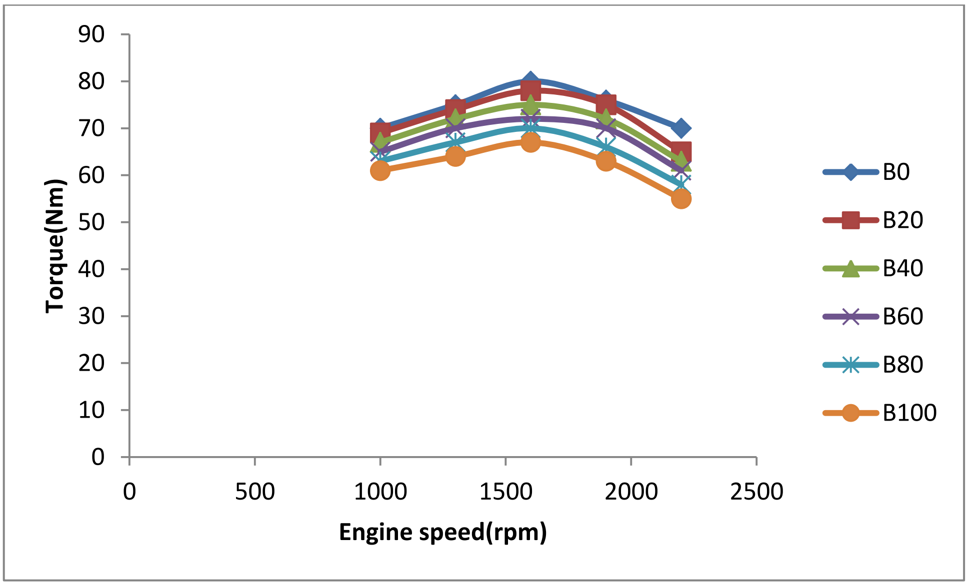

Figure 1: Variation torque with engine speed for diesel, USOFAME and their blends

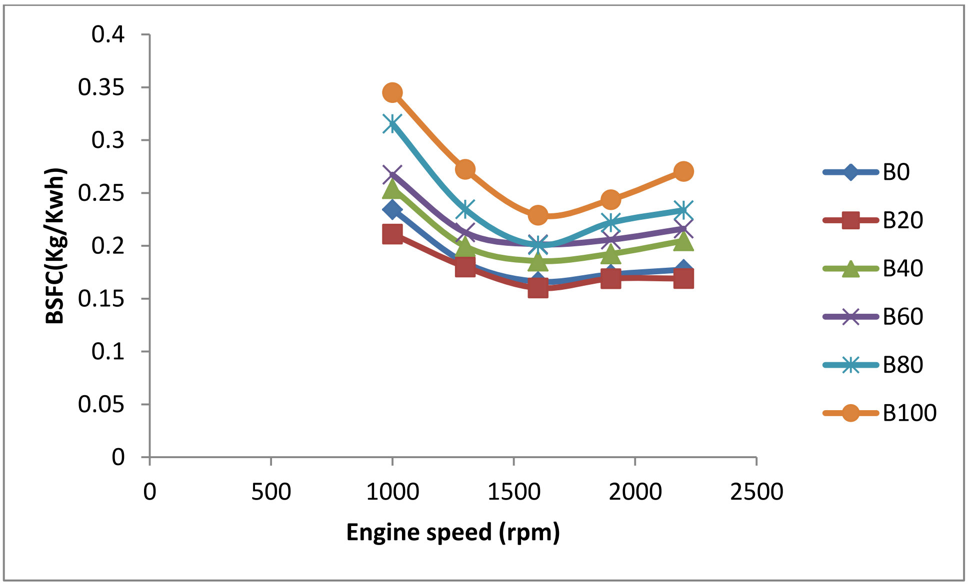

Figure 2: Variation of brake specific fuel consumption with engine speed for diesel, USOFAME and their blends

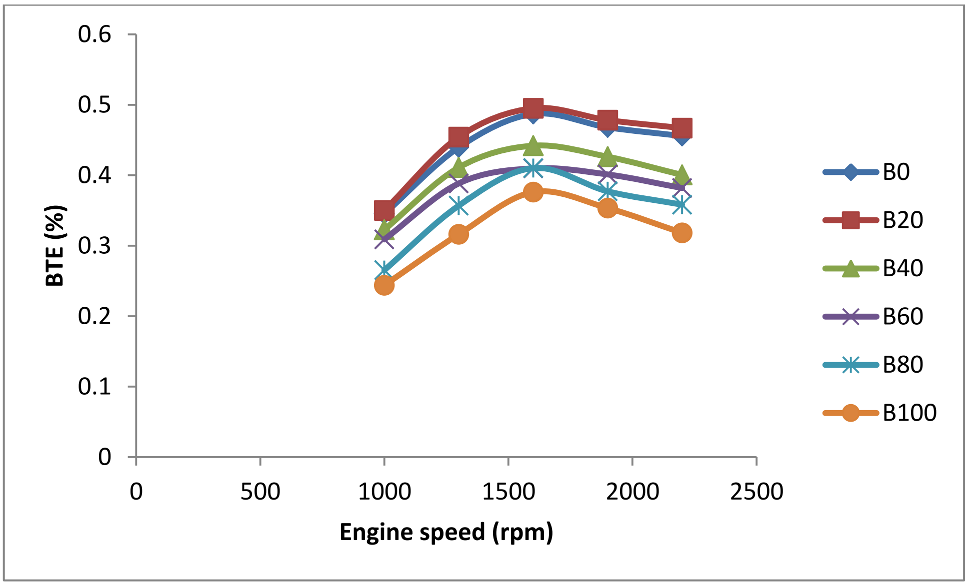

Figure 3: Variation of brake thermal efficiency with engine speed for diesel, USOFAME and their blends

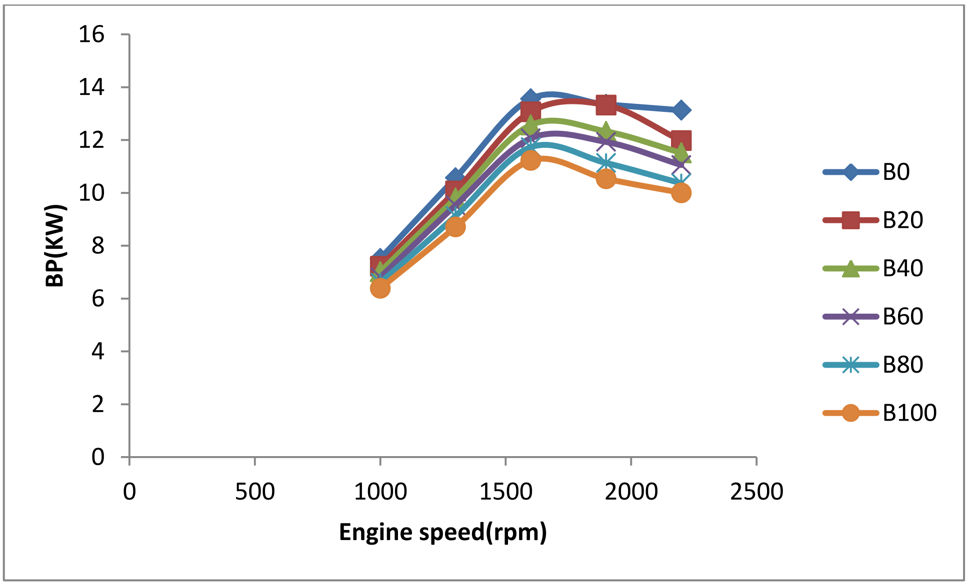

Figure 4: Variation of engine speed with break power for diesel, USOFAME and their blends

(f) Variation of CO and HC emissions with diesel, USOFAME and their blends

Figures 5 and 6 respectively show the variation of CO and HC emission with load at varying engine speed. It is observable from the figures that CO and HC emissions increase with increase in load. This is attributed to decrease in air-fuel ratio giving rise to incomplete burning and therefore less emission of CO and HC. Again, it is observed that at a specific load, CO and HC decreased with increase in biodiesel fraction in the blend. The researchers, [36], [31]-[33] in their reports of impact of biodiesel emission in diesel engine stated that the trend is reduction of CO and HC emission when diesel is replaced with biodiesel. Thus CO and HC reduce as the biodiesel content of the fuel increased, showing the fact that the use of biodiesel resulted in lower emissions of carbon monoxide (CO) and hydrocarbon (HC). This may be attributed to high oxygen content and lower carbon to hydrogen ratio in biodiesel. The oxygen molecules in biodiesel enhanced vaporization and atomization of biodiesel and blends leading to complete combustion and less presence of CO and HC compared to diesel fuel [37]. Lower carbon to hydrogen molecule in biodiesel presents less carbon to be burnt that will enhances the amount of CO and HC in the emission.

(g) Variation of NOx Emission with diesel, USOFAME and their blends

Figures 7 show the variation of NO_x with load for diesel, USOFAME and their blends. From the figure it could be seen that NOx emission increased with increase in load. This can be explained from the fact that, increase in load results in decrease of air-fuel ratio giving rise to incomplete combustion with higher emission of NOx. From the figure, it is also discerned that at specific load, NOx emission increase with increase in biodiesel fraction. Again, the researchers, [23], [31-[33] in their findings reported that the use of biodiesel increases the emission of NOx. This may be attributed to the oxygen content of the biodiesel which enhances vaporization and atomization of the biodiesel and the blends leading to complete combustion of the nitrogen component of the biodiesel to its oxides.

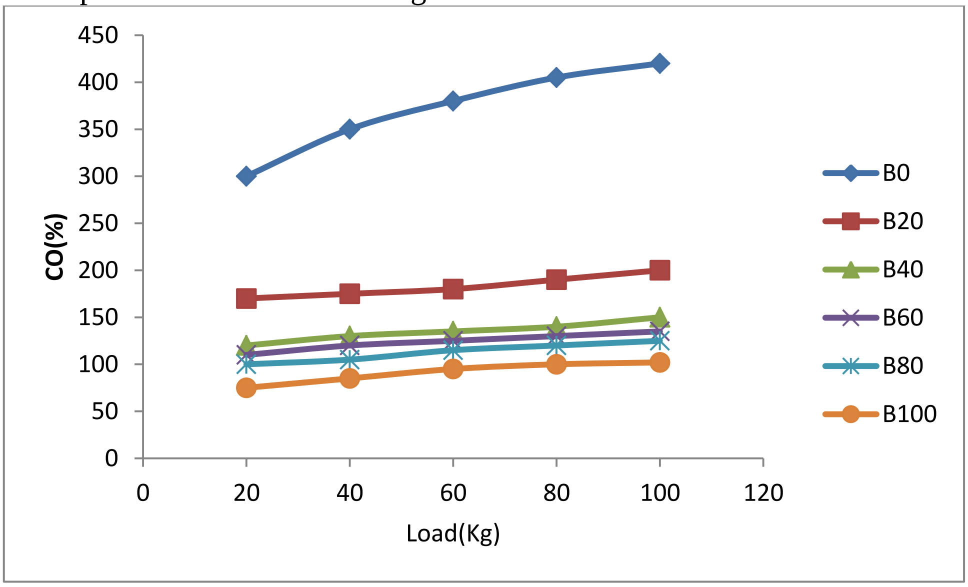

Figure 5: Variation of CO emission with load for varying biodiesel fraction

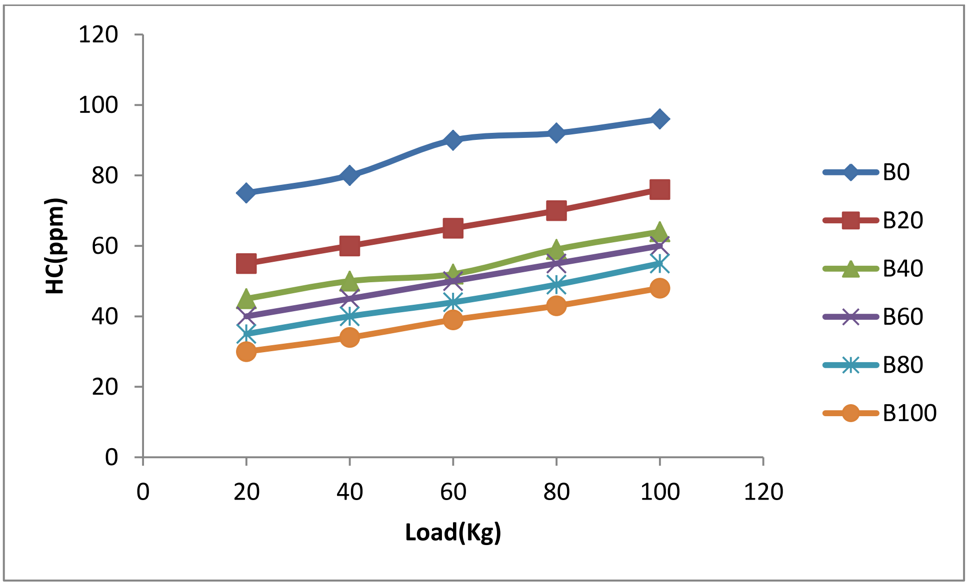

Figure 6: Variation of HC emission with engine load for varying biodiesel fraction

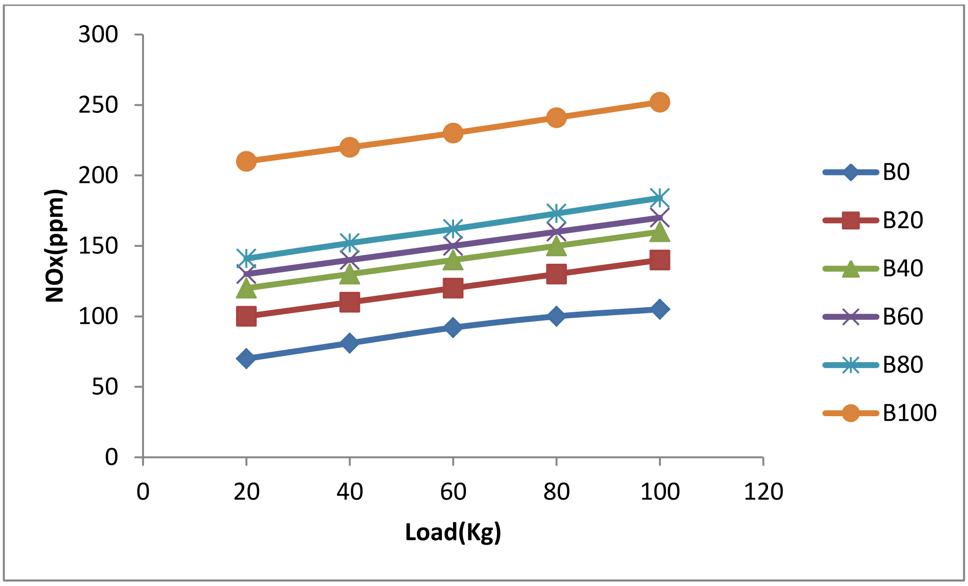

Figure 7: Variation of NOx emission with engine speed for varying biodiesel fraction

IV CONCLUSION

From the results obtained from the research, the following conclusions could be made. The torque, brake thermal efficiency, brake power and brake specific fuel consumption of USOFAME are close to but not necessarily equal to that of diesel. However, the torque, brake thermal efficiency, brake power and brake specific fuel consumption for B20 and blends with less content of biodiesel approximate that of diesel and in some cases even better. Therefore B20 and blends with less content of biodiesel can be used in place of diesel without modification of the engine considering their equivalent characteristics and engine performance evaluation parameters. The USOFAME should have less negative impact in the environment as the CO and HC emission decreased with increase in biodiesel fraction.

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