Fuel properties of Nigerian Castor Seed Oil Biodiesel

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Abstract: This paper presents an explicit account of the fuel properties of biodiesel produced from Nigeria castor seed oil. The oil was first characterized for its physico-chemical properties. This was subsequently followed by transesterification of the castor seed oil with methanol in a laboratory reactor using 1 % w/v potassium hydroxide (KOH) catalyst at a temperature of 45 ^{0} C , mole ratio of methanol to oil of 6:1 and reaction time of 60 minutes. Standard fuel characterization (ASTM fuel tests) was carried out on the resulting biodiesel. Experimental results shown that optimum of 96 % methyl ester yield were obtained at 45 ^{0}C with a corresponding purity of 98.06 % against the European Union lower limit of 96.5 %. The important properties of the biodiesel such as specific gravity, flash point, total sulphur, pour point, kinematic viscosity, cetane number, cloud point and water and sediment values were 0.88, 150 ^{O}C, 0.006 %, 1 ^{O}C, 2.5 mm^2/s, 48.32 ± 2, 6 ^{O}C and 0.04 % vol respectively. These values compared favorably with the ASTM and EN standards for biodiesel. The result validates that Nigeria castor seed oil methyl ester could be used as an alternative to petroleum diesel.

Keywords: Castor Oil, Biodiesel, Transesterification, Renewable Energy

1. Introduction

The exploration of new energy resources has become increasingly important in recent years due to the depleting fossil fuel reserve and the attendant adverse environmental effects from the combustion of fossil derived fuel. Consequently, the development of sustainable and eco-friendly energy resources has taken centre stage. One of the alternatives of renewable energy is fuel derived from plant and animal matter. These so-called "biofuels" can be produced by various processes, such as fermentation, pyrolysis, gasification, liquefaction, hydrotreatment and transesterification. Among these processes, transesterification of vegetable oil or animal fat to produce biodiesel has been successfully enjoyed commercial popularity. Biodiesel is a petroleum diesel substitute and can be readily used in most diesel engines without any modification. Furthermore engine performance using biodiesel has been shown to be comparable to that of conventional diesel fuel. Other merits of biodiesel include reduction in exhaust gases emission of carbon monoxides, particulates and hydrocarbon from the engine and enhanced engine lubrication. (Zakaria and Harvey, 2012).

Biodiesel is an alternative fuel produced from vegetable oils, animal fats, and greases through a chemical process known as transesterification, it is the reaction of natural oils with an alcohol, and then refining the mixture to create molecules which can be easily burned in a diesel engine (Cholada and Sathaporn, 2010; Chinmoy *et al.*, 2009; Bugaje and Mohammed, 2008). Its primary advantages includes; non-toxicity, renewability, biodegradable, reduction in exhaust gases emission of carbon monoxides, particulates and hydrocarbon, enhanced engine lubrication and can be used in diesels engine without extensive modification (Knothe *et al.*, 2005; Zakaria and Harvey, 2012).

Biodiesel have been produced from edible vegetable oils such as soya bean oil, palm oil, coconut oil, groundnut oil, shear butter oil e.t.c. Concerns have been raised about production of biofuels in general from Agricultural food crops, which virtually is going to compete with food production around the globe (Bugaje and Mohammed, 2008). This led to human rights activists calling for a ban on the production of biodiesel from food crops. Waste cooking oil and tallow from animal fats can be alternative feedstock for biodiesel production, but for large scale production may not be possible because of the lack of continuous and sufficient supply of these types of feedstock (Chinmoy *et al.*, 2009). European Union produces many Agricultural products to meet up with the demand of both sector and high premiums are paid for some Agricultural product and set aside land. Though the story is quite different here in Africa and to be specific Nigeria because the industry is its nascent status, use of non edible resources are at the fore front to form the bulk raw materials. Some of the non edible resources that could be used and majorly found in Nigeria are; Jatropha curcas planted by farmers as demarcation for small farm land and castor seed which grows very well in all Northern States as a weed. These oil bearing seed are non edible and so causes no threat to food security (Bugaje and Mohammed, 2008).

Castor oil *(Ricinus communis)* is a species belonging to the *Euphorbiaceae* family, has many common names known as "Zurman" in Hausa, "Laraa" in Yoruba, "Ogilisi" in Igbo, "Kpamfini gulu" in Nupe, "Jongo" in Tiv, and "Era ogi" in Bini (Chakrabarti and Ahmad, 2008). It is found in both wild and cultivated states in all the tropical and subtropical countries of the world, it is also growing on a wide scale on marginal and wastelands (Bello and Makanju, 2011; Chakrabarti and Ahmad, 2008). It seeds makes up about 35 % to 55 % of the weight of the seeds, and the oil contains 85 % to 90 % ricinoleic acid, a monounstaturated, 18- carbon fatty acid, with hydroxyl functional group on the twelfth carbon (12-hydroxy, 9-octadecenoic acid). Other fatty acid present include; palmitic, stearic, arachidic, hexadecenoic, linolenic, with Oleic and linoleic acids as the other significant components. The oil is colourless to very pale yellow liquid with mild or no odour or taste. Its boiling point is 313 ^{O}C (595 ^{O}F) and has a density of 961 kg/m^3, it has one of the highest viscosities among vegetable oils (Bello and Makanju, 2011; Chakrabarti and Ahmad, 2008). Refining vegetable oil for transesterification is employ to reduce the free fatty acid present in the oils which cause soap formation during the transesterification and difficulties in separation of biodiesel from the glycerol which leads to low biodiesel yield. However, castor oil was reported to have low FFA might not necessarily require refining for biodiesel production.

This work will focus on the transesterification of crude castor seed oil as a non edible vegetable oil and the characterization of the methyl ester produced.

2. Methodology

50 ml of crude castor oil was measured using a measuring cylinder into a beaker and was pre-heated to 70 °C using a hot plate magnetic stirrer equipped with a thermometer, to remove moisture in the reaction. The oil sample was then allowed to cool to about 45 °C and was maintained at this temperature.

Prior to the conversion of oil into biodiesel, 1 %w/v of potassium hydroxide was measured into a beaker using electronic weighing balance and tightly closed to avoid reaction with air and was completely dissolved into a measured methanol (having 99.5% purity). The solution (methoxide) was then poured into the beaker containing the pre-heated oil to react. The reaction took place for 30 minutes at 45 °C with constant stirring using a magnetic stirrer at 1000 rpm.

After the reaction, the mixture was poured into a separating funnel and allowed to settle under gravity for 24 hours. The mixture separated into two distinct layers. The upper layer contained biodiesel, excess methanol, soap, and residual catalyst while the lower layer contained glycerol. The glycerol was gradually drained off leaving the upper layer.

Phosphoric acid was added to neutralize the residual catalyst, washed with warm distilled water of between 40 °C to 45 °C to remove methanol, residual catalyst and soaps. In washing, warm water was added to the biodiesel produced in the separating funnel and allowed to settle. The lower layer was drained off again until a clear lower layer with no trace of soap was observed. The biodiesel was then dried using a hot plate to remove the water content. The resulting product was amber coloured.

2.1 Characterization of *Jatropha curcas* Biodiesel

The biodiesel produced was tested for its fuel properties; the flash point was determined in a Pensky–Martens closed-cup tester (ISL, Model FP93 5G2) using ASTM D 93. Cloud point and pour point determinations were determined using ASTM D 2500 and ASTM D 97. The kinematic viscosities were determined at 25 °C, using a Viscometer (Model VT-03) following the ASTMD 7042 procedure. The water contents were determined following ASTM D 95 procedure. Sulphur content by elemental sulfur analysis. While the cloud and pour point was obtained according to ASTM D2500-91 and ASTM D97-96 method respectively (Alhassan *et al.*, 2005).

The cetane number and high heating value was calculated (Krisnangkura, 1986; Demirbas, 1998). The acid value was obtained by titration. The yield of the transesterification process was calculated as:

$$\text{Yield (\%)} = \frac{\textit{Total weight of methyl esters}}{\textit{Total weight of oil sample}} \times 100\ \% \quad (1)$$

3. Results and Discussion

The vegetable oil was transeterified, the result obtained from the characterization of the oil and the properties of the methyl esters are as shown in Table 1 and 2 respectively

Table 1: Properties of the crude castor oil

Parameters	Value
Moisture Content (%.)	2.4
Oil Content (w/w %)	45.49 – 55.05
Specific Gravity at 25 °C	0.89
Refractive Index	1.43
Viscosity @25 °C (cst)	6.9
pH	5.9
Acid Value (mg KOH/g)	0.9
% Free Fatty Acid	0.45
Peroxide Value (Meq/kg)	3.0
Saponification Value(mgKOH/g)	178
Iodine Value (g I_2/100g)	85
Hydroxyl Value	163

Table 2: The ASTM and EN specification for biodiesel production

Property	ASTM D 6751		EN 14214		This work	1	2
	Method	Limit	Method	Limit			
Specific gravity (Kg/L)	D1298	0.87-0.9	EN ISO3675	-	0.88	0.9268	0.886
Flash point (°C)	D93	130 Min	ISO CD3679e	101 Min	150	190.7	160
Distillation IBP (°C)	D1160	360 °C max	-	-	250	-	-
10 % (°C)					312	-	-
50 % (°C)					336	-	-
90 % (°C)					340	-	-
Total sulphur (% wt)	D5453	0.05 Max	-	-	.006	-	.006
Pour point (°C)	D2500	-	-	-	1	-45	-26
Kinematic viscosity (mm^2/s)	D445	1.9 – 6.0	EN ISO3104	3.5-5	2.5	15.98	10.43
Biodiesel index	D976	-	-	-	48.32	-	-
Cetane number	D613	47 Min	EN ISO5165	51 Min	48.32 ± 2	-	53
Free gylcerine(%mass)	D6584	0.02	pr EN14105m	-	0.01	-	-
Total gylcerine (%mass)	D6584	0.240	pr EN14105m	0.25 max	0.2	-	-
Cloud point (°C)	D2500	-	-	-	6	-23	7
Water by distillation (% vol)	D2709	0.05 Max	-	-	0.05	-	-
Bottom sediment & water (% vol)	D2709	0.05 Max	-	-	0.04	-	-

Source: Gerpen *et al.*, 2004a; Gerpen *et al.*, 2004b; Chakrabarti and Ahmed, 2008; Leung *et al.*, 2010; Alptekin and Canakci, 2011; 1. Carmen, 2004; 2. Bello and Makanju, 2011.

3.1 Specific Gravity/Density

It is important to determine the density of the produced fuel as it is a requirement for the estimation of the Cetane index of the fuel (Demirbas, 2009). The specific gravity for transesterified castor oil using potassium hydroxide as catalyst is 0.88. This value is in accordance with 0.88 – 0.90 by Patil and Deng (2009) and 0.86 – 0.90 by Bajpai and Tyagi (2006) but slightly lower than 0.9268 by Carmen, 2004. The result obtained shows an appreciable consistency with previous work.

3.2 Flash Point

The flammability or non-flammability behavior of the diesel fuel is generally characterized by the flash point (Oghome and Ibe, 2009). It is the lowest temperature at which the fuel will be flammable and the ASTM D93 standard specifies 150 ^{O}C as minimum temperature. Result of this present work obtained 150 ^{O}C. The result obtained is also in agreement with 164 ^{O}C reported by Oghome and Ibe (2009). This shows that Biodiesel from Castor seed oil is safe for handling and storage, non flammable and safe for engine. As was reported by Bajpai and Tyagi, (2006) that the US Department of Transport considers a material with flash point of 93 ^{O}C or higher to be non-hazardous and that from the storage perspective and fire hazard, biodiesel is much safer than petroleum diesel. Since flash point measure the residual alcohol in the biodiesel. This indicates that greater portion of the methanol was used during reaction (Oghome and Ibe, 2009).

3.3 Sulphur Content

Biodiesel is non-aromatic and does not contain sulfur (Bajpai and Tyagi, 2006). The sulphur content of the biodiesel produced was 0.006. This value is in agreement with 0.05 % maximum stipulated by ASTM standard and 0.0087 reported by Bajpai and Tyagi (2006). This shows that the biodiesel produced from castor seed oil is environmentally friendly.

3.4 Pour Point

The pour point is the lowest temperature at which a fuel sample will flow. In this work, the pour point obtained was 1 ^{O}C. The result obtained is within the acceptable range of -15 to 10 ^{O}C by the ASTM specification, - 6 to 2 by Patil and Deng (2009) for Jatropha, canola, corn and karanja methyl esters. The result shows that biodiesel from castor seed oil will be satisfactory for use in the winter.

3.5 Viscosity

The measure of a fluid's resistance to flow is referred to as viscosity. The result obtained shows a kinematic viscosity of 2.5. From the results obtained, biodiesel has higher viscosity than conventional diesel fuel. This is in agreement with reports from several researchers (Bajpai and Tyagi, 2006; Gerpen *et al.*, 2004; Oghome and Ibe, 2009; Alamu *et al.*, 2007). However, the result is lower than 3.8 to 4.1 by Bajpai and Tyagi (2006) for soy methyl ester, 5.88 by Oghome and Ibe (2009) for groundnut methyl ester, but is in accordance with 1.9 – 6.0 by the ASTM specification. Fuels with low viscosity may not provide sufficient lubrication for the precision fit of fuel injection pumps, resulting in leakage or increased wear. Diesel fuels with high viscosity tend to form larger droplets on injection, which can cause poor combustion, increased exhaust smoke and emissions (Encinar *et al.*, 2002). Wang *et al.* (2006) reported that high viscosity may lead to poor atomization of the fuel, incomplete combustion, choking of the injectors, ring carbonization and accumulation of the fuel in the lubricating oils. The kinematic viscosity of the produced biodiesel was much lower than that of the crude castor seed oil, thereby indicating that its use will not have any negative effect on the engine.

3.5 Cetane Index/Number

Cetane number is a measure of ignition quality of diesel fuel. The higher the cetane number, the easier the fuel will ignite when it is injected into the engine (Demirbas, 2009b). Gerpen *et al.* (2007); Demirbas (2005); all reported that biodiesel has a higher cetane number than petrol diesel because of its higher oxygen content. This implies that the engines will run smoother and create less noise when running on biodiesel (Demirbas, 2005). Result for cetane index of this work is 48.32, which is quite in agreement with 47 minimum by ASTM specification. This value is less than 61 reported by Chhetri *et al.* (2008) for waste cooking oil, 50.58 and 51.22 by Alhassan *et al.* (2005) for methyl ester from new and waste cotton seed oil respectively. Fuels with higher cetane number results in higher engine performance compared to other fuels, resulting in lower emission of all pollutants other than Oxides of Nitrogen (NOx) (Chhetri *et al.*, 2008). This shows that since the obtained result from castor seed oil is higher than the petrol diesel, it has the capability to run an engine smoothly, create less noise and emit less pollutant.

3.6 Water and Sediment

Result of water and sediment in this work is 0.04 wt%. 0.05 wt% is the maximum allowable content of water and sediment in biodiesel by ASTM specification which is in agreement with the result obtained. Chhetri *et al.* (2008) reported that there was no water and sediment content in the sample. Tint and Mya (2009) reported a trace in the jatropha methyl ester. 0.2 wt% was reported by Oghome and Ibe (2009). From the result obtained it implies that the drying method employed after washing to remove traces of soap and free glycerol is efficient and that the product will not support microbial growth in storage tanks.

3.7 Cloud Point

Clogging is a major disadvantage of the use of some vegetable oils and animal fats. Gerpen *et al.* (2004b) and Chhetri *et al.* (2008) reported that cloud point is the temperature at which a cloud of wax crystals first appears in the liquid sample when cooling. The result from this work for cloud point was 6 ^{0}C. This is greater than – 1 ^{0}C reported by Chhetri *et al.* (2008) for ethyl ester produced from waste cooking oil and in agreement with 6 ^{0}C by Alamu *et al.* (2007) for palm kernel methyl ester. This shows that castor methyl ester is safe to use at winter or regions with low temperature.

4. Conclusion

The transesterification of the crude castor seed oil without pre treatment using potassium hydroxide as catalyst was successful. The results of fuel characterization of the castor biodiesel clearly shows that there was substantial improvement in the fuel properties such as viscosity, density and cetane number when compared to castor oil as the biodiesel produced exhibit relatively close properties to the petroleum diesel than the crude castor oil. These fuel properties compared favorably with references values of notable Standard and reported values in literatures.

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