CHARACTERIZATION OF CASTOR BIODIESEL BLENDED WITH CONVENTIONAL DIESEL FUELS

Rasheed Amao Busari[1*], Joshua Olanrewaju Olaoye[2], Adeshina Fadeyibi[1], Timothy Denen Akpenpuun[2], Murtala Olayode Iyanda[2] and Segun Emmanuel Adebayo[3]
[1]Department of Food and Agricultural Engineering, Kwara State University Malete, Kwara State, Nigeria.
[2]Department of Agricultural and Biosystems Engineering, University of Ilorin, Ilorin, Nigeria
[3]Department of Agricultural and Bioresources Engineering, Federal University of Technology, Minna, Niger State.

*Corresponding Author's email address: rasheed.busari@kwasu.edu.ng

ABSTRACT

Compression Ignition Engines have proved its usefulness in agriculture, transportation, and power sector. In this research, the physicochemical properties of different blends of castor biodiesel were compared with conventional diesel fuel. Samples of the castor biodiesel prepared using transesterification processwere blended with the conventional biodiesel in different mixed ratios, namely B5, B10, B15, B20, B25,B50 to B100. The physicochemical properties, including density, flash point and kinematic viscosity were determined following standard and international procedures (ASTM). Results show that the B100 has higher density, kinematic viscosity and flash point compared to the conventional diesel at 280 °C. But the calorific value was lower in comparison. A gradual decrease in the density, flash point and kinetic viscosity were observed with a decrease in the biodiesel blends from B100 to B5. This implies that the castor biodiesel can be used as a close substitute for the conventional diesel fuel and has substantial advantages, especially in area of greenhouse control and energy security.

Keywords: Castor biodiesel, Diesel fuel, Analysis, Diesel engine and Physico-chemical.

1. INTRODUCTION

Fossil fuels are energy sourced from non-renewable and environmental unfriendly resulting from the combustion of fuels either from heavy duty machines, transport vehicles, industrial machines, or residential homes. Alternative fuels from non-edible or domestic sources are emerging as a solution to the declining reserves of convectional fuels. Biodiesel is becoming more popular in developed nations, a renewable mono-alkyl ester that is produced from vegetable oils, by a transesterification reaction. Serrano *et al.* (2012) reported that the use of biodiesel in Europe from 2007 to 2010 represented a share of more than 80% of the transportation biofuel consumption, and 30.26% of the total road transportation fuels consumed in 2010. When fossil fuels are burned, a lot of carbon dioxide is released into the atmosphere and the gas that absorbs heat and contributes to the greenhouse effect. Another harmful gas released when fossil fuel is burned is sulfur dioxide which mixed with water in the atmosphere to form sulfuric acid. This leads to acid rain which altered the normal pH of soil that supports plant growth (Innocent *et al.*, 2013). Biodiesel is been considered today worldwide as result of high level of atmospheric pollution caused by the intense use of fossil fuel leading to the ozone layer depletion and greenhouse effect. It is against this backdrop that fuels namely, castor biodiesel and petroleum diesel are comparatively analyzed

The production of biodiesel and energy applications have been reported for different biomass sources. Cumali*et al.* (2011) used biodiesel fuel produced from sunflower oil blended with petro-diesel on a compression ignition engine. Knothe and Steidley (2005) reported that biodiesel has a better lubricity than conventional diesel, as result of the polarity that is introduced with the presence of oxygen atoms which is lacking in petroleum diesel. Lubricity reported to be improved with the chain length and the presence of double bonds. Reddy *et al.* (2010) compared the brake thermal efficiency of diesel fuel and cotton seed methyl ester (biodiesel) blends and it was reported that the brake thermal efficiency was found to be lower with biodiesel blends as compared with petroleum diesel. Some engineering properties of Castor Nut Relevant to the design of processing equipment had been carried out (Olaoye, 2000). Busari and Olaoye (2016) investigated selected physical properties of African Pear seed for consideration in the design of mechanical expeller. Also, Busari and Olaoye (2017a) conducted investigation of the optimization of mechanical expression of Castor Seeds Oil (Ricinus communis) using Response Surface Methodology. However, the production and application of biodiesel from castor seed and the characterization of its blend with conventional diesel fuel have not been reported hitherto. Thus, this research was carried out to determine the physicochemical properties of different blends of castor biodiesel with conventional diesel fuel and pure fuel for agricultural, industrial and transportation applications.

1.1 Diesel Engine Fuel Requirement

The criteria for a fuel to be used in compression ignition engines; the thermal energy is released by burning the biodiesel or diesel fuel in the engine cylinder. The burning of fuel in the engine is quite fast but the time required to get a proper air/fuel mixture depends mainly on the nature or origin of fuel and the method of injection into the combustion chamber. The compression ignition engines fuel should therefore satisfy the following performance (Dwivedi *et al.,* 2013):

1. high energy density,
2. excellent combustion characteristics,
3. high thermal stability,
4. low deposit forming tendencies,
5. Compatibility with the engine hardware,
6. good fire safety,
7. low toxicity.
8. little or no pollution.
9. easy transferability and fuel storage.

The burning process in the cylinder should take as little time as possible with the release of maximum heat energy during the time of operation. Operational delayed will results in the deposits formation which may be mixed with other combustion products and result into excessive wear and corrosion of cylinder, piston and piston rings (Dwivedi *et al.,* 2013). The combustion product should be less toxic when released to the atmosphere. These requirements can be meet using several liquid and gaseous fuels. The biodiesel from non-edible sources such as castor, loofah seeds oil etc. meets the above-mentioned engine performance and therefore can offer perfect viable alternative to diesel oil (Dwivedi *et al.,* 2013).

2. MATERIALS AND METHODS

2.1 Conversion of castor oil into Fuel

The castor seeds were gathered from the wild, cleaned, and dried. The oil was trans esterified utilizing methanol as liquor and potassium hydroxide (KOH) as a catalyze. Each 250 ml of castor oil required 62.3 ml of methanol (molar proportion of 1:4) and the measure of potassium hydroxide was 1% by weight of the methanol utilized. Since water advances saponification, the catalyze used was kept dry in a sealed shut holder during the experiment. The measure catalyze was estimated and broken up in the liquor before filling the relating volume of the Castor oil. The blend was mixed and secured to evade dissipation of the liquor into the climate and left to make due with 24 hours after which there was an away from of methyl ester at the top and glycerin which settled at the base. The liquor (methanol) responded with the unsaturated fats in the castor oil within the sight of the impetus (Potassium Hydroxide) to frame monoalkyl (Biodiesel) and glycerin

2.1.1 Esters Yield Determination

Biodiesel yield was determined using Equation 1as reported by Bello and Daniel (2015).

$$Biodiesel\ yield = \frac{mass\ \ of\ biodiesel\ \ produced}{mass\ of oil\ \ used} \times 100\% \qquad (1)$$

2.1.2 Biodiesel Blending Proportion

The properties of biodiesel produced from castor oil seeds vary as result of production methods, equipment used and varieties or species of feed-stocks. The United States of America, Europe union and India have adopted usage of biodiesel in existing diesel engines and biodiesel modified engines. As result, they stipulated standards and specifications for biodiesel. These standards play a major role in quality control of biodiesel (Enweremadu and Mbarawa, 2009). For this investigation work, the properties of B100 and its B5, B10, B15, B20, B25, and B50 blends were tested and compared to that of conventional diesel and acceptable value were obtained within the specified standards (ASTM-D6751, EN-14214 and IS -15607). The proportion of blended biodiesel are presented in Table 1 while Figure 1 also shows the samples of blended biodiesel.

Figure 1: Samples of blended biodiesel produced

Table 1: Blends of Biodiesel

Type	Biodiesel	Diesel Fuel
B5	5% biodiesel	95% diesel fuel
B10	10% biodiesel	90% diesel fuel
B15	15% biodiesel	85% diesel fuel
B20	20% biodiesel	80% diesel fuel
B25	25% biodiesel	75% diesel fuel
B50	50% biodiesel	50% diesel fuel
B100	100% biodiesel	0% diesel fuel

2.2 Characterization of the Diesel from Castor Oil Seeds

The properties of different blends were examined at Industrial Chemistry Research Laboratory, Kwara State University, Malete and Agricultural and Biosystems Engineering Departmental Laboratory, University of Ilorin, the following the recorded procedures were used for determine physico- chemical properties of castor biodiesel and it blends. The methods adopted is similar to the procedure reported in Busari and Olaoye (2017b).

2.2.1 Determination of Specific Gravity and Density

Density meter (Rudolph Research Analytical: DDM 2911 Automatic Density Meter; Accuracy to 0.00005 g/cm^3; Manufactured in United State of America)was used to examine both the specific gravity and density of the biodiesel and it blends. TheASTM D1298 were used in measuring the density and specific gravity as reported by Okey and Okey (2013).

2.2.2 Determination of pH, Cloud Point and Flash Point

The protective cap of the pH meter (ST20; Ohaus enterprise) was removed; the pH cathode glass bulb was cleaned off with refined water and featured systems were followed as reported by Akpan *et al.* (2006). The flash point was measured, as indicated by ASTM-D93 (ASTM, 2008) while cloud point was measured as described by Akpan *et al.*(2006).

2.2.3 Determination of Kinematic Viscosity

The thickness of the example was estimated adhering to the ASTM D445 standard methodology at 40°C utilizing an aligned Viscometer (NDJ – IB Rotational Viscometer; Shanghai Chamgji). The kinematic viscosity was measured as reference above.

2.2.4 Determination of Calorific Value/Heat of Combustion

The warmth of burning was resolved utilizing standard bomb calorimeter (IKA Calorimeter, System C200 Basic Control) following the technique of ASTM D240. The sample with known mass was scorched under standard condition. Ignition was initiated by including oxygen contained in a gas chamber at a weight of 20 – 35 Atm. what's more, result was shown on bomb calorimeter screen (ASTM, 2004).

2.2.5 Determination of Pour Point

Mechanical assembly utilized in pour point assurance were test container, plug conveying thermometer, water shower with warmer and squashed ice. Exploratory methodology is as listed beneath; A sample of worm crude was filled to the level imprint. The test container was firmly shut by the cork carrying the test thermometer and placed in a bath of crushed ice.

a) The test container was checked at interval of three (3) minutes holding in a horizontal position for a couple of seconds before returning it to cool.

b) The pour point was reached when the oil surface remained in the vertical situation for a time of 5 seconds without sagging. Now the thermometer was inserted to cool for 10 seconds and the temperature of the oil was taken.

3. RESULTS AND DISCUSSION

The result of physico-chemical properties obtained of castor biodiesel were presented in Figures 2 – 7.The calorific value of biodiesel fuel reduces from 41, 800, to 38, 470 kJ/kg as biodiesel concentration increases while the calorific value of conventional diesel was 42, 000 kJ/kg as reported by Acharya *et al.*(2016). The lower calorific value of castor biodiesel may be due to high density and kinematic viscosity of the fuel (Acharya *et al.* 2016). Also, the lower energy value in the biodiesel may be due to its high oxygen content (Acharya *et al.* 2016).Therefore, increase in biodiesel concentration in the blends resulted in a decrease in energy content. The result is similar to the findings of Bello and Daniel (2015) in their work on optimization of groundnut oil biodiesel production and characterization and obtained the calorific value of 39,800 kJ/kg. Also, Xue*et al.,* (2011) reported that calorific value of fuels is an important measure of its releasing energy for producing work. So, the lower heating value of biodiesel is attributed to the decrease in engine power, which is commonly agreed by the literatures which report that engine power reduces with biodiesel. In addition, both high and low calorific values are measures of a fuel's heat of combustion, with the difference between them being the water's heat of vaporization. Biodiesel contains, on average, 10−12% w/w oxygen, which leads to proportionally lower energy content and heating value, thus more fuel needs to be injected in order to achieve the same engine power output Giakoumis (2013). There is no specification as regards the biodiesel calorific or heating value, neither in the ASTM nor in the EN. According to research carried out by Giakoumis (2013) methyl esters exhibit calorific values ranged from 35,990 to 38,800 kJ/kg for 26 different feedstocks studied, with an average value of 37,610 kJ/kg; thus, this is 10−11% lower than the corresponding mineral diesel fuels. Figure 2 present calorific value of different biodiesel blends with respect to diesel fuel

One major interests of this research work are castor biodiesel viscosity. Viscosity plays an important role on diesel engine combustion and exhaust emissions. Figure 3shows the variations of kinematic viscosity of different biodiesel blends with respect to diesel fuel. It is clear from the figure that kinematic viscosities of different biodiesel blend increase with increase in biodiesel concentration and vice versa this implied viscosity of feedstock increases with chain length (number of carbon atoms) and degree of saturation (Aydin and Bayindir, 2010). For proper functioning of the engine, it is necessary to reduce the viscosity of a fuel. Fuel with relatively higher viscosity will not break into fine particles when sprayed (change of fuel atomization and distribution inside the cylinder). Large particles will burn slowly, resulting in poor engine performance. On the other hand, if the viscosity is too low, the fuel will not lubricate the moving parts of the injection pump and injection nozzle. This will cause rapid wear of those parts (Raheman and Ghadge 2007). The kinematic viscosity of conventional diesel is just 2.3 cSt as compared to castor biodiesel that has higher kinematic. From the obtained result, B5-B25 has very comparable viscosity to conventional diesel (according to ASTM and EN standard specifications on biodiesel). Though, the result is in contrast with the results obtained by Anastopoulos*et al.*(2009)they worked on three different vegetable oils and got 4.63, 4.84 and 4.0

cSt for Sunflower oil methyl esters, Rapeseed oil methyl esters and Olive oil methyl esters, respectively. Also, Raheman and Ghadge (2007) reported that the kinematic viscosity of mahua biodiesel was reduced to 3.98 cSt after transesterification. They found the viscosity of blends increased with increasing concentration of biodiesel in the blends. However, a few literatures suggested that higher viscosity results in the power losses because the higher viscosity decreases combustion efficiency due to bad fuel injection atomization (Aydin and Bayindir, 2010; Utlu and Kocak, 2008).

Density (function of specific gravity) and the specific gravity of castor biodiesel werepresented in Figure 4 and 5. As a result of high density of castor biodiesel, specific fuel consumption would be higher than diesel fuel. The result obtained for castor biodiesel was close to the previous work carried out on the same seeds by Asmare and Gabbiye (2014) whose result was 920 g/cm^3. Similar trend was observed by Raheman and Ghadge (2007), they found out that the density of crude mahua oil was lower by about 9% on its conversion to biodiesel. The densities of the oil were observed to increase linearly with the increasing concentration of biodiesel in the blends. Slightly higher densities of blends wereobserved compared to diesel fuel. However, biodiesel fuels are generally, characterized by higher density than conventional petroleum diesel, which implies that volumetrically, engine fuel pumps will inject greater mass of biodiesel than conventional diesel fuel. This in turn will affect the air-fuel mixing ratio, if the engine retains original diesel-fuel calibration (Giakoumis, 2013; McCormick *et al.* 2001). Giakoumis, (2013) argued that there exists a relationship between density and NOx emissions, with lower densities favoring lower NOx. He also, investigated densities of 25 methyl esters (feedstocks) excluding castor and reported that their range from 870.8 to 891.5 kg/m^3, with the average value of 880.2 kg/m^3 (almost 5% higher than convectional diesel). He further stated that castor biodiesel has higher density than other feedstocks with an average density of 917.6 kg/m^3. ASTM had no specification for biodiesel density; EN on the other hand, specified range of 860 – 900 kg/m^3 as the acceptable limit. (Giakoumis, 2013). Specific gravity affects the engine performance as the volume of fuel injected into engine system is affected by change in specific gravity (Acharya *etal.*,2016). It was noted from the Figure 5, thatlinear relationship exists between the blends of biodiesel due to increase in the biodiesel concentration in the blends.

The flash point is a measure of the temperature to which a fuel must be heated such that the mixture of vapor and air above the fuel can be ignited. It also varies inversely with the fuel's volatility (Giakoumis, 2013). Figure 6compared the flash point of castor biodiesel and its blends with that of conventional diesel. In addition, it is comparatively safer to transport and store castor biodiesel than conventional diesel (Giakoumis, 2013). The flash point of castor biodiesel was 280°C, which is 5 times higher than conventional diesel fuel (53°C). Thus, overall flammability hazard of biodiesel and biodiesel blends is much less than that of conventional diesel fuel (Giakoumis, 2013). The flash point obtained was slightly higher than findings of Raheman and Ghadge (2007), they determined flash points of mahua biodiesel to be 208 °C, and this is quite high compared to 53°C for the diesel fuel as result of higher viscosity of biodiesel as reported by Giakoumis (2013). More so, Giakoumis (2013) examined 26 differences and He results ranged from127.7°C to 174.5°C with the mean value from all feedstocks being 163.3°C. European specifications require biodiesel fuels to have at least 101°C flash point, whereas, in the American specification, the minimum level required is lower (130°C); both are meant to determine a lower limit of purity in the final methyl ester. Thus, overall flammability hazard of biodiesel and biodiesel blends is much less than that of conventional diesel fuel.

The pH values obtained was represented in Figure 7. The results obtained agree with the work carried out by AL-Harbawy and AL-Mallah (2014), who worked on production and characterization of biodiesel from seed oil of castor (*Ricinus communis L.*) plants and obtained pH of 6.3, 6.5 and 6.7 for crude, refined and hot method castor oil, respectively. Akpan *et al.* (2006) reported that the pH value of the crude oil which was found to be 6.11 indicates that the oil is more acidic as compared to 6.34 obtained for the refined oil. They attributed the difference to degumming and neutralization carried out during the refining process of castor.

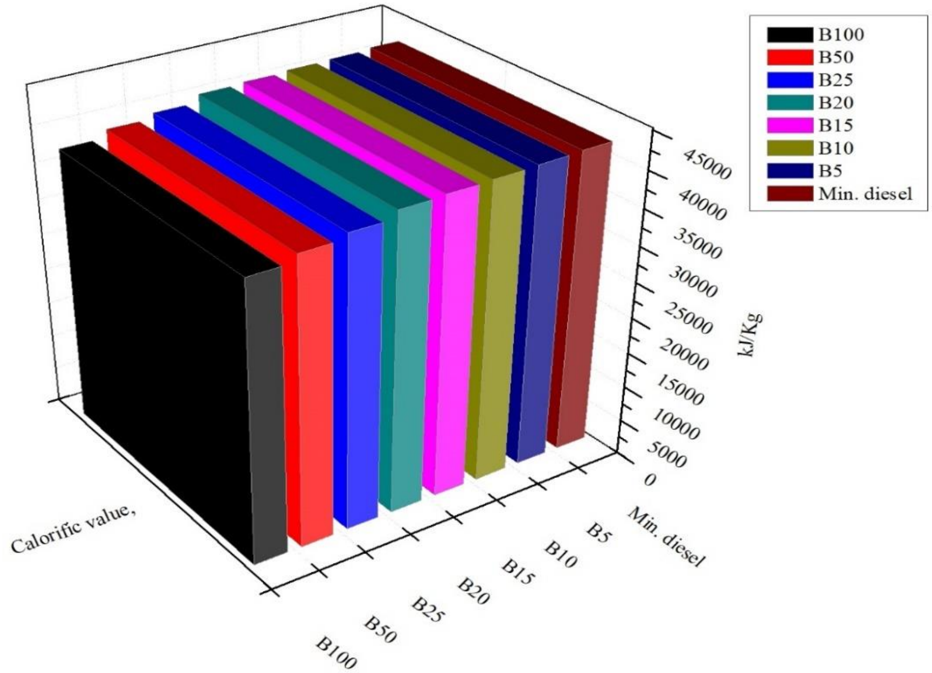

Figure 2: Calorific Value of Different Biodiesel Blends with Respect to Diesel Fuel

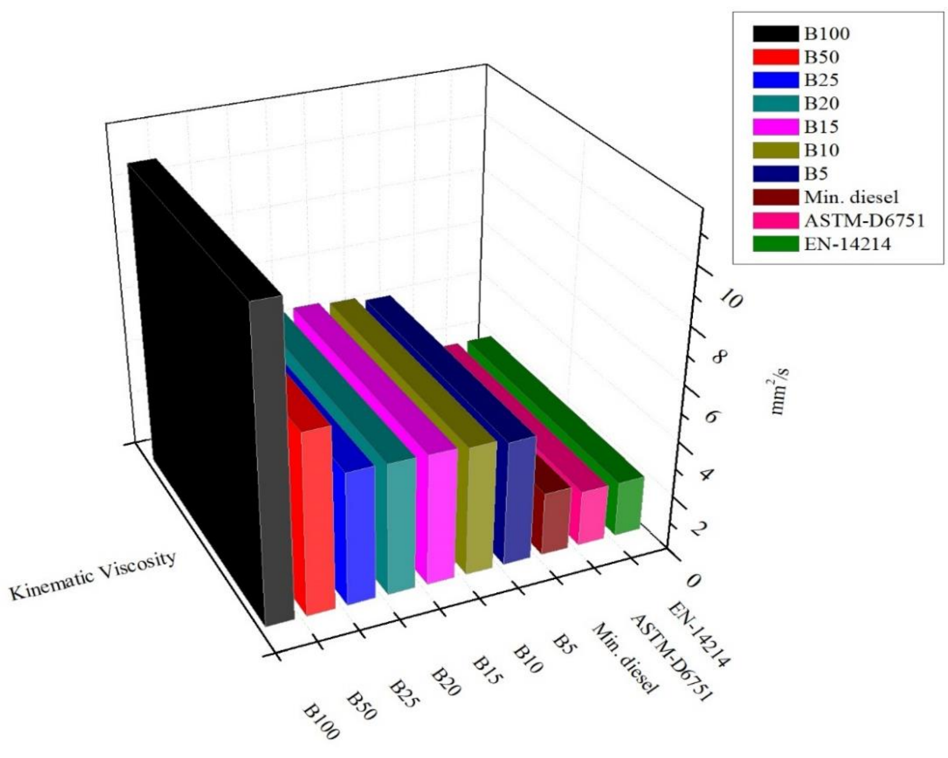

Figure 3: Kinematic Viscosity of Different Biodiesel Blends with Respect to Diesel Fuel

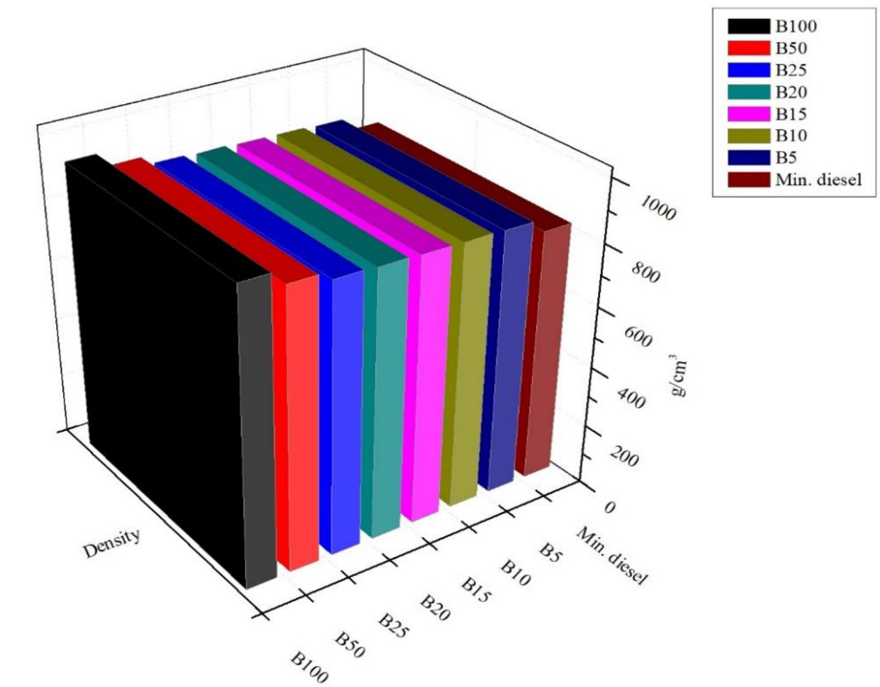

Figure 4: Density of Different Biodiesel Blends with Respect to Diesel Fuel.

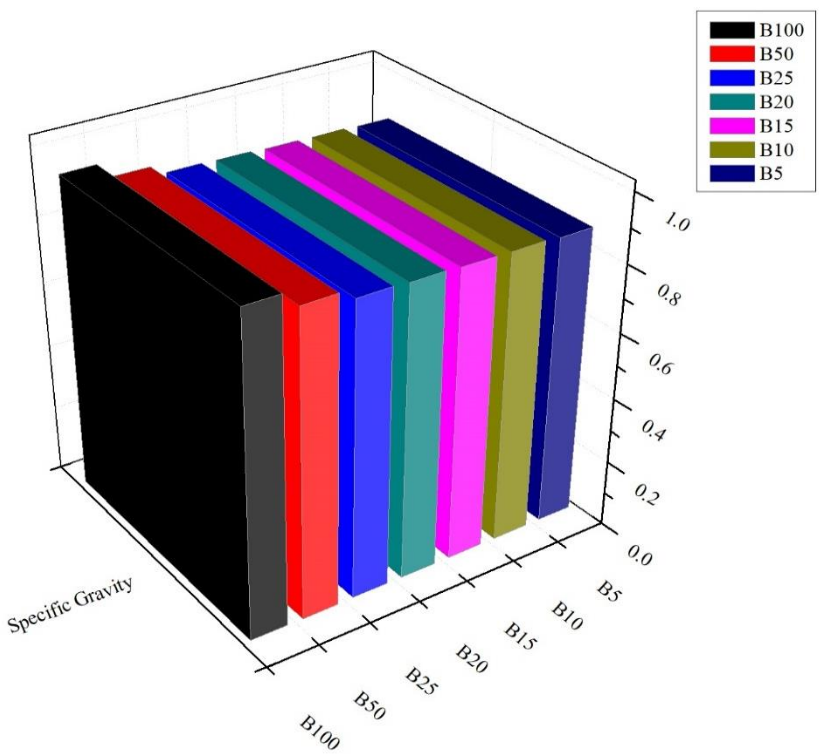

Figure 5: Specific Gravity of Different Biodiesel Blends with Respect to Diesel Fuel

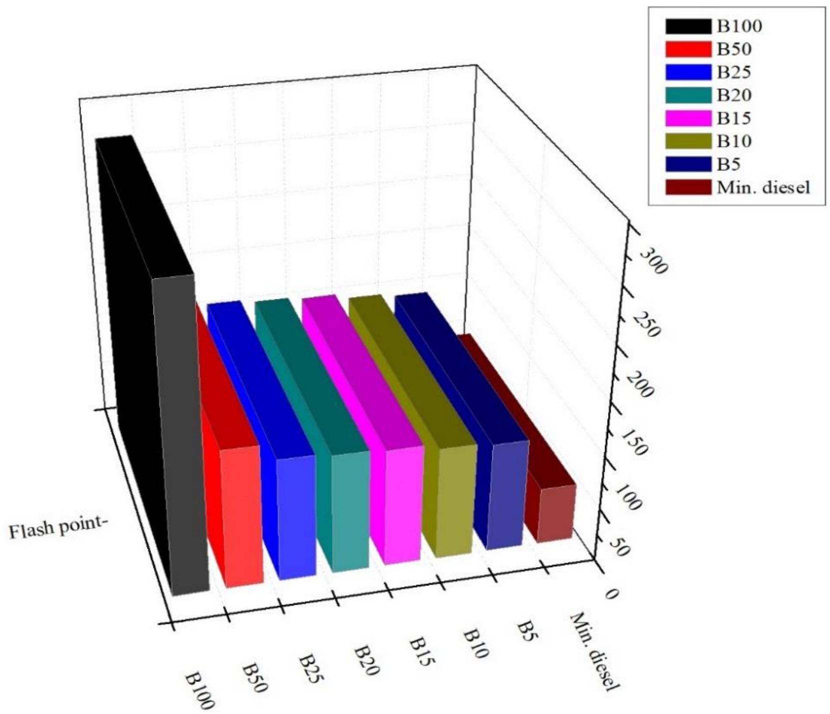

Figure 6: Flash Point of Different Biodiesel Blends with Respect to Diesel Fuel

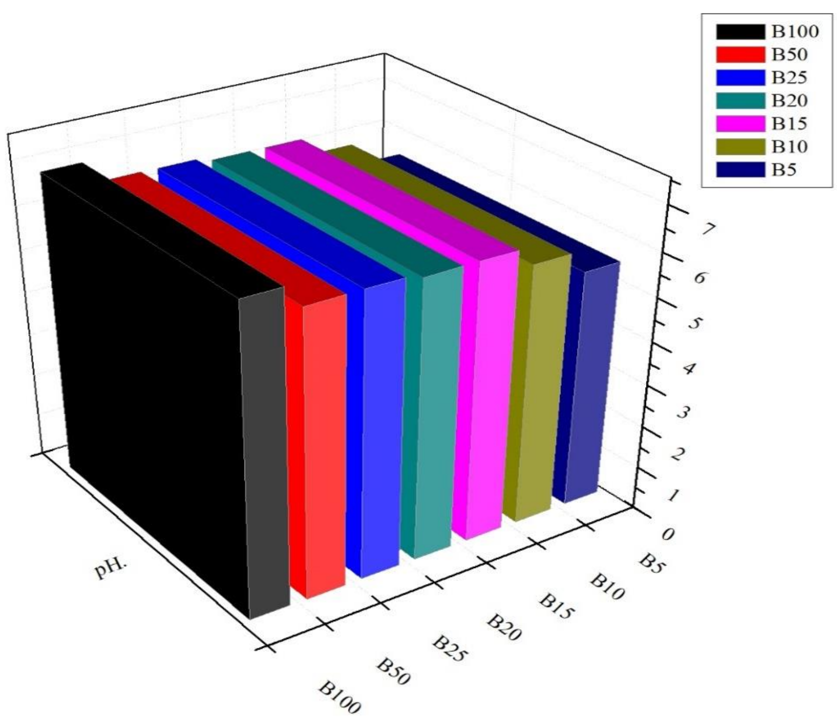

Figure 7: pH value of Different Biodiesel Blends with Respect to Diesel Fuel

3.1 Comparative Performance Analysis of Castor biodiesel and Convectional Diesel Fuel

The performance of compression ignition engines depends on the the spray performance innernozzle flow. The spray performance and innernozzle flow in diesel engine, controlsthe air fuel mixture, which is vital in the combustion process. As result of differences in both physical and chemical properties of castor biodiesel and convectional diesel, the spray structure and inner nozzle flow are may be altered. Som *et al* (2010) reported that as result of low vapour pressure of castor biodiesel, it is expected to perform less than convectional diesel fuel. A sluggish in injection velocity and lower flow efficiency were observed due to castor biodiesel high viscosity. It was observed that as castor biodiesel concentration increase the brake specific fuel consumption also increases. Therefore, the brake specific fuel consumption of castor biodiesel is higher than that of conventional diesel as result of lower calorific of heating value, as well as the higher viscosity of castor biodiesel. Hence, the volume of biodiesel fuel introduced or injected into the cylinder is more than convectional diesel, in order toget desired energy required from the engine. The research work carried out by of Zheng *et al.*, (2008) confirmed the result. They reported that up to 23% increase fuel consumption was observed when the engine was runned on biodiesel. The brake thermal efficiency of the engine was also observed, the efficiency decreased as the concentration of biodiesel increases. This implied castor biodiesel gave lower thermal efficiency as compared to diesel fuel. The poor combustion of castor biodiesel was due to high viscosity and poor volatility of the fuel. Nabi *et al.* (2009) observed that decrease in brake thermal efficiency with biodiesel from vegetable oils was as a result of low heating value, higher kinematic viscosity, poor spray nature of the fuel, inadequate air-fuel mixture, and high density of the fuel. Rao *et al.*, (2007) reported that ignition delay of castor biodiesel may result to combustion initiation before the piston get to top dead center which may end up heating loss and reduction in the engine efficiency. In contrary, Canakci (2007) stated that there is no major difference between castor biodiesel and diesel fuel as diesel engines converts the chemical energy in the fuel to mechanical energy with the same efficiency. For the engine brake power, the engine supplied fuels in volumetric basis and castor biodiesel density is higher than that of conventional diesel, which means more castor biodiesel will be supply to compensate for the lower heating value of the fuel. The higher viscosity of diesel from vegetable oil may leads to large spray droplet of fuel which may result into fuel spray penetration of higher momentum, thus improving air-fuel mixing (Nwafor, 2004).

4. Conclusions

This research focused on the characterization of castor biodiesel blended with conventional diesel fuel. It can be concluded that:

(1) Biodiesel is a sustainable elective fuel that can be utilized in a diesel engine either unadulterated or in mixes with convectional diesel.
(2) It has the capability of supplanting oil diesel or being utilized in mixes with petroleum diesel to improve execution and decrease poisonous fumes outflows.
(3) It has substantial advantages, especially in area of greenhouse control and energy security. The poor lubricity of petro-diesel fuel has led to the failure of engine parts such as fuel injectors andpumps which was addressed bybiodiesel. The betterlubricity is because of polarity that was introduced with the presenceof oxygen atoms which is lacking in petro-diesel

REFERENCES

Acharya, N. Nanda, P., Panda, S. and Acharya, S. (2016). Analysis of properties and estimation of optimum blending ratioof blended mahua biodiesel. *Engineering Science and* Technology, an International Journal. 10(5): 10 – 16 http://dx.doi.org/10.1016/j.jestch.2016.12.005.

Akpan, U. G., Jimoh, A. and Mohammed, A. D. (2006). Extraction, Characterization and Modification of Castor Seed Oil; Leonardo Journal of Sciences, (8): 43-52.

AL-Harbawy, A.W. and AL-Mallah, M. K. (2014). Production and Characterization of Biodiesel from seed oil of Castor (*Ricinus communis*L.) plants; International Journal of Science and Technology; 3 (9): 508-515

Anastopoulos, G., Zannikou, Y., Stournas, S. and Kalligeros, S. (2009). Transesterification of Vegetable Oils with Ethanol and Characterization of the Key Fuel Properties of Ethyl Esters; Energies; (2): 362-376.

Asmare, M. and Gabbiye, N. (2014). Synthesis and Characterization of Biodiesel from Castor Bean as Alternative Fuel for Diesel Engine; American Journal of Energy Engineering; 2 (1): 1-15

ASTM, (2004).America Society for Testing and Material, Standard Specification for Biodiesel Fuel (B100). Blend stock for Distillate Fuels. Designation D6751-02.ASTM International, West Conshohocken, USA.

ASTM, (2008).American society for testing and materials. Standard test for flash point by Pensky–Martens closed cup tester. ASTM-D93.

Aydin, H. and Bayindir, H. (2010). Performance and emission analysis of cotton seed oil methyl ester in a diesel engine", Renewable Energy; 35 (3): 588-592.

Bello, E.I and Daniel, F. (2015). Optimization of Groundnut Oil Biodiesel Production and Characterization; Applied Science Reports; 9 (3): 172-180

Busari R. A. and Olaoye J. O. (2016).Selected Physical Properties of African Pear Seed for Considering in Design of Mechanical Expeller; ARPN Journal of Engineering and Applied Sciences. 11(8): 5462 - 5468.

Busari, R. A. and J. O. Olaoye (2017a). Biodiesel Production from Castor Bean seed: An Optimization Process Using Response Surface Methodology; Annals. Food Science and Technology (AFST). 18(2); 110 – 116.

Busari, R. A. and J. O. Olaoye (2017b). Optimization of Mechanical Expression of Castor Seeds Oil (Ricinus communis) using Response Surface Methodology. Arid Zone Journal of Engineering, Technology and Environment.(AZOJETE). 13(4);878 - 887.

Canakci, M., (2007): Combustion characteristics of a turbocharged DI compression ignition engine fuelled with petroleum diesel fuels and biodiesel. Bioresource Technol.; 98: 1167– 1175.

Cumali. I., Selman. A., Rasim. B. and Hüseyin.A. (2011). Biodiesel from safflower oil and its application in a diesel engine; Fuel Processing Technology; 92:356–362.

Dwivedi, G., Jain, S and Sharma, M. P. (2013).Diesel engine performance and emission analysis using biodiesel from various oil sources – Review; J. Mater. Environ. Sci. 4 (4): 434-447; ISSN: 2028-2508; (www.jmaterenvironsci.com)

Enweremadu, C. C. and Mbarawa, M. M. (2009). Technical aspects of production and analysis of biodiesel from used cooking oil—A review; Renewable and Sustainable Energy Reviews; (13): 2205–2224

Giakoumis, E. G. (2013). A statistical investigation of biodiesel physical and chemical properties, and their correlation with the degree of unsaturation; Renewable Energy; (50): 858-878

Innocent, D. S., Sylvester, O. P., Yahaya, M. F., Nwadike, I.and Okoro, L. N. (2013). Comparative Analysis of Biodiesel and Petroleum Diesel; International Journal of Education and Research; 1 (8): 1 – 8

Knothe. G. and Steidley. K. R. (2005). Lubricity of Components of Biodiesel and Petrodiesel. The Origin of Biodiesel Lubricity; Energy & Fuels; 19: 1192-1200.

McCormick, R. L., Graboski, M. S., Alleman, T. L. and Herring A. M. (2001). Impact of biodiesel source material and chemical structure on emissions of criteria pollutants from a heavy-duty engine; Environ Sci. Technol.; (35): 1742–1747.

Nabi, M. N., Rahman, M. M. and Akhter, M. S., (2009). Biodiesel from cottonseed oil and its effect on engine performance and exhaust emissions; Appl. Therm. Eng.; (29): 2265 – 2270.

Nwafor, O. M. I., (2004). Emission characteristics of a diesel engine operating on rapeseed methyl ester; Renew. Energy; 29:119–29.

Olaoye, J. O. (2000) Some Engineering properties of Castor Nut Relevant to the Design of Processing Equipment.Journal of Agricultural Engineering Research (JAER).77(1); 113 – 118, Published for Silsoe Research Institute in Association with the European Agricultural Engineers (EurAgEng) by ACADEMIC PRESS, London.U.K Okey, E. N. and Okey, P. A. (2013).Optimization of biodiesel production from nonedibleseeds of Delonix regia (Gul Mohr);International Journal of Bioresource Technology; 1 (1): 1 - 8

Raheman, H. and Ghadge, S. V. (2007). Performance of compression ignition engine with mahua (Madhucaindica) biodiesel; fuel; (86): 2568 -2573

Rao, G. L. N., Prasad, B. D., Sampath, S., Rajagopal, K., (2007): Combustion analysis of diesel engine fueled with jatropha oil methyl ester—diesel blends; Int. J. Green Energy.; 4: 645 – 658.

Reddy.A.V.K, Shiva.S. and Apparao.K. (2010). Experimental Determination of Brake Thermal Efficiency and Brake Specific Fuel Consumption of Diesel Engine Fuelled with Biodiesel; International Journal of Engineering and Technology; 2 (5): 305-309

Serrano. L., Carreira. V., Carama.R. and Gameiro da Silva.M. (2012).On-road performance Technology, 103, 125-133.

Som. S., Longman. D. E., Ramirez. A.I., & Aggarwal. S.K. (2010). A comparison of injector flowand spray characteristics of biodiesel with petrodiesel. Fuel, 89, 4014-4024.

Utlu, Z. and Kocak, M. S. (2008). The effect of biodiesel fuel obtained from waste frying oil on direct injection diesel engine performance and exhaust emissions; Renew.Energ.; (33): 1936–1941.

Xue, J., Grift, T. E. and Hansen, A. C. (2011). Effect of biodiesel on engine performances and emissions; Renewable and Sustainable Energy Reviews; 15 (2): 1098- 111.

Zheng, M., Mulenga, M. C., Reader, G. T., Wang, M., Ting, D. S. and Tjong, J. (2008). Biodiesel engine performance and emissions in low-temperature combustion, Fuel; 87 (6) 714-722.