Effects of Catalyst Type and Concentration on Biodiesel Yield and Quality

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Abstract: This paper present study report the effect of catalyst type and concentration on yield and quality of biodiesel produced from cotton seed oil. This was achieved through the production of biodiesel from refined cottonseed oil via the transesterification process by studying the effects of various catalysts on biodiesel yield. The catalysts studied include; sodium hydroxide, potassium hydroxide, iron sulphate and potassium carbonate at different concentrations. The yield of biodiesel decreased with increase in catalyst concentration from 0.25 to 0.75 wt % thus, highest conversion was obtained at 0.25 wt % concentration for sodium hydroxide (NaOH), potassium hydroxide (KOH), iron sulphate (FeSO4) and potassium carbonate (K_2CO_3) catalysts with corresponding yields of 96 %, 94 %, 92 % and 82 %. The fuel properties from the transesterified refined cottonseed oil show its suitability with the ASTM standard for the production of biodiesel.

Keywords: Biodiesel, Catalyst Type, Catalyst Concentration, Cottonseed Oil

1 Introduction

The search of newer sources of energy has been triggered by the decline in the available fossil fuel reserve, limitations of its usage, the threat to environment resulting from the emission of green house gases that results from the combustion of fossil derived fuel and technological changes that promotes newly available energy forms (Dias *et al.*,2012). Vegetable oils have been perceived as a renewable alternative to compete with petroleum derived diesel fuel but in early 1980s difficulties were encountered due to their high viscosity and low ignition power (Agarwal, 2008). These have led to the emergence of biodiesel; a promising alternative to diesel fuel which has received considerable attention over the years due to its unique properties: it is biodegradable, renewable, non toxic, less emission of gaseous and particulate pollutants with higher cetane number than normal diesel, absence of carcinogens and lower sulphur content than the mineral diesel (Fan *et al.*, 2011).

Biodiesel is mostly produced from transesterification (alcoholysis); a process whereby an alcohol (such as methanol and ethanol) are reacted with vegetable oil in the presence of a catalyst (e.g. base, acid or an enzyme depending on the properties of the raw material) (Bugaje and Mohammed, 2008). Common vegetable oil in the Nigeria includes palm oil, palm kernel oil (PKO), peanut oil, cottonseed oil and soybean oil (David, 2006).

However, there are a lot of vegetable sources still available have not been extensively investigated as prospective feedstock for biofuel production, examples are Cotton seed, Sesame, seed etc.

Cotton plant is a perennial grown warm-weather tree that grows naturally. The plant belongs to the *Malvaceae* family, the tribe *Gossypieae*, and the genus *Gossypium*. The principal domesticated species of cotton of commercial importance are *hirsutum, barbadense, arboreum, and herbaceum*. Cottonseed bears oil that has finds extensive application in the production of biscuits, crackers, doughnuts and potato chips and the preparation of ice cream substitutes. Other industrial uses of cottonseed oil include alkyl resins for interior paints, special lubricants and soft soaps (Orhevba and Efomah, 2012). The oil is reported to contain high levels of saturated fat, and tends to have high levels of pesticide residue as well; hence it is not healthy for human consumption (Fan *et al.*, 2011). Due to presence of gossypol a natural toxin that protects the plant from insects (Olaibi, 2011). In the last three decades, the proportion of cotton seed being crushed to produce oil and meal has dropped from 91% to less than 40 %. Instead the seed are used as feed for cattle (Ash and Dohlman, 2008). This can be attributed to the protein, energy and fiber content of the overall seed (Blasi and Drouillard, 2002).However the presence of gossypol, is a probable problem for cattle when whole seed is consumed rather than meal. Other reason for the decreased in demand for cottonseed oil in the food industry is as a response to various health concerns that are likely to emanate from it consumption (Santos *et al.*, 2005). In recent times it has been reported for biodiesel production (Fan *et al.*, 2011; Abdulwakil *et al.*, 2012). This is because the use of cottonseed oil as a feedstock for biodiesel would not have a large impact on food-grade vegetable oil supplies. Ash and Dohlman (2008) reported that United State (US) net consumption of all edible fats and oils was 30.1 x 10^9 pounds, of which only 708 x 10^6 pounds (2%) was from cottonseed. The author added the diversion of use of this seed oil from food related uses to fuel is not anticipated to have a considerable impact on food value. The benefits of cottonseed oil are mainly viewable from a manufacturing standpoint. It has an incredibly long shelf life and also a very high smoke point (450 degrees) (Abdulwakil *et al.*, 2012). The oil content the seed have been reported to be 15.05 % wt of seed (Orhevba and Efomah, 2012).

This study report the effect of different catalyst type and concentration of the yield and quality of biodiesel from cotton seed oil.

2 Methodology

The characterization of cotton seed oil was done in accordance with the report of Akpan *et al.*, (2005). The properties characterized includes specific gravity, acid value, free fatty acid, saponification value, moisture content, iodine value, refractive index, peroxide value and viscosity. The biodiesel was produced in accordance to the literature of Musa *et al.*, (2012). The transesterification of the triglyceride from cotton seed oil was conducted using four different catalysts (which include sodium hydroxide (NaOH), potassium hydroxide (KOH), potassium carbonate (K_2CO_3) and iron sulphate ($FeSO_4$)) at different catalyst concentrations of 0.25, 0.5 and 0.75 % at constant reaction time (1 hour), temperature (60 ^oC) and mole ratio of oil to alcohol (1:6). The biodiesel produced from the use of the each catalyst was characterized for specific gravity, flash point, cloud point, kinematic viscosity and pour point. This was done in accordance to the American

Standard for Testing and Material (ASTM) reported by Musa *et al.*, (2012).

3 Results and Discussion

The result of the characterization of the commercially obtained cottonseed oil is shown in Table 1. The properties of the oil were compared with the standard and the values reported by other researchers.

Table 1: Characterization of the cottonseed oil

Properties	Units	ASTM Limit	Experimental Values	Ankapong (2010)
Moisture Content	%	0.2max	0.12	-
Specific Gravity	-	0.918-0.926	0.917	0.938
Acid Value	mgKOH/g	0.6max	1.12	3.45
FFA	% Oleic	< 1	0.56	1.73
Refractive Index	-	1.468-1.472	1.468	1.474
Iodine Value	g/100 oil	98.0-118.0	111	121.0
Saponification Value	mgKOH/g	189-198	193	192
Peroxide Value	meq/kg	< 1	0.90	-

Table 2: Percentage Yield using NaOH

Runs	NaOH	Glycerol (ml)	Yield	
			ml	%
1	0.25	6	48.0	96
2	0.50	15	47.0	94
3	0.75	22	38.5	77

Table 3: Percentage Yield using KOH

Runs	KOH	Glycerol (ml)	Yield	
			ml	%
1	0.25	10	47.5	94
2	0.50	13	46.0	92
3	0.75	18	36.0	72

Table 4: Percentage Yield using $FeSO_4$

Runs	$FeSO_4$	Glycerol (ml)	Yield	
			ml	%
1	0.25	4	46.0	92
2	0.50	5	43.0	86
3	0.75	6	41.0	82

Hence, from the result obtained for each of the catalyst, the optimum yield was obtained using 0.25 % catalyst concentration.

Table 5: Percentage Yield using K_2CO_3

Runs	K_2CO_3	Glycerol (ml)	Yield	
			ml	%
1	0.25	5	41.0	82
2	0.50	6	40.0	80
3	0.75	8	27.0	54

3.1 Effect of Catalyst Concentration

The results for all catalyst types (Table 1-4) shows a decrease in yield as the catalyst concentration increased. The decrease in ester yield may be due to soap formation at higher catalyst concentrations hence loss of methyl ester during washing (Oghome and Ibe, 2008). Ankapong, (2010) reported that, ester yield increases as the amount of catalyst increased from 0.25 to 1.0wt% for refined soybean, unrefined soybean and palm kernel oil.

Table 6: Properties of biodiesel produced using different catalyst type

Test	Unit	ASTM	Biodiesel produced using Different catalyst			
			NaOH	KOH	$FeSO_4$	K_2CO_3
Specific gravity@ 25 °C	-	0.88 – 0.95	0.88	0.88	0.92	0.89
Density	g/ml	0.875 – 0.95	0.95	0.95	0.99	0.96
Kinematic viscosity	mm^2/s	1.9-6.0	3.2	3.8	4.8	4.0
Flash point	°C	130 min	146	138	139	130
Pour point	°C	-	3	2	-5	-4
Cloud point	°C	-	5	4	1	2

3.2 Effect of catalyst type

The various catalysts used for this study had different effect on the methyl ester yield produced. The result shows sodium hydroxide catalyst gives the best yield with refined cottonseed oil with a yield of 96 %. This is in agreement with the European norm which ipulate a minimum of 96.5 wt %.

3.3 Properties of Biodiesel

The flash point is a key property in the determination of the flammability of a fuel. The flash point obtained from this work shows sample produced ranging from 130 -148 °C for all catalyst type as shown in Table 1. These values are consistent with the ASTM standard.

These results also show that the biodiesel produced using the various catalysts were safe for handling. This is because a typical flash point of pure methyl esters should be greater than 93°C, classifying them as "non-flammable" (Gerpen *et al.,* 2004). However, during production and purification of the biodiesel, not all methanols may be removed thus making the fuel flammable and more dangerous to handle and store if flash point falls below 130 °C. Excess methanol may also affect engine seals and elastomer and corrode metal components (Gerpen *et al.*, 2004).

The cloud point is the temperature at which a cloud of wax first appears in a liquid when it is cooled down under conditions prescribed in ASTM D2500 test method (Gerpen *et al.*, 2004). The value determined for the cloud point in this work for the various catalysts ranges from 1 °C - 5 °C, for all catalyst used. The cloud point is a critical factor in cold weather performance for all diesel fuels. For temperatures below these cloud point temperatures, biowax begins to form which thickens the oil and clog fuel filters and injection in engines. This shows biodiesel produced using $FeSO_4$ can be use in a cooler region than the other catalyst.

Pour point is a measure of the fuel gelling temperature, at which point the fuel can no longer be pumped. The values of pour point for the biodiesel produced in this work shows $FeSO_4$ with a value of -5 °C as the lowest compare to the other catalyst. According to ASTM standard D 6751, no limit is specified for Pour point. The reason is that the climate conditions in the world vary considerably, thus affecting the needs of biodiesel users in a specific region.

The standard for biodiesel states that the fuel should have a density between 0.875 and 0.950 g/ml. This property is important mainly in airless combustion systems because it influences the efficiency of atomization of the fuel. The results obtained showed that for the four catalysts studied, NaOH and KOH with a density of 0.95 each fall within the acceptable range of the ASTM standard while $FeSO_4$ and K_2CO_3 have a density of 0.99 and 0.96 respectively, which are slightly above the ASTM standard. Density increases with decreasing chain length and increasing number of double bonds, this explains the high values for fuels rich in unsaturated compounds (Ankapong, 2012).

According to ASTM D 6751, for biodiesel to be used in diesel engines, the kinematic viscosity must be between 1.9 and 6.0 mm^2/s. The kinematic viscosities of the biodiesel produced from the four catalysts ranged from 3.0 to 4.8 mm^2/s. The values are in agreement with the standard specified by ASTM. Viscosity is closely related to the fatty acids composition of a given biodiesel sample. It increases with increasing length of fatty acid chain. Viscosity is inversely related to the number of double bonds. This explains the high viscosity ratings for biodiesel obtained from saturated materials such as palm oil (6.20mm^2/s) and palm kernel oil (5.92mm^2/s) and low ratings for highly unsaturated compounds such as soybean methyl ester (4.14mm^2/s). Unexpected high viscosity value of methyl ester above the ASTM standard may be attributed to high fuel ageing during storage (Ankapong, 2010).

4 Conclusion

This work showed cottonseed oil to exhibit good physiochemical properties and could be useful as biodiesel feedstock. Among the catalyst studied, NaOH gives the optimum yield of 96 % at 0.25 wt% catalyst concentrate. However all the biodiesel produced from various catalysts satisfactory qualify for diesel engine application.

It was obvious that biodiesel yield is dependent on catalyst type and concentration but the quality of the biodiesel does not depend on the catalyst type.

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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 ^{0}C, 0.006 %, 1 ^{0}C, 2.5 mm^{2}/s, 48.32 ± 2, 6 ^{0}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 ^{o}C	0.89
Refractive Index	1.43
Viscosity @25 ^{o}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 (^{O}C)	D93	130 Min	ISO CD3679e	101 Min	150	190.7	160
Distillation IBP (^{O}C)	D1160	360 °C max	-	-	250	-	-
10 % (^{O}C)					312	-	-
50 % (^{O}C)					336	-	-
90 % (^{O}C)					340	-	-
Total sulphur (% wt)	D5453	0.05 Max	-	-	.006	-	.006
Pour point (^{O}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 (^{O}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 ^{o}C. This is greater than – 1 ^{o}C reported by Chhetri *et al.* (2008) for ethyl ester produced from waste cooking oil and in agreement with 6 ^{o}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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