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Exploring the biodiesel potentials of waste avocado fruit oil

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The biodiesel potential of waste avocado fruit was investigated. This study is essential for utilizing the enormous waste generated from avocado cultivation in Nigeria. Biodiesel was produced using a two-step acid-base catalyzed transesterification process. The acid catalyzed esterification step was required to convert the free fatty acids present in the oil to methyl esters. Important biodiesel properties such as flash point, viscosity, cetane value and density were determined to be 154°C, 5.58 cSt, 62.69 and 873 kg/m^3 respectively. The optimum condition for maximum biodiesel yield was established. The engine performance test was carried out using a Perkins diesel engine, the effect of break power and engine speed on both Break Thermal Efficiency (BTE) and Break Specific Fuel Consumption (BSFC) of the biodiesel and its blend were studied while performing at average load. The emission test was carried out using a portable gas analyzer. The CO and HC emission from the APO (Avocado pear Oil) biodiesel was significantly lower than that of petrol diesel but with slightly higher traces of NO_X present. The obtained results showed that APO biodiesel can be comfortably used in a compression ignition engine without undergoing any modification while also generating better emission.

Key words: Biodiesel, avocado oil, transesterification reaction, engine test, emission test.

INTRODUCTION

There has been a continuous surge in the demand for energy on a global scale, and this is as a result numerous factors such as of an increase in the world's population, the presence of more industrialized nations and technological advancements. Most of this energy been utilized for industrial purposes were generated from natural gas, coal and petroleum sources. These sources are commonly known as fossil or non-renewable resources (William, 2006). These fuels which are being derived from the earth crust are said to be limited and are being depleted at a very fast rate. The use of these energy sources also generates harmful gases which are very toxic to the environment. The problems associated with the use of these fuels prompted top research institutions and organizations to seek out alternative sources of fuel which possesses desirable qualities better than fossil fuels**.** This has led to the increased popularity, demand and development of biofuels such as biodiesel which is more environmentally friendly, renewable, and biodegradable, as well as requires no engine modification before it can be used in a diesel engine. Biodiesel is said to be a vegetable oil or animal

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Figure 1. Waste avocado sample

fat-based fuel comprising of long chain alkyl esters (Berrios and Skelton, 2008). Biodiesels can be produced from vegetable oils via a number of methods, one of which is tranesterification of triglycerides. A number of researches have been carried out on producing biodiesels from different feedstock such as castor oil, Jatropha, soybean, sunflower. Altmann et al. (2021) worked on the use of alternative fuels in high-power non-road mobile machinery (NRMM) combustion engines by using rapeseed oil.

Avocado (*Persea americana* Mill.) of the Lauraceae plant family is a very popular fruit with high oil content (Mooz et al., 2012). Avocado is a tropical fruit that stands out for its high nutritional value. It is also a good source of monounsaturated fatty acids and palmitic acid; they have low amounts of polyunsaturated linoleic acid and stearic acid (Ogunwusi and Ibrahim, 2016)**.** Avocado oil has been used for cooking, cosmetics, and treating diseases, but its potential as a good source of oil for renewable energy has not been investigated (Knothe, 2013). This fruit which is largely cultivated in Nigeria has a large post-harvest loss rate which is caused by many factors such as lack of preservation facilities, the fruits rate of maturation, wind fall fruits, infected fruits and the marshy nature of the fruit. Therefore, there is the need to explore the potential recuperation of these incurred losses by processing an otherwise spoiled food crops into viable products by converting its abundant oil content into biodiesel.

From previous studies, it has been reported that use of biodiesel in ignition engines reduces the level of emission when compared to petroleum diesel, these has been confirmed by various researchers while working with biodiesel samples from various feedstock. Engine performance and emission tests are usually carried out on biofuels to help qualify the produced biodiesels. Parameters such as break Specific fuel consumption and break thermal efficiency are important properties which help us understand the performance of fuel in an ignition compression engine. Simek et al. (2021) in his findings concluded that the brake specific fuel consumption increases for biodiesel with respect to mineral diesel and there is no much difference between the brake thermal efficiency of biodiesel and mineral diesel. Teoh et al. (2022) mentioned that biodiesels have higher break specific fuel consumption to mineral diesel due to the biodiesel's lower energy content. Nabi et al. (2022) performed the emission test on waste tire Oil-Diesel-Glycine max biodiesel. The NOx content of the biodiesel blends was higher than the reference diesel. This was associated with higher flame temperature for different blends. The higher NOx emissions at increasing engine speeds were associated with the higher gross heat release. Vedaraman et al. (2011) tested biodiesel from palm feedstock in a diesel engine and discovered that CO and HC emissions reduced 28 and 30% for B20 blend respectively when compared to diesel fuel, and NOx emissions were comparable to that of diesel fuel. This is also similar to the study by (Lapuerta et al., 2008) that used B30 and B70 biodiesel blends from waste cooking oil where there was a minimal increase in NOx emissions and a clear reduction in the amount of HC emitted. Lin et al. (2009) also agreed that emissions from biodiesel fueled engines was lower than that of petroleum diesel, he attributed this characteristic to the presence of oxygen in the biodiesel. In this study the use of waste avocado pear oil as a feedstock for biodiesel production and its performance in an ignition compression engine was investigated.

MATERIALS AND METHODS

Materials and sample collection

The waste or mashed avocado samples (Figure 1) used were collected from a local avocado plantation in Uga Anambra State, the analytical grade methanol and n- hexane were purchased from CONRAWS Chemicals Limited, Asata, Enugu Nigeria. The seeds and its coating were removed and the pulp was left to dry. This was necessary to remove the moisture content of the avocado pulp as the pulp is known to contain high volume of moisture. All chemicals used were obtained from the university laboratory and are of analytical grade.

Oil extraction and pre-treatment

The method used for extracting oil from the dried avocado sample was cold solvent extraction. Ethanol was used as the extracting solvent. The solvent choice was based on a study by (Anawe and Folayan, 2018), which reported a higher yield for avocado pulp extraction with ethanol when compared with other solvents. The extracted oil was degummed using phosphoric acid, and this was carried out by adding 20 ml of phosphoric acid to 300 g of the extracted oil and the mixture heated and continuously stirred for 30 min and allowed to settle for 1 h after which the phospholipids was separated from the degummed oil.

Determination of acid value

The acid value of the extracted oil from waste avocado was quite high, which makes it unsuitable for human consumption. This value was calculated by mixing 25 ml of diethyl with 25 ml alcohol and 1 ml phenolphthalein solution which acts as the indicator. 1 ml of the oil is then dissolved in the mixture; this was then titrated with aqueous 0.1M NaOH until a pink colouration which persists for about 15 sec is obtained. The final value if obtained by using the equation (1):

$$Acid\ Value = \frac{Titre\ (ml) \times 5.61}{weight\ of\ sample} \quad (1)$$

Biodiesel production

The extracted oil was converted into biodiesel using a two-step transesterification process. In this process, the first step is acid catalyzed esterification used to convert free fatty acids (FFA) present to methyl esters, followed by a base-catalyzed transesterification process

Esterification reaction

The extracted oil was placed in a reacting vessel and heated to a temperature of about 60°C using magnetic hot plate stirrer. 100 ml of methanol was poured into a 500 ml flask with 22.9g of H_2SO_4. The flask content was stirred for 30 min. The methanol H_2SO_4 mixture was then added to the heated oil and continually stirred at 55°C for 60 min after which it was allowed to cool for 1 h until FFA value of less than 2% was achieved.

Transesterification reaction

The Biodiesel was produced through a process known as trans-esterification. Specified amount of the catalyst (by weight of refined oil) potassium hydroxide (KOH) was dissolved completely in the required amount of methanol. This was to ensure total dissolution of KOH to produce a clear solution of potassium methoxide. The new solution was poured into the measured oil placed in a flat bottom flask. The oil-methoxide mixture was tightly enclosed, maintained at a specified temperature and continuously stirred at a constant speed of 400 rpm on a magnetic stirring hotplate. This allowed trans-esterification reaction to take place and the required reaction time and temperature for each experimental set up was observed.

Purification of biodiesel

At the end of the transesterification process, the product obtained was then transferred into a separating funnel for about 24 h after which two separate layers was observed, the topmost layer being the biodiesel while the bottom layer contained the glycerol. The glycerol (bottom layer) was easily drained off using the funnels bottom tap. It was easy to separate the two liquids because of their difference in colour. The biodiesel was purified by washing with warm distilled water repeatedly until a clean clear solvent is obtained. This was needed to remove every form of impurities (unreacted methanol, catalyst and traces of glycerol) from the biodiesel. The biodiesels moisture content was removed by drying it in an oven for a specified number of hours till the biodiesel is completely free of moisture.

Engine and emission test

The Engine performance test was carried out using a Perkins 4:108 diesel engines. The engine's dynamometer was controlled by a microprocessor system equipped with data acquisition device. Logged sensors were fitted to the engine and dynamometer to measure relevant parameters like engine speed, torque, lubricating oil temperature, fuel consumption, and cooling water temperature. The engine was tested in a series of exhaustive steady state operating conditions at engine speeds of 1200, 1400, 1600, 1800, 2000 rev/min. The performance parameters measured includes brake torque (Nm), fuel consumption (kg/s), Brake power (kW) specific fuel consumption and brake thermal efficiency. The engine is four cylinders water cooled, naturally aspirated and four-stroke CI engine. The engine specifications are listed in Table 4. The experiments were performed using petroleum diesel, biodiesel and its blends ranging from B100 (representing pure biodiesel), B80, B60, B40, B20 and B0 (representing pure petroleum diesel) in order to optimize the blend concentrations for usage in compression engines. The ambient temperature and pressure were noted. A short test run was also conducted on the engine before the experiment proper; this is to ascertain a perfect working condition and to identify areas needing adjustments or replacement.

In the process of performing the engine test, the engine was started and operated at constant load using tachometer attached with the dynamometer, while operating at relatively low speed of 1200 rpm and then the value of the torque at that speed was recorded using dynamometer. The time taken for a given volume (50 ml) of the fuel to be consumed at this speed was noted. The procedure mentioned above was then repeated for other values of 1400, 1600, 1800, and 2000.

For the emission test, the content of the gaseous fumes including CO, NOx and HC were measured with a portable gas analyzer (Testo XL-450) for different engine speeds. The gaseous fumes required for the test were collected at the pipe end of the engines exhaust pipe

RESULTS AND DISCUSSION

Biodiesel properties

The properties of the produced methyl ester were determined using standard test procedures and the

Table 1. Physicochemical properties of avocado oil and biodiesel.

Property	Raw avocado oil	Avocado oil biodiesel	Biodiesel ASTM standards
Acid value	14.3	0.62	0.5
Density (kg/m^3)	913	873	880
Kinematic viscosity at 40°C (mm^{2}s^{-1})	14	5.58	1.9 - 6
Fire point (°C)	153	160	197
Flash point (°C)	120	154	130 - 170
Cetane index	-	62.69	47 - 65
Refractive index	1.46	1.45	1.38
Calorific value (MJ/kg)	-	34.683	42.06

Table 2. Table of measured data for engine performance Test

Variable	Measured data
Ambient air temperature	Ta =28°C
Barometer pressure	0.95 bar = 95 KN/m^2
Calorific value of diesel fuel used Qnet,v	44200 kj/kg
Gas constant for air,	287 J/kgK
Density of diesel fuel used	835 kg/m^3

results were presented in Table 1**.** The quality of biodiesel is a function of its properties such as viscosity, flashpoint, density and cetane number etc. it can be seen from the tabulated results that properties such as density and viscosity of the biodiesel reduced significantly after the transesterification process which makes it a suitable fuel for a compression ignition engine The viscosity value of 5.58 cSt was within the ASTM standard. The viscosity of any biodiesel is an important property. Fuels with high viscosity can plug the fuel filter and injection system in the engines (Tat and Van, 1999).

The cetane value of the fuel was gotten to be 62.69. This is an important parameter which tells the quality or performance of a fuel. The higher the number the better the fuel burns within the combustion engine, since biodiesel is composed of long chain hydrocarbon groups with virtually no branching or aromatic structures, it typically has a higher cetane number than petroleum diesel (Hoekmana et al., 2012). This is in agreement with values obtained for biodiesel obtained from waste avocado oil.

Calorific value measures the energy content of the fuel which suggests it’s suitability as an alternative to petroleum diesel. The calorific value of FAME was measured using parr 6100 calorimeter and was found to be 34.6 as against 44.34 MJ/Kg which is the calorific value of petroleum diesel. A lower calorific value is usually attributed to the presence of oxygen in the methyl esters. The flash point value of 154°C gives the temperature at which each fuel forms a flammable mixture in air.

Effect of process parameters on biodiesel yield

Effect of methanol oil ratio

The methyl ester yield as a function of Methanol to oil molar ratio was studied between the range of 1:1 to 12:1 while other variables where kept constant. From the plot, an increase in methanol to oil ratio gave a steady increase in methyl ester yield up to the ninth ratio with a biodiesel yield of 90%. A further increase in methanol ratio was not favourable for the conversion of the triglycerides to methyl esters. A higher molar ratio than the stoichiometric value results in higher rate of ester formation and could ensure incomplete reaction. The yield reduced when the solvent to oil molar ratio exceeded 9:1. Rashid and Anwar (2008) reported that when too much alcohol is used in transesterification reaction, the polarity of the reaction mixture is increased, thus increasing the solubility of glycerol and promotes the reverse reaction between glycerol and biodiesel, thereby reducing biodiesel yield (Figure 2).

Effect of catalyst concentration

The effect of catalyst weight on biodiesel yield was studied between 0.25 to 1.5% (based on weight of oil) while other variables were constant. In a typical chemical reaction, the reactants bond must first be broken before the reaction would commence. Breaking bonds require energy and the minimum energy required to start a

Table 3. Table of equations for calculating values.

Variable	Equations for calculation of values
Fuel volume flow rate	V_f (m^3/s) = $\frac{v}{t}$
Mass flow rate of fuel M_f (kg/s)	M_f (kg/s) = $\rho_f V_f$
Brake power bp (kw)	bp (kw) = $\frac{\tau \times N}{9549.305}$
Brake thermal efficiency	= η_{BT}(%) $\frac{bp}{m_f \times Q_{net,v}}$
BSFC (kg/kwh)	(kg/kwh) = $\frac{3600 m_f}{bp}$

Table 4. Table of the Perkins engine component with its values.

Components	Value
Engine	
Type	Perkins 4:108
Bore	79.735 mm
Stroke	88.9 mm
Swept volume	1.76 L
Compression ratio	22:1
Maximum BHP	38
Maximum speed	3000 rpm
Number of cylinder head	4
Diameter of exhaust	$1^{1}/_{2}$”
Length of exhaust pipe	36”31’
Dynamometer	
Capacity	112kw/150hp
Maximum speed	5000 rpm
KW	(N_m x rev/min)/9549.305
Center height	14.5”
Fuel guage	
Capacity	50,100,200 ccs
Air box	
Drum size:	42” long by 27” diameter
Orifice size	58.86 mm
Coefficient of discharge	0.6

reaction is referred to as Activation Energy. Catalyst tends to provide alternative reaction pathways for breaking and remaking of bonds. It was observed from Figure 3 that as catalyst weight increases the oil conversion to biodiesel also increased from 0.25 wt% up to 0.75 wt% fraction and decreased with any further increase in the weight of catalyst. The higher yield of methyl esters with increase in the weight of catalyst used is due to the high availability of catalyst in the reaction medium. Increasing the catalyst beyond the optimum weight of 0.75% showed decrease in the amount of methyl ester yield. This may be attributed to the addition of excess catalyst resulting in the production of more amount of soap and reduction catalyst.

Effect of temperature on biodiesel yield

Figure 4 showed the effect of temperature on the biodiesel yield. An Increase in biodiesel yield with increase in reaction temperature is in agreement with Arrhenius equation which indicates increase in rate of reaction with increase in temperature. An increase in temperature of molecules usually leads to an increased kinetic energy of those molecules invariably increasing the molecules kinetic rate. The effect of temperature

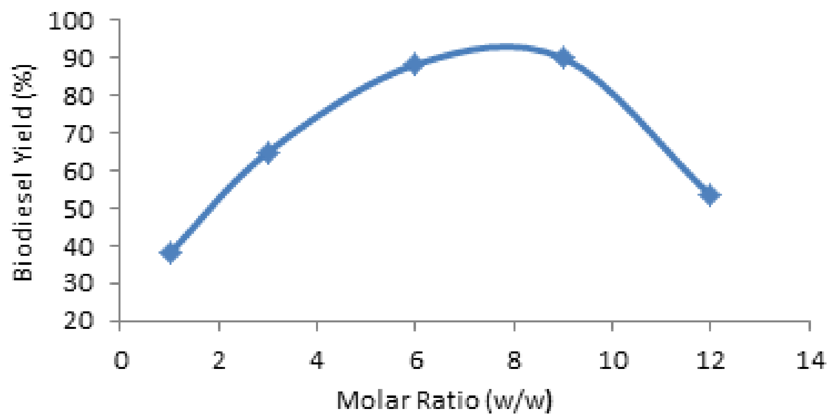

Figure 2. Effect of methanol ratio on biodiesel yield.

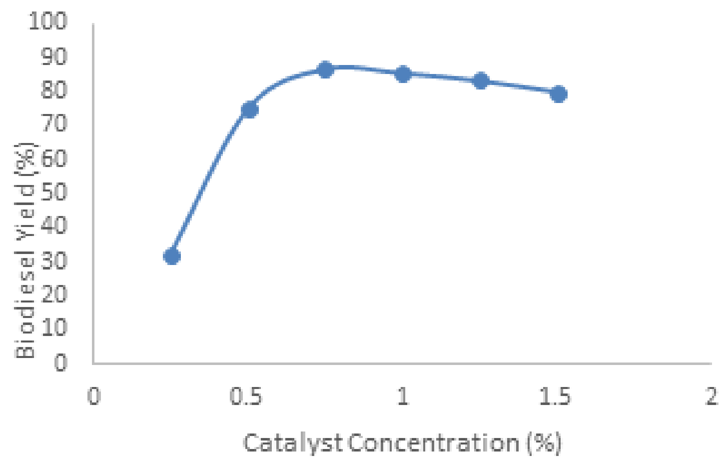

Figure 3. Effect of catalyst concentration on biodiesel yield.

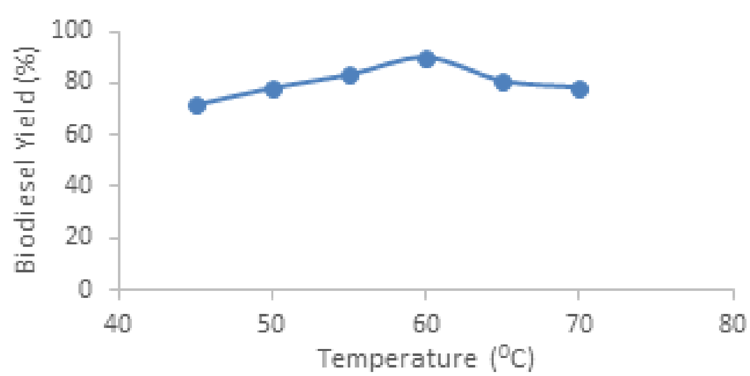

Figure 4. Effect of temperature on biodiesel yield

between 45 and 70°C on biodiesel yield was studied while keeping other parameters constant. The conversion to biodiesel was quite low at 45°C. A further increase in the temperature showed an appreciable increase in the volume of methyl ester produced. This is likely because higher temperature accelerates the side saponification

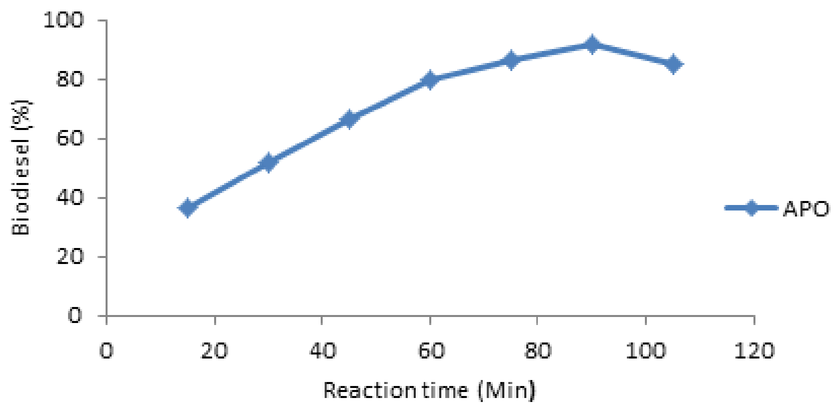

Figure 5. Effect of time on biodiesel yield.

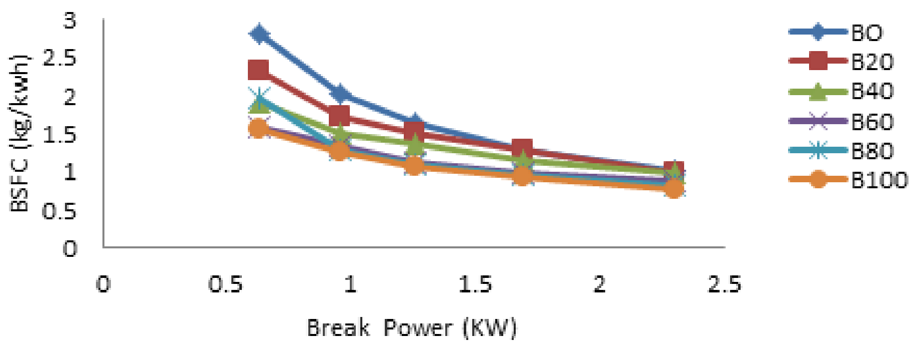

Figure 6. A plot of BSFC (kg/kwh) against break power (kw).

reaction of triglycerides. A further increase in temperature could also have an adverse effect on the conversion process**.** This can be observed from the plot where biodiesel yield decreased beyond 60°C. This could be ascribed to the fact that methanol is lost because it tends to evaporate rapidly with temperature ranges close to its boiling point (64.7°C) and beyond.

Effect of reaction time

The effect of reaction time on the transesterification process was studied and the results plotted in Figure 5. The reaction time was varied from 15 to 105 min, while keeping every other parameter constant. From the plots, as the process commenced, it can be seen that the yield was very low at shorter durations which can be attributed to inadequate dispersion or mixing of methoxide into the oil. As the reaction progressed, an increase in the yield was observed as there was enough time reaction conversion to take place. There was steady increase up to the 90th minute, before a decline in volume of methyl esters was observed. This was because the reaction time has reached equilibrium hence a reversible reaction is initiated (Table 2 and 3).

Engine performance

Variation of BSFC with break power

Figure 6 shows the variation of BSFC with Break Power for the APO biodiesel. The BSFC of the biodiesel fuel with their blends is seen to decrease as the break power of the engine is increased from 0.6 to 2.303 KW. In some compression engines, it can be seen that high frictional loss reduces break power leading to increased basic specific fuel consumption. The BSFC is usually given as the inverse of BTE multiplied by fuels heating value, its curve trend is usually contrary to that of break thermal efficiency.

Variation of BTE with break power

The break thermal efficiency tells how much of the fuel is been utilized in the combustion process and power development. It can be seen from Figure 7 that when the

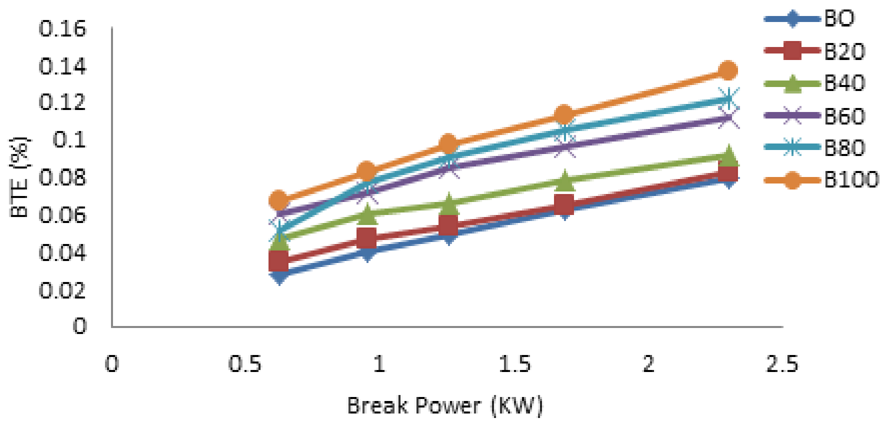

Figure 7. A plot of BTE (kw) against break power (kw).

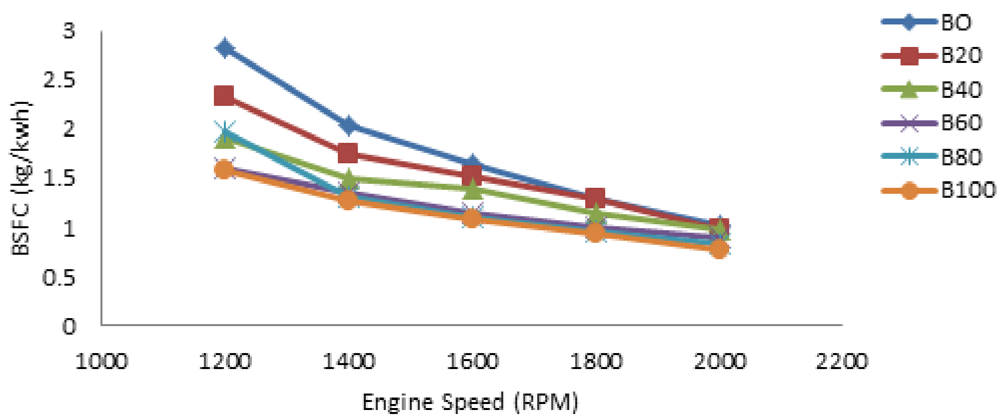

Figure 8. A plot of BSFC (kg/kwh) against engine speed (RPM).

break power is increased from, 0.6 to 2.3 KW, the break thermal efficiency increased as well for biodiesel fuel, blends and pure diesel. From the plot, the biodiesel had a better thermal efficiency than petroleum diesel. Yamin et al. (2009) attributed this occurrence to the presence of oxygen in the biodiesel fuels which aid in improving the process of combustion.

Variation of BSFC with engine speed

The BSFC of the fuel gives the quantity of fuel required by the compression engine to generate 1 kw/hr of useful energy output. Figure 8 shows the variation of BSFC with speed for APO biodiesels and blends ranging from 1200 to 2000 rpm. The BSFC is seen to decrease as the engine speed is decreased; this trend is the same for biodiesel fuels, blends and pure petroleum diesel. This could be attributed to the increased time needed for heat transfer from the working fluid to the cylinder walls (Yamin et al., 2009).

Variation of BTE with engine speed

The Break thermal efficiency which simply gives the ratio of the power output to the energy supplied is plotted against engine speed for the biodiesel fuel and its blend in Figure 9. The fuels BTE increased as the engine speed is increased from 1200 to 2000 rpm. As the engine speed is increased, there is also an increase in its operating torque which invariably leads to an increase in the brake thermal efficiency.

Emission test

Variation of CO emission with engine load

Figure 10 shows the variation of carbon monoxide (CO) emission with engine load for the biodiesel and its blend. An increase in the engine load reduced the concentration of CO emission; this can be as a result of incomplete combustion process occurring at lower engine loads. This

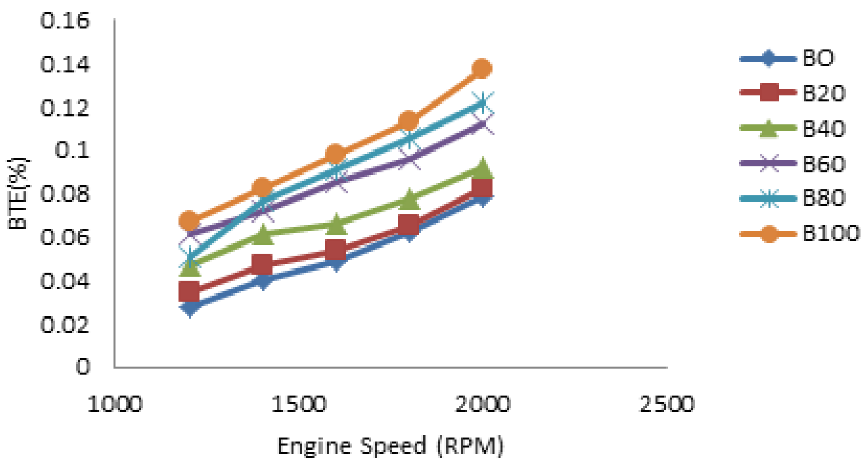

Figure 9. A plot of BTE (%) against Engine Speed (RPM).

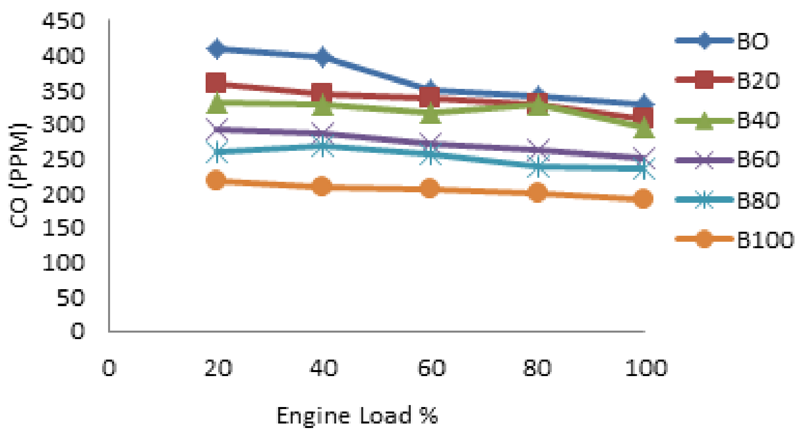

Figure 10. A plot of CO (PPM) against engine load (%).

pattern was the same for all biodiesel blends. Emissions recorded for APO biodiesel fuel emitted significantly less carbon monoxide when compared to petroleum diesel. The pattern obtained is similar to a study by Rachan (2018).

Variation of NOx emission with engine load

Figure 11 represents the variation of NOx emission with engine load for the biodiesel and its blends. The NOx emission of the biofuel was higher than that of petroleum diesel, there was also considerable increase in NOx emission with increase in biodiesel content. The NOx emission is usually determined by oxygen concentration, combustion temperature, peak pressure and time. The oxygen content in biodiesel can explain the increase in the NOx emission across the blends since additional oxygen for NOx formation may be provided by the biodiesel's oxygen content (Adaileh and AlQdah, 2012). Zhu et al. (2010) attribute this to the fact that under higher loads, more heat is generated in the combustion chamber causing an increase in NOx emission as engine load is increased. In addition, Umeuzuegbu et al. (2020) mentioned that increasing the engine load can reduce the air-fuel ratio resulting in incomplete combustion of the nitrogen components of the biodiesel, thus emitting the oxides of nitrogen or NOx.

Variation of HC emission with engine load

Hydrocarbon (HC) emissions are usually formed due to incomplete combustion of fuel. It is one of the most important parameters that define the nature of combustion (Du et al., 2022). The variation of HC emission with engine load is presented in Figure 12 which depicts the hydrocarbon HC content of the

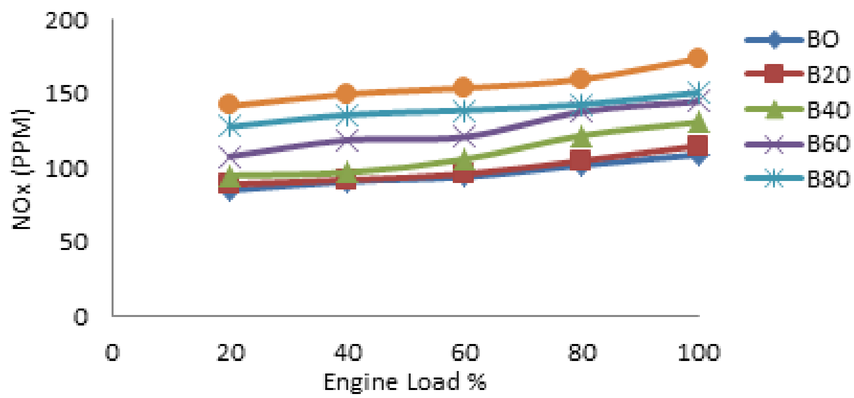

Figure 11. A plot of NOx (PPM) against engine load (%).

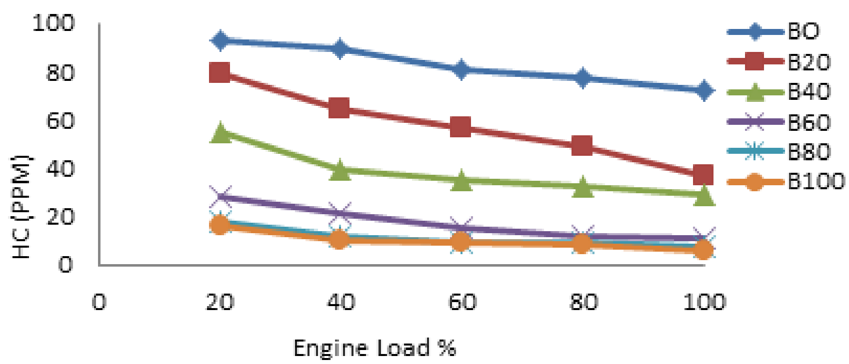

Figure 12. A plot of HC (PPM) against engine load (%).

variation blends. Petroleum diesel generated higher HC emission when compared to the biodiesel fuel, there was significant decrease in HC emission as quantity of biodiesel in the blends increased at higher engine loads, and this may be attributed to the availability of oxygen in biodiesel, which facilitates better combustion (Yadav, 2010). HC emission for biodiesel also decreased with increase in engine load and this may be attributed to high fuel consumption. This was similar to the trend obtained by Onwudili et al. (2023). According to (Rachan, 2018), an increased air to fuel ratio in the combustion chamber as a result of an increase in engine load enables better combustion leading to a reduction in the quantity of unburned HC.

Conclusion

Based on the research conducted, the acid-base catalyzed transesterification process proved suitable for producing biodiesel from waste avocado pear oil. This oil contains a high level of fatty acids, necessitating an esterification step to convert free fatty acids into methyl esters before undergoing the base-catalyzed transesterification process. Several parameters, including reaction temperature, reaction time, oil-to-methanol ratio, and catalyst concentration, were found to influence the biodiesel yield from the feedstock oil. Furthermore, the properties of the biodiesel met ASTM standards and exhibited similarities to conventional diesel, making the feedstock oil a suitable candidate for biodiesel production. The biodiesel also demonstrated a better Break Thermal Efficiency of 0.14% compared to diesel fuel's 0.08% when the compression engine operated at average load. In terms of emissions, the biodiesel fuel had lower levels of HC (hydrocarbons) and CO (carbon monoxide) compared to diesel fuel. However, as engine load increased, there was a relatively higher presence of NOx (nitrogen oxides) in the emissions.

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CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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