British Journal of Applied Science & Technology
4(25): 3716-3725, 2014

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Potential of Waste Vegetable Oil for Biodiesel in Nigeria

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Authors' contributions

This work was carried out in collaboration between all authors. Author HI designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript and managed literature searches. Authors HI, NIO and MACC managed the analyses of the study and literature searches. All authors read and approved the final manuscript.

Original Research Article

Received 12th April 2014
Accepted 24th June 2014
Published 7th July 2014

ABSTRACT

Based on the alarming level of the problems associated with non-renewable energy sources, the critical effects of global warming and the need to curb environmental pollutions, there is now a shift of emphasis on serene renewable energy sources. Waste Vegetable Oil which refers to vegetable oil that has been used in food production and is no longer viable for its intended use is a potential feedstock for biodiesel production. The cost of production of biodiesel is high compared to conventional diesel fuel. However, it is cheaper to produce biodiesel from waste vegetable oil than pure vegetable oil. The conversion of waste vegetable oil to biodiesel using the acid esterification process followed by alkali transesterification in the laboratory and the subsequent determination of physicochemical properties of about four different blends of the produced biodiesel are undertaken in this study. The B100, having a percentage yield of about 95% with a density of 0.89 g/cm^3, sulfur content of 2.30ppm, cloud, pour and flash points of 5ºC, 4ºC , 164ºC respectively; and viscosity of 4.7 mm^2/sec at the temperature of 40ºC as the standard for biodiesel specification was obtained. The other blends performed reasonably well as the results lowered along with the composition. This study is therefore, necessary for new and existing Fast Food Companies, restaurant, hotel and biodiesel manufacturing companies to make decisions on ways of exploring the opportunities made available by the continual generation of waste vegetable oil as a result of the increasing population of Nigeria coupled with the resultant need for survival.

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Keywords: Waste vegetable oil; biodiesel; energy; environment.

1. INTRODUCTION

Energy is an essential aspect of human society and can be derived from renewable and non-renewable sources. The renewable energy resources are considered as a green and clean form of energy that replenishes naturally such as solar, wind, biomass, geothermal, etc. While non-renewable energy resources are energy that can't be replaced in a reasonable amount of time, examples are fossil fuel, coal, nuclear energy and natural gas. In recent times, the consumption of energy has increased because of the significant growth in population and change in life style. This increase in energy demand has been supplied majorly by fossil resources. Fossil fuels are unsustainable source of producing energy in terms of cost of extraction, environmental pollution, non renewable and politics related problem. Also the principal cause of global warming is widely believed to be the combustion of fossil fuels. For these reasons, there is a strong focus on energy production from sustainable resources currently in the world today, which many countries have embraced. Thus, biofuel technology has been accepted as an alternative replacement for conventional fossil fuel, so as to resolve the problem of fossil fuels depletion and increase in the price of energy due to high rate of demand [1].

Biodiesel is one of the promising alternative fuel sources with many economic and environmental advantages such as its potential contribution to the reduction in the emission of greenhouse gases. It prolongs engine life and reduces the need for frequent maintenance (the lubricating qualities of biodiesel is better than fossil diesel). It is safer to handle being less toxic, more biodegradable, and having a higher flash point. Also, it reduces some exhaust emissions, according to [2]. Biodiesel can be produced from non- edible and edible oil such as animal fat, waste vegetable oil and vegetable oil. Presently, the price of biodiesel is high compared to petroleum-diesel due to the sources of production as reported by [3]. The controversies of edible oils being converted to fuel bring a new dimension to the transesterification process. Prolonged dependence and increasing demand for edible oil as feedstock create a siphon, which draws a bigger portion of edible oils into the fuel industry. Consequently, this has threatened the supply of edible oil to the food industry thereby promoting starvation and inflation.

Waste vegetable oil (WVO) is oil used in food production that is no longer useful for its original purpose. It can be gotten from domestic (homes), commercial (restaurants, eateries) and industrial (hotels). The problem associated with improper disposal of WVO is enormous. For instance, disposing WVO via kitchen sink could cause sewage pipe blockage on solidification. It is also conductive to corrosion of metal and concrete elements which also affect mechanisms in waste water treatment plants. Consequently, it adds to the cost of treating effluent or pollutes waterways. Biodiesel can be created from waste vegetable oil, which would previously have ended up in a landfill. The use of waste vegetable oil as feedstock reduces biodiesel production cost by about 60–70% because the feedstock cost constitutes approximately 70–95% [4] of the total cost of biodiesel production. [5] reported that, this price is said to be reduced approximately by half with the use of low cost feedstock.

The uniqueness of this work in Nigeria is that, Nigeria has a growing population of over 160 million people and as such, there is an increase in the rate at which fast food companies, restaurants and hotels are being set up. The large amount of WVO generated from these establishments on a daily basis can now be sold at a cheap price to biodiesel manufacturers who in turn will recycle and make it a fuel.

[6] carried out a study on biodiesel production from different oils: such as soybean oil, canola oil, palm oil, waste vegetable oil and coconut oil. [7] produced biodiesel using sunflower oil, and [8] work was on palm oil. As reported by the various researchers, the major problem of biodiesel is their cold flow property such as the pour point and the cloud point; the temperature at which fuel just begins to liquefy and solidify, is often utilized to indicate the cold temperature usability of fuel oil. [9] showed that neat biodiesel has a pour point of 3ºC in cold weather, and forms gel which can cause plugging of fuel lines. This study was carried out to assess some basic qualities of biodiesel produced from waste vegetable oil and its blend with petroleum diesel when compared with the American Standard and Testing Method (ASTM). The properties in-view are density, viscosity, pour point, cloud point, sulfur content and flash point which are of utmost importance because of the role it plays in a diesel vehicle/engine.

2. MATERIALS AND METHODS

The WVO was collected from a local restaurant in Lagos as a single feedstock (vegetable oil), and then filtered to remove impurities. Theoretically the molar ratio of alcohol to oil in transesterification reaction is 3:1, and for alcohol to catalyst 30ml to 1.06g. However, extra amounts of alcohol is recommended, so as to shift the equilibrium to the product side and increase the conversion, because transesterification is a reversible reaction. 70ml Analar grade methanol of 99.8% purity was made to react with 2.12g Merck potassium hydroxide pellets of pure grade obtained from the Mon Scientific store, Lagos, to form potassium methoxide (KCH_3O) in a closed system. All other solvents used were analytical grade.

The conversion of WVO to biodiesel was carried out firstly, by the acid esterification process, and then by the alkali transesterification. The catalyst, 46ml of sulfuric acid, was dissolved in 26.50ml of methanol in a 500ml flask containing a magnetic stirrer and then mixed with the 200ml preheated WVO. The mixture was heated and stirred at a temperature of 55ºC for 1hour, so as to remove the excess free fatty acid (FFA) content for an improved biodiesel yield. The transesterification process followed by adding the potassium methoxide into an airtight 500ml flat bottom flask containing the oil. The reaction was carried out in a closed system to prevent the loss of alcohol. The temperature of the system was maintained between 60-65ºC (methanol has a boiling point of 65ºC, above this temperature, it will escape from the reaction mixture) for one hour, after which the mixture was transferred into a 500ml separating funnel and left for 24 hours, so as to separate the biodiesel from glycerol. The glycerol being more soluble than biodiesel was filtered out from the separation funnel, and the biodiesel left in the funnel was washed with lukewarm water five times to a neutral pH to remove the residue glycerol, catalyst and other impurities. Below in Fig. 2.1 is shown a schematic diagram of biodiesel production.

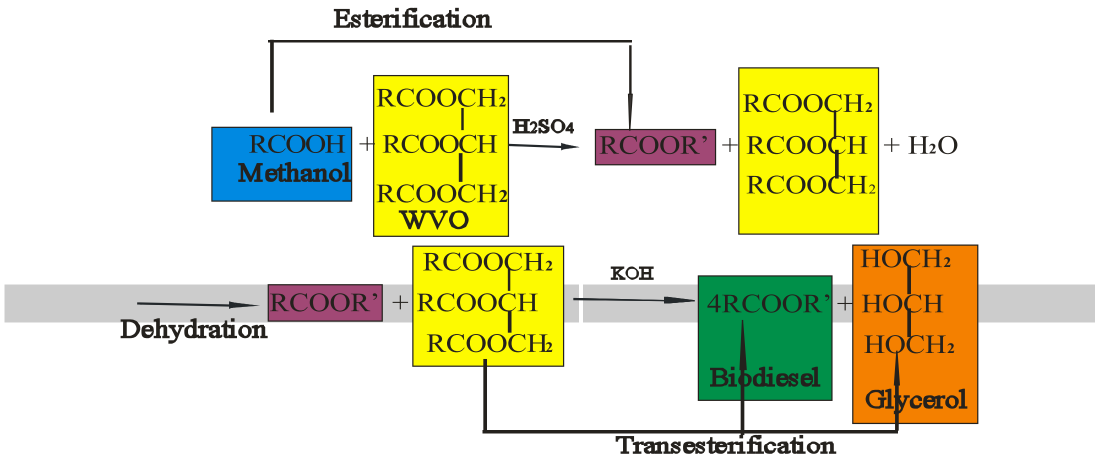

Fig. 2.1 Schematic diagram of biodiesel production

The following properties were determined: - The amount of free fatty acid in the oil by titration method; unlike the acid–base neutralization titration, in this case, the base is titrated against the oil. 1ml of WVO was measured into a conical flask containing 10ml of isopropanol, and then 4 drops of phenolphthalein were added into the mixture. The base is prepared with 1g of KOH and 1ml of distilled water in a burette.

$$RCOOH_{(aq)} + KOH_{(aq)} \rightarrow RCOOK_{(aq)} + H_2O_{(L)}$$

Mole ratio of FFA to base=1:1

This implies that, 1Moldm^{-3} of FFA requires 1Moldm^{-3} of KOH for complete neutralization.

The viscosity value was determined by Digital Viscometer SVM 3000 (Anton Paar) at different temperatures, according to the ASTM D-445. The density was determined using a density bottle. The pour point and the cloud point were also determined according to ASTM D6371 - 05. The Sulfur content which determines the pollution level of the fuel was determined according to ASTM D5453. The flash point was determined by an automated Pensky-Martens closed-cup apparatus in the temperature range of 60 to 190ºC according to ASTM D93- 11 Standard Test Methods for Flash Point.

Below in tables 2.1 and 2.2 is shown the ASTM biodiesel and petroleum diesel standard respectively.

Table 2.1. ASTM D 6751-02 biodiesel specification

Property	Testing Method	Limits
Flash point (^{o}C)	D 93	100-170
Viscosity, 40 ^{o}C (mm^{2}/s)	D 445	1.9 - 6.0
Density (g/cm$^{3)}$	D 1298	0.88
Cloud point(^{o}C)	D 2500	-3 to 15
Pour point (^{o}C)	D 97	-5 to 10
Sulfur(ppm)	D5453	15

Table 2.2 ASTM D 975-13 diesel specification

Property	Testing Method	Limits
Flash point (ºC)	D 93	100-130
Viscosity, 40ºC (mm^2/s)	D 445	1.3 – 24.0
Density ($g/cm^{3)}$)	D 1298	0.86
Cloud point(ºC)	D 2500	35
Pour point (ºC)	D 97	35
Sulfur(ppm)	D5453	15

3. RESULTS AND DISCUSSION

To calculate FFA% from a titration value the formula is:

$$FFA\% = (v - b) \times N \times 28.2 / w$$

V is the volume in ml of titration solution
b is the volume in ml of the blank
N is the normality of the titration solution
w is the weight of the sample of oil in grams
v = 4ml volume of titration blank b = 0; initial titration value.
N=1/56.1;1g/L of KOH used for titration
w = 0.92grams; 1ml of oil typical weight
28.2 is the molecular weight of oleic acid divided by ten.
Substituting all the values

$$FFA\% = 0.546 \times 4 = 2.18$$

The WVO feedstocks resulted in significantly higher yield. This is due to the acid esterification process that was first applied to remove the excess free fatty acid (FFA) content in the WVO, followed by the alkali transesterification. Of the 200 ml of WVO used during the production process, biodiesel yielded 191ml, which is 95.2% of the total input, while glycerine a by-product yielded 75ml, which is 4.80%. Fig 3.1 shows the result of percentage yield.

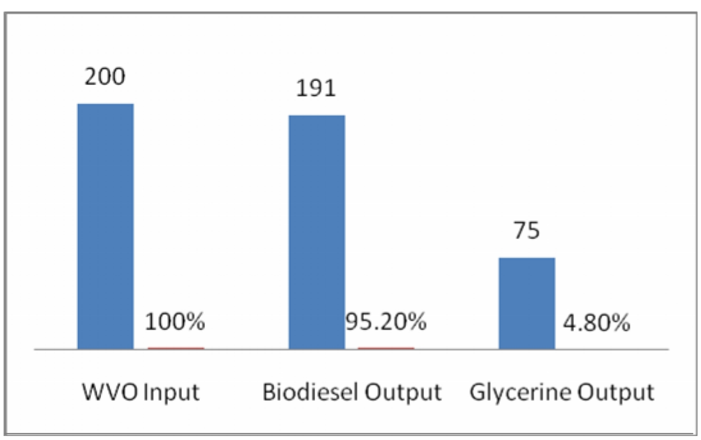

Fig. 3.1. Percentage yield chart

It was also observed that the values of the viscosities obtained for all the blends were within the recommended ASTM range of 1.9 to 6.0mm^{2}sec of both diesel and biodiesel for reference temperatures for viscosity (i.e., 40ºC) as shown in Table 3.1.

Table 3.1 Viscosity values

Temp(ºC)	B100 (mm^2/Sec)	B80 (mm^2/Sec)	B50 (mm^2/Sec)	B20 (mm^2/Sec)
10	7.212	6.024	5.422	4.893
20	6.338	5.696	4.886	4.592
30	5.215	4.932	4.411	4.118
40	4.706	4.343	4.117	3.743
50	4.224	4.101	3.921	3.415
60	4.103	3.811	3.556	3.222

Fig. 3.2 shows a chart of Viscosity-Temperature of different blends of biodiesel produced from WVO. At 20ºC the viscosity value obtained is more than the recommended value. This may affect the fluidity of the fuel and thus leads to poorer atomization of the fuel spray and less accurate operation of the fuel injectors. The implication is that, there will be larger drops of fuel in the engine combustion chamber which may not burn as clean compared to fuel with low viscosity that produces smaller drops. The unburned oxidized fuel will accumulate around the valves, injector tips and on piston sidewalls and rings of the engine. This results in a poor fuel spray and poor ignition, and thus emission of greenhouse gasses. Therefore, the accurate determination of viscosity is essential to many product specifications.

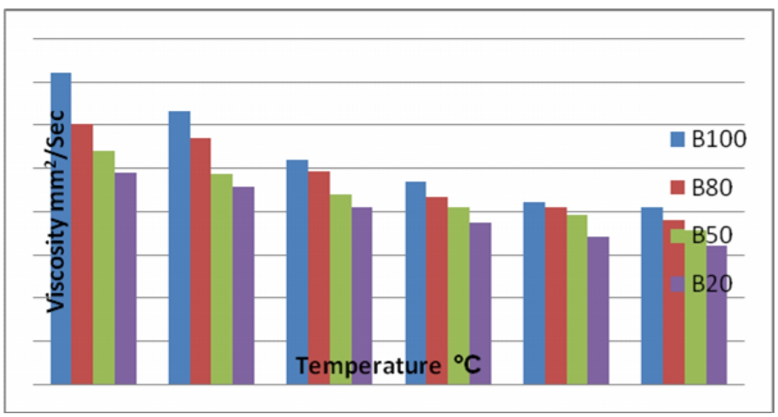

Fig. 3.2 Viscosity chart

Table 3.2 shows values obtained for the cold weather performance, i.e. the cloud point and the pour point. Also values for flash point, density and sulfur content for all the biodiesel blends were obtained.

Table 3.2 Cloud point, pour point, flash point, density and sulfur content values of biodiesel

Properties	B100	B80	B50	B20
Cloud Point (ºC)	5	2	-1	-3
Pour Point (ºC)	4	0	-2	-4
Flash Point (ºC)	164	152	139	124
Density (g/cm^3)	0.8883	0.8792	0.8703	0.8625
Sulfur content (ppm)	2.30	5.70	10.10	14.40

For the cold weather performance; the cloud point and the pour point, the values obtained are within the recommended range as shown in Fig. 3.3.

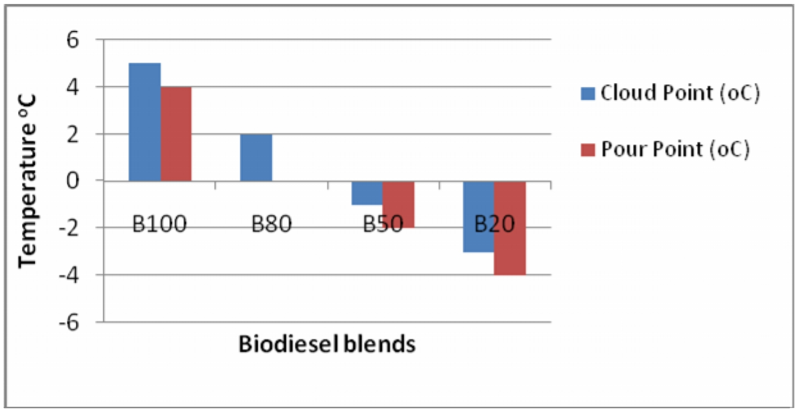

Fig. 3.3 Cold weather performance chart

However, these values are higher than petrol- diesel, which has value from -15ºC to 5ºC for cloud point and -35ºC to -15ºC for pour point. The blends gave better values than the B100 indicating that B100 biodiesel will tend to gel at higher temperatures than diesel. This implies that biodiesel fuels need to be used cautiously in cold climates, as wax crystals can form in either fuel at lower temperatures. These wax crystals can plug fuel filters, causing engine problems. Preferable lower percentage biodiesel blends B20, B50 should be used in cold weather.

The flash point is a parameter that determines the safety of fuel during its handling and storage. It is the lowest temperature at which the vapour above the fuel becomes flammable [9]. Fig. 3.4 shows a chart of flash point for all the blends. The flash points obtained for B100 and the blends are higher than that of petroleum-based diesel and well above the 103ºC minimum ASTM recommended range, hence, no risk of fire outbreaks in case of an accident. Also, comparing the properties of the B100 and the blends, there is just a little change in their flash point values. This infers that biodiesel produced from waste vegetable oil can be conveniently blended with petroleum diesel with the quality of the biodiesel still effective as an alternative fuel.

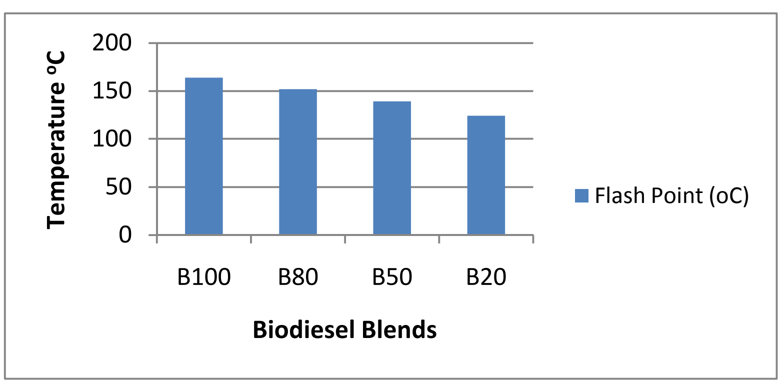

Fig. 3.4 Flash point chart

The values of the densities obtained for both B100 and all the blends for the feedstocks used in this work agreed with those of the ASTM range. As shown in Fig 3.5. It is recommended that, these values be maintained within the tolerable limits to allow optimal air to fuel rations for complete combustion, because high-density biodiesel or its blend can lead to incomplete combustion and particulate matter emissions. This may result in environmental pollution, as such one of the reasons for considering alternative energy would be defeated.

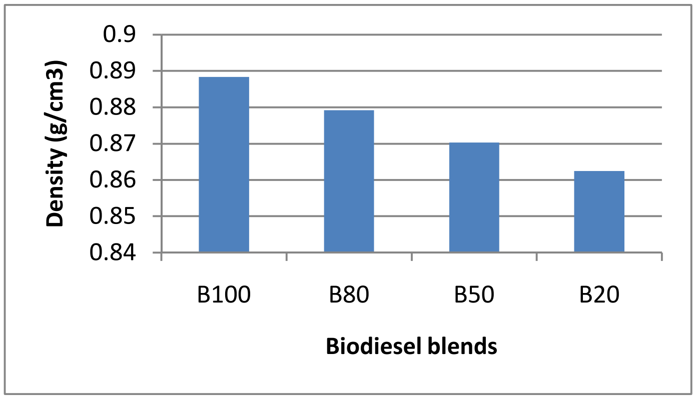

Fig. 3.5 Density chart

Report by [10] shows that, sulfur in fuel forms sulfur dioxide (SO_2) and sulfate (SO_4) particulate matter during combustion. SO_2 can affect the respiratory system and the functions of the lungs, mucus secretion, swelling of the respiratory tract, causing coughing, irritation of the eyes, the exasperation of asthma and severe bronchitis. It also makes people more prone to infections of the respiratory tract. Sufficient level of sulfur content in fuel is essential for the lubrication and functioning of fuel system machinery such as fuel pumps and injectors [11]. High sulfur levels in fuel, when combined with water vapour forms sulfuric acid; this is the main component of acid rain which causes corrosive wearing on cylinder liners and valve guides resulting in premature engine failure. Fig. 3.6 shows a chart of sulfur content for various biodiesel blends considered in this work. The sulfur content values obtained for the B100 and the blends is in compliance with the Environmental Protection Agency (EPA) Regulations (15ppm) on-highway diesel fuel, which took effect from June 1st, 2006.

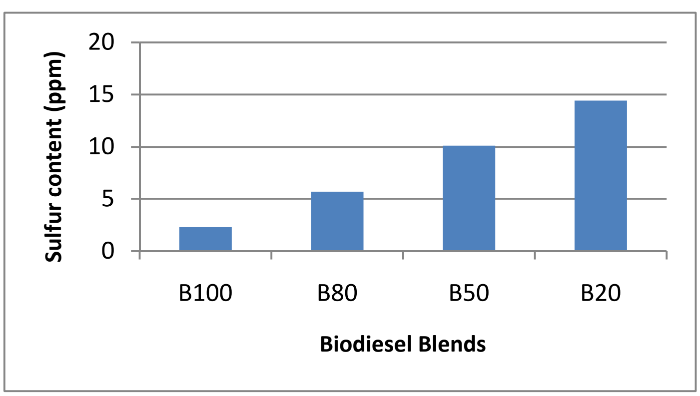

Fig. 3.6 Sulfur content chart

This work like other works shows that the flash point of biodiesel is significantly higher than petroleum-based diesel. This means that fire related accidents in storage, transportation and utilization of biodiesel is much less than that of petroleum-based diesel. A work on waste vegetable oil to biodiesel done by [12], showed the viscosity to be 5.03 mm^2/Sec at 40ºC and 7.2mm^2/sec at 21ºC; the flash point was found to be 164ºC, sulfur content was 2 ppm, cloud point was -1ºC and pour point was -3ºC. Another work by [13], showed the Specific gravity to be 0.88, Viscosity to be 3.10mm^2/sec at 40ºC, Pour point -4ºC. The work done by [12] and [13], when compared with this work, were in good agreement.

4. CONCLUSION

This article is about producing biodiesel from waste vegetable oil. The study aims to simplify the processes involved in achieving a high percentage biodiesel yield, testing its quality by determining some parameters such as density, viscosity, sulfur content, flashpoint, cloud point and pour point and comparing it with ASTM standard.

The result shows a higher percentage yield as compared to others as referenced. This is due to some alterations in the process of the biodiesel production. The densities of biodiesel and its blends from B20 above fall within the ASTM standard range. At temperature below room temperature, the viscosity of higher blend biodiesel is higher than recommended values, resulting in incomplete combustion and subsequent emission of Greenhouse gas. Lower percentage biodiesel blends B20; B50 should be used in cold weather to avoid formation of wax crystals causing engine problems. The flash point is higher than petroleum-based diesel making it suitable for use in terms of fire hazard. Also, environmental pollution resulting from engine exhaust due to the high value of sulfur content in petroleum diesel can now be resolved by the use of biodiesel made from waste vegetable oil. A complete understanding of the basic physical properties of the biodiesel production from various feedstocks is necessary to the development of fuel using this feedstock.

The quality of the biodiesel is in total agreement with the ASTM standard, which means larger amounts of WVO generated from various establishments on a daily basis can now be sold to biodiesel manufacturers who in turn will recycle and make it a fuel. This analysis will be useful either when starting a new business such as Fast Food Company, restaurant, hotel, biodiesel manufacturing company, or identifying new opportunities for an existing business. With the staggering population of Nigeria, coupled with the corresponding need for survival, waste vegetable oil will be continuously generated and rather than constituting more problems to the environment, its conversion to biodiesel is highly recommended.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sciencedomain.org/review-history.php?iid=588&id=5&aid=5213