Engine performance operated with biodiesel produced from the transesterification of African pear seed oil catalyzed with acidified empty palm fruit bunch ash

Umeagukwu O.E[1*], Ude N.C[2], Onukwuli O.D[1], and Okey-Onyesolu C.F[1]

[1]Department of Chemical Engineering, Nnamdi Azikiwe University (NAU), Awka, Nigeria.
[2] Department of Chemical Engineering, Michael Okpara University of Agriculture, Umudike, Umuahia, Abia State, Nigeria.

[*]Corresponding Author's E-mail: callyjoe4real@gmail.com

Abstract

This research evaluates the performance of Africa pear seed methyl ester operated on a diesel engine produced from transesterification reaction in a heterogeneous catalyzed process. The Africa pear seed oil was extracted using sohxlet apparatus via solvent extraction while the empty palm fruit bunch ash (EPFBA) was synthesized from palm fruit bunch and then activated with acid. The oil was characterized using American Society for Testing Materials (ASTM) standard. The results showed that the oil has an acceptable acid value less than 5% and has comparable properties with other edible and non-edible oils. The EPFBA was discovered to have more pores and surface area on activation with acid. The physiochemical and thermal properties of biodiesel produced met the ASTM standard and were within the acceptable limit. The convectional diesel, biodiesel, and their blends were used to run a two-cylinder, four-stroke engine at different engine speeds and at constant load. The engine performance shows that more fuel is consumed with biodiesel and the rate of consumption decreases when blended with diesel. The brake power (Bp), torque and brake thermal efficiency (BTE) of engine performance increased as the speed increased to 2000rpm and slightly decreased as the speed increased beyond 2000 rpm, and these properties are best with engine operated with biodiesel. The engine performance result shows that biodiesel blend (B20) has Bp and BTE less than that of petro-diesel by 3% and 17% respectively. Therefore, the acid activated empty palm fruit bunch ash (AAEPFBA) catalyst has the potential to convert the Africa pear seed oil (APSO) to biodiesel, and the biodiesel/blends can perform in a diesel engine without engine modification.

Keywords: Engine performance, acid activated empty palm fruit bunch ash, African pear seed oil, Biodiesel.

1. Introduction

Different research has been carried out on bio-energy, but biodiesel, an alternative to diesel, has remained vital because of its usage in diesel engines to convey heavy loads, which is impossible with other fossil fuels or bio-energy. In addition, biodiesel is biodegradable, non-toxic, environmentally friendly, economical, and renewable, and this has made research on biodiesel paramount across the globe. In recent years, several countries (and states) have embarked on legislative and/or regulatory pathways that encourage increased use of biodiesel fuel using both incentives and prescriptive volumetric requirements (Hoekman *et al*., 2012). For example, in the U.S., the Energy Independence and Security Act (EISA) of 2007 established a 0.5 billion gallon/year (bg/y) requirement for biomass-based diesel fuel in 2009, with this amount increasing to 1.0 bg/y by 2012 (U.S. Congress 2007).

Biodiesel is a mono alkyl ester of long chain fatty acid produced from the organic reaction of lipids (edible oil, animal fat, non-edible oil) with alcohol in the presence of a catalyst. Biodiesel was used in place of oil in diesel engine because it is less viscous. Moreover, oil becomes rancid on reacting with atmospheric oxygen, and water which makes the oil to have free fatty acid. The level of free fatty acid in the oil determines the kind of transesterification to adopt.

Transesterification, also referred to as alcoholysis, is the most widely adopted chemical process for producing biodiesel because this method is reliable, economical, and has reusability properties. Transesterification uses alcohols in the presence of a catalyst (e.g., base, acid or enzyme depending on the free fatty acid content of the raw material) that chemically breaks the molecules of triglycerides into alkyl esters as biodiesel fuels and glycerol as a by-product (Fan et al., 2012). Pyrolysis and the micro-emulsion process are other methods of producing biodiesel. Micro emulsion is a process that involves colloidal dispersion of fluid microstructures (1–150 nm) in a solvent, forming two immiscible phases (Elangoven et al., 2015). Like transesterification, micro emulsion reduces the high viscosity of vegetable oil with alcohol. Pyrolysis is simply subjecting the triglyceride to high temperature in the presence of a catalyst; the catalyst speeds up the reaction. Different products can be obtained from the same material depending on different paths of reaction, and this makes pyrolytic chemistry difficult (Elangoven et al., 2015). Pyrolysis of vegetable oil gives different lower hydrocarbons that can be used as fuel (Elangoven et al., 2015).

The catalyst in any of the production processes of biodiesel could be organic or inorganic; homogenous or heterogeneous. Homogeneous catalysts like KOH and NaOH used in biodiesel production are difficult to recover and often form undesired side products like soap and emulsion by the transesterification process (Naomi et al., 2007). The challenges posed by the use of homogeneous catalysts have continued to propel researchers to develop novel heterogeneous catalysts from different cheap and available biomasses. Some of the biomasses that have been studied are clay (Onukwuli and Ude, 2018), rice husk ash (Jibril and Nedumaran, 2017), plantain ash (Enontiemonria et al.,2016), waste animal bone (Ulakpa et al.,2019), egg shell (Niju et al.,2016), periwinkle shell (Okoye et al., 2020), saw dust e.t.c. The heterogeneous catalysts were observed to have good catalytic properties for transesterification reactions and gave high yield of biodiesel. To the best of my knowledge, biomass such as empty palm fruit bunch ash (EPFBA) treated with acid is yet to be explored as catalyst for the production of biodiesel. The need to adopt EPFBA as a catalyst is pertinent because the empty palm fruit bunch (EPFB) is considered to be an emerging issue because of its disposal cost and its effect on drainage systems when not used or disposed of properly. Catalysts are modified by subjecting the catalyst to chemicals (acid or alkaline) or heat to increase the frequency of collisions between reactants and activation energy.

The optimal yield of biodiesel from the transesterification process depends on these variables: time, type of catalyst, alcohol/oil ratio, speed, and temperature. The interactions between these variables affect the biodiesel yield. It is difficult to optimize the process by 1-factor or 2 factors at a time approach. Alternatively, response surface methodology (RSM) is a reliable technique to use. The diesel engine is typically more efficient than the gasoline engine due to its higher compression ratio and does not suffer from size and power limitations, which the spark ignition engine is prone to (Sandeep et al., 2015). Biodiesel can be used directly on diesel engines or can be blended with diesel to have different engine performance parameters and particulate pollutants. Therefore, this study focused on the transesterification of Africa pear seed oil using acid activated EPFBA and the engine performance fueled with biodiesel and its blends.

2. Methodology

2.1 Procurement/processing of Africa pear seed

The Africa pear seeds were gotten from Africa pears that were purchased from Uturu in Abia State during their availability of the season. The seeds were dried in sunlight for thirty days at 55°C, deshelled and the kernel was crushed using Kenwood electrical grinder KEFP580 prior to oil extraction. The solvent extraction method was used to extract oil from the seed. The extraction was carried out by using a soxhlet extractor containing the crushed kernel (particle size of 900 μm), fitted with a round bottom flask (2 L capacity). The extraction was achieved on a water bath for 6 hrs, with n-hexane solvent (Bpt 40-60°C). The beaker containing the oil and extracting solvent is subjected to a temperature above 70°C to vapourize and recover the n-hexane. The percentage mass of oil is calculated using Equation 1. The Africa pear seed oil was subjected to some tests with some accompanied with mathematical models to determine the physiochemical properties. This method of solvent extraction was employed by (Zahira et al., 2011) in the extraction of *Jatropha seed oil*.

$$N = \frac{M_o}{M} * 100 \qquad\qquad (1)$$

Where, N is the oil yield (%),
M_o is the mass of pure oil extracted (g),

M is the mass of the sample of seed used in the experiment

Methanol used was a product from India (Merck, Mumbai, India). All chemicals used were of analytical grade, and used without further treatment. These chemicals were bought from Obyno Scientific Limited at Ogbete market, Enugu.

2.2. Synthesis of Catalyst
2.2.1 Preparation of catalyst

Raw empty palm fruit bunch (EPFB) was obtained from local oil palm mill in Uturu, Abia state. It was cut into small pieces and air dried for 30 days at 55ºC . The dried EPFBA was pulverized using kenwood laborataory blender BL335. The pulverized biomass was sieved through a 250 ɥm diameter sieve to get fine particle and submerged in distilled water for 12 hrs. It was decanted to remove impurities, after which it was allowed to drain and dried in axiom laboratory hot air oven Rs 4500 Ultra Smart at 104ºC until constant weight was attained. Then, the EPFB was burned in a furnace, Muffle ECF3 (Finlab product) at a temperature of 800°C for 4 hrs to prepare empty palm fruit bunch ash, EPFBA. This ash was further modified using acid as support for the active catalyst.

2.2.2 Acid modification of the catalyst

The dried EPFBA sample was added to phosphoric acid, H_3PO_4 0.5M (Vetec 85) in ratio of 1:2 (g/ml) to form EPFBA-H_3PO_4 solution. The reaction was carried out in a round bottom flask at the condition under vigorous stirring and at the temperature of 100ºC for 2 hrs. The system was heated in TCS glycerine bath Rs 155000 connected to a reflux condenser. Then the acid activated EPFBA was washed with distilled water until the pH was close to 7 and dried at 110ºC for 6 hrs. It was finally milled into a fine powder.

2.3. Physiochemical Properties of Catalyst

The characteristics of the acid modified EPFBA samples were determined using various analytical instruments. The ASTM D4067 method, and multi-point **Brunauer-Emmet-Teller** BET, (Nova station Quantachrome instrument version 11.3) were used to determine their physiochemical properties of the raw and activated EPFBA. Fourier Transform Infra-red Spectrometer (FTIR) transmission method using KBr (BUCK model 500M) was employed to determine the functional group or organic compound and chemical bond between atoms of the catalysts while Carl Zeiss sigma field emission scanning electron microscope (SEM) was to determine the morphology of the EPFBA samples, which include the pore size, pore volume, texture, imaging purpose (rough or smooth), and the group and the crystallographic structures of the EPFBA were recorded using X-ray Diffractometer (XRD). The X-ray diffraction measurements were obtained in a Shimadzu diffractometer model XRD-7000 with Cu Ka X-ray source (40 kV, 30 mA, λ = 1.5418 Å),

2.4 Transesterification Reaction

The extracted oil from Africa pear seed react with methanol in the presence of acid activated empty palm fruit bunch ash (AAEPFBA) to produce fatty acids methyl ester FAME, (biodiesel) and glycerol. The oil sample was measured and transferred into a flat bottom flask placed on an overhead digital hot magnetic stirrer (LX653DMS model). Then acid activated catalyst (2% weight of oil sample) and methanol (10:1 methanol/oil molar ratio) solution were added, and the flask kept on a hot magnetic stirrer under constant temperature with defined agitation speed of 250rpm throughout the reaction. At the defined time of 2 hrs, the flask was taken out, cooled, and the biodiesel at the upper layer was separated from the by-product (glycerol) in the lower layer by settlement overnight under ambient temperature. The catalyst was recovered by filtration using filter paper and the upper layer was subjected to IKA rotary evaporation (RV 10 model) to recover excess methanol. The percentage of the biodiesel yield was determined by comparing the weight of biodiesel with the weight of oil used as shown in Equation 2

$$Biodieisel\ (\%) = \frac{weight\ of\ biodiesel}{weight\ of\ oil\ used} * 100 \qquad (2)$$

2.5 Engine Test Analysis

The performance of the bio-diesel produced by the transesterification process was evaluated on a Perkins 4:108 Diesel Engine mounted on a steady state engine test bed at University of Nigeria, Mechanical Engineering Department. The engine was subjected to different speeds and at constant load. The time taken for a given volume (50 ml) of the fuel to be consumed at each speed was noted using a stop watch. The manometer reading, the torque, and exhaust temperature were measured. Then the mass flow rate, brake power, brake specific fuel consumption (BSFC), and brake thermal efficiency were calculated.

3. Results and Discussion

3.1 Properties of Africa pear seed oil

The physiochemical properties of the oil extracted from Africa pear seed, presented in Table 1, confirm the potential of the seed as a feedstock suitable for producing biodiesel in the near future when the fossil fuel goes into extinction. It has less free fatty acid, is less expensive (does not require a two-step transesterification method), has significant energy value, and low viscosity, which could compare favorably with some other non-edible oils such as neem oil (Muthu *et al.,* 2010), kanji oil (Khayoon *et al.,* 2012), Jatropha curcas seed oil (Aminul Islam *et al.,* 2012), The physiochemical properties of the APSO oil in this research are in agreement with Ude *et al.* (2019).

Table 1: The summary of characterization of Africa pear seed oil

Properties	Africa pear seed oil
Specific gravity	0.9195
Kinematic viscosity (centistoke) at 40^0C	7.42
Refractive index	1.4715
Melting point (ºC)	26.00
Energy level (J/g)	30164
Flash point (ºC)	176
Fire point (ºC)	198
Acid value (mgKOH/kg)	6.01
Saponification value (mgKOH/kg oil)	202.26
Free fatty acid value (mgKOH/kg)	3.005
Peroxide value (meq/kg)	2.7421
Iodine value (mg I_2/100g oil)	25.13
Molecular weight (g/mol)	880.87
Ester value (%)	94.46
Moisture content (%)	0.44

3.2 Properties of modified catalyst

The acid activated catalysts were analyzed with ASTM; BET, FTIR, SEM, and XRD

3.2.1 Catalysts characterization

The ASTM result in Table 2 shows the disparity between the raw and acidified catalysts, which is an indication of variation in biodiesel production via transesterification. The yield of biodiesel was high in acidified catalyst. This is as a result of high contact between the reacting molecules due to high pore volume, low density, low pore diameter, and ash.

Table 2: Properties of Catalysts by ASTM analysis

Sample/Properties	Raw EPFBA	Acidified EPFBA
Conductivity (w/mk)	2.74	2.99
Ash (%)	6.08	1.35
Bulk density (g cm^{-3})	0.8147	0.4520
Organic carbon (%)	0.26	0.22
Organic matter (%)	0.80	0.65
Fixed carbon (%)	53.60	79.62
Volatile matter (%)	39.93	18.09
Particle density (g cm^{-3})	1.0030	1.0000
Total porosity (%)	18.77	54.80

3.2.2 BET analysis of the catalysts

Brunauer-Emmet-Teller (BET) analysis ascertained the surface area, pore volume and pore size as shown in Table 3 with the Nitrogen as the adsorbate and carbon as the adsorbent. Each sample volume is 1cc at analysis time of 79 mins and temperature of 273 K. The pore volume and surface area make the rate of the transesterification faster in acidified EPFBA than in raw catalyst. This is because surface area affects the rate of reaction. The result of BET analysis is in agreement with the ASTM result.

Table 3: BET analysis of different catalysts

Catalyst	Surface area (m²/g)	Pore volume (cc/g)	Pore diameter (nm)	Adsorption energy(kj/mol)
Raw EPFBA	173.955	0.108	2.144	4.530
Acidified EPFBA	210.528	0.117	2.133	4.165

3.2.3 Fourier transform infrared (FTIR) analysis of the catalysts

A Fourier Transform Infrared spectrometer (FTIR) was used to determine the functional group of the surface characteristics. The presence of OH and SiO_2 functional groups was confirmed by FTIR spectra. The peak appearance was assigned to various functional groups according to their respective wave numbers. In Figure 1, at the peak and the intensity of 1028.7–1159.2cm-1 at a transmittance of 71, the functional group present is the SiO2 group, and this peak around 1000 cm $^{-1}$ may be due to the Si–O–Si bonds (Binitha and Sugunan, 2006). The spectrum shows the OH functional group at the wave number of 2922.2–3295.0cm^{-1} at a transmittance of 85. The presence of OH and SiO_2 and having the alkali properties makes the catalyst a potential feedstock in the production of biodiesel via transesterification
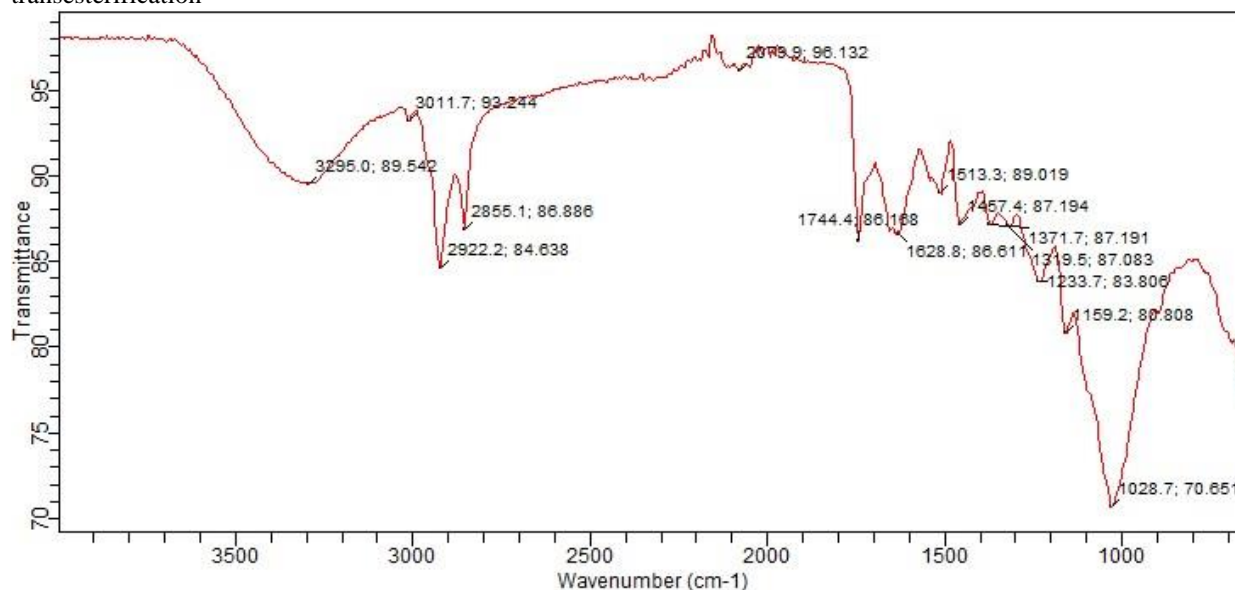

Figure 1: FTIR spectrum of acidified EPFBA.

3.2.2 Scanning electron microscopes (SEM) of the acidified catalysts

The morphology of the raw catalyst and acidified EPFBA catalyst was investigated by SEM as shown in Figures 2 and 3 respectively. Their micrographs using a magnification of 300x show pore sizes of 889 μm and 885 μm respectively. The acidified EPFBA has smaller pore sizes, and the highest number of pores and surface area when compared to the raw catalyst. The surface area and pore volume are very important factors because the efficiency of solid catalysts depends on their surface areas. The surface area and pore sizes of the two catalysts offer a greater area of contact during chemical reaction, which makes the reaction faster.
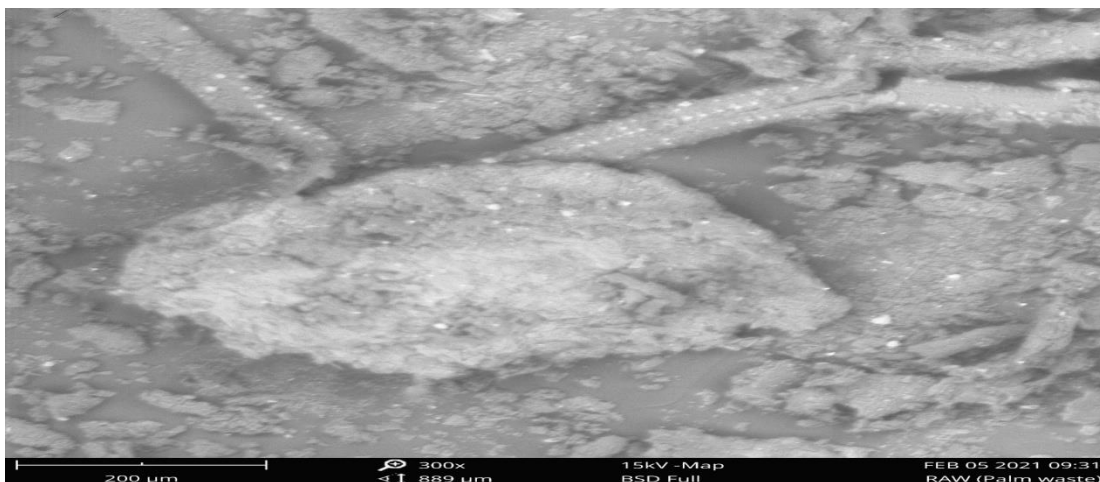
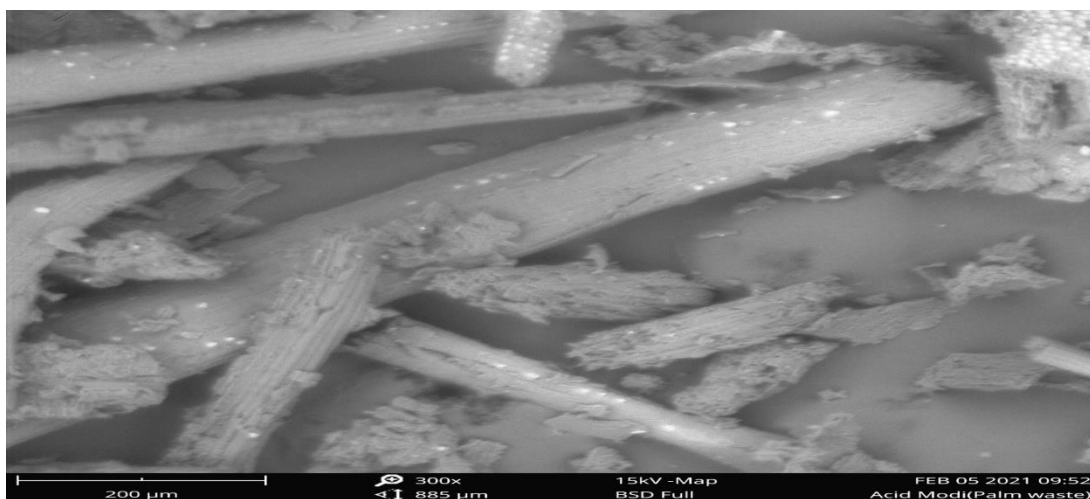**Figure 2: SEM for raw EFBA catalyst at 300x magnification.**

Figure 3: SEM of acidified EPFBA at a magnification of 300x

3.2.3 X-ray diffraction pattern of the raw catalyst

Figure 4 presents an X-Ray Diffractogram of the acid modified EPFBA catalyst. The Diffactogram showed the predominance of silicon IV oxide and potassium chloride in cristobalite form and sylvite form, respectively, at 2θ =21°. It is observed that acidified EPFBA contains sylvite, davyne, graphite, and marialite, confirming the presence of alumina, calcium, and carbon. The activation of the catalyst using phosphoric acid intensified the corresponding peaks in the XRD pattern.
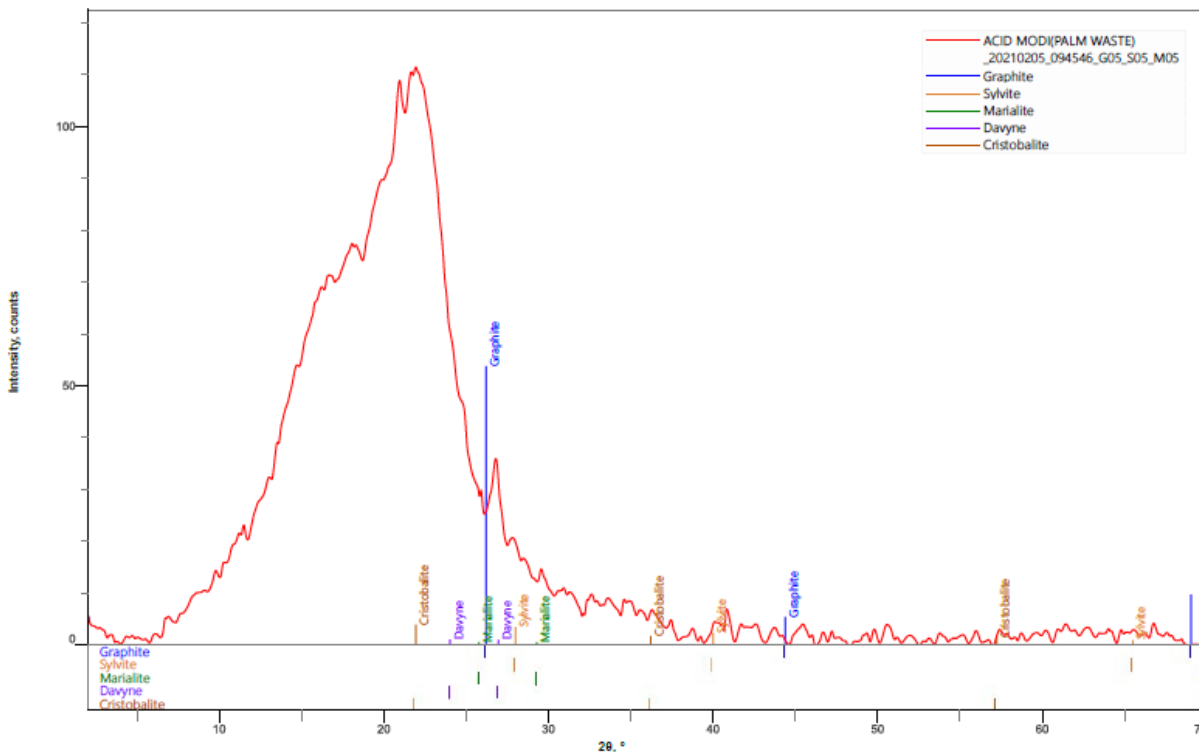.

Figure 4 XRD of acidified EPFBA.

3.3 Properties of Biodiesel

Table 4 presents the physio-chemical properties of biodiesel and its blends produced from Africa pear seed oil. The advantage of biodiesel over diesel can be trace to variables like density, cetane number, combustion as shown in Table 4. Biodiesel burnt completely than diesel because of the oxygen content, making it a better lubricant. The combustion property reduces as the biodiesel diesel is blended with diesel. B80 gives a better oxidative property when compared to other blends. Biodiesel has high cetane number (a measure of ignition quality) because it is chemically active with a low caloric value (Hasan and Rahman 2017). Biodiesel, on the other hand, is sulfur free and is one of the reasons diesel engines emit less toxic substances when operated with biodiesel. When the percentage of diesel in the blend is higher, the blend will emit a lower toxic substance than pure diesel. The energy content (caloric value) is high in diesel and produces high engine torque and brake power. This may be as a result of the low viscosity existing between the layers of the fluid. It can be seen that the calorific value of biodiesel–diesel blend ranges from 45.6 to 46.6 MJ/kg, which is slightly lower than that of the convectional diesel. This result is in agreement with the results of Silitonga et al. (2013). Biodiesel can not be used during the winter season at a temperature below 11°C unless blended with diesel. Biodiesel blend (B20) can function even at a temperature below 3° C.

Table 4: Physio-chemical properties of Biodiesel and its Blends produced from Africa pear seed

Parameters	B_0	B_{20}	B_{40}	B_{60}	B_{80}	B_{100}
Viscosity @40°C (mm²/s)	1.229	1.310	1.998	2.156	2.408	2.808
Density (g/cm³)	0.8283	0.8500	0.8652	0.8737	0.8869	0.8928
Flash point (°C)	56.00	95.00	104.00	126.00	143.00	174.00
Fire point (°C)	78.00	118.00	122.00	147.00	161.00	195.00
Cloud point (°C)	4.00	4.50	6.00	7.50	9.00	10.50
Pour point (°C)	2.00	2.50	3.50	4.50	5.00	5.50
Acid value (mg KOH/g)	-	0.02	0.034	0.04	0.044	0.050
Free fatty acid(mg KOH/g)	-	0.01	0.017	0.02	0.022	0.025
Aniline Point (°C)	58.50	54.00	51.50	45.50	39.50	35.00
Diesel index	54.08	45.18	39.96	34.68	28.91	25.64
API Gravity	39.33	34.97	32.05	30.45	28.04	26.99
Cetane Number	47.55	53.18	56.96	59.68	61.91	64.14
Gross calorific value (J/g)	47074	46553	46491	46274	45923	45622

3.4 Engine Performance

3.4.1 Variation of engine speed with torque

Figure 5 shows the plot of engine torque against speed for biodiesel, blends, and standard diesel at full load. From the Figure, the torque increases as the engine speed increases to a speed of 2000rpm and slightly decreases beyond 2000 rpm. This could be as a result of an increase in the fuel temperature and pressure and a reduction in the viscosity and lubricity. However, the torque of the engine operated at standard diesel was higher than that of biodiesel and its blends. This may be attributed to the low calorific value of biodiesel. Onoh et al. (2011) obtained similar results.
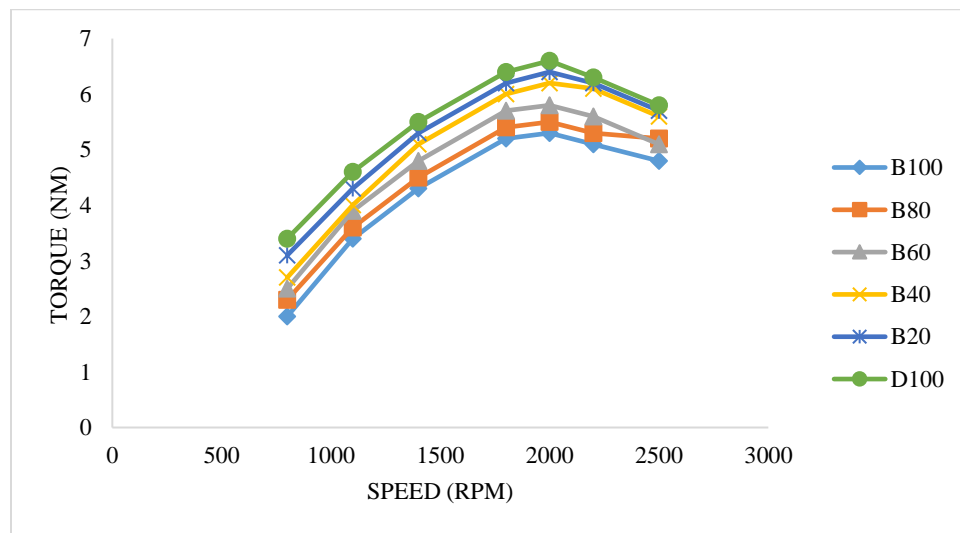

Figure 5: Variation of torque with Engine Speed for Standard Diesel and APSO FAME Blends

3.4.2 Variation of engine speed with brake thermal efficiency (BTE)

Figure 6 shows that the brake thermal efficiency of the engine gradually increases with an increase in engine speed at constant load. After reaching its maximum value, it then decreased. This is due to the fact that, initially, with the

increase in engine speed, the torque produced by the engine increased, hence efficiency increased. But at higher rpm (>2000 rpm) more fuel is injected into the engine cylinder per cycle, and due to the higher engine speed, this fuel does not get sufficient time to burn completely, which reduces the efficiency of the engine. Biodiesel and blends of biodiesel have lower thermal efficiency than standard diesel, as shown in Figure 6. This may be attributed to their oxygen content, high cetane number, and low energy value. The result is in agreement with that obtained by Ude *et al.* (2011).
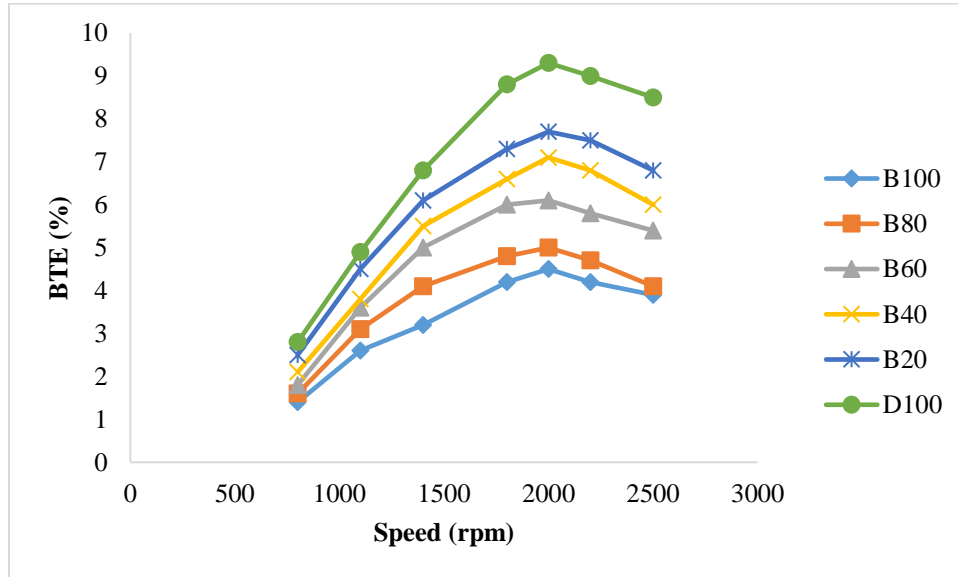

Figure 6: Variation of BTE with Engine Speed for Standard Diesel and APSO FAME Blends

3.4.3 Variation of engine speed with brake power (BP)

Brake power is the engine's output power. From Figure 7, it can be seen that brake power increases as the speed increases at full load and decreases after reaching a maximum value. This may be attributed to a reduction in lubricity and fuel pressure at higher speeds. Moreover, the brake power of the engine with standard diesel was higher than for biodiesel and blends at any speed. This is due to the lower calorific value of biodiesel and its blends. This is in agreement with results obtained by Abdullah *et al.* (2011).
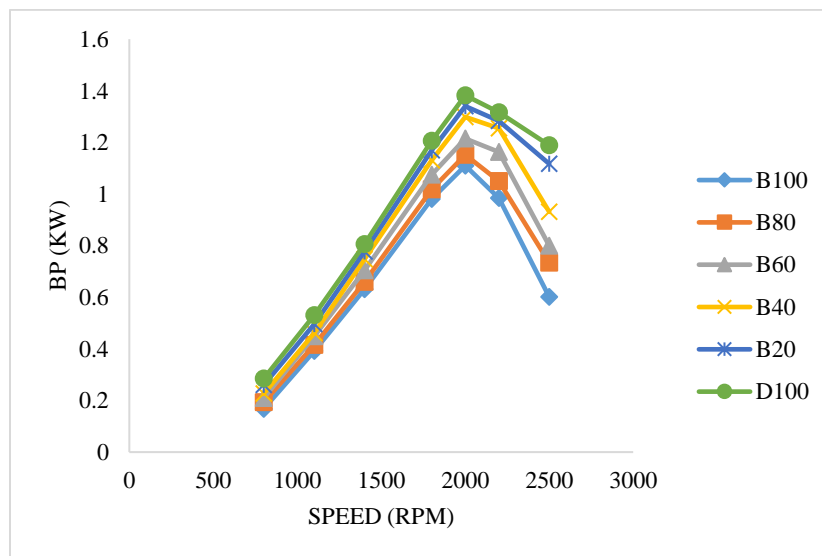

Figure 7: Variation of Brake power with Engine Speed for Standard Diesel and APSO FAME Blends

3.4.4 Variation of engine speed with brake specific fuel consumption (BSFC)

Brake specific fuel consumption is the rate of fuel consumption per unit of power operation. Figure 8 shows that the BSFC for biodiesel, blends, and standard diesel decreased as the speed increased to 2000rpm and slightly increased as the speed increased beyond 2000rpm. This may be attributed to the collective outcome of the higher fuel density, high fuel consumption, and lower brake power due to the lower calorific value of the biodiesel. Abdullah *et al.* (2011) obtained similar results.
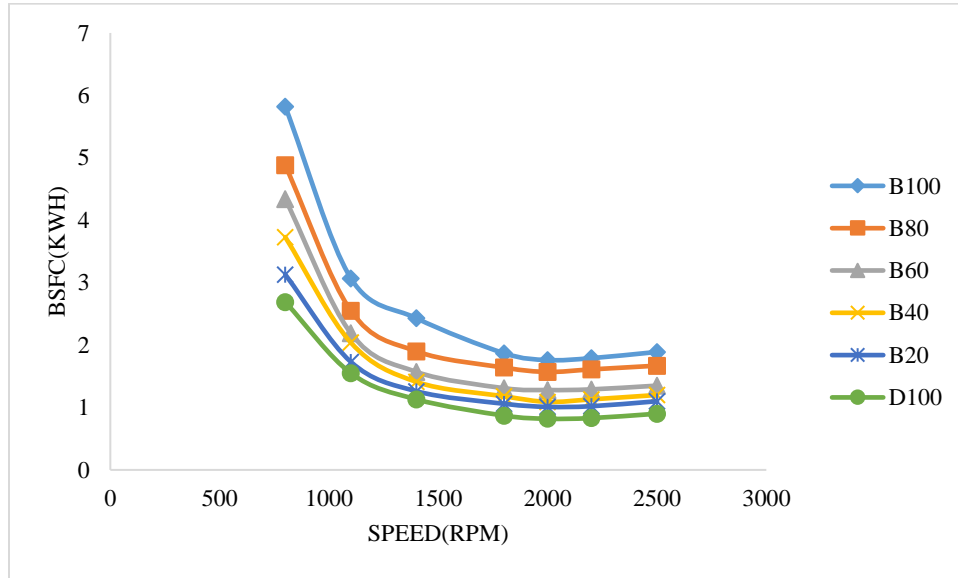

Figure 8: Variation of Brake Specific fuel consumption with Engine Speed for Standard Diesel and APSO

FAME Blends

4.0 Conclusion

The production of biodiesel from Africa pear seed oil using acid activated empty palm fruit bunch ash (AAEPFBA) and the performance study of diesel engine operated with biodiesel and blends of biodiesel were carried out. There was no prior treatment in the transesterifcation of the oil. This was due to the low free fatty acid (FFA). The catalyst (EPFBA) was discovered to have more pores and surface area when activated with acid. This is reflected in the yield of biodiesel produced. The physiochemical properties and thermal properties of biodiesel produced were within the ASTM standard limit. Biodiesel, diesel, and blends of biodiesel follow the pattern of design engine performance plot. It was discovered that torque, BP, BTE increased as the engine speed increased and beyond 2000rpm the torque, BP and BTE decreased. The cloud points of biodiesel blends show that they can be used to run diesel engines during winter at a temperature below 7°C.

5.0 Recommendation

More research should be carried out to investigate the effects of regeneration of the AAEPFBA heterogeneous catalysts on the yield of biodiesel production.

Acknowledgement

References

Abuhabaya, A., Fieldhouse, J., & Brown, R. 2011. The effects of using bio-diesel as fuel on compression ignition (CI) engine and its production from vegetable oils. In *Proceedings of International Conference on Environmental, Biomedical and Biotechnology (ICEBB 2011)* 41, p. 46.

Aminul Islam A. K. M., Zahira Y., Nurina A., & Sri Rizki P. P. 2012. Physiochemical properties of *Jatropha Curcas* seed oil from different origins and candidate plus Plants. *J Am Oil Chem. Soc.*, 89: 293-300. Available from: https://doi.org/10.1007/s11746-011-1908-7.

Binitha, N. N., & Sugunan, S. 2006. Preparation, characterization and catalytic activity of titania pillared montmorillonite clays. *Microporous and mesoporous materials*, 93(1-3), 82-89. Available from : https://doi.org/10.1016/j.micromeso.2006.02.005.

Elangovan T. & Jerryajkumar L. (2015) Biodiesel and its properties from various feedstock. *Internal Journal for trends in Engineering and Technology*, *1*(2).

Enontiemonria, E. V., Abiodun, O. J., & Eric, K. E., 2016. Extraction and use of potassium hydroxide from ripe plantain peels ash for biodiesel production. *Journal of Biobased Materials and Bioenergy*, *10*(1), 1-9. Available from: https://doi.org/10.1166/jbmb.2016.1567.

Fan, X., Niehus, X., & Sandoval, G. 2012. Lipases as biocatalyst for biodiesel production. *Lipases and phospholipases*, 471-483. Available from: DOI: 10.1007/978-1-61779-600-5_27.

Hasan, M. M., & Rahman, M. M. 2017. Performance and emission characteristics of biodiesel–diesel blend and environmental and economic impacts of biodiesel production: A review. *Renewable and Sustainable Energy Reviews*, 74, 938-948. Available from: https://doi.org/10.1016/j.rser.2017.03.045.

Hoekman, S. K., Broch, A., Robbins, C., Ceniceros, E., & Natarajan, M. 2012. Review of biodiesel composition, properties, and specifications. *Renewable and sustainable energy reviews*, *16*(1), 143-169. Available from: https://doi.org/10.1016/j.rser.2011.07.143 .

Jibril, G. B., & Nedumaran, B. 2017. Potential Application of Rice Husk for Synthesis of Catalyst for Biodiesel Production. *International Journal of Scientific & Engineering Research, 8*(12), 1158, 2229-5518

Khayoon M.S., Olutoye M.A., & Hameed B.H., 2012.Utilization of crude Karanj (Pongamia Pinnata) Oil as a potential feedstock for the synthesis of Fatty acid Methyl esters. *Bioresource Technology*, *111*, 175–179. Available from: https://doi.org/10.1016/j.biortech.2012.01.177.

Muthu H., Sathya S. V., Varathachary T.K., Kirupha S. D., Nandagopal J.,& Subramanian S. 2010. Sythesis of Biodiesel from Neem Oil using Sulfated Zirconia via Transesterification. *Brazilian Journal of chemical Engineering, 27*(04), 601 – 608. Available from: https://doi.org/10.1590/S0104-66322010000400012.

Naomi, S.K., Hiroki, H., Homare, K., Takuji, T., Takuya, F., Toshikuni, Y., 2007. Biodiesel production using anionic ion-exchange resin as heterogeneous catalyst. *Bioresour. Technol*. *98*, 416–421. Available from: https://doi.org/10.1016/j.biortech.2005.12.010.

Niju, S., Meera, K. M., Begum, S., & Anantharaman, N. 2014. Modification of egg shell and its application in biodiesel production. *Journal of Saudi Chemical Society*, *18*(5), 702-706. Available from: https://doi.org/10.1016/j.jscs.2014.02.010.

Nwabanne, J. T., & Omoniyi, M. H. 2010. The effect of process variables on the physico-chemical properties and oil yield of rubber seed. *Journal of Engineering and Applied Sciences*, 6, 47-51.

Okoye, C. C., Okey-Onyesolu, C. F., Nwokedi, I. C., Eije, O. C., & Asimobi, E. I. 2020. Biodiesel Synthesis from Waste Cooking Oil Using Periwinkle Shells as Catalyst. *Journal of Energy Research and Reviews 4*(4), 32-43. Available from: DOI: 10.9734/JENRR/2020/v4i430135.

Onoh, I. M., Mbah, G. & Elendu, C. C. 2018. Evaluation of performance of biodiesel produced fromAfrican Pear (dacryodes edulis) seed oil. *Explorematics Journal of Science and technology*, *2*(1), 1-13

Onukwuli, O. D., & Ude, C. N. 2018. Kinetics of African pear seed oil (APO) methanolysis catalyzed by phosphoric acid-activated kaolin clay. *Applied Petrochemical Research*, *8*(4), 299-313. Available from: https://doi.org/10.1007/s13203-018-0210-0.

Sandeep S., Sumeet S., & Mohapatra S.K. 2015.A production of Biodiesel from waste cotton seed oil and testing on small capacity diesel engine. *International Journal of Advance Research in Science and Engineering*, *4*(02), ISSN-2319-8354(E).

Silitonga, A. S., Masjuki, H. H., Mahlia, T. M. I., Ong, H. C., Chong, W. T., & Boosroh, M. H. 2013. Overview properties of biodiesel diesel blends from edible and non-edible feedstock. *Renewable and Sustainable Energy Reviews*, *22*, 346-360. Available from: https://doi.org/10.1016/j.rser.2013.01.055.

Ude, C. N., Onukwuli, O.D., Nwobi –Okoye, C., Anisiji, O.E., Atuanya, C. U. & Menkiti, M.C. 2017. Performance evaluation of cottonseed oil methyl esters produced using CaO and prediction with an artificial neural network. *Biofuel*, *11*(1), 77-84. Available from: https://doi.org/10.1080/17597269.2017.1345355.

Ulakpa, W. C., Ude, C.N. & Ulakpa, R.O. (2019). Optimization, Kinetics and Thermodynamics Study of Transesterification of Neem Oil Using Heterogeneous Catalyst Derived from Waste. *International Journal of Emerging Engineering Research and Technology Volume 7*(9), 7-18

U.S. Congress 2007. Energy independence and security act of 2007. *Public law*, *2*, 110-140.

Zahira Y., Irwan S. B. S., Binitha N., Siti R. S. A. & Manal I., 2011. Utilization of palm empty fruit bunch for the production of biodiesel from Jatropha curcas oil. *Bioresource Technology*, *10(4),* 695–700. https://doi.org/10.1016/j.biortech.2011.10.058.