Emission Properties and Performance Characteristics of Jatropha Curcas L. and Spirulina Platensis Microalgae oil-based biodiesel in diesel Machines

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Abstract-
The article aims at investigating the performance of diesel engine and emission properties of non-eatable oils methyl esters of J. Curcas L. and Spirulina Platensis microalgae based biodiesel in diesel engines (DE). Kirloskar Six cylinder diesel engine was the test engine used to ascertain the level of Break Power (BP) and BSFC and the Emissions of Carbon (IV) Oxide (CO2), Hydrocarbons (HC), Carbon monoxide (CO) and Nitrogen Dioxide (NOX). Different ratios of biodiesel were mixed with diesel fuels using 10.0 and 20.0 percent by volume of methyl esters with the diesel fuels for example AB10 (10% by vol. Biodiesel and 90% by vol. Diesel fuels), JB10, AB20 and JB20 respectively. However, the procedures of the experiment was in agreement with EN 14214 and ASTM D6751 procedures. The biodiesel fuel samples used decreases the brake power (BP) and increase brake-specific fuel consumption (BSFC) when compared to conventional oils. Results from emission indicates that the blended biodiesel reduces CO, CO2 and HC Emission and causes an increase in NOX emission. Since AB10 gives lesser emissions, it is a better option for diesel fuels in engines that are not modified to minimize exhaust releases in the environment.

Key words: Jatropha curcas L, Spirulina Platensis Microalgae, Methyl esters,

1. Introduction
Fuels from Biodiesel are compactible blends of diesel fuels [1]. The triglycerides transesterification frequently used in the biodiesel production. Much attention has been given to biodiesel fuels in recently as a result its environmental nature, non-harmful properties and biodegradable when likened to fossil diesel fuels [2]. The esters are obtained from transesterification of organic material. The feed stocks such as coconut, soybean, safflower, cotton seeds and rapeseed are measured as prospective substitute oils for diesel engines [3]. Therefore, the potential feedstock for microbial oils, for example bacillus, fungi, yeast and algae produces high quality of biodiesel fuels and are potential feedstock. Some of its characteristics include high lipid content and are relatively cheap. Some disadvantages associated with biodiesel oil obtained from vegetable oil are that they perform poorly in cold weather as their polyunsaturated fatty acids (PFA) have a tendency to reduce its firmness, however, algal oil has overwhelmed this challenge due to the lower melting point of their PFA [4,5]. Algae oil are less expensive and environmentally friendly over the diesel fuel. Biodiesel is produced from any source of fatty acids by a transesterification reaction [6]. Biodiesel oxygen content increases the biodegradability of the process, resulting to quick biodegradation, biodiesel gives better emission properties, excellent eco-friendly performance on road transportation and decrease in global warming [7,8]. Biodiesel has some shortcomings which include: higher cloud point,
higher pour point, higher NOx emissions, low speed in engine, higher viscosity, lower energy content[9,10].

Algae possesses some features, for example it has high biomass yield per unit of light and area, oil/starch content is high, may not need land for agric. purpose, (d) fresh water is not required (d) supplying of nutrient is by wastewater and carbon (IV) oxide by combustion gas. Algae are eukaryotic, meaning it has nucleus, they do not have any tissue differentiation. They are composed of cells that are generally all the same. Algae contain chlorophyll, they are one-celled or multicellular plant-like organisms, they don’t possess stems and roots, leaves, tissue [11]. Algae manufacture their own energy from the sun but they also require water, adequate temperature and nutrients to develop. They live in water which makes it absorb CO₂ from the atmosphere to produce its energy [12]. Some algae grow in warm waters and others prefer cold waters[13]. Algae are also able to survive on land. Three factors are responsible for the growth of algae, they include: sunlight, CO₂ and H₂O. Figures 1.1, 1.2, shows pictures of algae from seas and rocks and figures 1.3 shows pictures of Jatropha, its fruits and seed. Table 1 compares different biodiesel source.

**Table 1: Comparing different source of biodiesel**

| Crop           | Yield (L/ha) |
|----------------|--------------|
| Jatropha       | 1892         |
| Corn           | 166          |
| Canola         | 1170         |
| Soyabeans      | 445          |
| Coconut        | 2563         |
| Oil palm       | 5912         |
| Microalgae     | 137098       |
| **Microalgae** | **59008**    |

Biodiesel characteristics of microalgae biodiesel depends on several kinds fatty esters that exist in the oil. However, its physicochemical properties ought to relate to the biodiesel Standard for Vehicles. Table 2 gives the specifications of biodiesel in various countries.

**Table 2: Various countries biodiesel specification**

| Properties          | Units | Eur. 14214 | EN 15132 | USA 6751 | ASTM D 908 | Germany DIN-EN-590 | India BIS 15607 | Austria ONC-1191 | Reference |
|---------------------|-------|------------|----------|----------|------------|--------------------|------------------|------------------|-----------|
| Viscosity 040 °C    | mm²/s | 5–6        | 1.8–6    | 4.5–6    | 2.1–6.0    | 3.7–5              | [6,15]           |                  |           |
| Flash point 0°C (min)| >104  | >128       | 112      | 125      | 100        | [9]                |                  |                  |           |
| Properties             | Units         | Eur. EN 14214 | USA ASTM D 6751 | Germany DIN-EN-590 | India BIS 15607 | Austria ONC-1191 | Reference |
|------------------------|--------------|---------------|-----------------|---------------------|----------------|-----------------|-----------|
| Sulphur content        | mg/kg        | 12            | <0.04 wt%       | –                   | 52 ppm max     | –               | [7, 10]   |
| Cetane number          | min          | 53            | 46 min          | ≥48                 | >39            | ≥48             | [16]      |
| Sulphated ash content  | % (m/m)      | 0.03          | <0.03 wt%       | –                   | 0.03           | –               | [2, 19]   |
| Water & sediment       | mg/kg        | 500           | <0.005 vol.%    | –                   | 5000 ppm max   | –               | [21]      |
| Acid value             | mg KOH/g     | 0.5           | 0.8 max         | –                   | 0.5            | –               | [17, 20]  |
| Free glycerol          | % (m/m)      | 0.02          | 0.02 max        | –                   | 0.02           | –               | [3, 4]    |
| Total glycerin         | % (m/m)      | 0.25 max      | 0.24 max        | –                   | 0.25           | –               | [11, 14]  |
| Phosphorus content     | mg/kg        | 10            | <0.001 mass %   | –                   | 10             | –               | [13]      |
| Carbon residue         | % by mass    | 0.3 max       | <0.05 mass %    | ≤0.05               | 0.05 max       | ≤0.05           | [17, 18]  |
| Distillation T90 AET   | °C           | –             | 360 max         | –                   | –              | –               | [8, 17]   |

Fig. 1. Microalgae biomass [20, 21].
Fig. 4: Jatropha curcas L., Its fruits and seed

*Jatropha curcas* L., tree grows in Nigeria, under certain climatic conditions. They are plant that belongs to Euphorbiaceous family producing a substantial amount of *Jatropha oil*. The oil shrub is prevalent in arid and tropical areas of the universe [14]. The plant is a earthy resilient perennial tree that propagates in marginal lands for several years. Report shows that Jatropha seed oil ranges from 38 to 55 percent of the seed weight and ranges from 50 - 65 percent of the kernel weight [15]. *Curcas* as at 2017 ranks the most potential sources of oil in biodiesel production. They grow less than 1500 m of elevation from sea level and needs at least 260mm rainfall [16]. Table 4 gives the catalytic transesterification methods for Jatropha Curcas.

| Non-edible oil | Catalysts | Catalyst Concentration | Alcohol(s) | Molar Ratio | Temperature (°C) | Reaction Time | Yield FAME |
|----------------|-----------|------------------------|------------|-------------|----------------|--------------|------------|
| J. Curcas L    | Pretreatment acid catalysed (H₂SO₄, KOH, MeOCH₃) | 0.8% | CH₃OH | 9:1 | 45 | 2 hrs | 90–91% |
| J. Curcas L    | One Step alkali catalysed (NaOH) | 1.6% | - | 70 | 1 hr | |
| J. Curcas L    | KOH | 0.55% (w/w) | CH₃OH | 5:1 | 60 | 24 min | 99% |
| J. Curcas L    | Glycyrhiza (RL) | 4% (w/w) | CH₃OH | 3:1 | 30 | 60 hrs | 80% |
| J. Curcas L    | Pseudomonas cepacia lipase immobilized | - | C₃H₆OH | - | 50 | 8 hrs | 98% |
| J. Curcas L    | H₂SO₄  | 1% (w/w) | CH₃OH | 0.60% (w/w) | 50 | 1 hr | 90% |
| J. Curcas L    | NaOH | 1.4% (w/w) | 0.24% (w/w) | 65 | 2 hrs | |
| J. Curcas L    | H₂SO₄  | 1% (w/w) | CH₃OH | 3:10 (v/v) | 65 | 1 hrs | 21.2% |
| J. Curcas L    | NaOH | 1% (w/w) | 3:10 (v/v) | 50 | 2 hrs | 90.1% |
| J. Curcas L    | SO₄²⁻/TiO₂(ST) | 4% (w/v) | CH₃OH | 20:1 | 90 | 2 hrs | >98% |
| J. Curcas L    | KOH | 1.3% (v/v) | CH₃OH | 0.28 (v/v) | 60 | 88 min | >99% |
| J. Curcas L    | KOH | 0.55% (v/v) | 0.16 (v/v) | 60 | 24 min | |

There are several researches on biodiesel production from non-edible seed which have been researched on, its importance as energy especially for DE, but very few researchers have discussed the potentials of obtaining biodiesel from non-eatable oils of Spirulina Platensis microalgae and Jatropha Curcas L. However, research haven’t explain a fundamental assessment of the performance of Green Algae and Jatropha Curcas L blends in DE has stated the performance and emission characteristics of their methyl esters and its blends in a diesel engine under several load condition. For engine emissions, Spirulina Platensis microalgae and Jatropha Curcas L methyl ester blend produce lower Hydrocarbons, Particulate matter, CO and
CO₂ emissions but higher NOx emission, compared to Diesel fuel. This article aimed at evaluating non-eatable oil sources as a prospective feedstock for the production of biodiesel. Thus, a mixture of 10% and 20% by volume of Spirulina Platensis microalgae ME and Jatropha Curcas ME with 80% and 90% by volume of diesel fuel was carefully chosen as a B0 reference fuel to increase its physicochemical characteristics and evaluate its performance in a DE by Covenant University Research Centre, Nigeria.

2. Methodology

1 Liter Reactor (batch), Separating funnel, Magnetic stirrer, thermometer, Mechanical Press. chemicals and reagents were source in Abeokuta.

Spirulina Platensis Microalgae were collected from Covenant University, Ota Nigeria. The samples were dried for about 48 hours for the water to evaporate which is associated with biomass. The samples dried were ground, and the powder was passed through a 75micron sieve, to get rid of the oversize particles. An extracts of up to 95 percent oil from Spirulina Platensis Microalgae was obtained using the hexane solvent method. First, the oil was squeeze out by pressing. Then, remaining algae are mix with hexane, filtered and cleaned. After extraction, it was refined using a catalyst such as NaOH mixed with methanol. This generates a biodiesel fuel combined with glycerol. The glycerol was remove by refining the mixture to produce algae biodiesel fuel. Likewise, Jatropha seeds were obtained from Covenant University, the kernels were pulled out from its shells to extract the oil and cold pressed in Mechanical Engineering Research Laboratory of the University to obtain the oil. The oil was transesterified following same processes in obtaining algae methyl esters. Table 4 shows the properties that compares ME of Biodiesel and Diesel fuels. Table 5 shows the Properties of Crude Jatropha oil (CJO) and Spirulina Platensis Crude Algae oil (CAO) Table 6 shows Physical and chemical characteristics of Jatrophar and Algae oil ME blends. Table 7 shows Details specification of the Engine to be tested. Tables 8 and 9 gives the required Equipment.

| Properties                                      | ME of Biodiesel | DF       |
|------------------------------------------------|----------------|----------|
| Sulphur Content                                | 0.006 – 0.020  | 0.020 – 0.050 |
| Nitrogen Content                               | 0.0020 – 0.007 | 0.0001- 0.003 |
| Iodine Content                                 | 65 -156        | 0        |
| Aromatics                                      | 0              | 28-38    |
| Ash Content                                    | 0.002 – 0-036  | 0.006 – 0.010 |
| Higher Heating Values                          | 39.2 – 40.6    | 45.1 – 45.6 |

| Property                                      | Units | CJO   | CAO  |
|-----------------------------------------------|-------|-------|------|
| Specific gr. at 10 °C                         |       | 0.922 | 0.925 |
| Kinematic Viscosity (KV) at 40 °C             | mm²/s | 35.3  | 37.1  |
| Flash Point                                   |       | 184   | 187   |
| Water content                                 | %     | 5     | 9     |
| Property                          | Units | B0 | AOM E | JOM E | AB1 | AB2 | JB10 | JB20 | AST M D675 | EN 1421 |
|----------------------------------|-------|----|-------|-------|-----|-----|------|------|-------------|---------|
| Flash point                      | °C    | 68.5 | 188   | 166   | 143.6 | 139.6 | 137.6 | 132.6 | 130 min     | 120 min  |
| Density                          | kg/m³ | 824.2 | 861.4 | 855   | 851 | 833 | 837 | 829 | -           | 860-900 |
| Cloud point                      | °C    | -2  | -5    | -5    | -3  | -2  | -3  | -1  | -           | -       |
| KV at 40 °C                      | Mm/s  | 3.12 | 5.02  | 4.88  | 4.70 | 4.22 | 4.00 | 3.82 | 1.9-6       | 3.5-5   |
| Pour point                       | °C    | -7  | -6    | -4    | -3  | 0   | -2  | -1  | -           | -       |
| Calorific Value                  | mJ/kg | 45.3 | 38.6  | 37.4  | 40.4 | 42.7 | 39.8 | 41.3 | -           | -       |
| Cold filter plugging point       | °C    | -2  | 1     | 2     | 2   | -1  | 2   | -1  | -           | -       |
| Cetane number                    |       | 43  | 54.7  | 53.2  | 52.1 | 50.3 | 51.6 | 49.8 | 47 min      | 51 min   |
| Iodine value                     | g/L/100 | -   | 109   | 104   | -   | -   | -   | -   | -           | -       |
| Carbon Residue value             | %m/m  | -   | -0.025 | -     | -   | -   | -   | -   | 120 max     | -       |
| Acid Value                       | mgKOH/g | -  | 0.21  | 0.24  | -   | -   | -   | -   | -           | -       |

Table 6: Physical and Chemical parameters of Jatrophar and Algae oil ME and their blend.
Figure. 2.4 Schematic diagram of engine test bed [18]

Table 7: Details specification of the Engine to be tested

| Properties                          | Description of Engine     |
|-------------------------------------|---------------------------|
| Model of Engine.                    | Inline, Four stroke, DI   |
| Cooling system                      | Radiator cooling          |
| Power output @ 1500 rpm             | 309 H.P                   |
| Dynamometer Arm length              | 185mm                     |
| Number of Cylinder                  | 6                         |
| Cylinder pressure                   | 165 bar                   |
| Cylinder Diameter                   | 118mm                     |
| Piston Stroke                       | 135mm                     |
| Compression ratio                   | 15.5                      |
| Direction of rotation               | Anticlockwise             |

Table 8: Equipment Required

| Item                              | Equipment    | Manufacturer          | Test method      |
|-----------------------------------|--------------|-----------------------|------------------|
| KV                                | SVM 3000     | (Annton P., U.K)      | ASTM D445        |
| Density.                          | SVM 3000     | (Annton P., U.K)      | ASTM D4052       |
| Flash point.                      | Open Cup     | SYD-3536              | ASTM D93         |
| Cloud point and pour point..     | C and P.     | SYD-3536              | ASTM D2500,      |
| Caloric value                     | Bomb calorimeter | Shanghai, China | ASTM.D97         |
| Viscosity index                   | SBN 3500     | (Annton Paar, UK)     | N/A              |
| Cold filter plugg point           | Cold filter  | (Norma lab, France)   | ASTM D6371       |
| Oxidation..Stability              | NTL 450o     |                       | EN ISO 14112     |
5 oil samples were investigated, which are: Diesel fuel (B0), the AB10 (90% diesel and 10% Algae methyl esters blend, the AB10 (10% Jatropha oil methyl esters and 90% diesel) blend, the AB20 (80% diesel and 20% Algae oil methyl esters) blend, and the JB20 (20% Camelina oil methyl esters and 80% diesel) blend. **Kirloskar Six** cylinder diesel engine was the test engine used, Table 10 shows Engine specification of Diesel oil run for 10-15 min. there after the biodiesel was added. The engine ran for about 15 minutes by first using diesel fuels to allow warm up, thereafter introducing the biodiesel fuel in the engine. The engine was allowed to run with pure diesel before shut down. This process was replicated for the biodiesel blends prepared. The speed at which the engine was ran was between 1000 and 4000 rev/min. which was in agreement with the SAE J1515 MAR88 procedure for engine performance determination and its emission properties. Kirloskar 6 cylinder DE test conditions were tested, using REOA-DCA controller which is linked from end to end to a computer to the engine test bed [Refer to figure 1]. A HM-5000 Gas Analyser was employed to take readings of carbon (II) oxide, Nitrogen Oxides, Carbon (IV) oxide and Hydrocarbons emissions. The gas analyser specifications are shown in Table 6. Thus, Table 5 gives the physical and chemical characteristics of Algae and Jatropha methyl esters and their blend.

**Table 9: Gas Analyser for the process**

| Gas            | Range          | Resolution | Accuracy |
|----------------|----------------|------------|----------|
| Hydrocarbons   | 0 – 10,000ppm | 1ppm       | ±2%      |
| Carbon monoxide| 0 – 10%        | 0.001ppm   | ±2%      |
| Carbon dioxide | 0 – 20%        | 0.001ppm   | ±2%      |
| Nitrogen dioxide| 0 – 25%        | 1ppm       | ±2%      |
| Oxygen         | 0 – 5,000ppm   | 0.001ppm   | ±1%      |

### 3. Result and discussions

Pure biodiesel effect on engine power will reduce as a result of heating value loss of biodiesel produced. The loss in performance of the engine occurs as a result which contributed to the difficulties. Report shows no substantial alteration in engine power between the fuels in fuel atomization as an alternative of the loss of heating value. Carraretto [19] explained how increasing the proportion of biodiesel in the blends may have affected a trivial decrease in brake power over the complete speed range for several blends (AB10, JB10, AB20, JB20) on a SIX-cylinder diesel engine. Biodiesel lower heating value is as a result of the reduction in engine power. Some authors believed that when viscosity is high, it may cause power losses thereby decreasing combustion efficiency as a result of bad fuel injection atomization. Higher lubricity in biodiesel reduces friction loss, thereby improving the brake effective power. From figure 3.1 the break power increases by 9.2%, 14%, 25.2% and 28.4% for AB10, JB10, AB20, JB20 with respect to Diesel fuels.
Engine low-cost of biodiesel is critically affected by the engine type and its working environments, which include injection pressure, load, injection timing and speed with an upturn in load, the BSFC of biodiesel increases. However, increased in break specific fuel consumption result to increase in engine speed as presented in figure 3.2 as follows AB10 (0.9%), JB10 (1.69%), AB20 (5.38%), and JB20 (3.60%) when compared with the diesel fuels.

It’s well known that emissions from CO decreases, when diesel is substituted by pure biodiesel. CO emission tends to reduce during the blending of pure biodiesel to diesel oil, this arise due to oxygen content present in the biodiesel. However, one factor responsible for this is the biodiesel feedstock. Biodiesel’s oxygen content supports complete combustion which may lead to CO emissions reduction. Some of the attributes of biodiesel is that the cetane number is high, thereby reducing the emissions of CO. Advance in the biodiesel injection also has an effect on emissions of CO. However, the carbon contents in biodiesel yields diminishes CO emission, since biodiesel has lower carbon content than diesel fuels. One of the major effect of CO emission is attributed to Engine load. CO emissions decreases with respect to engine speed increasing for biodiesel as the percentages increases as shown in figure 3.5 AB10 (12.85%), JB10 (17.13%), AB20 (24.58%), and JB20 (9.68%) with respect to diesel fuels.

Many authors established the fact that Hydrocarbon emissions reduction with percentage increase in the biodiesel blend. Researchers have given attention to the influence of cetane number, content of oxygen and advances in injection and combustion of biodiesel on Hydrocarbon emissions. Research showed that the content of oxygen and cetane number causes the reduction in HC emissions. The latter in terms of biodiesel may possibly reduce the burning delay, thus reduces hydrocarbon emissions. Biodiesel feedstock and its characteristics influence Hydrocarbon emissions, particularly for the several chain length and level of saturation on biodiesels. From figure 3.3 the BSFC values are AB10 (0.9%), JB10 (1.69%), AB20 (5.38%), and JB20 (3.60%)

Fewer CO2 emissions occur in biodiesel compared to diesel fuels during complete combustion as a result lower carbon to hydrogen ratio. CO2 emissions causes global warming or greenhouse gases emission. The effect of biodiesel on these will lead to 45–90% decrease in the emissions CO2 when likened to diesel fuels as shown in figure 3.4, the results are as follows AB10 (8%), JB10 (26.4%), AB20 (87%), and JB20 (34.75%).

The NO emissions from blends of biodiesel reported by several researchers are higher when compared with diesel fuels. High NOx in biodiesel occur due to the content of oxygen of in biodiesel. The average percentage increase in emissions of NOx in biodiesel is 9.24%, 7.32%, 7.42% and 5.77% for AB10, JB10, AB20 and JB20 respectively as shown in figure 3.6. NOx emissions can be influenced by several conditions for example pressure, cylinder temperature and air-fuel ratio. All through combustion O2 and N2 reacts at high temperatures which result in the emissions Nitrogen oxides. Bulk modulus, humidity and Viscosity also have an effect on NOx emissions. The results obtained above best explained that Biodiesel blends have higher emissions of NOx than diesel fuels.
Fig. 3.1: Break power vs Engine Speed

Fig. 3.2: BSFC vs Engine Speed

Fig. 3.3: HC Emission vs Engine Speed

Fig. 3.4: CO2 vs Engine Speed

Fig. 3.5: CO Emission vs Engine Speed

Fig. 3.6: NO Emission vs Engine Speed
4. Conclusion

Various blends of crude algae and Jatropha oil, about 10% and 20% biodiesel by volume in a diesel engine were analysed. Engine emission was examined in a common rail fuel system diesel engine. Algae and Jatropha oil biodiesel blend with diesel fuel were used as test fuel at the variously mixed ratio. The results obtained were compared with that of diesel fuels. Diesel fuel from CO₂ emission was found to be higher in diesel fuels when compared to Biodiesel blends (AB10, JB10, AB20, and JB20), however, the average CO₂ emissions of biodiesel blends are as follows; 8%, 26.4%, 87% and 34.75%; the same goes for the HC emissions biodiesel blends, they include; are 2.9%, 23.66%, 85% and 35.06%; while that of CO are; 12.85%, 17.13%, 24.58% and 9.68% respectively. For NOₓ, values of (AB10, JB10, AB20, and JB20) were found to be higher than the Diesel fuels by 9.24%, 7.32%, 7.42% and 5.77% respectively for all blends. During the process of combustion, O₂ and N₂ react at high temperatures resulting in the emissions of NOₓ. It happens as a result of high cetane numbers of the biodiesel blends. Physicochemical properties of the Algae oil and Jatropha oil ME and its blends are in line with the EN 14214 and ASTM D6751 procedures. BSFC and BP results are attributed to lower energy content, high viscosity and density of these biodiesel blends. Algae oil ME blend gives low Carbon dioxide, Carbon(II) oxide and Hydrocarbon emission, therefore it is a promising feedstock to produce biodiesel. AB20 gives the minutest emissions when compared to other biodiesel in unmodified engine.

Acknowledgements

This article is sponsored by Covenant University and will acknowledge the university for her financial support.

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