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**Research Article**

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# The Effects of Fatty Acid Methyl Ester-Petrodiesel Blend on the CO and NOx Emissions Toxicity in CI Diesel Engine

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## ABSTRACT

*The stringent global emission regulation requires significant efforts to enhance efficient combustion while satisfying the quality of exhaust emissions demand. This present work investigates the emission and combustion characteristics of African Pear (Dyacrodes edulis) Seed Oil Methyl Esters in different blends (25%, 50%, 75% and 100%) when compared with diesel fuel. The blends with petrodiesel were run on Perkins 4:108 CI diesel engine and the CO and $NO_X$ emissions were measured using Bacharach $PCA_2$ 235 – Q51007 emission gas analyzer at varying loads of 5 Nm, 10 Nm, 30 Nm and 40 Nm and constant speed of 1500 rpm. The NOx emission was comparatively higher than that of petrodiesel while CO emission was very close to that of petrodiesel. The overall result shows that the combustion of blends of methyl esters from Dyacrodes edulis seed oil with diesel in CI engine had close emission toxicity with petrodiesel.*

**Keywords:** CI diesel engine; Exhaust emissions; African pear; Biodiesel; Pollution

## INTRODUCTION

The issue of biodiesel as an alternative diesel fuel has been gaining great importance globally for its high quality exhaust and renewability [1]. Diesel fuel is largely consumed by the transportation sector and internal combustion engine have fallen victim of fossil fuel depletion and environmental degradation. In cities across the world, the personal automobile is the only greatest polluter. The emission of regulated air pollutants include: Lead (Pb), Carbon (II) oxide (CO), Ammonia ($NH_3$), Benzene ($C_6H_6$), Arsenic, Nickel, Sulphur (IV) oxide ($SO_2$), Nitrogen dioxide ($NO_2$), Particulate Matter (PM), Ozone ($O_3$), etc. The CO reacts with haemoglobin in the blood forming carboxyhemoglobin ($H_6CO$) rather than oxyhemoglobin ($H_6O_2$), prevents oxygen transfer, causes headaches, nausea, fatigue to possible death, cardiovascular and neurobehaviour, Sulphur dioxide causes bronchoconstriction, ear-nose-throat (ENT) irritation, respiratory illness, and aggravates existing heart diseases, Nitrogen dioxide results in pulmonary fibrosis, lung tissue damage and pneumonia while Particulate Matter causes reduction in life expectancy, increase in chronic obstructive pulmonary disease and adverse effects on cardiovascular system [2]. Also, the combustion of neat biodiesel decreases $CO_2$ emissions by 46.7%, PM emission by 66.7% and unburned hydrocarbon by 45.2%. Also, sulphur content of petrodiesel is 20-50 times that of biodiesel. Therefore, biodiesel has demonstrated a lot of promising characteristics in the reduction of exhaust emissions [3]. In Nigeria, the regulatory agency for environmental protection has stipulated maximum values of 20 $mg/Nm^3$ of Particulate matter from pharmaceutical manufacturing as well as petroleum based and chemical industries, 300 $mg/Nm^3$ of $NO_X$, 500 $mg/Nm^3$ $SO_X$, and 500 $mg/Nm^3$ of CO from petroleum based and chemical industries [4]. The global warming potential of green House gase (GHGs) has been reported to be 296 for $N_2O$ against 10 for $CO_2$ overtime horizon of

100 years against 275 ppb and 315 ppb for $N_2O$ and 27 ppm and 360 ppm for $CO_2$ as pre-industrial and year 1997 concentrations respectively [2].

Therefore, among all the emissions pollutants from combustion of diesel and biodiesel, CO and $NO_X$ appear to be more of concern considering the fact that more biodiesel results in the emission reduction of other pollutants but $NO_X$ increases. Afican pear (*Dyacrodes edulis*) is indigenous fruit free grown in humid low lands and plateau regions of West Central Africa. A plantation can produce 7-8 tons of oil per hectare [5]. The pulpy pericarp is eaten and the seeds are discarded [6,7]. The work done on this feedstock has not gone beyond production of biodiesel though Esonye et al. [7] has reported that Dacryodes edulis shows high potential for biodiesel production because of its high oil content (>55%) and its non-competitiveness with food. It is for this reason that this study was undertaken to investigate the emission concentrations of $NO_X$ and CO when blended with methyl esters derived from the seed oils of Dyacrodes edulis when run in Direct Injection Compression Ignition diesel engines.

## MATERIALS AND METHODS

### Materials

Sodium hydroxide (99% Sigma-aldrich), potassium hydroxide (loba chemie, gmbH 85%), methanol (Merck, Germany 99.5% purity), carbon tetrachloride (chloroform), Wij's solution (iodine monochloride), potassium iodide solution and phenolphthalein (Merck Germany) were all of analytical grade.

### Biomass Preparation, Oil extraction and Biodiesel Production

The oil extraction and biodiesel production followed the method applied by Esonye et al. [7].

### Physico chemical Characterization of the Biodiesel

The properties of the seed oils were determined in accordance with Association of Official Analytical Chemists [8] method (the acid value by AOAC Ca5a-40, saponification value by AOAC 920:160; iodine value by AOAC 920:158 and peroxide value by AOAC 965.33) while the viscosity was determined by using Oswald viscometer apparatus, the density by using density bottle, moisture content by the Rotary Evaporator Oven (BTOV 1423), the ash content by heating to dryness in Veisfar Muffle furnance and the refractive index by using Abbe Refractometer (Model: WAY-25, Search tech. Instruments). The fuel properties of the synthesized biodiesel at optimum conditions were determined by ASTM standards: the kinematic viscosity was determined by ASTM D-445 method, the density was determined by ASTM D-1298 method, and the pour point determination was made using ASTM D-97 methods. The flash point of the fuel was determined as ASTM D-93, the value of cloud point was estimated according to ASTMD-2500, and Acid value was measured following the ASTM D-664 method. The copper corrosion test was carried using copper strip test according to ASTM D130 method.

### Engine Pollutant Emission and Combustion Evaluation

The diesel engine clamped to a test bed and its shaft is connected to the hydraulic dynamometer. The torque exerted by the engine through the turning rotor is indicated by the dynamometer dial indicator, when the engine torques exceeds 80Nm, weights graded in torque values are placed on the scale provided on the end of the spring scale as a support for the circular scale such that:

$$T = T_R + T_W \qquad (1)$$

Where, $T_R$ = Torque reading from the spring dial; $T_W$ = Torque indicated on the weight

The brake power calculated by the dynamometer reading is given on the dynamometer circular scale. To increase the load on the engine, the wheel is rotated in the clockwise direction while rotating it in the anti-clockwise direction reduces the load on the engine. The ambient air temperature (Ta) and barometric pressure (Pa) are measured. A four stroke, four cylinder, water cooled direct injection diesel engine connected to an eddy current dynamometer which develops a power output of 112 Kw in the Internal Heat combustion Laboratory of University of Nigeria, Nsukka, was used to study the emission and combustion characteristics of the biodiesel , petrol diesel and their blends. The engine specifications are given in Table 1. The emission characteristics from the exhaust was measured using Bacharach $PCA_2$, 15068, P/N 24 – 7305, S/N – QS1007 model, New Kensington $P_A$, USA emission gas analyzer. The digital gas analyzer records the amount of the each gas in the composite exhaust gas as well the temperature. The procedure involves the following process: rapid examination of the test bed was made. The positions of all controls were noted and such features as the engine throttle and stop control were checked for correct functioning. The state of fuel supply, lubricant and cooling water were checked by starting the pumps without the engine running. The testing involves the recording of a considerable number of different readings.

**Table 1: The CI engine specification**

| S/N | Description | Specification |
|---|---|---|
| 1 | Make and Model | Perkins 4:108 (Plint and Pastery ) |
| 2 | Type | Four Cylinder, vertical, direct injection, variable speed water cooled four stroke diesel engine |
| 3 | Bore | 79: 735 mm |
| 4 | Stroke | 88.90 mm |
| 5 | Stroke length | 0.089 m |
| 6 | Compression ratio | 22.1 |
| 7 | Orifice Diameter | 58.86 cm |
| 8 | Maximum BHP | 38 |
| 9 | Power | 112 kw/150 hp |
| 10 | Rated Speed | rpm maximum (1500) |
| 11 | Loading Device | Eddy Current Dynamometer |
| 12 | Injection Pressure (Baromemeter Pressure) | 0.95 bar = 95 KN/$m^2$ |
| 13 | Swept volume | 1.76 litres/cycles |
| 14 | Engine Number | 108us7258 |
| 15 | Dynamometer Type | Heenam and Erdude, DP ×2 (Hydrauche) |
| 16 | Dynamometer capacity | 112 kw/150 hp |
| 17 | Dynamometer maximum speed | 7500 rpm |
| 18 | Dynamometer Brake Number | 2B × 337451 |
| 19 | Dynamometer Centre Height | 14.5" |
| 20 | Fuel Gauge Capacity | 50, 100, 200 $cm^3$ |
| 21 | Drum Size (water flow meter) | 42" (length) × 2711(diameter) |
| 22 | Exhaust Pipe Length | 36" |
| 23 | Exhaust Pipe Diameter | 3/2" |
| 24 | Indicator Tapping | 14mm in ND: 4 Cylinder head |
| 25 | Coefficient Discharge | 0.6 |

Also, Ambient Temperature (Ta) = 28˚C=301K; Barometric Pressure, (Pa) = 0-95bar =95 KN/$m^2$; Gas Constant for Air (Ra)=287J/kgK; Swept Volume (given in the engine description manual).

After ambient temperature and pressure were measured and the biofuel blends density and calorific values determined, the water pumps to the engine and dynamometer were turned on. The engine was connected to the battery terminal. The start button was pressed while the choke is in return position. The throttle was placed at relative low speed, 800 rpm and allowed to run idly for about 15minutes to attain a uniform temperature. The value of the torque was recorded. The time for a given value of the fuel to be consumed at the speed of 1500 rpm was measured by using the stopwatch to measure the time for the fuel to move between appropriate spacers while supply tank fuel gauge is turn off. The manometer reading, oil temperature and oil pressure were measured. Also the readings on the two water systems for both engine and dynamometer *viz.*: the water inlet temperature, water outlet temperature and water flow rate/head were measured. The process starting from recording the torque was expected for higher torque values: 10, 20, 30, 40 Nm.

## RESULTS AND DISCUSSION

The kinematic viscosities of all the blends of African Pear Seed Oil Methyl Ester (APSOME) with petrodiesel were all found to be higher than the petro-diesel. The values decreased with decrease in the amount of biodiesel in each blend (Table 2). However all the blends had specific gravity values within the tolerable limits allowable for effective air fuel injection systems as specified in the ASTM standard. The ash content of the blends increases with increase in the amount of petrodiesel in the blend. This could be due to increase in the amount of mineral elements introduced from the petro-diesel. This increase in ash content with decrease in the amount of biodiesel in the blends may likely result in increase in the emission of some air pollutants like $SO_x$ and $NO_x$. The kinematic viscosity results follow the trend of results obtained by Elango and Sentinkumar [9] in Jatropha diesel oil blends with diesel. They obtained 4.2 $mm^2$/s at B20 blend and 4.6 $mm^2$/s at B50 blend. The values of the sulphur content were found to increase with increase in petrodiesel in the blend. B100 had sulphur content of 3.11 ppm while B25 had 13.72 ppm sulphur content against 30.50 ppm recorded for the petrodiesel. This indicates that there is a clear correlation between the ash content and sulphur content in biodiesel blends with petrodiesel.

**Table 2: The Physico-chemical characteristics of the biodiesel blends with diesel**

| S/N | Parameters | B100 | B75 | B50 | B25 | D |
|---|---|---|---|---|---|---|
| 1 | Viscosity($mm^2/s$) | 3.52 | 3.47 | 3.4 | 3.3 | 3.21 |
| 2 | Specificgravity | 0.852 | 0.85 | 0.846 | 0.84 | 0.83 |
| 3 | Ash Content | 0.1 | 0.19 | 1 | 1.15 | - |
| 4 | Acid Value(mgKOH/g) | 0.92 | 1.01 | 1.28 | 1.49 | - |
| 5 | Saporification Value(mg/KOHg) | 242.51 | 239.68 | 227.11 | 224.68 | - |
| 6 | Freefatty acid (%) | 0.46 | 0.52 | 0.79 | 0.81 | - |
| 7 | Refractive Index | 1.4269 | 0.42 | 1.4111 | 1.4069 | - |
| 8 | Calorific Value(MJ/kg) | 34.42 | 35.8 | 37.2 | 38.7 | 43.5 |
| 9 | Flash Point(˚C) | 125 | 109 | 100 | 88 | 60 |
| 10 | Cloud Point(˚C) | -2 | 8 | 7.5 | 6.5 | - |
| 11 | Pour Point(˚C) | -1 | -1 | -5 | | -8 |
| 12 | Sulphur Content(ppm) | 3.11 | 5.91 | 11.01 | 13.72 | 30.5 |
| 13 | Copper Corrosion | Class 1 | Class 1 | Class 1 | Class 1 | Class 1 |

However, the sulphur content values obtained for B100 and the blends is in compliance with the Environmental Protection Agency (EPA) Regulation Standard (15 ppm max) on high way diesel fuel, which took effect from June 1st, 2006. The presence of sulphur in fuel forms $SO_2$ and $SO_4$ particulate matter during combustion, though sufficient level of sulphur content in fuel is essential for the lubricating and functioning of fuel system machinery such as fuel pumps and injectors [10] but high levels of sulphur in fuel when combined with water vapour forms sulphuric acid which is the main component of acid rain that causes corrosive wearing on cylinder liners and valve guides resulting in premature engine failure. Additionally, $SO_2$ affects the respiratory tract, causing cough, irritation of the eyes and exasperation of asthma and severe bronchitis. Consequently, it makes people prone to infections of respiratory tract. The result of the sulphur content is equally in line with 20-50% of diesel fuel values already recommended by Demirbas [11].

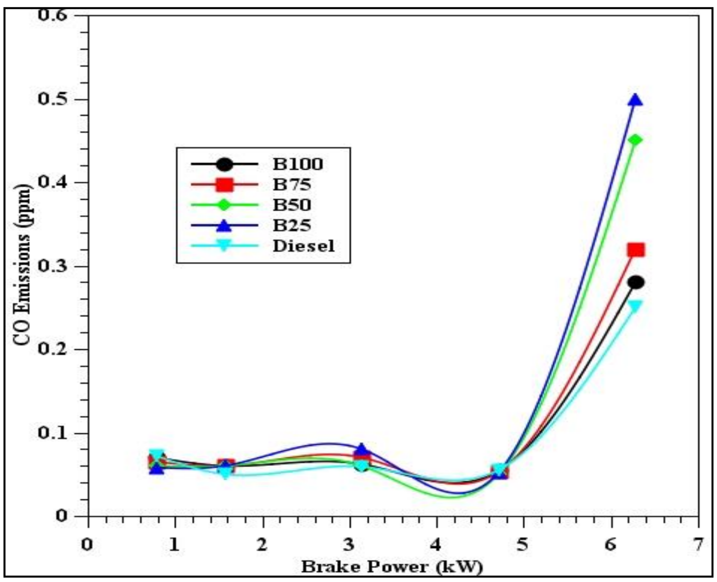


**Figure 1: Variation of blends CO emission with brake power**

The variation of Carbon Monoxide (CO) with brake power is shown in Figure 1. The carbon monoxide emissions are found to be increasing with increase in load. The CO emission for B25, B50, B75 and B100 fuels were not much different from those of diesel at low and medium loads. At full load the CO emission for B100 fuel is about 25% higher than that of diesel as the fuel-air ratio becomes greater than the stoichometric value the CO emission increases. The percentage change in the average emission impacts of CO at 10 N was the same for all the blends, but at 30 Nm, it was highest for B25 followed by B75 and least for B100 but the lowest CO emission was observed at brake power of 4.712 Kw (load of 30 Nm torque).

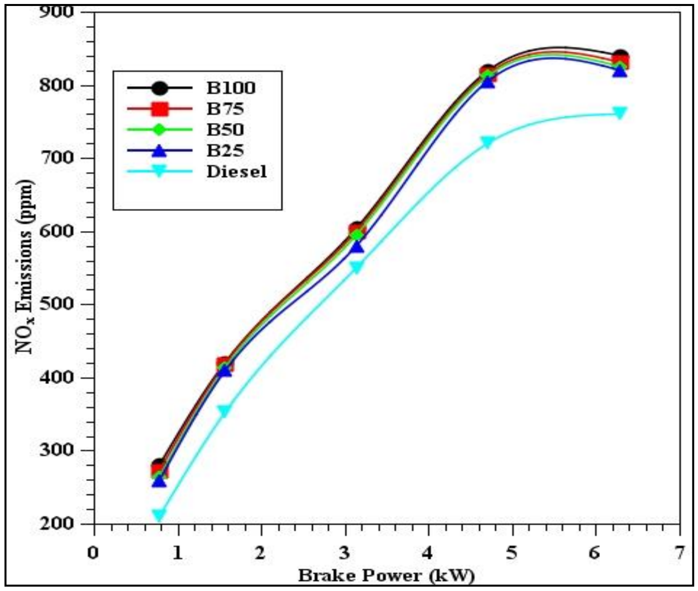


**Figure 2: Variation of blends NOx emission with brake power**

The variation of oxides of Nitrogen (NOx) with brake power is shown in Figure 2. $NO_x$ is observed to increase with load but at full load, B100 gave 0.5% higher $NO_x$ emission compared to that of petrodiesel. This is owed to the reduced heat release. It is observed that oxygenated fuel blends can result in higher $NO_x$ formation. Also complete combustion causes higher combustion temperature which results in higher $NO_X$ formation. This result agrees with the reports of Elango and Senthilkumar [9]. At low load of 5 Nm torque, B25 emitted 259 ppm against 210 ppm emitted by petrodiesel.

## CONCLUSION

The experiments are carried out on a four cylinder diesel engine using biodiesel derived from the seed oil of African Pear (*Dyacrodes edulis)* as an alternative biofuel. The combustion characteristics and its physico-chemical properties of the biodiesel and blends with petrodiesel are evaluated in comparable to that of petrodiesel with reduced pollutant emission. The values of percentage change in $NO_X$ showed decrease in values on the amount of petrodiesel increases in the blends but the percentage change of CO was more pronounced than $NO_X$. The CO emission slightly increased by 1.95% while $NO_X$ increased slightly by 18.95% while $NO_X$ increased slightly by 1.04% when compared to petrodiesel. The experimental results show that 25% volume blend of biodiesel from African Pear Seed Oil with petrodiesel is viable. Further research shall involve studying the engine performance parameters and the emission toxicity and exhaust temperature.

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