Nigerian Jatropha Curcas Oil Seeds: Prospect for Biodiesel Production in Nigeria

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Abstract-This study investigated production of biodiesel from oil seeds of *Jatropha curcas*, obtained in Nigeria, with a view to encouraging the cultivation of Jatropha plant in Nigeria and to providing a motivation for the development of biodiesel production from this feedstock. Also effect of oil-to-alcohol molar ratio on the biodiesel production from Nigerian *Jatropha curcas* seeds oil was investigated with a view to confirming established base case. A maximum yield of fatty acid methyl esters (FAME) of 87% was obtained at 333 Kelvin, oil-to-alcohol molar ratio of 1:6 and at 1wt% NaOH catalyst concentration. The physical properties of the BD obtained from Nigerian Jatropha oil met the ASTM standard of D-6751. Consequently, this study reveals that *Jatropha curcas*, an economically invaluable plant in Nigeria, could be a good feedstock for biodiesel production in Nigeria.

Keywords-Biodiesel, Transesterification, Nigerian *Jatropha curcas* oil, Biofuel

1. Introduction

The growth in the world's population has resulted in a surge of energy demand and for more than two centuries, the world's energy supply has relied heavily on non-renewable crude oil derived from fossil fuels, out of which 90% is estimated as being consumed for energy generation and transportation [1]. This has now led the world to be presently confronted with double crises of fossil fuel depletion and environmental degradation. Khan[2] has predicted that before the end of the 21st century the world's reserves of fossil fuels would be expended. Devanesan *et al*. [1] also confirmed that these known crude oil reserves could be depleted in less than 50 years at the present rate of consumption.

Horn [3] revealed that as at year 2010, 99.1 and 95 million barrels of crude oil will be consumed per day according to OPEC and Energy Information Administration (EIA) calculations respectively. This implies that as at year 2010, the world had consumed nothing less than 35 billion barrels of oil per year, but in new field discoveries, we are finding less than 6 billion barrels per year. With this fact, more dependants are on countries like Nigeria, Mexico and Venezuela known to be world oil production peaks. As a result of this, oil checks are becoming smaller and smaller and very soon will be insignificant relative to the world needs. These realities have a boost to the search for renewable and sustainable alternatives to fossil fuels. One of these renewable and sustainable alternatives is biodiesel (BD). Biodiesel is a clear amber-yellow liquid obtained from vegetable oils, animal fats or grease. Its non-flammability, biodegradability, non-toxicity and non- explosiveness makes it more environmentally friendly compared to petroleum diesel (PD) [4].

Several vegetable oils have been used as raw materials for biodiesel production. Vegetable oils such as palm oil, soybean oil, sunflower oil, coconut oil, rapeseed oil and tung oil have been used. Even the use of oils from algae,

microalgae, bacteria and fungi has been investigated [5-8]. Some of these feedstocks are found in abundance in Nigeria and they could be edible or non-edible. The edible oil seeds found in Nigeria are soybean, groundnut and palm kernel oils, coconut oil while the non-edible ones that are most commonly found are *Jatropha curcas* (*Jatropha curcas L.*) and Neem (*Azadirachta indica*). Advantages of vegetable oils as diesel fuel compared to diesels from fossil fuel include high heat contents; ready availability, liquid nature-portability, lower sulfur content, lower aromatic content, biodegradability and renewability [9]. However the drawbacks of the oils include higher viscosity, lower volatility and reactivity of the unsaturated hydrocarbon chains present in the oils [9].

According to Gui *et al*[10], 95% of biodiesel is still made from edible oils which are competitive with consumption. Among the two common non edible oils in Nigeria, *Jatropha curcas* plants are usually found economically un-useful and invaluable. These plants are mostly used as fences for houses and are present in abundant quantity in abandoned lands while the usefulness of neem plants is felt across the nation. *Jatropha curcas* is drought-resistant oil bearing multipurpose shrub/small tree, belonging to the family of *Euphorbiaceae* [11]. It originates from Central America and is widely grown in Mexico, China, north-east Thailand, India, Nepal, Brazil, Ghana, Mali, Foso, Zimbabwe, Nigeria, Malawi, Zambia and some other countries [11]. The *Jatropha curcas* plant, which can easily be propagated by cuttings, is widely planted as a hedge to protect fields, as it is not browsed by cattle or other animals. It is well adapted to arid and semi-arid conditions and often used for prevention of soil erosion [12]. Also, it grows in a wide range of rainfall regimes, from 200 to 1500 mm per annum [13]. The plants grow quickly forming a thick bushy fence in a short period of time of 6–9 months, and growing to heights of 4 m with thick branches in 2–3 years [14]. It has a life span of 50 years [15]. Seeds of *Jatropha curcas* resemble castor seeds in shape, but are smaller and brown. *Jatropha curcas* can tolerate high temperatures and grows very well under low fertility and moisture conditions [14]. It can survive in poor stony soils [16]. Due to leaf-shedding activity, Jatropha plant becomes highly adaptable in harsh environment because decomposition of the shed leaves would provides nutrients for the plant and reduces water loss during dry season. Thus, it is well adapted to various types of soil, including soils that are poor in nutrition such as sandy, saline and stony soils [15]. Jatropha cultivation in wastelands would help the soil to regain its nutrients and will be able to assist in carbon restoration and sequestration [17].

Studies on the use of *Jatropha curcas* plant revealed that ithas oil yield of 47.5% [18] and 49.1% [19] compared to oil yield of 39.7% from neem[19]. Table 1 compares selected studies on biodiesel production from *Jatropha curcas* oil from different countries. Lu *et al.*[20] studied biodiesel production from *Jatropha curcas* oil obtained in China; Baroi *et al.*[11] also investigated biodiesel production from Indian *Jatropha curcas* oil. Juan *et al.*[15], in their review work, reported a number of research efforts expended on the transesterification of Jatropha oil with methanol and ethanol, using alkaline catalysts such as KOH and NaOH. Furthermore, Table 2 compares fatty acid composition of

Jatropha curcas oil with fatty acid composition from other common vegetable oils. Results from these research efforts suggest that *Jatropha curcas* oil could be a useful feedstock for biodiesel production, with a dramatic reduction in costs of production. Also the use of *Jatropha curcas* oil could promote global acceptance and commercialization of biodiesel as an alternative source of energy [21].

Various techniques have been employed for biodiesel production namely direct use and blending, micro emulsions, thermal cracking (pyrolysis) and transesterification[22]. However, the most commonly used method is transesterification of vegetable oils and animal fats [22], due to its simplicity. These methods have been reported to give yields as high as above 90% [22]. Transesterification method is not new, its history can be traced back to 1846 when glycerol was produced from castor oil via ethanolysis as reviewed by Balat [23]. Demirbas defined transesterification as a process whereby molecule of the raw renewable oil is chemically broken down into methyl or ethyl esters in the presence of an alcohol (methanol, ethanol, propanol or butanol) and a catalyst, giving glycerol as a by-product [9]. This transesterification technique could either be acid, alkali or enzyme transesterification.

Homogenous catalysts (base and acid catalysts) are conventionally used [20, 21, 24-26]. Recent studies have also made use of heterogeneous catalysis [27-30]. Studies have shown that ester yields during transesterification depend on molar ratios of alcohol to vegetable oil, catalysts loading/type of catalysts, reaction temperature, reaction time, content of the free-fatty acid and water content [4, 31]. While alcohol-to-oil ratio, catalysts loading /type of catalysts, reaction temperature, reaction time are operating conditions, free fatty acid and water content determine the quality of the oil used and may mar transesterification reaction if they are not reduced [20, 25]. However, for this study, the most common transesterification process, alkali transesterification, was used to enable good comparison between the biodiesel obtained from Nigerian *Jatropha curcas* and those from other countries.

Nigeria, one of the countries with oil production peaks, still faces energy crises like shortage of petroleum products and incessant increase in prices of fuel. With this kind of problem, also coupled with the predicted shortage of fossil fuel, it is essential for Nigeria as a country to search for alternative source of energy. Up till now, research effort to source for alternative source of energy in Nigeria is still limited. A few studies, such as, reports from Alamu et al [32] on the investigation of biodiesel production from Nigerian palm kernel oil, Belewu et al [33] on the comparison of physico-chemical property biodiesel from Nigerian and Indian *Jatropha curcas* oil and study from Aransiola et al [24] on the production of biodiesel from soybean oil are available in open literature. Also, comparison of level of global biodiesel production is depicted in Figure 1. In Figure 1, it is obvious that Nigeria biodiesel production per year from year 2005 to year 2009 was zero when compared with biodiesel production from other countries. In view of the aforementioned statement, it is therefore imperative for a country like Nigeria to begin research on production of biodiesel from available and economically feasible feedstock

to backup her dependency on fossil fuel. A good example of readily available and economically feasible feedstock in Nigeria is oil from *Jatropha curcas*. Therefore, in this study, production of biodiesel from Nigerian *Jatropha curcas* oil with a view to encourage the cultivation of Jatropha plant in Nigeria is presented.

Table 1: Comparison of Reaction Conditions and FAME Yield of Biodiesel produced using *Jatropha curcas* Oil from Nigeria and other Selected Countries

S/N	Source of Jatropha curcas oil	Catalyst Type	Catalyst Concentration	Methanol: Oil	Reaction Time	Reaction Temperature (^{o}C)	Speed Agitation (rpm)	Final FAME Yield (%)	Ref.
1	India	H$_2$SO$_4$ (Homogeneous)	1% w/w	3:7(v/v)	3 h	65	400	90.1	Jain and Sharma [17]
		NaOH (Homogeneous)	1% w/w	3:7(v/v)	3 h	50	400		
		CaO + Fe$_2$(SO$_4$)$_3$ (Heterogeneous)	5% w/w	6:1	3 h	60	300	100	Endalew et al [27]
		Li - CaO + Fe$_2$(SO$_4$)$_3$ (Heterogeneous)	5% w/w	6:1	3 h	60	600	100	
2	Egypt	CaO	1.5% w/w	12:1	2.5 h	70	700	95	Hawash et al [28]
		CaO activated with ammonium carbonate	1.5% w/w	12:1	1 h	200	700	96	
3	China	H$_2$SO$_4$ (Homogeneous)	0.4% w/w	8:1	0.5 h	60	600	86.2	Wang et al [21]
		KOH (Homogeneous)	1% w/w	6:1	0.5 h	60	600		
4	Indonesia	H$_2$SO$_4$ (Homogeneous)	1% w/w	3:5 (60%w/w)	1 h	50	400	90	Berchmans and Hirata [25]
		NaOH (Homogeneous)	1.4% w/w	6:25 (24%w/w)	2 h	65	400		
5	Nigeria	H$_2$SO$_4$ (Homogeneous)	1% w/w	3:5 (60%w/w)	1 h	50	200	87	This Study
		NaOH (Homogeneous)	1 w/w	6:1	3 h	60	200		

Table 2: Fatty acid composition (%) of *Jatropha curcas* oil and other oils

Fatty acid	Groundnut oil[a]	Palm kernel oil[b]	Sunflower oil[b]	Soybean oil[b]	Palm oil[b]	Neem oil[c]	*Jatropha curcas* oil[b]
Oleic (18:1)	58.68	15.4	21.1	23.4	39.2	44.5	44.7
Linoleic 18:2	21.77	2.4	66.2	53.2	10.1	18.3	32.8
Palmitic 16:0	8.23	8.4	-	11.0	44.0	18.1	14.2
Stearic 18:0	2.46	2.4	4.5	4.0	4.5	18.1	7.0
Palmitoliec 16:1	0.11	-	-	-	-	-	0.7
Linolenic 18:3	0.34	-	-	7.8	0.4	0.2	0.2
Arachidic 20:0	1.83	0.1	0.3	-	-	0.8	0.2
Margaric 17:0	-	-	-	-	-	-	0.1
Myristic 14:0	0.12	16.3	-	0.1	1.1	-	0.1
Caproic 6:0	-	0.2	-	-	-	-	-
Caprylic 8:0	0.01	3.3	-	-	-	-	-
Lauric 12:0	0.28	47.8	-	-	0.2	-	-
Capric 10:0	0.01	3.5	-	-	-	-	-
Behenic 22:0	3.89	-	-	-	-	-	-
Saturated	16.81	82.1	11.3	15.1	49.9	37	21.6
Monounsaturated	58.79	15.4	21.1	23.4	39.2	44.5	45.4
Polyunsaturated	22.11	2.4	66.2	61.0	10.5	18.5	33

[a]Aluyor et al.[34] ; [b]Akbar et al [35]; [c]Martín et al. [19]
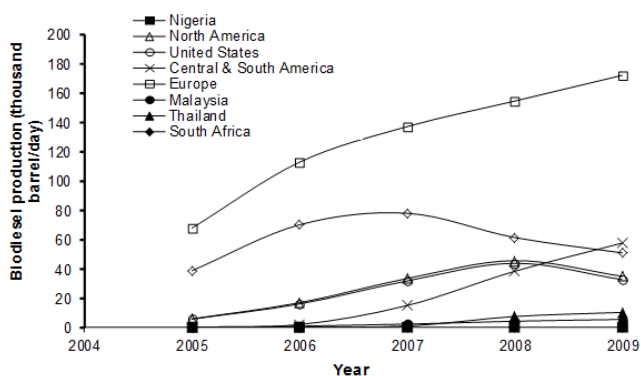
Fig. 1: World biodiesel production of selected countries

2. Experimental

2.1. Material and Methods

Jatropha curcas seeds were obtained from Ikere-Ekiti, a town in Nigeria. Jatropha curcas seeds are abundant in this town and the inhabitants usually use the plants are fences around their houses or as cross-bars to control erosion. All the chemicals used in this study, such as, methanol, sodium hydroxide, anhydrous calcium chloride, methyl oleate, acetone, acetonitrile were all of analytical grade purchased from Sigma Aldrich, Germany.

The oil from the seed was extracted according to the method of Akintayo [18]. The acid value of the crude Jatropha curcas oil was 35.8 mg KOH/g; usually the free fatty acid value should not be more than 1% [36], therefore pre-treatment of the oil is essential. The pre – treatment was carried out according to the method of Berchmans and Hirata [25].

2.2. Alkali Catalyzed Transesterification of Jatropha curcas Oil

Optimum reaction temperature and amount of catalyst concentration had been investigated and reported by Aransiola et al. [24] to be 333 K and 1 wt% NaOH as reaction temperature and catalyst loading, respectively. These conditions were used in the transesterification that was carried out in batch mode using a 250 mL Erlenmeyer flask with 100 g of Jatropha curcas oil. The rate of agitation of 200 rpm was used and kept constant throughout the reaction while the alcohol(methanol)-to-oil ratios were 3:1, 4:1, and 6:1. Catalyst, 1wt% of sodium hydroxide, was dissolved into an amount of alcohol according to the aforementioned alcohol-to-oil ratios. Firstly, the oil was heated up to the reaction temperature in the Erlenmeyer flask and the alcohol-base mixture was added to the oil, and the reaction time was varied between 15 minutes and 180 minutes.

After the reaction, sample collected was allowed to settle for twelve (12) hours in a separating funnel by gravity settling into a clear, golden liquid biodiesel on the top with the light brown glycerol at the bottom. After this period, the glycerol was drained off from the bottom of the separating funnel. The raw biodiesel was water washed three times so as to remove the non - reacted catalyst and glycerol. To get pure biodiesel free of methanol, the water-washed sample was purified in a rotary evaporator in order to remove the excess methanol. Following this, the ester phase was dried in a desiccator over anhydrous calcium chloride. Samples of the produced biodiesel were analyzed with methyl esters, pour points, flash points, cloud points, density, moisture content, and kinematic viscosity as the sought parameters.

2.3. Analytical Methods

2.3.1. Proximate Analysis

The Proximate analysis is used to determine the composition of the seed sample to get the moisture content, ash content, crude fibre and crude protein. This was carried out by the methods of analysis stipulated in [37].

Determination of Percentage Ash

About 2g sample of Jatropha curcas seeds was heated in a crucible dish at 100°C until all the traces of water was expelled. Few drops of pure olive oil was added and slowly heated over flame until swelling stopped. The dish was then placed in a furnace at 525°C and left until white ash was obtained. The weight of the white ash obtained was noted and the following calculation was made to calculate percentage ash in the sample.

$$\% \, Ash = \frac{100 \, (W_i - W_f)}{2g}$$

Where

$W_i = Initial \, weight \, of \, the \, Ash$

$W_f = Final \, weight \, of \, the \, Ash$

Determination of Percentage Crude Protein

In determining the percentage crude protein, the sample undergoes three distinct processes: Digestion, Distillation and Titration

Digestion:

About 2 grams of ground sample was put into a digestion flask. Sufficient quantity of a digestion mixture (consists of copper sulphate, selenium (catalysts) and sodium or potassium sulphate to raise the boiling point) and 20ml - 30ml of concentrated sulphuric acid was added to the sample. The mixture was digested for three hours using the Tecator Digestion System 1007 Digester.

Distillation:

The product of digestion was diluted to 50ml with water. 50ml of 2% boric acid (mixed with methyl red and bromsogreen) was poured into a 250ml Pyrex flask. 50ml of 40% sodium hydroxide was added to 20ml of the diluted sample. The digestion tube and Pyrex flask are placed in the distillation unit (with the Pyrex flask under the receiving tube). The distillation process was then activated until the total content of the Pyrex flask was about 100ml.

Titration:

The distillate was titrated with 0.097 HCl until the green colour disappeared. The net volume of acid (v) used was noted

$$\% \; Nitrogen = \frac{v \times 0.097 \times 14 \times 100 \times 2.5}{2g}$$

Molecular mass of Nitrogen = 14

% crude protein = 6.25 × % Nitrogen

Determination of Crude Fibre

About 2g of the oil sample was transferred into a 500ml conical flask. 100ml of digestion reagent was added to the flask and then boiled as rapidly as possible. The heat was turned down and allowed to simmer under reflux for exactly 40 minutes from first adding the reagent using an air condenser consisting of a glass long fitted in a rubber bung. The content of the flask was swirled from time to time to ensure even digestion. The flask was removed and cooled under a cold water tap. The contents was filtered through a 15cm Whatman No 4 paper and washed six times with hot water and then once with industrial spirit in which all the content was transferred into a flat bottomed porcelain dish. The residue was dried for two hours at 100oC and then cooled for 3 minutes in a dessicator and weighed. The residue was burnt in a muffle furnace at 600oC for 30 minutes then cooled in a dessicator and re-weighed.

$$\% \; Crude \; fibre = \frac{W_i \times 100}{W_s}$$

Where W_1 = Weight loss on ashing

W_s = Weight of sample

2.3.2. Percentage Oil Yield

The difference in weight of the seed sample just before and after the extraction of oil is taken as the weight of oil expelled. Percentage oil yield is then calculated thus:

$$Y_{OIL} = \frac{W_{OE}}{W_{IS}} \times 100$$

where Y_{OIL}, the percentage oil yield expressed in %; W_{OE}, the weight of the oil expelled in g and W_{IS}, the weight of the initial sample in g.

2.3.3. Physico-Chemical Analysis

The extracted seed oils were analyzed for some physicochemical properties (saponification value, acid value) by methods described by the association of Official Analytical Chemists [24, 37].

Saponification Value

A measure of 5g of *Jatropha curcas* oil was weighed into a conical flask and 25ml of alcoholic KOH was added to the oil in the flask. A long air condenser was attached and the flask was heated until the solution became homogenous (saponification was complete). The boiling, accompanied by agitating the content occasionally, was done for 30minutes at such rate as to prevent loss of alcohol from the air condenser. The solution was allowed to cool and 1ml of phenolphthalein indicator was added, while the excess alkali was titrated with 0.5N HCl. A blank determination at the same time and under the same condition using the same quantity of KOH solution was carried out.

$$Saponification \; value, mgKOH/g \; of \; Sample = \frac{(B - S) \times N \times 56.1}{W}$$

Where

B = Blank titre value.
S = Titre value for oil sample
N = normality of HCl
W = mass, grams of sample.

Acid Value

A measure of 5g of Jatropha oil was weighed into a conical flask. A quantity of 50ml of solution made up of equal volume of 95% ethanol and diethyl ether was added and then gently mixed to dissolve the oil. The mixture was heated to enhance homogenization and was then titrated against 0.1 N KOH in methanol, using 1ml of phenolphthalein indicator, until a slight pink colour persisted for 15 seconds. The acid value was computed using the equation below

$$Acid \; Value = \frac{T \times N \times 56.1}{m}$$

Where, T is titre value in mL; N is normality of methanolic KOH and m is mass of sample in g.

HPLC Method

The free fatty acids of the crude and pre - treated oil as well as the ester concentration were analyzed on LC -20AB Prominence consisting of binary pump, controller, ultraviolet detector and an auto-sampler. The column used was 4.6 mm ID x 15 cm CLC- ODS (T) of 5 μm particles and 100 Å pore size. It has two mobile phases; Acetonitrile and Acetone at 51: 49 at a flow rate of 0.7 Ml.min-1. Acetone was used to make 1mg/ml of the sample. 10μl of the sample was injected into an auto - sampler vials. The HPLC analysis was conducted according to the method shown by Dubé et al. [38] and Darnoko and Cheryan [39].

2.3.4. Characterization of BD

The characterization of the biodiesel was carried out according to the methods used by Aransiola et al. [24]. The parameters are determined with the standard methods used

which are presented in Table 3. Flash point was determined by the Flash cup closed tester. Cloud and Pour points were determined simultaneously as per the ASTM methods. About 50 mL of the biodiesel was placed in a coning flask. This was closed tightly with a cork carrying a test thermometer. This flask was placed in a jacket filled with ice and sodium sulphate. The coning flask was removed periodically without disturbing the oil in order to inspect for cloud and pour points.

The density and the viscosity were measured at room temperature using the density bottle and the Brooke auto viscometer (DV-I PRIME, Brookfield, USA) respectively.

3. Results And Discussions

3.1. Quality Analysis of the Feedstock

3.1.1. Proximate Analysis of the Jatropha curcas Seed

To be so sure of the contents of the seed sample before carrying out any extraction, proximate analysis was performed on a small portion of the sample. The results obtained are shown in Table 3. The results obtained are similar to the reported values obtained by Food and Agriculture Organization (FAO) of the United Nations. However, a significant 48% reduction in the ash content might be attributed to compositional variation associated with the fertility of the soil used for cultivation.

Table 3. Proximate analysis of Nigerian Jatropha curcas seed and FAO Jatropha seed

Properties	Nigerian *Jatropha curcas* seed	FAO *Jatropha curcas* seed*
Ash	3.25	6.21
Protein	23.2	21.0
Crude Fibre	23.12	19.92
Moisture	4.03	4.05

*Source: [40]

3.1.2. High Free Fatty Acid (FFA) Reduction of the Jatropha curcas Oil

Although high free fatty acid content of Jatropha curcas oil is reported [20, 41], this was also tested. Transesterification of a small portion of the oil using NaOH catalyst produced a significant amount of soap (data not shown). Acid-catalyzed pretreatment method was therefore employed to reduce the free fatty acid (FFA). Ninety grams of methanol (60% w/w of oil) and 0.815 mL of concentrated sulphuric acid (1% w/w of oil) were added together and allowed to warm for about 15 minutes on a hot plate. This mixture was added slowly to the oil and agitated for one hour at 333 K - 338 K. After this, the mixture was allowed to settle and methanol-water mixture rose to the top. The methanol, water, and sulfuric acid layer was decanted. The bottom fraction which is now the pre - treated oil has a free fatty acid (FFA) level measured to be less than 0.5%. This value is satisfactory; *Jatropha curcas* oil with FFA level less than 1% will give a high yield of biodiesel [21].

3.1.3. Chemical and Physical Properties of the Jatropha curcas Oil

The data obtained from the study of the physical and chemical properties of the test samples showed that the oil content of Jatropha curcas kernel was determined at 52.20% which was comparable with the oil content of 47.25%, 49.1% and 63.16% gotten by Akintayo [18], Martín et al. [19] and Akbar et al. [35] respectively. Oil content of Jatropha curcas kernel was found higher than linseed, soybean, and palm kernel which is 33.33%, 18.35% and 44.6%, respectively [42]. Its high oil content is indicative of its suitability as non-edible vegetable oil feedstock in oleo chemical industries (biodiesel, fatty acids, soap, fatty nitrogenous derivatives, surfactants and detergents, etc) [35]. The chemical and physical properties of this oil as shown in Table 4 also fell within the range of the ones gotten by Akintayo [18].

Table 4. Chemical and physical properties of *Jatropha curcas* oil

Parameters	Values
Acid value (mgKOH.g^{-1})	35.8
Percentage oil content yield (%)	52.2
Density at room temperature (kg.m^{-3})	895
Viscosity at room temperature (cSt)	41.4
Saponification value (mgKOH.g^{-1})	193
Percentage free fatty acid (%)	18.1
Cloud point (K)	283
Pour point (K)	275

3.2. Alkali Transesterification of the Pre-treated Nigerian Jatropha curcas Oil to BD

3.2.1. Quality of the BD Obtained from the Nigerian Jatropha curcas Oil

Table 5 presents the quality of the BD obtained from the oil. The standardized characteristics for BD are also included in Table 5. The quality of the BD obtained in this study compared very well with the standard.

Table 5. Results of characterization of Jatropha curcas oil biodiesel

Properties	Jatropha curcas oil Biodiesel	Biodiesel Standard	Test Method
Flash point (°C)	170	130(min)	ASTMD–93
Moisture content	Nil	0.050 max	ASTMD–2709
Kinematic viscosity	5.64	1.9 – 6.0	ASTMD–445
Cloud Point (°C)	3	-	ASTMD–2500
Specific gravity at 15/15°C	0.88	0.860–0.900	-
Pour point (°C)	-6	-	ASTMD – 97

3.2.2. Production of Fatty Acid Methyl Ester (FAME) via Transesterification of Nigerian Jatropha curcas Oil

Figure 2 depicts the effect of alcohol to oil molar ratio on the ester concentration during the alkali transesterification

of the pretreated Jatropha oil at 333 K. At this temperature, ester concentration increased with increasing alcohol to oil molar ratio. This can be attributed to the content of alcohol that is above the stoichiometric value resulting in the enhanced formation of the product during the transesterification of oil. In addition, the results revealed that at 2nd and 3rd hour, the fatty acid methyl ester (FAME) concentration obtained with alcohol-to-oil ratio of 4:1 approached the FAME concentration at alcohol-to-oil ratio of 6:1. However, alcohol-to-oil ratio of 6:1 gave highest yields of ~87% at 333 K during the transesterification when compared to the yields obtained at alcohol-to-oil molar ratios of 3:1 and 4:1. The optimum yields at alcohol-to-oil molar ratios 3:1 and 4:1 were 80.54% and 84.31% respectively at 333 K. The results obtained in this study regarding the influence of alcohol-to-oil molar ratio on BD production are consistent with the studies reported in the literature [21, 26]. Wang et al. [21] reported obtaining a maximum yield of 86.2% of BD during alkali transesterification of using Jatropha curcas oil to BD at alcohol-to-oil ratio of 6:1 with 1% w/w alkali catalyst and at reaction temperature of 333 K. Furthermore, the results reported in the article showed that conversion of oil to BD is enhanced at higher alcohol-to-oil molar ratio. This is in agreement with the report documented in the review of Ma and Hanna [22] regarding the influence of alcohol-to-oil molar ratio on the production of BD from vegetable oils.
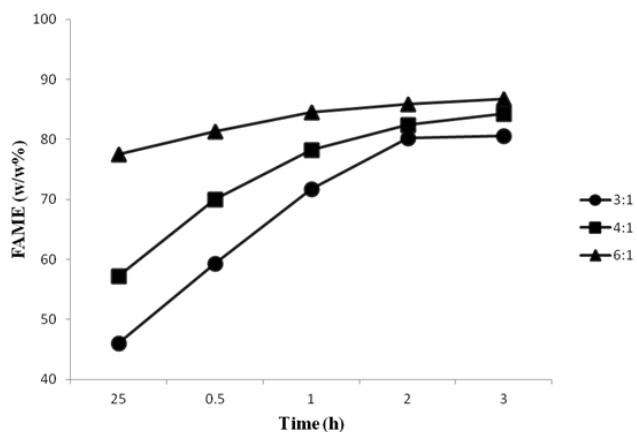

Fig. 2. Effect of oil to alcohol molar ratio on fatty acid methyl ester concentration for pretreated Jatropha curcas oil at 333 K

3.2.3. Quality of Nigerian Biodiesel Compared with Biodiesel from Selected Countries

Outcome of this study compared with literature is shown in Table 1. It is noteworthy to mention that the results compare favourably with literature putting into consideration the variation in the reaction conditions (see Table 1). Furthermore, the results from India and Indonesia using the homogenous catalysts have shown an improvement of 3.4% and 3.3% increase in yield of FAME compared to the results of this study. This might be attributed to the increase in the total reaction time and speed agitation for Indian BD while that of Indonesia may be due to increase in the base catalyst concentration and also speed agitation. Likewise, Nigerian

BD showed an improvement of 0.9% increase in yield of FAME over the BD produced from China using also the homogenous catalysts. This might also be as a result of reduced acid catalyst concentration in China BD and reduced total reaction time. Though the difference in the FAME yield between Nigerian BD and China BD is not as high as that of India and Indonesia, this might have been compensated by the high speed agitation of 600 rpm of China BD. For further work in using Nigerian Jatropha curcas oil for BD production, high speed agitation should be used.

Looking at effect of heterogeneous catalysts on the FAME yield in all the countries (see Table 1), it is clear that FAME yield between 95% and 100% was obtained. Though heterogeneous catalyst has not been conventionally used but rigorous researches are being carried out on it. Great advantages of heterogeneous catalysts over homogenous one is that it can be re-used which will finally lead to reduced cost of production, not as toxic as homogenous making it more environmentally friendly. Application of heterogeneous catalysts with high rate of agitation on the conversion of Nigerian Jatropha curcas oil to BD will be of high benefits. This will lead to high FAME yield, reduced production costs and cleaner technology.

Nevertheless, more conversion of Nigerian *Jatropha curcas* oil to BD could again be possible by overcoming the equilibrium limitation. Overcoming the hurdle is possible with the use of extractor-type catalytic membrane reactors (e-CMRs). In e-CMR, glycerol selective or ester selective membranes could selectively extract glycerol or ester from the reaction zone as soon as they are produced, thereby shifting the equilibrium forward. The forward-shift of the equilibrium position would enhance conversion and hence increase in the yield of BD. Application of e-CMRs has been demonstrated for isomerization reaction, which is an equilibrium limited reaction. (Daramola et al., 2010a; Daramola et al., 2010b) In the study of Daramola et al., 2010a, a 33% increase (above equilibrium conversion) in conversion of m-Xylene into p-Xylene during isomerization of m- Xylene to p-Xylene and o-Xylene over Pt-HZSM-5 catalyst in an e-CMR equipped with a nanocomposite MFI-alumina membrane as a separation unit is reported. In addition the authors reported production of ultra-pure p-Xylene as product in the reactor [43]. Although application of e-CMRs for transesterification is not reported in this article (or perhaps in any open literature), but it is expected that the conversion of Jatropha curcas oil to BD might be enhanced if an e- CMR is applied. However, major hurdle could be the development of high flux defect-free membranes (polymer or inorganic) displaying high selectivity for BD or glycerol.

4. Conclusion

In this study, biodiesel was produced from Nigerian *Jatropha curc*as seed oil using an established method. The quality of the biodiesel agrees well with the standards of the American Standard Testing Method and the literature. The maximum yield obtained from the pre-treated *Jatropha curcas* oil (non edible oil) was 87 % at 333 K when the alcohol-to-oil molar ratio and catalyst concentration were 6:1

and 1% w/w NaOH, respectively. The results of this study could be thought-provoking to Nigerian scientists and engineers towards the development of active research efforts that aim at producing biodiesel research from *Jatropha curcas* plants. In addition, the results could also trigger off the interest of Nigerian farmers and other stakeholders to be actively involved in the cultivation of *Jatropha curcas* plants for biodiesel production.

Acknowledgements

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