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A Study of Production and Comparative Analysis of Biodiesel as an Alternative Fuel for Diesel Engines

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---***ABSTRACT***---
There is need to consider other forms of alternative fuels to provide energy security for the disappearing non-renewable fossil fuels. This is necessary in pursuit of a clean energy economy coupled with the desire to reduce anthropogenic emission especially those from diesel engines causing environmental pollution. Biodiesel is a renewable biodegradable fuel manufactured domestically from vegetable oils, animal fats, or recycled restaurant grease. This study considers the production and comparative analysis of biodiesel as an alternative fuel derived from plants. The fuel properties of coconut oil biodiesel and other biodiesel sources have been compared to that of the distillate (diesel). This paper discusses and clarifies the sources of biodiesel and their fuel properties together with the method of production. The characteristics of biodiesel was compared with different blends and the fuel characteristics considered include density, acid value, specific gravity, viscosity, flash point, calorific value, ash content, and cetane number. Results showed that biodiesel has a higher flash point than distillate fuel. The study also showed that biodiesel has zero Sulphur oxide (SOX) emission with a little increase in nitrogen oxide (NOX) emission than distillate fuel. Finally, other parameters such as density, calorific value, cetane number, acid value, viscosity, specific gravity and moisture content was equally found to be very close in value to that of distillate fuel. Thus, signifying a high possibility that biodiesel can replace of distillate fuel in future.
Keywords*: Biodiesel Production, Fuel Characteristics, Comparative Analysis, Alternative Fuel, Coconut Oil Biodiesel. Diesel Engines*
KEYWORDS: - Biodiesel*, Alternative Fuel, Diesel Engines, Clean Energy, Environmental Pollution, Fuel Characteristics*

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I. INTRODUCTION

Distillate diesel fuel is currently known to be the only commercially used fuel in diesel engines in developing countries. Though this is not the case in advanced countries of the world. Distillate fuel has been known over the years as a major contributor to environmental pollution, especially air pollution [1]. This is as a result of the dangerous gases emitted from the exhaust of our power generators which are known to endanger both our ecosystem and humans alike. The waste gases released by the engines are known to be of very high toxic quality [2]. These gases include carbon (iv) oxide, carbon (ii) oxide and Sulphur oxides. There is also concern about possible disappearance of distillate diesel fuel by the next century since it is non-renewable fossil fuel. Hence the need for an alternative is therefore eminent in an attempt to both save our environment and also secure continuity when its supply would have been cut off. Biodiesel is therefore predicted as a possible replacement of distillate diesel fuel since it is a renewable source of energy. The ability of biodiesel to perfectly replace the distillate fuel however depends on its ability to possess the relevant qualities which are also sufficiently competitive with that of the existing distillate (diesel) fuel [3], and this forms the basis of this work. This paper presents a report on the study which examined whether biodiesel possesses the relevant physicochemical properties such as flash point, calorific value, density, cetane number, kinematic and viscosity, that can guarantee its replacement of distillate fuel in diesel engine. The rest of the paper is organized as follows. The materials and methods for collection, preparation and extraction of oil samples are explained in section II. Analysis and calculation are presented in section III. Experimental results and discussion are presented in section IV. Concluding remarks are given in section V.

II. LITERATURE REVIEW

Distillate diesel fuel is currently known to be the only commercially used fuel in diesel engines in developing countries. Though this is not the case in advanced countries of the world. Distillate fuel has been known over the years as a major contributor to environmental pollution, especially air pollution [1]. This is as a result of the dangerous gases emitted from the exhaust of our power generators which are known to endanger both our ecosystem and humans alike. The waste gases released by the engines are known to be of very high toxic quality [2]. These gases include carbon (iv) oxide, carbon (ii) oxide and Sulphur oxides. There is also concern about possible disappearance of distillate diesel fuel by the next century since it is non-renewable fossil fuel. Hence the need for an alternative is therefore eminent in an attempt to both save our environment and also secure continuity when its supply would have been cut off. Biodiesel is therefore predicted as a possible replacement of distillate diesel fuel since it is a renewable source of energy. The ability of biodiesel to perfectly replace the distillate fuel however depends on its ability to possess the relevant qualities which are also sufficiently competitive with that of the existing distillate (diesel) fuel [3], and this forms the basis of this work. This paper presents a report on the study which examined whether biodiesel possesses the relevant physicochemical properties such as flash point, calorific value, density, cetane number, kinematic and viscosity, that can guarantee its replacement of distillate fuel in diesel engine. The rest of the paper is organized as follows. The materials and methods for collection, preparation and extraction of oil samples are explained in section II. Analysis and calculation are presented in section III. Experimental results and discussion are presented in section IV. Concluding remarks are given in section V.

III. MATERIALS AND METHODS

Collection, Preparation and Extraction of Oil Samples

The initial step of this process includes collection or harvesting and removal of the coconut from the tusk. The coconuts was obtained from a private coconut farm in Ukam, Mkpat Enin local government area of Akwa Ibom State, Nigeria. After the collection process was completed, this was followed by the process of preparing the samples. This involved fragmenting the coconuts to take away the soft inner parts containing the oil. In order to aid grinding these soft inner parts were sliced to about 20mm x 3mm pieces after which the washing and grinding process was performed. A smooth crushing of around 0.01 inches was obtained and transferred into a washing container of approximately 50 liters capacity with an open surface diameter of around 85 centimeters. The washing container was filled with water up to three quarters of its capacity and left undisturbed for approximately twenty-four hours. During this period the first extraction process was completed. The oil separated itself from the chaff and settled above water covering the entire surface of the container. In the second separation process, the oil and water mixture was separated by transferring the mixture of oil containing some quantity of water into a heating container. The oil and water mixture was then subjected to a peak heat of about 5000c [4]. This temperature was maintained until the water completely evaporated leaving only the oil floating on some deposits of impurities. The heat source was then removed and the oil decanted into a smaller container and allowed to cool. The oil was finally refined by simple filtration process [4]. Fig. 1 shows the entire process of biodiesel conversion.

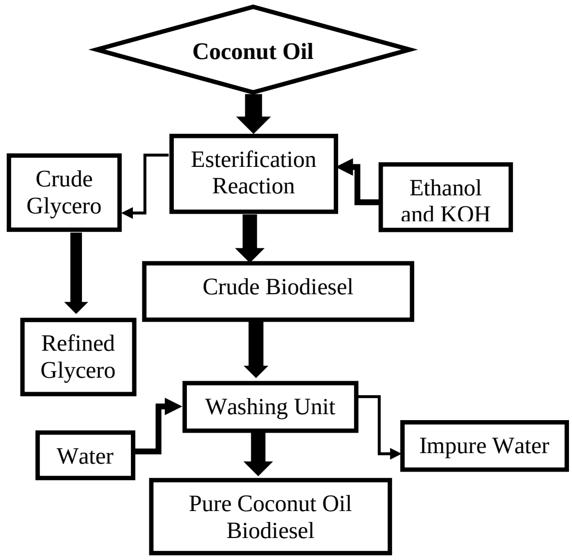

Fig. 1. Block Diagram of Biodiesel Conversion Process

Biodiesel Preparation and Production

In this study, biodiesel was prepared from coconut oil with the addition of ethanol to the coconut oil in the ratio of 8:1(i.e. 8moles of coconut oil to 1mole of ethanol). The catalyst, potassium hydroxide (KOH) was used to speed up the rate of reaction since the conversion is uniquely slow by nature process [4].. A reaction temperature and time of 70℃ and 2hours was maintained respectively. The three mixtures coconut oil, ethanol and potassium hydroxide were stirred together in a stirred reactor within the allowable time and later left to settle. On settling, two distinct layers of liquid were observed. At the bottom was glycerol and methyl ester (biodiesel) at the top. The biodiesel was carefully decanted leaving the glycerol in the container. The separated biodiesel was washed by mixing it with water in the separating funnel and allowing the mixture to settle for about ten minutes. Thereafter, the mixture separated into two distinct layers with the denser liquid (water) at the base and the less dense biodiesel at the top of the funnel. The water was carefully released first before the washed biodiesel was finally collected. The coconut oil sample was analyzed for its fuel properties which include: Density, Acid Value, Viscosity at 40°C, Flash Point, Moisture Content, Specific gravity, Calorific Value and Cetane number.

C. **Reaction Process**

Biodiesel is made up of long hydrocarbon chains that do not contain Sulphur or aromatic compounds [3]. The conversion process of vegetable oil or animal fat into biodiesel requires that one mole of triglyceride reacts with three moles of alcohol to produce a mole of glycerol and three moles of tri-alkyl esters [5]. The exhaust products of biodiesel are comparatively cleaner than that of distillate fuel [1,3]. The procedure for blending of esters is such that the volumes of each ester and distillate diesel were measured using a measuring cylinder and mixed in the ratios 10:90, 30:70, 50:50, 70:30 and 90:10 ester to distillate diesel respectively [4].

III. Analysis and Calculation

Acid Value (AV: This is the quantity of base expressed in milligram of potassium hydroxide that is required to neutralize all acidic components present in 1.0g of sample [4]. This was done by titrating the sample with alcoholic potassium hydroxide using the formula*:*

$$AV = \frac{\text{Vol.of titrant (mg)} \times \text{normality of KOH X 56.1}}{\text{mass of Oil sample}} \quad \ldots\ldots (1)$$

Calorific Value (CV) : The calorific value of the coconut oil sample, biodiesel, biodiesel/distillate fuel blends and the distillate fuel was determined using Table 1 which relates the specific gravity of Fuel and gross calorific value [6].

Table 1: Approximate Relation Between Gross Calorific Value And Specific Gravity [6].

Specific gravity Relation Density 15%4℃	Gross Calorific value (Specific Energy)		
	Cal/g	**Cal/cm**	**KJ/kg**
0.80	11,050	8,840	46,287
0.81	11,010	8,920	46,101
0.82	10,970	8,990s	54,915
0.83	19,920	9,060	45,720
0.84	10,870	9,130	45,520
0.85	10,830	9,200	45,334
0.86	10,780	9,270	45,124
0.87	10,730	9,340	44,938
0.88	10,690	9,410	44,752
0.89	10,640	9,470	44,543
0.90	10,590	9,540	44,357
0.91	10,540	9,590	44,147
0.92	10,400	9,660	43,938

0.93	10,440	9,710	43,729
0.94	10,390	9,770	43,510
0.95	10,340	9,830	43,310
0.96	10,290	9,880	43,101
0.97	10,240	9,940	42,891
0.98	10,190	9,990	42,682
0.99	10,140	10,040	42,475
1.00	10,090	10,090	42,263

Viscosity: The procedure for analyzing the viscosity is such that each sample (100mL) was measured and mechanically stirred for 2 hours at room temperature with magnetic stirrer. Thereafter, the sample was transferred into spindle of digital Ostwald type viscometer to determine the viscosity at different time intervals. The average viscosity value was then deduced and recorded.

Flash Point: The flash point refers to the temperature at which the volatiles evolving from the heated oil will flash, but not support combustion. The procedure is such that each sample (10mL) was measured into an evaporating dish. Thermometer was suspended into the centre of the dish containing sample, ensuring that the thermometric bulb dipped into the sample did not touch the bottom of the dish. Thereafter, the temperature of the sample was raised using kerosene stove. The temperature at which the oil sample started flashing (when the flame was applied) without supporting combustion was noted and recorded as flash point.

Moisture Content: The procedure for examining the moisture content is such that: A petri-dish was washed and dried in oven at 150°C for 30minutes. It was cooled in the desiccators and weighed empty. Exactly 5.0045g of the sample was weighed into the petri-dish. The weight of the petri-dish and sample was noted before drying. The petri-dish and the sample were put in the oven and heated at 150°C for 1hour, the result was noted. The heating was continued at regular time interval until a steady result was obtained and the weight was noted. The drying procedure was continued until a constant weight was obtained. Table 2 presents the weight of dish plus sample and weight of sample.

Table 2: Weight of dish Plus sample and Weight of sample

S/No	Time (minute)	Weight of dish + sample (g)	Weight of sample (g)
1	0.0	112.7848	5.0045
2	30.0	112.6533	4.8730
3	60.0	112.6503	4.8700
4	90.0	112.6370	4.8630
5	120.0	112.6370	4.8630

$$\% \text{ Moisture content } = \frac{W_1 - W_2}{W_1} \times 100 \quad \text{.....(2)}$$

Where:
weight of petri-dish and sample before drying = 112.7848g
weight of petri-dish and sample after drying = 107.7803g
weight of sample W_1 = 5.0045g
weight of dried sample W_2 = 4.8630g

$$\% \text{ Moisture content } = \frac{5.0045 - 4.8630}{5.0045} \times 100 = 2.8275\ \%.$$

Specific Gravity:The specific gravity of the oil sample was measured using the specific gravity bottle. The bottle was filled with water and weight recorded. After which, the bottle was emptied and dried. It was later filled with oil sample and the weight recorded. The specific gravity (s.g.) was then calculated using the formula:

$\text{Specific gravity} = \frac{\text{Weight of oil obtained}}{\text{weight of water measured}} = \frac{W_3 - W_1}{W_2 - W_1}$ ……(3)

Where:
W_1 = weight of density bottle = 15.3263g
W_2 = weight of density bottle + water = 41.3979g
W_3 = weight of density bottle + oil = 39.3615g

$$\text{Specific gravity of oil sample} = \frac{39.3615 - 15.3263}{41.3979 - 15.3263} = 0.922.$$

Following the same procedure, in the case of coconut oil biodiesel we have that:
W_1 = weight of density bottle = 15.3263g
W_2 = weight of density bottle + water = 41.3979g
W_3 = weight of density bottle + biodiesel = 38.0514g

$$\text{Specific gravity of oil sample} = \frac{38.0514 - 15.3263}{41.3979 - 15.3263} = 0.87.$$

Density: The density of a liquid is the ratio of weight of a liquid (mass) to the equal volume of the liquid. Hence*:*

$\text{Relative Density} = \frac{\text{Weight of oil}}{\text{Volume of oil}}$ ……(4)

Similarly, the density of a substance can also be defined as the product of the specific gravity of the substance and density of equal volume of water. Hence:

$\text{Specific gravity} = \frac{\text{density of substance}}{\text{density of water}}$ ……(5)

Therefore, Density of oil = specific gravity of oil × density of water\;

$$\text{Density} = 0.922 \times 1000\,\text{kg/m}^3 = 922\,\text{kg/m}^3$$

Cetane Number: The cetane number of the coconut oil biodiesel was determined using the formula:

$\text{Cetane no.} = 4.63 + \frac{5458}{SV} - 0.225 \times IV$ ……(6)

Where:
SV = Saponification value
IV = Iodine value

Percentage Oil Yield: This is defined as the percentage of the seed oil divided by kernel seed. Where the Seed kernel = 2580g and Seed oil = 672.5g, hence

$$\text{Percentage oil yield} = \frac{672.5}{2580} \times 100 = 26.1\%.$$

IV. RESULTS AND DISCUSSION

1. Comparative Analysis of Biodiesel

Table 3 andTable 4 shows the results of each of the tests conducted on the seed oil sample of coconut, coconut oil biodiesel together with the corresponding distillate diesel fuel standards. In fuel analysis the density (kg/m^3) of a fuel is very important because of its potential in determining the viscosity and the calorific value of the fuel [7]. As shown in Table 2 the density of the biodiesel was found to be 910 (kg/m^3) which is higher than that obtained for the distillate fuel being 870 (kg/m^3). The difference can be attributed to the higher molecular weight fatty acid constituents of the coconut oil [5]. The value obtained is within the allowable ASTM range for biodiesel and it is consistent with existing literatures [1,8]. This consolidates the anticipation of the biodiesel as a possible replacement of the distillate diesel fuel in diesel engines. In Table 3 a constant proportion between density and viscosity of the fuels can be observed. The calorific value varies inversely as the density, as it gets higher with decrease in density. This trend is consistent with existing literature [9]. Therefore, suggesting that the density of a fuel can be used to characterize the fuel in order to provide a guide for predictions that may emerge from the fuel properties.

The flash point of a fuel plays an important role when transportation and storage of fuel are taken into consideration. The flash point ***(^0C)*** of a fuel is the lowest temperature at which the vapors of the fuel will ignite given an ignition source. In Table 3, it can be observed that the flash point of coconut oil biodiesel is around 143℃. This is higher than that of the distillate diesel fuel which is around 104℃. The value obtained is within the acceptable range for biodiesel according to ASTM standard. Assuming there is an ignition source, this simply suggest that at temperature higher than 143℃, the fuel is bound to ignite. This offers vital information for its safe handling, as it places coconut oil biodiesel at an advantaged position with regards to its possible replacement of the distillate fuel. In Table 4, a comparison of the flash point of various biodiesel blends and the distillate fuel suggests that as the biodiesel blend increases from B10 to B90, the flash point also increases, showing a comparative advantage of biodiesel over the distillate fuel - storage wise [10]. Furthermore, as shown in Table 3 the acid value of the coconut oil was 0.95mgKOH/g prior to transesterification. The value reduced to 0.38mgKOH/g at the end of transesterification. Nevertheless, it was higher than that of the distillate fuel, and was within the acceptable range for biodiesel. The Acid Value (mgKOH/g) is the quantity of base expressed in milligram of potassium hydroxide that is required to neutralize all acidic components present in one gram of sample. It provides information on the storage potential of the fuel as regards to how long it can remain in storage without losing its fuel properties [11]. A good fuel is expected to remain durable for an ideal length of time. For this to be achieved, the acid value of the fuel must be reasonably low. Fuels with high acid value are bound to corrode their containing vessels. Hence, are not suitable for long storage [11]. One of the important criteria in evaluating diesel fuel quality is Viscosity. When the viscosity is High, this often leads to operational problems including engine deposits. It is observed that biodiesel has higher viscosity. This may cause poor injection and atomization performance [12]. However, it is useful to the engine as it provides lubrication and protection of the moving parts of the engine more than the distillate diesel [5]. In this study, the kinematic viscosity ($mm^{2/}s$) of the coconut oil was found to be 13.02($mm^{2/}s$) prior to transesterification. But this value drastically reduced to 3.12 ($mm^{2/}s$) after the reaction as shown in Table 3. This value is slightly less than that of the distillate fuel which was found to be 2.75 ($mm^{2/}s$). According to [13] the result is however within the ASTM standard which is in the range (1.6 – 6.0) ($mm^{2/}s$), The percentage moisture content was found to be approximately 2.8% which is very close to that of distillate diesel 2.6%. This equally meant that biodiesel was a suitable substitute for distillate fuel.

Table 3 Comparative Results of the Properties of Coconut Oil, Coconut Oil Biodiesel and Distillate Fuel

S/N	Fuel Property	Coconut Oil	Coconut Oil Biodiesel	Distillate Fuel
1	Specific Gravity	0.922	0.910	0.870
2	Density(kg/m^3)	922	910	870
3	Flash Point (^0C)	--	143	104
4	Acid Value (mgKOH/g)	0.95	0.38	0.29
5	Kinematic Viscosity ($mm^{2/}s$)	13.02	3.12	2.75
6	Moisture Content (%)	2.83	0.03	0.02
7	Cetane Number	--	54.53	50
8	Calorific Value (MJ/kg)	43.938	44.147	44.938

In addition, Cetane Number is commonly used as a measure of fuel combustibility. Higher cetane numbers result in greater ease of combustion. for these reasons cetane number is a rating of the ignition time for diesel fuel. [4] mentioned that the ASTM specification D6751 provides a minimum cetane number in the range of (45 – 67) for biodiesels. In this study the cetane number of the coconut oil biodiesel is around 54.53 as shown in Table 3. As observed, this exceeds the ASTM minimum value of 45. This also exceeded that of the distillate fuel given as 50. The cetane number of the several biodiesel blends, B10 (52.40), B30 (52.83), B50 (53.30), B70 (53.75) and B90 (54.20) are presented in Table 4. These were equally above the minimum standard for biodiesel and comparatively higher than that of the distillate fuel. With respect to the value of cetane number obtained from different studies it is observed that the cetane number of biodiesels has been found to exceed the minimum requirement. For example, in [13], the value of 51 was found. This suggests the suitability of biodiesel as an alternative fuel for diesel engine. Considering the different biodiesel blends and the corresponding distillate fuel examined in this study, a steady increase in the cetane numbers from the distillate diesel (B0) to the highest biodiesel blend (B90) was observed. This indicates that biodiesel has a comparatively higher cetane number than the distillate fuel. This is also considering the fact that as the biodiesel volume increases in the blend, there is a corresponding increase in the cetane number value of the blends. This also suggest that biodiesel possess better combustibility properties than the distillate fuel [14]. Moreover, [7] obtained a calorific value of 39.17MJ/Kg for biodiesel fuel and the fuel was adjudged suitable for diesel engine operations. The calorific values obtained in this study is slightly higher. On examining the fuel properties of the calorific value (MJ/kg) It was observed that all the different blends are higher in their respective calorific values than the pure biodiesel. Although they are relatively lower than that of the distillate fuel. As shown in Table3 the calorific value of the coconut oil biodiesel was found to be 44.147MJ/Kg. This value is comparatively lower than that of distillate fuel which is 44.938MJ/Kg. The calorific value of a fuel represents the amount of heat produced on complete burning of one gram of the fuel [7]. This provide additional information indicating that the calorific value of the distillate fuel is more superior to that of biodiesel [7]. In terms of fuel performance, the difference in the calorific values of biodiesel and distillate fuels is relatively too small to make any observable difference. In this respect, biodiesel possess a comparative advantage in terms of its replacement potential with distillate diesel.

Table 4 Comparative Results of The Properties of Different Coconut Oil Biodiesel Blends

S/N	Fuel Property	B10	B30	B50	B70	B90	B0
1	Specific Gravity	0.90	0.92	0.89	93	0.93	0.87
2	Density(kg/m^3)	900	920	890	930	931	870
3	Flash Point(^{0}C)	120	129	132	138	141	104
4	Acid Value (mgKOH/g)	0.63	0.98	1.23	1.48	1.35	0.29
5	Kinematic Viscosity @40℃ (mm$^{2/}$s)	6.92	6.74	5.87	5.32	5.12	2.75
6	Cetane Number	52.40	52.83	53.30	53.75	54.20	50
7	Calorific Value (MJ/kg)	44.357	43.938	44.543	43.729	43.729	44.938

(b) Engine Performance and Exhaust Emissions

There is useful information on the engine performance of different biodiesel sources in existing literature [8,9,12]. Hence engine performance and exhaust emissions from use of biodiesel are discussed based on information in existing literature [15,16], since there was no access to diesel engine to test engine performance and exhaust emissions of the fuels in this study. However, in the experiment conducted by [17] on a diesel engine using biodiesel fuel produced from safflower oil with Petro-diesel. They observed that using biodiesel in comparison to Petro-diesel increased the Brake Specific Fuel Consumption (BSFC), defined as the rate of fuel consumption divided by the power produced, but a decrease in pollutants such as particulate matter and carbon monoxide was also noticed. The result from the experiment conducted by [12] also showed that blending biodiesel with Petro -diesel decreases the Brake Thermal Efficiency (BTE), and conversely increases the BSFC. Comparing the brake thermal efficiency of diesel fuel and cotton seed methyl ester (biodiesel) blends; it was found that the brake thermal efficiency is always found to be lower with biodiesel blends as compared with Petro -diesel [12]. The BSFC of biodiesel and biodiesel blends were found to be higher in comparison to that of Petro -diesel. This could be attributed to the lower viscosity, density, and higher heating value of the Petro -diesel. The poor lubricity of Petro-diesel fuel has led to failure of engine parts such as fuel injectors and pumps, because these parts are lubricated by the fuel itself [18]. A major technical advantage of biodiesel over Petro -diesel is lubricity is due to the fact that lubricity was reported to improve with the chain length (structural formula) and the presence of double bonds [18]. [15] reported that biodiesel has a better lubricity than Petro -diesel hydrocarbons. This is attributed to the polarity that is introduced with the presence of oxygen atoms which is lacking in Petro -diesel. Neat biodiesel possesses inherently greater lubricity than Petro -diesel, especially low Sulphur petrol-diesel [9,10]. They also suggested that adding biodiesel at low blend levels (1%-2%) to low-Sulphur Petro -diesel restores lubricity to the latter.

V. CONCLUSION

The experimental study to establish the criteria for biodiesel to be used as an alternative fuel in diesel engines has been performed. The materials and methods for collection, preparation and extraction of oil Samples for production of coconut oil biodiesel has been discussed. This includes analysis of the biodiesel properties [n order to ascertain the biodiesel can be used to replace distillate fuel in diesel engines. There is a comparative advantage of biodiesel over distillate fuel particularly with respect to availability and production. Biodiesel is mainly sourced from agricultural products, found to be dependent on human determination and as such man has the power of decision. Considering the physicochemical properties of the fuel, biodiesel was found to be a good replacement of the distillate fuel. Biodiesel is found to be a good competitor of distillate fuel in terms of engine performance and exhaust emissions. Biodiesel showed zero SOx emission and a favorably reduced NOx emission. Thus, achieving the criteria for environmental friendliness. Other comparative advantages of the biodiesel properties include significant improvement in calorific value which is a necessary property that can guarantee its possible replacement as an alternative for distillate fuel in marine diesel engine.

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