

REVIEW PAPER

Some physical properties and oxidative stability of biodiesel produced from oil seed crops

Fatai Abiola Lateef^{*,†}, Okechukwu Dominic Onukwuli^{**}, Uche Chukwu Okoro^{***},
Paul Madus Ejikeme^{***}, and Paul Jere^{*}

^{*}Department of Science Laboratory Technology (Chemistry Unit), Federal Polytechnic Idah, Kogi State, Nigeria

^{**}Department of Chemical Engineering, Nnamdi Azikiwe University, Awka, Anambra State, Nigeria

^{***}Department of Pure and Industrial Chemistry, University of Nigeria, Nsukka, Enugu State, Nigeria

(Received 22 October 2013 • accepted 22 January 2014)

Abstract—Biodiesel is a cleaner burning fuel than petrodiesel and a suitable replacement in diesel engine. It is produced from renewable sources such as vegetable oils or animal fats. Biodiesel fuel was prepared from castor (CSO), palm kernel (PKO) and groundnut (GNO) oils through alkali transesterification reaction. The biodiesel produced was characterized as alternative diesel fuel. Fuel properties such as specific gravity, viscosity, calorific (combustion) value, The CSO, PKO and GNO were measured to evaluate the storage/oxidative stability of the oils to compare them with commercial petrodiesel. The biodiesel produced had good fuel properties with respect to ASTM D 6751 and EN 14214 specification standards, except that the kinematic viscosity of castor oil biodiesel was too low. The viscosity of castor oil biodiesel at different temperatures was in the range of 4.12-7.21 mm²/s. However, promising results which conformed to the above specification standards were realized when castor oil biodiesel was blended with commercial petrodiesel. At 28 °C the specific gravity recorded for CSO, PKO and GNO biodiesel was higher than the values obtained for petrodiesel. Commercial petrodiesel had the highest oxidative stability than biodiesel produced from CSO, PKO and GNO oils.

Keywords: Biodiesel, Petrodiesel, Transesterification, Fuel Properties

INTRODUCTION

The high energy demand, pollution problems and the global consensus that fossil energy sources are finite, make it increasingly necessary to develop a renewable energy source of limitless duration, smaller environmental impacts that are technically feasible and readily available [1-6]. Biodiesel has been reported as a promising long-term renewable energy source [7].

Biodiesel is pursued not only for the consideration of the future shortage of petroleum supplies, but also for the well being of the environment [8,9]. Diesel fuels have an essential function in the industrial economy of a developing country. They are used for the transportation of industrial and agricultural goods, and in operation of diesel tractors.

Various plant oils have been converted into biodiesel and they work well in diesel engines [10]. One possible alternative to fossil fuel is the use of oils of plant origin such as vegetable oil [2,11-13], waste fat and oil [4,14,15]. Although other crops such as mustard, hemp, jatropha and even algae show great potential as sources of raw materials for biodiesel production [16,17], available statistical data ranked Nigeria (as of 2011) as the largest oil producing country in Africa, although Libya has more reserves. Nigeria is also ranked as the 11th largest oil producing country in the world [18]. This amazing oil wealth notwithstanding, the Energy Commission of Nigeria (ECN) expressed fears over future depletion of these fossil fuels and the severe environmental impacts [19].

Petroleum-based energy sources pose severe threats to the environment from hazardous emissions. High level of fossil fuel combustion has resulted in the concentration of carbon dioxide, which causes dramatic global climate change and air pollution [20].

Biodiesel, an environmental friendly fuel, has many merits. It is derived from renewable, domestic resource. It is biodegradable and non-toxic [12,14,21]. Compared to petroleum-based diesel, biodiesel has a more favorable combustion emission profile, such as low emissions of carbon monoxide, particulate emission and unburned hydrocarbons. Biodiesel has a relatively high flash point, lubricating properties that reduce engine wear and extend engine life [12,14,19].

Plant-oils occupy a prominent position in the development of alternative fuels although, there have been many problems associated with using it directly in diesel engine (especially in direct ignition engine). These include carbon deposits, oil ring sticking, thickening of lubricants and high viscosity [5,22-24].

Biodiesel is produced by transesterifying the parent oil or fat with an alcohol [25,26]. Alcohols such as methanol, ethanol, 1-propanol and butanol have been used for biodiesel production. Using alcohol of higher molecular weight improves the cold flow properties of the resulting ester, at the cost of a less efficient transesterification reaction [27]. Alkaline catalyst such as sodium hydroxide (NaOH) and potassium hydroxide (KOH) are the most commonly used catalysts in transesterification, since their reaction is much faster than an acid-catalyzed reaction [28].

Two approaches for transesterification of plant-oils for production of biodiesel are the chemical method using alkali catalyst (NaOH, KOH or alkoxides) or acid catalyst (strong acids H₂SO₄, H₃PO₄) [29-31]. The product of the reaction is a mixture of esters, which is the biodiesel, and glycerol, which is a high value co-product. The

[†]To whom correspondence should be addressed.

E-mail: latfatab@gmail.com

Copyright by The Korean Institute of Chemical Engineers.

enzymatic method which is lipase-catalyzed is carried out in non-aqueous environment. Transesterification reaction is an equilibrium reaction and the transformation occurs essentially by mixing the reactants. However, the presence of a catalyst considerably accelerates the adjustment of the equilibrium [8].

These fuel properties may affect the engine performance and emissions, considering that the engines were originally optimized with petroleum diesel. Among these fuel properties, specific gravity is one of the most basic and most important properties because some important performance indicators such as cetane number and heating value are correlated with it. It also determines the storage and transportation capacities [32]. Another quality assessment to be considered in biodiesel usage in unmodified engine is the storage and oxidative stability that is undergone by fats and oil. Rancidity is brought about by the action of air (oxidative rancidity) or by micro-organisms (ketonic rancidity). Oxidative rancidity is accelerated by exposure to heat and light, by moisture and by the presence of traces of certain metals, e.g., copper, nickel, iron [33].

With most oils and fats, the free fatty acidity increases during storage, but with refined oils particularly, the free fatty acidity figure is not necessarily related to the extent to which rancidity has progressed. On the other hand, although the 'peroxides' are possibly not directly responsible for the taste and odor of rancid fats, the concentration of them as represented by the peroxide value is often useful for assessing the extent to which spoilage has advanced [33]. Fortification of fats and oils with antioxidants extends the storage time and protects essential nutrients [34]. The main substrates for oxidation of lipids are the unsaturated fatty, which generally oxidize faster in a free state than when they form part of triglycerides or phospholipids [35].

The two major methods available for biodiesel production are the batch transesterification and continuous processes [36]. The batch reactor has the advantage of high conversions that can be obtained by leaving the reactant in the reactor for long periods of time [37].

Various plant oils have been converted into biodiesel which work well in diesel engines. Several researchers have used biodiesel as alternative fuels in the existing compression engine (CI) without any modification. Promising results have been obtained by running CI engines on plant oil based biodiesels [38]. However, in Nigeria, the production of biorenewable and environmentally friendly biodiesel has not been remarkable.

Nigeria is rated to be the third world's largest producer of palm-kernel oil and groundnut oil next to Malaysia and India, respectively [39]. It was also reported that the castor oil plant originates in Africa. However, industrial use of these plants' oil has been limited to soap, detergent, lubricants, paints etc. This shows that despite the abundance of these plant oils, it has been underutilized in Nigeria. Successful reports on transesterification of some Nigerian oils in the preparation of biodiesel are an indication of better industrial utilization of these plant oils in Nigeria, as considerable research efforts are now focusing on this alternative diesel fuel worldwide [40].

This project is aimed at producing biodiesel using various plant oils. Its objectives are therefore,

- To carry out some physical characterization on the biodiesel produced.
- To determine the optimal catalyst weight for the transesterification reaction.

- To determine the oxidative stability (rancidity) of the biodiesel produced.

MATERIALS AND METHODS

The raw materials used in the work were castor, palm kernel, and groundnut seeds. These were obtained from a market in Nsukka, Enugu State, South Eastern Nigeria. These raw materials were pre-treated by the process of degumming and refining, to remove phospholipids and fatty acids, respectively.

1. Pre-treatment of Oils

Three hundred milliliters of the oil was heated to 75 °C in a beaker using electric heater. The oil was mixed with 0.1 (v/v) % of 85% phosphoric acid and distilled water to about 0.2 w% of the oil. The oil was homogenized for about 30 minutes with a magnetic stirrer. The resulting gum was allowed to settle and the oil was decanted into a 500 ml beaker for refining.

The oil was heated again to 75 °C under magnetic stirrer. 9.5 w% of NaOH solution was added gradually, as the mixture was continuously homogenized. 15 w% distilled water of the total mixture was used to wash the oil free of soap in a 500 ml separating funnel. The washed oil was later dried in an oven at 105 °C for about 30 minutes.

2. Determination of Optimal Catalyst Weight

The laboratory scale transesterification reaction (using batch reactor) was carried out in a 200 ml conical flask (air-tight flask) and mounted on a magnetic stirrer. The magnetic stirrer was set to a constant speed throughout the experiment, to ensure uniform agitation and thorough homogenization of the reaction mixture.

Optimal catalyst tests were determined for each oil sample using 50 ml of the refined oils. 1-propanol was mixed with oil in of 3 : 1 molar ratio, respectively. NaOH pellet was used as catalyst. The weights of the catalyst were varied from 0.05, 0.10, 0.15, 0.20, 0.25, 0.30, 0.35 and 0.40 g. NaOH pellets were dissolved in 15 ml of 1-propanol and the mixture was stirred for 15 minutes to form sodium propoxide ($\text{CH}_3\text{CH}_2\text{CH}_2\text{ONa}$) in an air-tight conical flask.

The sodium propoxide ($\text{CH}_3\text{CH}_2\text{CH}_2\text{ONa}$) formed was introduced gently into the heated oil in the reactor. The entire content was heated to 55 °C for 60 minutes. The product of the reaction was allowed to separate into two phases by standing for 6 hours in a 100 ml separating funnel. This was to separate glycerol from the biodiesel. The two layers - superior (biodiesel) and inferior (glycerol) were separated by washing with warm distilled water to remove impurities. The denser soapy mixtures were carefully drained from the bottom of the separating funnel, leaving behind the superior biodiesel layer. The volumes of the biodiesel obtained were determined in a measuring cylinder. A graph of biodiesel yield fraction against catalyst weight per volume of oil was plotted. This was done for all the oils.

3. Alkali-catalyzed Batch Production of Biodiesel

One hundred milliliters of each of the three oil samples was heated to 65 °C and placed in a 250 ml flat bottom flask-batch reactor at 6 : 1 alcohol to oil molar ratio. 100 ml of castor and palm kernel oil required 60 ml of 1-propanol and 100 ml of groundnut oil required 50 ml of 1-propanol. 0.50 g and 0.40 g NaOH catalyst were used for castor oil and palm kernel oil, respectively. This was dissolved into the alcohol by vigorous stirring in a separate air-tight 200 ml container. The alcohol-optimal catalyst weight mixtures were poured

into the oils and the final mixture was stirred vigorously for 60 minutes in an air-tight container. The reaction product mixture were allowed to separate into two phases at the end of the reaction by allowing it to stand standing for 15 hours in a separating funnel so as to separate glycerol from the biodiesel. The inferior layer (glycerol) was evacuated by opening the tap of the separating funnel. The crude biodiesel was left in the separating funnel.

50 ml warm distilled water at 45 °C was used to wash the crude biodiesel three times. This was dried in an oven at 105 °C for 60 minutes. The volumes of the biodiesel obtained were recorded, and the products were used for characterization.

4. Specific Gravity

Specific gravity was determined for each of the fuels as the ratio of the density of fuel to the density of water at the same temperature. This was done using a density bottle of 20 ml capacity.

5. Kinematic Viscosity

Kinematic viscosity of the biodiesel produced was determined with Ferranti portable viscometers (Model VL for PKO and GNO, Model VH for CSO) at 30 °C following the standard method as outlined in the Ferranti portable viscometer manual. About 150 ml sample was placed under an outer cylinder. The outer cylinder was immersed in the sample fluid by allowing the cylinder to rotate to stable reading. The viscometer was raised above the fluid and tilted to allow the sample to flow from the annulus back into the container and the readings were taken from the Ferranti portable viscometer calibrations by selecting the appropriate speed.

Dynamic and kinematic viscosity was obtained for all the oils and biodiesel produced from each of the oils. The viscosities in poises, at a given speed and cylinder combination, were obtained by multiplying the instrument reading by the appropriate multiplying factor given on the calibration chart.

6. Calorific (Heating/Combustion) Value Using Bomb Calorimeter (Model: XRY - 1A)

The biodiesel obtained from each of the oils was characterized for its combustion value, and compared to conventional diesel fuel (Petrodiesel). Both outer and inner canisters of the bomb calorimeter were filled with water. 1 g of biodiesel/petrodiesel sample to be evaluated was measured and placed in a mould (small metal crucible). A 10 cm ignition thread (wire) connected to the electrodes of the oxygen bomb, was placed and allowed to keep in touch with the sample. The bomb was filled in with oxygen at 2.8-3.0 mPa and then transferred into the inner canister (filled with 300 cm³ of distilled water). The necessary wires were connected and the temperature sensor was placed into inner canister.

The power was switched on and the water inside the inner canister was stirred for about 2 minutes. The initial temperature of the water was noted and denoted T_o . The Bomb calorimeter was fired and the final temperature (T_f) was recorded in 31 minutes. Length of the pieces of unburnt firing wire was measured (l) and the inner lining of the oxygen bomb and crucible were washed with distilled water into a conical flask. The wash solution was titrated against 0.0709N $\text{Na}_2\text{S}_2\text{O}_3$, using 2 drops of methyl red indicator.

Calorific values of the samples were calculated from the expression:

$$W = \frac{E\Delta T - \Phi - V}{m}$$

where w =heat of combustion of sample (calorie/g)

m =mass of sample to be evaluated (g)

E =13,039.308 calories/g, Benzoic acid standard

T =change in temperature= $T_f - T_o$

F =2.31 (where l =length of the unburnt wire)

V =volume of alkali ($\text{Na}_2\text{S}_2\text{O}_3$ solution) cm³

The combustion value were converted to Joules from the expression

1 calorie=4.148 Joules

7. Peroxide Value

1.0 g of biodiesel produced was weighed into a 100 ml conical flask containing 20 ml of solvent mixture (2 : 1 volume of glacial acetic acid and chloroform respectively), 20 ml of 50% potassium iodide (KI) solution and 1.0 g of potassium iodide (KI) crystals. The whole mixture was agitated and placed in boiling water at 100 °C for 30 seconds. About five drops of starch solution were added to the mixture, turning the mixture from yellow to black. This was titrated against 0.1 M sodium thiosulfate ($\text{Na}_2\text{S}_2\text{O}_3$) until the black color turns white (colorless). This process repeated in triplicate and the average titer value was calculated [41].

8. Physical Characterization of Castor, Palm Kernel and Groundnut Oils Biodiesel and Petrodiesel

The suitability of the castor, palm kernel and groundnut oils biodiesel produced as alternative diesel fuel for commercial grade fossil diesel was determined by evaluating their heats of combustion (heating/calorific value), specific gravity and kinematic viscosity. The results obtained are given in Table 3.

9. Castor Oil Biodiesel/Petrodiesel Blending

To obtain acceptable kinematic viscosity result for castor oil, the biodiesel produced was blended with petrodiesel in the following manner.

Petrodiesel (90%) - biodiesel (10%) : B10

Petrodiesel (80%) - biodiesel (20%) : B20

Biodiesel (propyl esters) : B100

The results are shown in Table 4.

RESULTS AND DISCUSSION

1. Extraction of Crude Plant Oils

The yield of the oils is given in Table 1.

The three oil samples showed good yield, with castor seed, having highest percentage (%) yield.

2. Pre-treatment of Oils

Crude plant oils contain some free fatty acids and phospholipids. The three oil samples used for biodiesel production were, therefore, pretreated to remove the free fatty acids and phospholipids. The result of the pre-treatment is shown in Table 2.

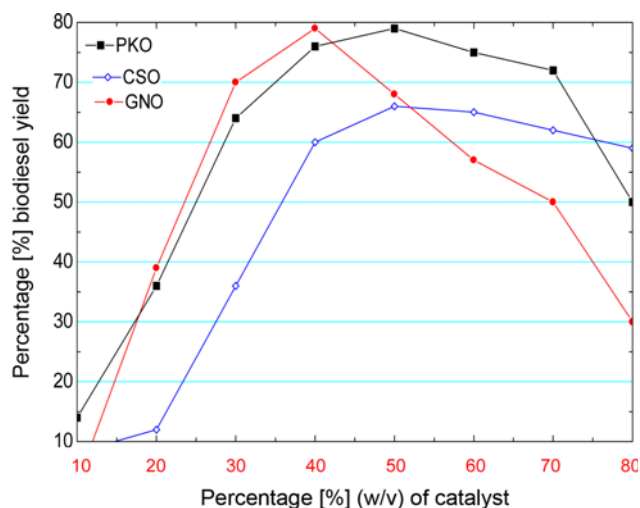
The significant losses recorded during pre-treatment could be probably as a result of the removal of free fatty acids and phospho-

Table 1. Yield of oils

Sample	Weight of seeds (kg)	Weight of extracted oil (kg)	Percentage (%) yield
Castor seed oil	7.80	3.80	48.72
Palm kernel oil	6.56	2.78	42.38
Groundnut oil	8.10	3.76	46.42

Table 2. Percentage loss on pre-treatment

Sample	Weight of unrefined oil (kg)	Weight of refined oil (kg)	Percentage (%) loss on pre-treatment
Castor seed oil	3.80	3.58	5.78
Palm kernel oil	2.78	2.61	6.12
Groundnut oil	3.76	3.52	6.38

**Fig. 1. Variation of percentage yield of biodiesel with percentage (w/v) of catalyst for CSO, PKO and GNO.**

lipids. The oil extracted from groundnut had high acid values, which could be responsible for its high percentage loss during pre-treatment.

3. Optimal Catalyst Weight Test

The graphical relationship between the biodiesel yield (%) and percentage weight per volume of the catalyst (% w/v) is given in Fig. 1.

The biodiesel yield increased steadily from 0.10% w/v of the catalyst until it reached a peak at 0.5% w/v of catalyst. Thereafter, it decreased for CSO and PKO. However, GNO reached a peak at 0.4% w/v, but decreased thereafter. It was clear, therefore, that the increment in percentage weight per volume of the catalyst did not give further volume increase in biodiesel obtained from castor seed, palm kernel and groundnut oils. This could be explained in accordance to Darnoko [26] that catalyst concentration levels greater than one may have favored the backward reaction - the formation of glycerol. The optimal catalyst weight test helped to confirm that increase in the amount of catalyst only led to production of soaps and not

Table 3. Physical characterization of biodiesel and petrodiesel

	Specific gravity at 28 °C	Calorific value MJ/kg	Kinematic viscosity (mm ² /s) at 30 °C
CSO biodiesel	0.87	37.54	7.21
PKO biodiesel	0.90	38.64	3.56
GNO biodiesel	0.89	37.52	4.12
Petrodiesel	0.83	45.52	2.85

biodiesel.

4. Specific Gravity

The specific gravity of CSO, PKO and GNO biodiesels was higher than the values obtained for petrodiesel. CSO, PKO and GNO were 1.049, 1.048 and 1.078 times that of petrodiesel, respectively.

The specific gravity obtained for the castor, palm kernel and groundnut oils biodiesel falls within the limit specified for biodiesel fuel in Europe (EN 14214:0.86-0.90). The specific gravity values for CSO, PKO and GNO biodiesel are important pointers to the suitability of the biodiesel as fuel substitute. This is because important fuel performance indicators such as heating values and fuel storage are correlated with specific gravity [42,32].

5. Calorific Value

The petrodiesel showed the highest calorific value - 45.52 MJ/kg, which is higher than the biodiesel produced from the oils. All the oils propyl esters (biodiesel) behaved comparably to diesel fuel (petrodiesel) in terms of rate of heat release.

6. Kinematic Viscosity

Biodiesel of all the oils had higher viscosity than conventional diesel fuel (petrodiesel). This is in agreement with reports from Alamu et al. [19], Ajav and Akingbehin [42]. The viscosity of biodiesel from castor oil was three times that of fossil diesel (petrodiesel); groundnut oil biodiesel had a viscosity which was twice that of petrodiesel.

The kinematic viscosity for PKO and GNO biodiesel fell within the specified limits by ASTM D6571 (3.5-5.0), but that of castor oil biodiesel did not. Knothe and Steidley [23], reported that castor oil biodiesel, in its neat form exceeds all kinematic viscosity specifications in biodiesel standards due to the high content of ricinoleic acid. The reported technical implication of higher viscosity biodiesel is that it decreases the linkages of fuel in a plunger pair and, in turn, changes the parameters of a fuel supply process [43].

The viscosity of castor oil biodiesel esters was in the range of 4.1-7.21 mm²/s which was higher than that of European biodiesel standards (EN 14214:3.5 - 5.0) and American Society of Testing Material Standards (ASTM D6751. 1.9 - 6.0). Knothe and Steidley [23] reported that the introduction of an OH group significantly increases viscosity and this is of significance for production of castor oil-based biodiesel. This fuel in its neat form exceeds all kinematic viscosity specifications in biodiesel standards due to the high content of ricinoleic acid in castor oil. However, the limit values of viscosity can be met through transesterification, followed by dilution or blending with conventional diesel fuel and vegetable oil [44]. Meanwhile palm kernel and groundnut biodiesel esters conform to ASTM D 6751 standards.

The kinematic viscosity and specific gravity of biodiesel and petrodiesel blend for castor oil in comparison with unblended biodiesel are given in Table 4.

The properties of the B100, B20 and B10 mixtures are compa-

Table 4. Result of kinematic viscosity and specific gravity of biodiesel and petrodiesel blend for castor oil in comparison with unblended biodiesel

Properties	B10	B20	B100	P100
Specific gravity (28 °C)	0.85	0.86	0.87	0.83
Kinematic viscosity mm ² /s (40 °C)	4.24	4.98	7.21	2.85

Table 5. Peroxide values of castor, palm kernel, groundnut oils and petrodiesel

Sample	Peroxide value (mmol peroxide/kg sample) in days		
	30	60	90
CSO biodiesel	80	80	81
PKO biodiesel	20	40	50
GNO biodiesel	10	50	60
Petrodiesel	Neutral	Neutral	Neutral

rable to those of petroleum diesel P100 and acceptable within what is specified for biodiesel in the ASTM D6751 standards (with the exception of viscosity of B100).

7. Biodiesel Oxidative Stability (Rancidity) Measurement

The biodiesel produced at 65 °C using alkali-transesterification method was exposed to light and air. The peroxide values were determined at one month interval each. The most significant undesirable change in liquid fuel with time is the formation of filtrate sediments. During long-term storage, oxidation due to contact with air (autooxidation) presents a legitimate concern with respect to maintaining fuel biodiesel quality [45]. The progress of the oxidation was monitored by measuring the peroxide value over a period of three months (a month interval) at room temperature. Garpen et al. [46] reported that biodiesel does not undergo conversion for a period of time, due to presence of natural antioxidant in the biodiesel oil sample. Three months is called the induction period after which it oxidizes quickly. The peroxide values of the oils are shown in Table 5.

Conventional diesel (petrodiesel) showed greater stability than the biodiesel produced from the oils. It showed no trace when peroxide value was determined. This could probably be due to the fact that the compositions of petroleum based diesel are different from that of biodiesel. Petroleum-based diesel does not actually contain as much unsaturated fatty acids as found in biodiesel. Petroleum-based diesel fuels are treated with a wide range of additives to improve lubricity, oxidative stability, corrosion resistance and many other properties. Biodiesel contains more or less unsaturated fatty acids in its compositions, which are susceptible to oxidation reactions accelerated by exposition to oxygen and their tendencies to polymerize [2].

Castor oil biodiesel was next in stability to petrodiesel. This is followed by palm kernel and finally, groundnut oils diesel. For castor oil biodiesel, the peroxide values remained constant for 30 and 60 days - 80 mmol peroxide/kg sample, respectively, and increased slightly at 90 days - 81 mmol peroxide/kg sample. Sujatha [44] reported that the presence of hydroxyl groups and double bonds impact unique chemical and physical properties that make castor oil a vital raw material, and stabilize the oil against oxidation.

The values of the peroxide value showed that castor oil biodiesel could withstand oxidation for more than three months. Palm kernel oil biodiesel, however, had a peroxide value which increased sharply from 20 mmol peroxide/kg sample (30 days) to 40 mmol peroxide/kg sample (60 days) and then increased to 50 mmol peroxide/kg sample in 90 days. Groundnut oil biodiesel showed the worst oxidative stability, as its peroxide value increased sharply from 10 mmol peroxide/kg sample to 50 mmol peroxide/kg sample in the 60 days and then 60 mmol peroxide/kg sample in the 90 days. Garpen

et al. [46] reported that oxidation is an autocatalytic process, so that when it starts it progresses at ever-increasing rate. This was exhibited by PKO and GNO biodiesel; but castor oil might have been probably stabilized against oxidation by the presence of hydroxyl groups and double bonds.

CONCLUSION

Population growth, ever increasing use of transport fuels, rising prices of fossil fuel, climate change and environmental pollution demand the use of renewable energy sources for a more sustainable energy solution. Vast scope exists for exploitation of castor, palm kernel and groundnut oils as bioenergy crops (although there are still some technological challenges to overcome, especially for castor oil biodiesel).

The following conclusions could be drawn from the present study:

- Biodiesel has been produced in a batch reactor using alkali-catalyzed method.
 - To obtain biodiesel, the transesterification process has been studied. Transesterification time controls the yield of product while purification is fundamental in order to fulfill the characteristics of propyl esters (biodiesel) as fuel.
 - Specific gravity of the biodiesel samples was found to be higher than that of petrodiesel and that specific gravity of biodiesel samples was temperature dependent. Also, specific gravity of castor oil biodiesel blend (B10 and B20) was lower than that of unblended biodiesel.
 - Calorific values of the biodiesel samples were lower than that of petrodiesel combusted under the same conditions of experiment.
 - The viscosities of biodiesel samples decreased as temperature increased. Both palm kernel and groundnut oils biodiesel conform to kinematic viscosities ASTM D6751 and EN 14214 specification standards.
 - Castor oil biodiesel has the highest storage stability.
- Lastly, relying on fossil fuel alone is no longer realistic due to global depletion of the non-renewable energy sources and the attendant negative environmental impact. The race for energy security in the face of imminent oil shortage is already gathering momentum. Countries in Asia, Europe, South American and many US state governments are not waiting for their fossil fuel to dry up completely before searching for alternatives, and only countries that don't value their own security and that of their citizens would stand alone.

RECOMMENDATIONS

GC should be carried out on the superior layer (biodiesel) in order to determine the amount of oils that have been converted to biodiesel. High viscosity limits the widespread use of castor oil as alternative to be used in diesel engine, as this report showed that castor oil biodiesel viscosity exceeds both European/American and all other specification standards. Likewise, in castor seed, research effort should be proposed for reduction of the toxic protein ricin and conversion of ricinoleic acid rich castor oil to oleic rich oil.

In future, much work can be done to reduce the cost of biodiesel if we consider non-edible oils, used frying oils instead of edible oils. Non edible oils such as Neem, Karanja, Jatropha etc. are easily available in Nigeria and very cheap compared to edible oils. With the

mushrooming of fast food centers and restaurants in Nigeria, it is expected that considerable amount of used frying oils will be discarded. These can be used for making biodiesel.

All potential feedstocks for biofuel (biodiesel) production are in abundance in the country (Nigeria). Nigeria, with her expansive arable land mass, can be one of the world's leading exporters of biodiesel, if the government puts a premium on energy security like many countries (such as US and some European countries) are now doing. However, there are fears that since biodiesel relies on primary agricultural products, a substantial growth in the biodiesel industry could make the prices of vegetable oil unaffordable to the common man. Hence, our approach to renewable energy sources should be gradual.

Lastly, government should provide funding, enabling environment and an enticing package of incentives. This involves providing comprehensive policy support and funding for research in the area of renewable energy source (biofuels).

ACKNOWLEDGEMENTS

The authors are grateful to all staff of the Department of Pure and Industrial Chemistry, University of Nigeria, Nsukka; the Departments of Science Laboratory Technology and Food Science and Technology, Federal Polytechnic, Idah for their contribution to the success of this work. We also acknowledge the assistance of Mr. B.I.D Obidiegwu of Analytical Laboratory of the Department of Soil Science Department, University of Nigeria, Nsukka, for his input towards the success of this work. Mr. Fidelis Eze of fluid Mechanics Laboratory and Mr. Oformata of Energy Research Center, University of Nigeria, Nsukka, are not left out, for their input to the completion of this research work. Finally, the indefatigable and unflinching administrative support received from Mr. Balogun Bashiru Bolaji of the department of Science Laboratory Technology, Federal Polytechnic Idah towards the publication of this manuscript is highly acknowledged.

REFERENCES

1. H. Fukuda, A. Kondo and H. Noda, *J. Biosci. Bioeng.*, **92**(5), 405 (2001).
2. C. L. Meher, V. D. Sagar and S. N. Nack, *Technical Aspects of Biodiesel Production by Transesterification - A Review*, Centre for Rural Development and Technological, Indian Institute of Technology, Delhi, New Delhi, India, 1 (2004).
3. A. I. Bamgboye and A. C. Hansen, *Institute of Agrophysics*, **22**, 21 (2008).
4. A. Gupta, S. K. Sharma and A. P. Toor, *J. Petrotech Society*, 40 (2007).
5. O. J. Alamu, T. A. Akintola, C. C. Enweremandu and A. E. Adeleke, *Scientific Research and Essay*, **3**(7), 308 (2008).
6. Y. C. Sharma, B. Singh and S. N. Updhyay, *Fuel*, **87**, 2355 (2008).
7. D. Tapasvi, D. Wiesenborn and C. Gustafson, *J. American Society of Agricultural Engineers*, **48**(6), 2215 (2005).
8. F. Ma and M. A. Hanna, *Bioresour. Technol.*, **70**, 1 (1999).
9. X. Zhao, B. El-Zahab and R. Broznahan, *J. Appl. Biochem. Biotechnol.*, **143**, 236 (2007).
10. D. Pimentel and T. W. Patrik, *Natural Resources Research*, **14**(1) (2005), DOI:10.1007/S/1053-005-4678-8.
11. H. Nouredдини and D. Zhu, *J. American Oil Chemists' Society (JOACS)*, **74**, 1457 (1997).
12. J. V. Garpen, *Fuel Processing Technology*, **85**, 1097 (2005).
13. B. Wenzel, M. Tait, A. Modenes and A. Kroumov, *Bioautomation*, **5**, 13 (2006).
14. Y. Zhang, M. A. Dube, D. D. McLean and M. Kates, *Bioresour. Technol.*, **89**, 1 (2003).
15. A. A. Refaat, N. K. Attia, H. A. Sibak, S. T. ElSheltawy and G. I. El-Diwani, *Int. J. Environ. Sci. Technol.*, **5**(1), 75 (2008).
16. S. Baroutian, M. K. Aroua, A. AbdulRaman and N. M. Sulaiman, *J. Appl. Sci.*, **8**(10), 1938 (2008).
17. A. B. Chhetri, M. S. Tango, S. M. Budge, K. C. Watts and M. R. Islam, *Int. J. Mol. Sci.*, **9**, 169 (2008).
18. *World Proved Reserved of Oil and Natural Gas*, United States Energy Information Administration (USEIA) (2007).
19. O. J. Alamu, M. A. Waheed, S. O. Jekayinfa and T. A. Akintola, Optimal transesterification duration for biodiesel production from nigerian palm kernel oil, *Agricultural Engineering International. The CIGR Ejournal*. Manuscript EE 07018, **IX** (2007a).
20. J. X. Kyu-Wan, L. Yu, J. H. Mei, Y. W. Kim, L. Yan and K. W. Chun, *J. Ind. Eng. Chem.*, **13**(5), 799 (2007).
21. M. Canakci and J. V. Garpen, *J. American Society of Agricultural Engineers*, **44**(6), 1429 (2001).
22. G. Knothe, *J. American Society of Agricultural Engineers*, **44**(2), 193 (2001).
23. G. Knothe and K. R. Steidley, *Elsevier*, **84**, 1059 (2005).
24. K. Krisnangkura, T. Yimsuwan and R. Pairintra, *Elsevier*, 2 (2005).
25. G. Knothe, *J. American Oil Chemists Society (JOACS)*, **83**, 10 (2006).
26. D. Darnoko and M. Cheryan, *J. American Oil Chemists' Society (JOACS)*, **77**(12), 1269 (2000).
27. Wikipedia, the Free Encyclopedia. *Biodiesel: A Historical Background*, Retrieved on August 2011 from <http://www.en.wikipedia.org/wiki/biodiesel>.
28. I. Titipong, *Biodiesel production from fryer grease*, Unpublished M.Sc. Thesis, Submitted to the College of Graduate Studies and Research, Department of Chemical Engineering, University of Saskatchewan, Saskatoon, Saskatchewan (2006).
29. Y. Zhang, M. A. Dube, D. D. McLean and M. Kates, *Bioresour. Technol.*, **89**, 1 (2003).
30. J. Jitputti, B. Kitiyanan, K. Bunyakiat, P. Rangsunvigat and P. Jenvanitanpanjakul, *Transesterification of Palm Kernel Oil and Coconut Oil by Difference Solid Catalysts*, The Joint International Conference on "Sustainable Energy and Environment, 1-3 December, Hua, Thailand (2004).
31. S. Shah, S. Sharma and M. N. Gupta, *J. American Chem. Soc., Energy and Fuels*, **18**, 154 (2004).
32. Y. A. Yuan and Q. Zhang, *The specific gravity of biodiesel fuels and their blends with diesel fuel*, *Agricultural Engineering International: The CIGR Journal of Scientific Research and Development*, Manuscript EE 04 004, **VI** (2004).
33. P. David, *The Chemical Analysis of Food*, 7th Ed., Churchill Livingstone. Edinburgh, London, 489 (1976).
34. V. M. Krause and A. M. Hunscher, *Food, Nutrition and Diet Therapy*, 5th Ed., W. S. Saunders Company, Philadelphia, London, 56 (1999).
35. C. Alais and G. Linden, *Food Biochemistry*, Aspen Publication,

- Gaithersburg, Maryland, 67 (1999).
36. T. Leevijit, W. Wisutmethangoon, G. Prateepchaikul, C. Tongurai and M. Allen, *Second Order Kinetics of Palm Oil Transesterification*, The Joint International Conference on "Sustainable Energy and Environment (SEE) (3 - 025(O)) 1-3 December, Hua Hin, Thailand, 277 (2004).
37. S. H. Fogler, *Elements of Chemical Reaction Engineering*, 4th Ed. Pearson Education International, United States, 10 (2006).
38. O. J. Alamu, *The Pacific Journal of Science and Technology*, **8**(2), 43 (2007).
39. J. J. Asiedu, *Processing tropical crops. A technological approach*, Macmillan Education Ltd., London, 124 (1989).
40. G. Knothe, *J. American Oil Chemists Society (JAOCs)*, **76**(7), 23 (1999).
41. A. A. Ibitoye, *Laboratory Manual on Basic Method in Plant Analysis*, Concept IT, Akure, Nigeria, 20 (2006).
42. E. A. Ajav and A. O. Akingbehin, *A study of some fuel properties of local ethanol blended with diesel fuel*, Agricultural Engineering International: the CIGR Journal of Scientific Research and Development, Manuscript EE 04 004 Vol. VI, (2002).
43. S. Lebedevas and A. Vaicekausas, *Research into the application of biodiesel in the transport sector of lithuania*, *Transport.*, **XXI**(2), 80 (2006).
44. M. Sujatha, *Biotechnological interventions for improving jatropha and castor for biofuels*, *Petrotech*, New Delhi, India (P09 - 869) (2009).
45. A. R. Ferrari, S. D. V. Oliveira and A. Scabio, *Scientia Agricola*, **62**(3) (2005).
46. J. V. Garpen, B. Shanks and R. Pruszek, *Biodiesel production technology*, National Renewable Energy Laboratory (NREL) Colorado, Sub-Contractor Report, 1 (2004).