

# Effects of Reaction Conditions on the Alkali-Catalysed Biodiesel Production from *Jatropha Curcas* Kernel of Nigerian Origin for Optimal Production

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**Abstract-** The blistering decline in the Nigerian petroleum reserves coupled with the crucial sustainable development goal (SDG) No 7 (which is concerned with ensuring a universal access to cost-effective energy with low carbon footprint by 2030) have made it highly imperative for Nigeria (the 7th most populous country in the world) to intensify research and industrial efforts towards attaining the SDG targets before the year 2030. Biodiesel has been produced in this work through alkali-catalysed transesterification from *Jatropha curcas* kernel (JCK) of Nigerian origin. The extensive characterization of the extracted *Jatropha curcas* kernel oil (JCKO) is indicative of its potential as a viable feedstock for biodiesel production in Nigeria. The analysis conducted to characterize the produced biodiesel by investigating the effects of various reaction parameters on its yield has given a set of optimum reaction conditions which are: oil-methanol ratio of 1:6, 1% catalyst dosage and reaction time of 60 min. at a pre-determined optimum temperature of 60 °C for the highest yield of 92.4%. The produced biodiesel properties compared satisfactorily with ASTM D6751 (standard for B100-100% biodiesel with zero blend). Undoubtedly, this possibility of biodiesel production from the Nigerian JCK is an impetus to Nigerian rural dwellers who will farm the plants while the comprehensive allied methods and data are aimed to serve as a database for the Nigerian urban entrepreneurs and Government Agencies who will process the kernels from harvesting stage and optimally produce biodiesel thereby enhancing the sustainability of Nigerian economy and environment to meet the global regulations.

**Keywords** *Jatropha-curcas* kernel, biodiesel, alkali-catalyst, optimisation, transesterification.

## 1. Introduction

Nigeria, as a country, is naturally endowed with both high quality renewable energy sources such as biomass, wind,

solar, hydropower, agricultural feedstocks and reasonably high grade of non-renewable energy resources such as coal, crude oil/fossil fuel, natural gas, tar sands etc. In spite of these natural endowments, en route to sustainable development, Nigeria is being delayed majorly both by

problem of extremely low accessibility to energy services and a poor level of energy consumption. It is of no doubt that, energy consumption is the biggest obstacle in the economic growth of a country [1]. Energy is one of the major components of economic and social development [2]. Surprisingly, about 90% of Nigeria economy is dependent on crude oil [3]. This level of the country's overdependence on fossil fuels is an awakening call for serious attention in order to salvage it from a looming energy crisis.

The world has the challenge of expanding electricity production, meeting demand and ensuring energy security for the support and development of society [4]. Concisely, Nigeria's power sector retains high energy losses, between 30% and 35%, from generation to billing. This is significantly high as compared with the US, where power losses across lines usually come to less than 7%, even across long distances [5]. This low performance of the national power sector has consequently made most owners of homes, offices and industries to unavoidably depend on non-environmental friendly fossil diesel-powered generating plants with poor fuel economy. These fossil fuels are known to pollute the environment by their allied harmful sulphur-related exhaust gases emissions which are directly linked to the causes of most human health hazards.

In addition, instead of pipelines that are being used in developed countries, the conventional mode by which Nigeria transports its petroleum fuel is with the aid of diesel-powered fuel trucks which consequently often leads to an undesirable surge in the nation's consumption of fossil fuel (diesel) thereby leading to incessant scarcity in diesel fuel. Looking at this from a broader scope, the global-oil-consumption is currently averaged 1.6 million barrels per day [6].

However, the world fossil fuels' reserves are finite, and it is foreseen it will run out nearly 50 years for oil, 60 years for natural gas, and 80 years for coal [7]. In addition, going by the current extraction trend, it has been estimated that Nigeria's fossil fuels will be depleted to an uneconomical point by the year 2050 [8]. Therefore, this blistering decline in the Nigerian petroleum reserves, coupled with the afore mentioned (which have always been the causes of the frequent and uncontrollable rise in petroleum prices) and also the consequences imposed on its environment by the exhaust gases resulting from these petroleum products-powered engines (internal combustion engines), have made it highly inevitable for Nigerians to respond to the needs of the dynamic global market by diversifying further into other areas of exploration of which biodiesel as an alternative fuel is inclusive. Environmentally, biodiesel is better as it does not contain sulfur, so sulfur emissions are eliminated [9].

Another expected trigger for the need of biodiesel exploration as an alternative fuel was the binding policy Nigeria with other countries consented to in a recent environmental forum held in New York to reduce carbon emissions by 20% by 2020. This, coupled with the crucial Sustainable Development Goal (SDG) No 7 which is concerned with ensuring a universal access to clean and cost-effective energy by 2030 have made it highly imperative for

Nigeria being the 7th most populous country in the world with over 200 million people to intensify research and industrial efforts towards the attainment of cheap and clean energy target of the SDGs before the year 2030.

Production of biodiesel from jatropha curcas (JC) has become an attractive subject of research in the recent years owing to its environmental benefits and its renewable source. JC plant, referred to as "miracle tree" by [10], is purposely cultivated for the extraction of jatropha oil from its seeds. JC (Physic nut) is a drought-resistant shrub belonging to the family Euphorbiaceae [11]. JC has high productivity of seed oil [12] and the biodiesel produced has similar properties to that of petroleum-based diesel [13]. From the results of the proximate analysis carried out by Akintayo [14] on the seeds flour of JC presented in Table 1, it is evident that almost 50% of the constituents of JC seeds are oil which confirms the potential of JC seeds as a viable source of bio-oil for biodiesel production.

**Table 1.** Proximate composition (%)<sup>a</sup> of JC seeds flour

Assay	Value
Crude fat	47.25 ± 1.34
Crude protein	24.60 ± 1.40
Crude fibre	10.12 ± 0.52
Moisture	5.54 ± 0.20
Ash	4.50 ± 0.14
Carbohydrate (by difference)	7.99

<sup>a</sup> Values are mean ± standard deviation of triplicate determinations

There have been reasonable efforts made by researchers to source for biodiesel as an alternative energy source from some agricultural feedstocks and vegetable oils like groundnuts oil, palm kernel oil, maize and soybeans oil whose uses as fuel sources often compete with man for food thereby causing food shortages in Nigeria. However, there are a few research efforts and limited data available to date on biodiesel production from the JC of Nigerian origin whose use as a fuel source does not pose any threat on the Nigerians' food security owing to the fact that it is inedible. JC plant is not unfamiliar to Nigerians because its medicinal potentials are not lost on them but the low level of technology in the country has undoubtedly deprived Nigerians of access to its economic and environmental potential.

Parkia biglobbossa (PKBS) and JC seeds oils were analyzed by Akintayo [14] for their proximate composition. The seeds oils were analysed for fatty acid, lipid classes, sterols and physicochemical characteristics. The results showed that the percentage crude protein, crude fat and moisture content in PKBS were 32.40%, 26.525% and 10.18% respectively while those of JC were 24.60%, 47.25% and 5.54% respectively. It was also revealed that JC oil had 72.7% unsaturated fatty acids with oleic acid predominating, while PKBS had 62% unsaturated fatty acids with linoleic acid mostly abundant. The author concluded from the physicochemical analysis results that the seed oils could be

classified as semi drying oils and that they could be found applicable in alkyd resin and soap manufacture.

Belewu et al. [15] conducted a comparative analysis on some physical and chemical properties between the oils and biodiesels produced from Nigerian and Indian JC seeds through parametric student's t-test model. The study results showed significant differences ( $p < 0.05$ ) between the yields of the Nigerian and Indian Jatropha oils (80% vs 56%). The acid value, free fatty acid, iodine value, peroxide and viscosity values of the Nigerian Jatropha oil were found to be significantly higher as compared to that of the Indian Jatropha oil whereas, there was no significant difference in the density and moisture content between the two oil species. A higher flash point was recorded for the Nigerian Jatropha diesel. The calorific value of the Nigerian Jatropha diesel was 48.31 MJ/kg while that of Indian Jatropha diesel was 47.50 MJ/kg. The authors reported that most of the properties of the Nigerian Jatropha diesel evaluated compared favourably with biodiesel standard values.

For the purpose of encouraging the cultivation of jatropha plant in Nigeria and motivating the development of biodiesel production from it, Aransiola et al. [16] investigated the production of biodiesel from the seeds oil of JC obtained in Nigeria. The effect of oil-alcohol molar ratio on the biodiesel produced was also investigated with the aim of confirming established base case. The results of the analysis revealed that 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% sodium hydroxide (NaOH) catalyst concentration. The authors reported that the physical properties of the produced biodiesel met the ASTM standard of D-6751.

Folaranmi [17] carried out the production of biodiesel from the oil already made from Nigerian jatropha seeds by alkaline-catalysed transesterification method. The results showed an optimum combination of the parameters as 8:1 molar ratio of methanol-oil, 1.0% potassium hydroxide (KOH) catalyst loading, reaction temperature of 60 °C and reaction time of 60 min. The author reported that the product met the set standard for biodiesel.

Odetoye et al. [18] conducted a study to investigate the thermochemical properties of the separate components of JC fruit shells and seed coat as biomass residues of Nigerian origin towards bio-oil production. The analysis revealed the structural compositions (extractives, hemicellulose, cellulose and lignin contents) of jatropha fruit shell as 3%, 34.0%, 40.0% and 12.7%, while that of the jatropha seed coat were 42.3%, 32.5%, 10.5% and 5.7%, respectively. Additionally, the results of the thermogravimetric analysis revealed an ash contents value of 0.8% for jatropha seed coat and 15.4% for jatropha fruit shell. The carbon contents were 48.3% and 41.5%, while measured calorific values were 20.06 MJ/kg and 17.14 MJ/kg for jatropha seed coat and fruit shell, respectively. The authors reported that the carbon, hydrogen, nitrogen and sulphur contents were found comparable with the data in the literature and as such, the Nigerian jatropha

fruit and seeds residues were found suitable for bio-oil production.

It is worth mentioning that, some private entrepreneurs in Nigeria have recently taken up the challenge. Some remarkable progress in the adaptation of simple technologies for the local production of biodiesel from JC of Nigerian origin has well been made by some Nigerian research institutes like the National Research Institute for Chemical Technology, Zaria. The Forestry Research Institute in Ibadan Nigeria has also developed some pilot plantations for the demonstration of the feasibility of Jatropha cropping for willing Nigerian entrepreneurs. With estimated diesel demands in Nigeria being 3600-4200 thousand metric tonnes by 2020, there is an expansive opportunity for jatropha biofuel enterprise in the country [19].

Obviously from the previous efforts, there has not been a detailed report and data available in the literature on the processes (spanning from harvesting through oil extraction to physical cum chemical analysis) involved in the optimum production of oil and biodiesel from the jatropha curcas kernel (JCK) of Nigerian origin. This study involves a comprehensive report on the standard processes and analytical methods involved in the production of biodiesel from JCK of Nigerian origin at optimum reaction conditions. The comprehensive methods and the allied analytical results obtained are aimed to fill the gap in the literature by serving as a reference guide and a database for the urban entrepreneurs and Government Agencies who will process the kernels from harvesting and optimally produce bio-oil and biodiesel thereby enhancing the sustainability of Nigerian economy and its environment.

## 2. Experimental procedures

### 2.1. *Jatropha curcas* kernel oil (JCKO) processing

The JC yellowish-brown ripe fruits were manually harvested from Erinmope Ekiti, a notable town in Moba Local Government Area of Ekiti State in Nigeria where the indigenes have always used the tree as hedges for their homesteads and farmlands with the aim of preventing animals from intruding and to control wind erosion. As recommended by Henning [20] and Achten et al. [21], the collected fruits were sun dried for 21 days after which they were deshelled and sorted to obtain the viable kernel meals of about 5 kg which were thereafter properly air dried for the removal of moisture. All the reagents employed in this research work were all of recognized analytical grade and all the experimental procedures were carried out at the Federal Institute of Industrial Research, Oshodi (FIIRO), Lagos state, Nigeria.

### 2.2. *JCKO* extraction

Soxhlet extraction method (with the use of n-hexane as the solvent) was preferred for this research because according to Achten et al. [21] and Patel et al. [22], though it takes a longer time, it is known for its continuous extraction process, complete oil recovery and ultimately the highest oil yield

as compared to other chemical extraction methods like aqueous oil extraction (AOE), aqueous enzymatic oil extraction (AEOE), three-phase partitioning etc. and other extraction methods as centrifugation, filtration etc. as shown in Table 2 as given by [22].

### 2.3. Pre-treatment of the crude JCKO

Basically, the yield of base-catalysed transesterification decreases when the free fatty acid (FFA) value of oil is greater than 2%. It has been found that transesterification would not occur if FFA content in the oil is high [23, 24]. The implication of higher value of FFA is that the catalyst (NaOH in this study) will be favoured to react with the FFA to produce soap and water which is to the detriment of optimum biodiesel yield. This benchmark necessitated that the FFA value of the obtained crude JCKO which was about 0.9 L should be determined prior to biodiesel production from it in order to prevent this undesired reaction.

#### 2.3.1. Determination of the FFA value of the crude JCKO

The acid value (AV) of the crude JCKO was investigated with the aid of acid-base titration technique by weighing 5 g of a sample of the crude JCKO and dissolving it in 25 mL of Isopropyl Alcohol (IPA) which was then titrated against a standard solution of 0.1 mole of potassium hydroxide (KOH) with phenolphthalein as an indicator. The FFA value was then estimated by the relationship given by Norris [25] which is concerned with oleic acid assumption that one unit of AV = 0.503% FFA. The crude JCKO FFA value which was then estimated to be 6.312% made pre-treatment to be inevitable.

#### 2.3.2. Esterification

The FFA reduction was done by measuring 2.25 FFA volume of methanol and 0.05 FFA volume of concentrated H<sub>2</sub>SO<sub>4</sub>. The mixture of the duo was heated separately at a constant temperature of 50 °C after which it was slowly added to the already agitating (at 60 °C) crude JCKO in a conical flask. Then, the resulted mixture was allowed to continue agitating for one hour at a maintained temperature of 60 °C. Thereafter, the whole mixture was poured into a separating funnel and was then allowed to settle for two hours after which the separated JCKO was decanted and then rechecked for its FFA value which was found to be 0.9%, a value far below the benchmark.

The major problem associated with the use of pure vegetable oils as fuels for diesel engines is caused by its high

fuel viscosity in compression ignition. Hence, vegetable oils are converted into their ethyl or methyl esters (biodiesels) by transesterification [26].

### 2.4. Biodiesel production

Alkali-catalysed transesterification reaction of vegetable oils had been reported by May [13] and Knothe [27] to proceed faster than that catalysed by acid while 60 °C was investigated and reported by Aransiola et al. [28] as the optimum reaction temperature. Hence, these have been chosen for this work.

To about 100 g of the pre-treated JCKO already preheated to about 60 °C in a 250 mL round bottom flask, an alcoholic catalyst mixture of methanol in the different oil-methanol molar ratios varying from 1:4 to 1:8 and NaOH (1.0% of the weight of the oil) was added while stirring on the hot plate with magnetic stirrer at a speed of about 300 rpm at a maintained reaction temperature of 60 °C. The reaction time (considered from the point of addition of the alcoholic catalyst mixture to the JCKO) for the production of biodiesel was varied with 30 min., 45 min., 60 min., 90 min. and 120 min. for the purpose of optimisation. Each optimised batch was transferred to a separating funnel and then allowed to settle by gravity. The glycerol in the lower layer was decanted as a by-product into a glass storage bottle while the light yellow biodiesel in the upper layer was made to go through post-transesterification processes for purification purpose.

For the purpose of investigating the influence of catalyst concentration on the biodiesel yield, these above procedures were repeated with different catalyst dosages of 0.6%, 0.8%, 1.0%, 1.2% and 2.0% with all other variables being kept constant. Following this, the samples of the recovered biodiesel were taken for analysis and characterization.

## 3. Analytical Tests for the JCKO and the produced Biodiesel

### 3.01. Determination of biodiesel yield

The percentage yield of the biodiesel at each batch was estimated according to Eq. (1)

$$\text{Biodiesel yield} = \frac{\text{mass of biodiesel yield}}{\text{mass of JCKO used}} \times 100\% \quad (1)$$

**Table 2.** Comparison of oil yields by the use of various solvents and extraction methods

Organic solvent	Extraction method (% yield) for approximately 6 hours of continuous extraction			
	Separating funnel	Centrifugation	Filtration	Soxhlet extraction
Petroleum ether	28.6 ± 4.16	48.3 ± 0.57	10.3 ± 4.0	53.66 ± 1.05
Isopropanol	19.66 ± 2.3	53.33 ± 1.52	15.66 ± 4.0	59.66 ± 2.5
Hexane	36 ± 9.53	52.66 ± 4.04	20 ± 6.2	78.66 ± 0.9

### 3.02. Determination of Iodine Value (IV)

The iodine values of the JCKO and the produced biodiesel which are the measures of the degree of their total unsaturation were determined according to ISO 3961:2013 which involves the use of Wijs reagents.

**Procedure:** A starch solution was prepared by pouring 5 g of soluble starch already dissolved in 30 mL of cold water into a 1000 mL of already boiling water and the whole solution was allowed to boil for 5 min. and then allowed to cool. Thereafter 0.4 g of the test sample (JCKO or produced biodiesel as the case may be) was measured into a 500 mL conical flask after which 20 mL of already prepared mixture of cyclohexane and glacial acetic acid was added for the purpose of dissolving it. 25 mL of Wijs reagent was then added and the whole mixture was made to swirl after a stopper has been probably inserted. This mixture was left in a dark room for 60 min. after which 20 mL of potassium iodide (KI) (iodine free- 100 g/L) and 150 mL of water were added and the resulted solution was being titrated with 0.1 mol/L of standard sodium thiosulfate ( $\text{Na}_2\text{S}_2\text{O}_3$ ) solution until the iodine yellow colour was near disappearance. With the titration still ongoing, some requisite drops of the already prepared starch solution were added and this was coupled with aggressive shaking so that the blue colour could disappear. The titer values at this point were recorded. The same procedure under the same condition was carried out simultaneously but with a blank solution (no JCKO or biodiesel sample) for the purpose of blank determination after which the amount of  $\text{Na}_2\text{S}_2\text{O}_3$  solution required was recorded.

The IV in grams per 100 g of fat was estimated with Eq. (2) according to ISO 3961:2013.

$$IV = \frac{12.69 \times C \times (V_0 - V_s)}{m} \quad (2)$$

Where C is the  $\text{Na}_2\text{S}_2\text{O}_3$  concentration,  $V_0$  is the  $\text{Na}_2\text{S}_2\text{O}_3$  volume used for the blank test,  $V_s$  is the  $\text{Na}_2\text{S}_2\text{O}_3$  volume used for the determination and m is the mass of the test portion (JCKO or biodiesel sample as the case may be).

### 3.03. Determination of Peroxide value (PV)

The PV of the JCKO was determined according to ISO 3961:2007.

**Procedure:** 5 g of the JCKO was weighed into a clean dry 250 mL conical flask and 50 mL of the glacial acetic acid was then added after which the mixture was gently swirled to dissolve it. Then, 0.5 mL of saturated KI solution (of 175 g/100 mL mass concentration) was added after which the flask was stoppered and the whole was mixed with the aid of a magnetic stirrer. After exactly 60 seconds, the flask was opened, the stopper was carefully washed with water and altogether 100 mL of water was added. Immediately after this, the solution was titrated with 0.01 M of standard  $\text{Na}_2\text{S}_2\text{O}_3$  solution until the yellow colour was near disappearance. With the titration still ongoing, 0.5 mL of starch solution was added and this was coupled with

aggressive shaking until the pale purple colour was near disappearance. The titer values at this point were recorded. The same procedure under the same condition was carried out simultaneously but with a blank solution (no JCKO sample) for the purpose of blank determination after which the amount of  $\text{Na}_2\text{S}_2\text{O}_3$  solution required was recorded.

The PV in milli equivalents of active oxygen per kilogram was estimated with Eq. (3) according to ISO 3961:2007.

$$PV = \frac{(V_s - V_0) \times 1000 \times K}{m} \quad (3)$$

Where  $V_s$  is the  $\text{Na}_2\text{S}_2\text{O}_3$  volume used for the determination,  $V_0$  is the  $\text{Na}_2\text{S}_2\text{O}_3$  volume used for the blank test, K is the product of the normality factor and the concentration of the standard  $\text{Na}_2\text{S}_2\text{O}_3$  solution while m is the mass of the test portion.

### 3.04. Determination of Saponification Value (SV)

The saponification values of the JCKO and the produced biodiesel were determined according to ISO 3657:2013 by refluxing alcoholic KOH solution into the sample.

**Procedure:** 2 g of the JCKO or the produced biodiesel (as the case may be) was measured into a 250 mL conical flask and 25 mL of 0.1 M of ethanolic KOH solution was added after which the mixture was allowed to boil for 60 min. under reflux and then allowed to cool down a bit. Thereafter, 1 mL of phenolphthalein indicator was added to the warm mixture and then titrated against 0.5 M of hydrochloric acid (HCl) solution until its pink colour suddenly disappeared. Also, for the purpose of blank determination, the same procedure under the same condition was carried out but with a blank solution (no JCKO or biodiesel sample) after which the amount of HCl solution required was noted and recorded. The SV was computed with Eq. (4) according to ISO 3657:2013.

$$SV = \frac{56.1 \times C \times (V_0 - V_s)}{m} \quad (4)$$

Where  $V_s$  is the HCl volume used for the determination,  $V_0$  is the HCl volume used for the blank test, C is the normality factor of the HCl solution and m is the mass of the test portion (JCKO or biodiesel as the case may be).

### 3.05. Cetane Number (CN)

The CN of a diesel fuel, equivalent to the octane number for gasoline, is one of its prime quality indices. It is an indicator of the fuel readiness to ignite upon injection into an engine combustion chamber. Basically, the higher the CN of a diesel fuel, the faster it takes to ignite (shorter ignition delay) and vice-versa. The CNs of the JCKO and the produced biodiesel were computed with Eq. (5) according to Bart et al. [29].

$$CN = 46.3 + \frac{5458}{SN} - 0.225(IV) \quad (5)$$

Where SN and IV have been previously determined.

### 3.06. Mean molecular mass (MMM)

The MMM of the JCKO was estimated from Eq. (6) according to Ajiwe et al. [30].

$$MMM = \left( \frac{56}{SV} \right) \times 1000 \quad (6)$$

Where SV has been previously estimated.

### 3.07. Flash Point (FP)

The FP of the produced biodiesel, which is the minimum temperature at which its vapour will ignite upon the supply of an ignition source to it under the specified test conditions, was determined by open-cup flash test method within a temperature range of 60-190 °C. A requisite amount of the produced biodiesel was measured into the test cup and was being heated while an ignition source was supplied over it till the fumes suddenly got ignited and the flame was then self-extinguished. The temperature at which the flash suddenly appeared was then noted and recorded.

### 3.08. Pour point (PP) and Cloud Point (CP)

PP is the minimum temperature at which biodiesel will continue to flow when being cooled without stirring while CP is that temperature at which the fluid components precipitate on cooling under some specified test conditions. The duo is an indicator of biodiesel behaviour at low temperatures especially in cold weather. The duo was computed concurrently by weighing a requisite amount of the biodiesel into a coning flask (to an approximately half full level) which was then tightly closed with a thermometer-bearing cork while the thermometer bulb was aided to rest at the flask bottom. Thereafter, the whole unit was positioned on the jacket immersed in a constant temperature cooling bath to prevent excessive cooling. The flask was intermittently being mindfully withdrawn and replaced while watching out for pour and cloud formations. The temperatures at which the duo got formed were noted and recorded.

### 3.09. Density

The JCKO and the produced biodiesel densities were estimated with the use of two density bottles at ambient temperature. Each density bottle was firstly dried and then weighed empty and its weight was recorded after which it was filled up with the sample (JCKO or the produced biodiesel as the case may be) and then reweighed. The sample density was then computed according to Eq. (7)

$$Density = \frac{(mass\ of\ density\ bottle + sample) - mass\ of\ empty\ bottle}{volume\ of\ density\ bottle} \quad (7)$$

### 3.10. Specific gravity (SG)

The SG also referred to as the relative density of the JCKO and that of the produced biodiesel were estimated with the aid of a Hydrometer.

### 3.11. Kinematic Viscosity (KV)

The viscosities of both the JCKO and the produced biodiesel were measured with the aid of a viscometer (NDJ-5S LCD digital rotary viscometer) at ambient temperature with an error margin of ± 5%. The kinetic viscosities were then estimated by dividing the measured absolute viscosities with the already computed densities.

## 4. Results and Discussion

The results of the detailed analytical tests conducted to physically and chemically characterize the Nigerian JCKO and the allied biodiesel will be discussed under:

- Characterization of the JCKO
- Effects of reaction conditions on percentage biodiesel yield

### 4.1. Characterization of the JCKO

The physical and chemical properties obtained from the analysis done on a sample of the JCKO are presented in Table 3. As evident from this table, most of the JCKO properties are comparable to those reported in the literature and are also well accommodated within the acceptable range of standard specification for jatropha oil given in Table 4 as reported by Folaranmi [17]. The colour, SV, IV and MMM are all in agreement with those obtained by Akintayo [14]. The density and the KV are both well comparable to those reported by Aransiola et al. [16]. The obtained results are indicators of the potential of the Nigerian JCKO as a viable feedstock for biodiesel production.

**Table 3.** Characteristics of the JCKO

Parameter	Unit	Value
Acid Value	mg KOH/g oil	12.63
FFA	mg KOH/g oil	6.315
Iodine Value	g I <sub>2</sub> /100g oil	109.21
Saponification value	mg KOH/g oil	197
Peroxide value	milli equivalents/kg	2.7
Cetane number	-	49.43
Specific gravity at 15 °C	-	0.9258
Mean molecular mass	-	284.26
Density at ambient	kg/m <sup>3</sup>	920
Kinematic Viscosity at ambient	mm <sup>2</sup> /s	35.1
Colour	-	light yellow

**Table 4.** Standard specification of Jatropha oil

Property	Value
Colour	4.0
Specific gravity	0.9186
Carbon residue	0.64
Cetane value	51.1
Distillation point	295 °C
Kinematic viscosity	50.73 cs
Sulphur %	0.13%
Calorific value	9470 kcal/kg
Pour point	8 °C
Acid value	1.0–38.2
Iodine value	90.8–112.5
Saponification value	188–198

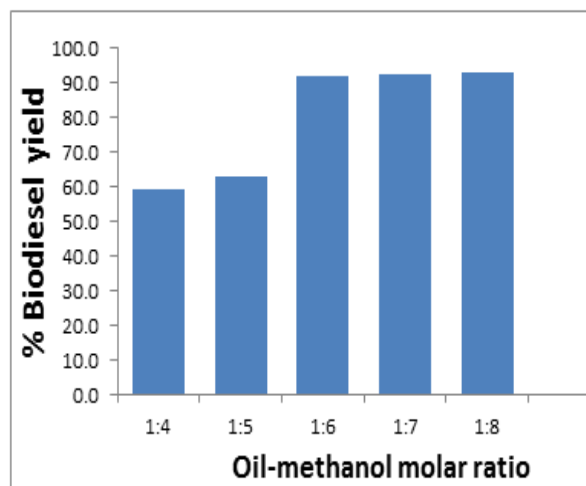
4.2. *Effects of reaction conditions on percentage biodiesel yield*

4.2.1. *Effect of oil-methanol molar ratio on percentage biodiesel yield*

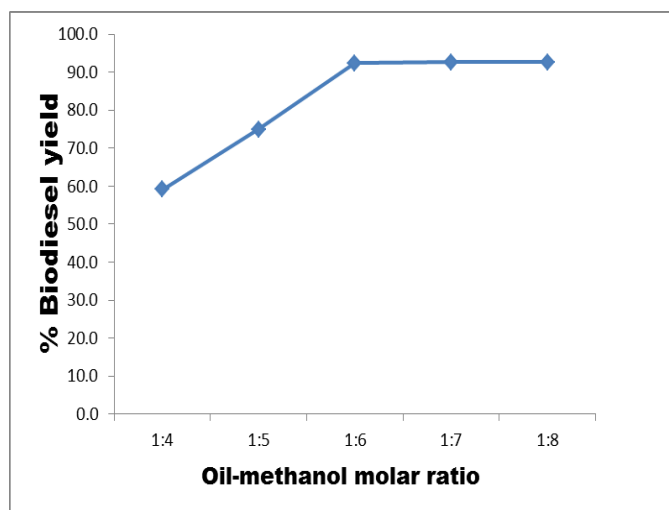
The stoichiometric ratio for the transesterification reaction involves 3 moles of alcohol and 1 mole of triglyceride to produce 3 moles of fatty acid ester and 1 mole of glycerol. Excess alcohol is used during transesterification to ensure that the oils will be completely converted to ester due to the forward reaction being more favourable. Furthermore, a higher alcohol to triglyceride ratio can result in a greater ester conversion in a shorter time [13]. Literature review has shown that the reaction requires far more amount of methanol than the stoichiometric ratio to push the reaction farther to the right for more biodiesel yield. For the purpose of investigating the influence the change in the oil-methanol molar ratio will have on the yield of the biodiesel produced in this work, different ratios of the mole of JCKO to that of methanol which are 1:4, 1:5, 1:6, 1:7, and 1:8 were used while keeping the catalyst dosage and the reaction time constant. The results are presented in Table 5. As indicated in Figs. 1 and 2, there is a significant increase in the percentage yield from 1:4 to 1:6 but the increase becomes almost marginal between 1:6 and 1:8. Hence, considering the price of methanol coupled with the fact that additional quantity of methanol seems not to result in any significant yield of the biodiesel beyond this condition, 1:6 can be taken as the optimum oil-methanol molar ratio for the production of biodiesel in this work.

**Table 5.** Variation of biodiesel yield with oil-methanol molar ratio

Oil-Methanol ratio	Yield of biodiesel (%)
1:4	59.0
1:5	75.1
1:6	92.4
1:7	92.6
1:8	92.7



**Figure 1.** Variation of percentage biodiesel yield with oil-methanol molar ratio



**Figure 2.** Effect of oil-methanol molar ratio on biodiesel yield

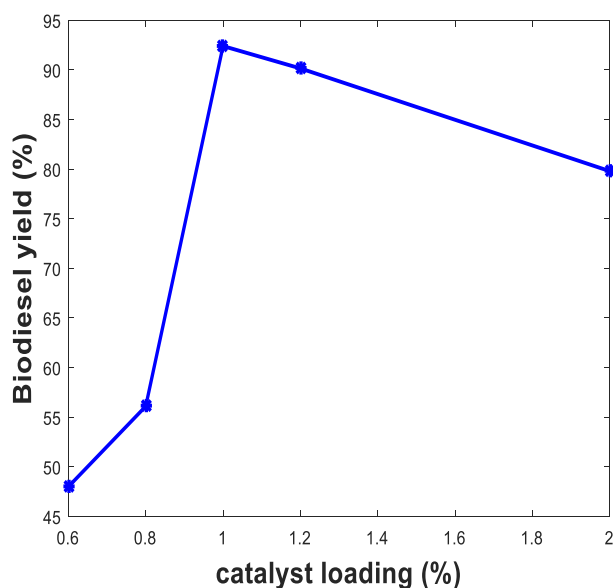
4.2.2. *Effect of catalyst loading on percentage biodiesel yield*

Catalyst dosages which are 0.6%, 0.8%, 1.0%, 1.2% and 2.0% were investigated as per the yield of biodiesel, keeping other variables constant as well. From the obtained results as presented in Table 6 and Fig. 3, it is obvious that the dosage of catalyst plays a germane role in the yield of biodiesel. As observed in Fig. 3, though there was biodiesel production at 0.6% catalyst dosage but with a very low yield which may be traced to the fact that the catalyst was insufficient to catalyse the reaction to give a better yield. Also, there was a corresponding increase in the yield as the catalyst dosage increased until at dosage 1.0% after which a sudden inverse relationship was observed between the catalyst dosage and the biodiesel yield. This inverse yield may be owing to the fact that the catalyst was undesirably reacting with the triglyceride to form more of soap. One may then agree that

1.0% is the optimum catalyst loading for the biodiesel production in this study.

**Table 6.** Variation of biodiesel yield with catalyst loading

Catalyst loading (%)	Biodiesel yield (%)
0.6	48.00
0.8	56.10
1.0	92.40
1.2	90.15
2.0	79.80



**Figure 3.** Effect of catalyst dosage on biodiesel yield

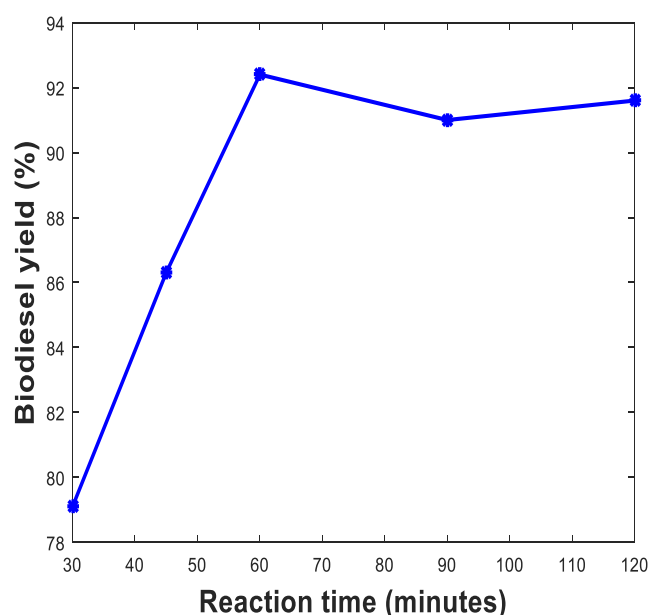
#### 4.2.3. Effect of reaction time on percentage biodiesel yield

The reaction time for the biodiesel production was varied from 30 min., 45 min., 60 min., 90 min. to 120 min. The obtained results presented in Table 7 and Fig. 4 show that the reaction time plays an important role in the yield of biodiesel. As it can be observed from the trend in Fig. 4, there was a significant increased yield as the transesterification process continued from 30 min. through 45 min. to 60 min. after which a decrease in the biodiesel yield was observed up to 90 min. After this time, a slight increase of about 0.6% was observed till 120 min. This unstable scenario in the production process may likely be traceable to some esters most possibly reverting to undesirably form soap with the catalyst. Sivaprakasam and Saravanan [31] obtained a similar trend in their work. Obviously, if only 0.6% yield increase was achieved for the whole of 30 min. (that is from 90 min. to 120 min.) as against the previous increment trend, there is every possibility that the process would not yield any significant increase and desirable outcome after this time. According to Eloka-Eboka et al. [32], longer reaction time after such

scenario often enhances the hydrolysis of esters (reverse reaction of transesterification), thereby resulting in a loss of esters (biodiesel) as well as encouraging soap formation. Therefore, from all indications and considering the allied economy, 60 min. stands as the optimum reaction time for the biodiesel production in this work.

**Table 7.** Variation of biodiesel yield with time

Reaction time (min.)	Biodiesel yield (%)
30	79.1
45	86.3
60	92.4
90	91.0
120	91.6



**Figure 4.** Effect of reaction time on biodiesel yield

#### 4.2.4. Optimum reaction conditions

It can be deduced from the comprehensive results obtained from the characterization of the biodiesel produced from JCKO of Nigeria origin in this work that the optimal conditions are: oil-methanol ratio of 1:6, 1% catalyst dosage and reaction time of 60 min. at a pre-determined optimum reaction temperature of 60 °C for the average highest yield of 92.4%. Both the physical and the chemical characteristics of the biodiesel produced from JCKO of Nigerian origin at these determined optimal reaction conditions are presented in Table 8 as compared with ASTM D6751 which is the required standard for B100, that is, 100% biodiesel without any blend. Noticeably from Table 8, all the properties of the biodiesel produced at these optimised conditions are well within the prescribed limit of ASTM standards.



**Table 8.** Comparison of the produced biodiesel properties to ASTM D6751

Property	Unit	Biodiesel from this study	ASTM D6751
Specific gravity	kg/L	0.872	≤0.95
Kinematic Viscosity at 40 °C	mm <sup>2</sup> /s	4.95	1.9-6.0
Flash point	°C	192	≥ 130
Pour point	°C	4	-
Cloud point	°C	7	Based on climatic zone
Saponification value	mg KOH/g biodiesel	266	-
Iodine value	g I <sub>2</sub> /100 g	61	-
Acid value	mg KOH/g	0.3	≤0.5
Cetane number	-	53.09	≥ 47

## 5. Conclusion

The results obtained from the detailed characterization of the biodiesel produced from the JCKO extracted from the JCK of Nigerian origin in this study has again confirmed the potential of the JCK of Nigeria origin as a good source of bio-oil and biofuel which will serve as an impetus to Nigerian rural dwellers who would farm the plants. The set of optimum reaction conditions obtained from the biodiesel characterization cum the comprehensive allied methods and data which have given a higher biodiesel yield than those reported in the literature are aimed to serve as a database for the Nigerian urban entrepreneurs and Government Agencies who will embark on the processing of the JCK from the harvesting stage and optimally (cost-effectively) produce oil and biodiesel, thereby enhancing the sustainability of Nigerian economy and her environment so as to meet the global regulations and targets.

Undoubtedly, biodiesel production has become an attractive subject of research in the recent years owing to its associated benefits. However, its inability to economically compete with its counterpart (fossil diesel) because of the high costs of edible oils being used for its production remains a great challenge. Even for the low cost inedible oils such as *jatropha-curcas*-derived oil, the cost of pre-treatment due to their high FFA and that due to extensive product purification often add to the overall production cost. Besides, the cost of raw materials accounts for 60–75% of the total cost of biodiesel fuel [33]. Leduc et al. [34] in their study with the aim of optimizing biodiesel production from Indian *jatropha curcas* also reported that the feedstock cost has the greatest influence (a rise of 40%) on the biodiesel cost. However, the decline in the global petroleum reserves coupled with its allied environmental hazards still make biodiesel a global interest. It is therefore imperative to intensify efforts both in reducing biodiesel production cost and in enhancing the production outputs.

Improvement of biodiesel production efficiency through the optimisation of the production process conditions as demonstrated in this work is a good window to explore in reducing the cost of biodiesel. Other areas of exploration are: reduction of the costs of the catalysts being used by the use of alternate technologies like heterogeneous and enzymatic catalytic transesterification which involve the use of reusable

and green catalysts with microwave and ultrasound systems being used to mitigate their associated diffusion and mass transfer problems; membrane reactors for transesterification; usage of green solvents in lieu of the conventional ones and characterization of biodiesel through unconventional methods such as photothermal techniques. Though a few of these technologies are recently being used, their further development still encounters some obstacles especially when scaling up experiments to industrial or pre-industrial stages [35, 36]. In addition, governments’ supports (especially those of developing countries) such as rewards for biodiesel industry and enforcement of biodiesel-related policies could be helpful in fostering the growth of the industry so as to fully compete with and replace the conventional oil and gas industry. Finally, another promising area of exploration is to initiate glycerol recycling related-researches which are aimed towards the reuse of glycerol as an admixture or a raw material for ethanol or methanol synthesis within the biodiesel production cyclic process.

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