

## PRODUCTION AND DETERMINATION OF PHYSICO-CHEMICAL PROPERTIES OF *Khaya senegalensis* BIODIESEL FOR USE AS FUEL IN COMPRESSION IGNITION ENGINE

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### Abstract

*In this study, Production and determination of physico-chemical properties of Khaya senegalensis biodiesel for use as a fuel in compression ignition engine has been presented. The biodiesel was produced using a two-step esterification and transesterification process. During esterification process, 4 liters of khaya-senegalensis oil reacted with 3.78 liters of methanol and 37g of H<sub>2</sub>SO<sub>4</sub> for one hour at agitation speed of 450rpm and temperature of 55°C. The free fatty acid content of the oil was reduced from 7.5% to 1.9%. Transesterification reaction was carried out by preheating the oil products from the first step to 50°C and poured into the biodiesel reactor. Mixtures of methanol and catalyst (1.11liters of methanol and 58.1g of NaOH) were heated to 50°C before adding to the heated oil products in the reactor. The contents of the reactor was heated and stirred at 450rpm and temperature of 55°C was maintained throughout the reaction time of two hours and 90 % conversion of Khaya senegalensis oil to biodiesel was achieved. The physico-chemical properties of Khaya senegalensis biodiesel (B100) were determined using standardized analytical methods. The physico-chemical properties of the biodiesel fuel shows that the moisture content is 0.035 % (vol.), density 905kg/m<sup>3</sup>, kinematic viscosity at 40 °C 5.09mm<sup>2</sup>/s, calorific value 37.0 MJ/kg, acid value 0.72mgKOH/g, cetane number 54, flash point 134°C, cloud point -5°C, pour point -25 °C, ash content 0.10% (wt.), and peroxide value 0.225 mgKOH/g. Considering the obtained physico-chemical properties of Khaya senegalensis biodiesel fuel, it could be concluded that Khaya senegalensis biodiesel fuel can be used as a substitute to fossil diesel in compression ignition engines with little modification of the fuel.*

**Keywords:** Physico-Chemical Properties, Transesterification, Biodiesel

### 1.0 Introduction

The depletion in fossil fuel reserve and environmental issues arising from the use of fossil fuel together with the depletion of ozone layer reserve due to the exhaust emission from combustion engines is pushing for search for alternative fuel for internal combustion engines, and biofuel is one of the solutions to the twin problems of fossil fuel depletion and environmental degradation [1].

The exhaust emission from fossil fuel combustion in spark ignition and diesel engines causes air pollution and poses a threat to public health. On the other side due to the presence of oxygen molecule in biodiesel fuel and lack of aromatic compounds and sulfur, biodiesel fuel combustion in diesel engines results in less air pollution than that of diesel fuel [2]. Biodiesel is one of the renewable energy sources, which could be produced locally and contribute to the economy of local communities. [2] summarized the benefits of biofuel production to include; job creation and protection of the environment, reduced greenhouse gas emission, good fuel properties for vehicles, increased employment in agricultural sector and conversion of waste land into productive land.

The state of the matter, as concerns the sourcing of alternative energy in Nigeria is that, despite the theoretical abundance of almost all of wind, solar, tidal and other sources of alternative energy, very little effort has been done to harness the said sources. The situation is worse in the case of biofuel sourcing from vegetable oils. Notwithstanding the abundance of arable land mass for the cultivation of vegetable oils, Nigeria is still not self-sufficient in edible oil production for human consumption not to talk about the use of it for production of biofuel. This fact necessitates the need to seek for a way out to produce biofuel while not obstructing the availability of the oils for human consumption. A good candidate for this purpose would be the vegetable oils obtained from the non-edible sources. A good number of such oilseeds, the likes of *Jatropha carcus* (jathropha), *Azadirachta indica* (neem), *Hevea brazillenses* (Rubber) and *Khaya senegalensis* (Africa Mahogany), are available in abundant quantities in Nigeria. Such oilseeds could be harnessed for the production of biofuels especially biodiesel. The abundant arable landmass of Nigeria can be used to grow these trees in order to produce biodiesel in commercial quantity. Such a measure would not only better the lots of Nigerians economically but would also serve as an ecological tool to arrest the dangerous situation of deforestation especially in the desert prone areas of the country. There are few attempts to use the said non-edible oils as substitutes for diesel. However, some works carried out in this connection on Jathropha and Rubber were mentioned [3].

In this research *Khaya senegalensis* oil was investigated as a potential source of biodiesel fuel as a non-edible oil sources. The use of non-edible plant oil sources are particularly important as the issue of competition of biodiesel feedstock with food products has drawn serious concern to the society [4].

*Khaya senegalensis* tree is a genus of seven species of trees in the mahogany family Meliaceae, native to tropical Africa and Madagascar. All species become big tree about 30-35m tall, with a trunk over 1m in diameter. The timber of *Khaya senegalensis* tree is called African mahogany, the only timber widely accepted as a mahogany besides that of the true mahogany. *Khaya senegalensis* tree, also known as the African dry zone mahogany is also used for non-timber purposes. In West Africa, Fulani herdsman prune the tree during the dry season to feed cattle, the oil is used for the control of insect pest and as a dry skin lotion in some parts of Nigeria, in medicinal purposes the leaves and bark are used for the treatment of stomach upset in both human beings and livestock [5]. The seeds have an oil content of 52.5%, consisting of 21.39% palmitic acid, 10.41% stearic acid, 64.62% oleic acid and 3.58% unidentifiable acid [6].

## **2.0 Materials and Methods**

### **2.1 Materials**

*Khaya senegalensis* oil was obtained from Yola market in Adamawa state, Nigeria. Methanol, sulphuric acid and all other reagents were purchased from an agent of BDH Chemicals Limited, Poole England in Yola, Adamawa state. Methanol and sulphuric acid were of 95% and 99% purity respectively.

### **2.2 Research equipment and apparatus**

The equipment and apparatus that were used during this study were obtained from chemistry department, Abubaksr Tafawa Balewa University (ATBU) Bauchi and are listed below; Biodiesel batch reactor, Measuring cylinders (1000liters and 250liters), Biodiesel reactor set up (shown in Figure 1), 250ml beakers and conical flask, 250ml separating funnels, Funnels, table spoons (plastic or stainless steel), Test tubes, Retort stand and clamp, Thermometer, Stop watch, Electronic precision balance (TL-600) and Transparent plastic bucket.



Figure 1. Biodiesel batch reactor constructed for this work.

### 2.3 Experimental set-up

Esterification and transesterification reactions were carried out in a reactor constructed for this work which is shown in Figure 1. A temperature sensor was immersed into the opening on the cover plate of the reactor to control the temperature of the reactor. Readings of temperature and the speed of agitation of the reactor were taken at five minutes interval for the duration of the reactions.

### 2.4 Esterification and Transesterification

During the esterification process, 4 liters of *Khaya senegalensis* oil reacted with 3.78 liters of methanol and 37g of  $H_2SO_4$ . The reaction was carried out at an agitation speed of 450 rpm and temperature of  $55^\circ C$  was maintained throughout the reaction time of one hour [7]. The esterification of the oil by the acid catalysis is necessary whenever the free fatty acid (FFA) level is greater than 2%.

Transesterification of the *Khaya senegalensis* oil was carried out by preheating the oil products from the first step to  $50^\circ C$  and pouring it into the reactor. Mixtures of methanol and catalyst (1.11liters of methanol and 58.1g of NaOH) were heated to  $50^\circ C$  before adding to the 'preheated oil sample in the reactor. The contents of the reactor was heated to a temperature of  $55^\circ C$  and stirred at 450 rpm and the temperature was maintained throughout a reaction time of 2 hours.

The mixture was allowed to settle over night before separating the glycerol layer to get the methyl ester of the fatty acid at the top. The biodiesel was then washed with warm water to remove lye, soaps, methanol and other impurities that are in the biodiesel. A straw-yellow and a cloudy liquid layer was formed, the cloudy liquid was drained out. The biodiesel was heated to  $55^\circ C$  on a hot plate to allow the remaining water to evaporate and

was finally filtered using filter paper [8]. The volume of the biodiesel obtained and that of the glycerine were recorded.

## 2.5 Determination of Physico-chemical Properties of *Khaya senegalensis* Biodiesel

The physical and chemical properties of *Khaya senegalensis* biodiesel (B100) were determined following the methods shown in Table 1.

Table 1. Test Methods and Equipment

S/N	Fuel Property	Unit	Khaya-senegalensis biodiesel	Diesel fuel	ASTM 6751 Standard [9]
1	Density	kg/m <sup>3</sup>	905	854	NS
2	Kinematic viscosity at 40 °C	mm <sup>2</sup> /s	5.09	2.71	1.9-6.0
3	Calorific value	MJ/kg	37.0	42.0	NS
4	Cetane number	-	54	-	NS
5	Acid number	mgKOH/g	0.72	-	<0.80
6	Flash point	°C	134	69	>130
7	Cloud point	°C	-5	-1	NS
8	Pour point	°C	-15	-16	NS
9	Ash content	% (wt)	0.10	0.10	NS
10	Moisture content	% (vol.)	0.035	0.010	0.050
11	Peroxide value	mgeqv/kg	0.225	0.20	NS

## 3.0 Results and Discussion

### 3.1 Esterification and Transesterification Process

During the esterification process 4liters of *Khaya-senegalensis* oil reacted with 3.775litres of methanol and 37g of H<sub>2</sub>SO<sub>4</sub> at 450 rpm for one hour and the FFA of the oil was reduced from 7.5% to 1.9%.

However, as the oil products from the esterification process was reacted with 1.11liters of methanol during the transesterification reaction with 58.1g of NaOH for a reaction period of 2 hours and at an agitation speed of 450rpm, 3.6 liters of biodiesel was obtained and this translate to 90% conversion of oil to biodiesel.

### 3.2 Physico-Chemical Properties of Produced *Khaya senegalensis* Biodiesel

The results obtained for the physico-chemical properties of *Khaya senegalensis* biodiesel fuel and diesel fuel are presented in Table 2.

### 3.3 Discussion of Results on production of *Khaya senegalensis* Biodiesel

The use of acid catalyst is required to maximize the biodiesel yield from the transesterification reaction whenever the FFA level of the oil is greater than 2%. The results of the 90% conversion of *Khaya senegalensis* oil to biodiesel achieved by the use of the improvised reactor is consistent with the finding of other researchers [7, 10, 11].

Table 2: The physico-chemical properties of *Khaya senegalensis* biodiesel fuel and diesel fuel

S/N	Property	Unit	Equipment used	Method [9]
1	Density	kg/m <sup>3</sup>	Relative density bottle	ASTM D4052
2	Kinematic viscosity	mm <sup>2</sup> /s	Redwood viscometer (Redwood No.1)	ASTM D 445
3	Calorific value	MJ/kg	Bomb calorimeter (Model CAL- 2K)	ASTM D 240
4	Cetane number	-	Potable octane analyzer (Model K88660)	ASTM D613
5	Acid value	mg KOH/g	Standard titrimetry	ASTM D 664
6	Peroxide value	meq/kg	Standard titrimetry	AOAC
7	Flash point	°C	Pensky martens closed cup flash tester (Model K-16270)	ASTM D 93
8	Pour point	°C	Koehler K46000 cloud and pour point tester.	ASTM D 97
9	Cloud point	°C	Koehler K46000 cloud and pour point tester	ASTM D2500
10	Water content	v/v (%)	Bench top centrifuge (Model PAC67310)	ASTM D2709
11	Ash content	w/w (%)	Muffle furnace (Model KSL-1100X-AC)	ASTM D 482

NS = Not stated

### 3.4 Discussion of Results on Physico-Chemical Properties of *Khaya senegalensis* Biodiesel

#### 3.4.1 Kinematic viscosity

Viscosity is a key property because it induces the atomization of a fuel upon injection into the diesel engine combustion chamber and ultimately, the formation of engine deposits [12]. The viscosity of *Khaya senegalensis* biodiesel was found to be 5.09mm<sup>2</sup>/s, this value is within the limit specified by ASTM D6751 standard of 1.9-6.0 mm<sup>2</sup>/s [9]. The viscosity of *Khaya senegalensis* biodiesel is lower than the values reported for other biodiesel fuels, for example, 5.81 mm<sup>2</sup>/s for soybeans oil methyl ester [3], 5.53 mm<sup>2</sup>/s for neem oil methyl ester [13] and 10.0729 mm<sup>2</sup>/s for Baobab oil methyl ester [14], but higher than the viscosity of 3.98mm<sup>2</sup>/s for mahua oil biodiesel [15] and 4.3 mm<sup>2</sup>/s for canola oil methyl ester [16].

Higher viscosity of biodiesel fuel causes pumping and atomization problems, poor cold engines start-up, misfire and ignition delay in diesel engines [3].

#### 3.4.2 Flash point

The flash point of *Khaya senegalensis* oil biodiesel was found to be 134°C, this value is within the limit specified by ASTM D6751 >130°C [9] and almost of the same value with soybean oil methyl ester 130°C [3] but higher than that of canola oil methyl ester (84°C) [16] and lower than the flash point of neem oil methyl ester (150°C) [13], palm oil methyl ester (164°C) [17] and cotton seed oil biodiesel (200°C) [18].

Higher value of flash point makes biodiesel fuel safer in terms of storage, handling and transportation, since fuel with flash point lower than the ambient temperature vapourises and catches fire easily [19]. Higher flash point of biodiesel is also an indication of complete transesterification process and the absence of residual alcohols in the biodiesel fuel [20].

### 3.4.3 Acid value

The presence of high value of free fatty acid in biodiesel fuel may result in corrosion of the fuel line components and other engine components. Acid value is therefore used to monitor the quality of the fuel. The acid value of *Khaya senegalensis* oil biodiesel was found to be 0.72mgKOH/g, this value is within the limit specified by ASTM D6751-02 ( $< 0.80$  mgKOH/g), but lower than that of castor oil methyl ester (1.008 mgKOH/g) [21], higher than that of mahua oil biodiesel (0.41 mgKOH/g) [15] and sunflower oil biodiesel (0.3mgKOH/g) [22].

### 3.4.4 Pour point

Cloud point is the temperature at which wax first becomes visible when the fuel is cooled, while pour point is the lowest temperature at which a fuel begins to flow. The pour point of *Khaya senegalensis* oil biodiesel is  $-15^{\circ}\text{C}$ , this value is lower than that of rape seed oil methyl ester ( $-12^{\circ}\text{C}$ ) [18], soybeans methyl ester ( $-8^{\circ}\text{C}$ ) [3], cotton seed biodiesel ( $-5^{\circ}\text{C}$ ) [18], baobab oil methyl ester ( $20^{\circ}\text{C}$ ) [14], and neem oil methyl ester ( $6^{\circ}\text{C}$ ) [13], groundnut oil biodiesel ( $4^{\circ}\text{C}$ ) [25] and Palm kernel oil biodiesel ( $10^{\circ}\text{C}$ ) [22], but higher than that of castor seed oil methyl ester ( $-32^{\circ}\text{C}$ ) [23].

Using biodiesel in internal combustion engines at low temperature may result in the formation of small crystals suspended in liquid phase, and can clog fuel filter partially or totally, the sedimentation of this crystal on the inner walls of the fuel systems pipes may reduce the flow sectional area, causing poor engine fuelling.

### 3.4.5 Cloud Point

The cloud point of *Khaya senegalensis* oil biodiesel was found to be  $-5^{\circ}\text{C}$ . This value is lower than that of soapnut oil biodiesel ( $-1^{\circ}\text{C}$ ) [24], cotton seed oil biodiesel ( $-2^{\circ}\text{C}$ ) [18], baobab oil methyl ester ( $10^{\circ}\text{C}$ ) [14], palm kernel biodiesel ( $5^{\circ}\text{C}$ ) [22], groundnut oil biodiesel ( $7^{\circ}\text{C}$ ) [25] and neem oil methyl ester ( $6^{\circ}\text{C}$ ) [13] but higher than that of castor oil methyl ester ( $-12^{\circ}\text{C}$ ) [23].

### 3.4.6 Density

The density of *Khaya senegalensis* oil biodiesel was found to be  $905\text{kg/m}^3$ . This value is slightly outside the limit specified by EN14214 standard of  $860\text{-}900\text{kg/m}^3$ , but higher than the density of diesel fuel ( $850\text{ kg/m}^3$ ) [15], Baobab oil biodiesel ( $0.860\text{kg/L}$ ), [14], manketti oil methyl ester ( $0.8878\text{kg/L}$ ) [26], but lower than the density of castor oil biodiesel ( $0.913\text{kg/L}$ ) [21], neem oil methyl ester ( $0.9182\text{kg/L}$ ) [13].

Fuel density affects the performance of the fuel in an internal combustion engines, since some of the fuel properties such as cetane number, heating value and viscosity are dependent on density, and it therefore affects the performance of pumps and fuel spray atomization, since fuel injection system operates on volume metering system, therefore higher density of biodiesel fuel results in the delivery of a slightly greater mass of fuel into the combustion chamber [24].

### 3.4.7 Calorific value

The calorific value of *Khaya senegalensis* oil biodiesel was found to be  $37\text{MJ/kg}$ , this value is lower than that of menketti oil biodiesel ( $39.07\text{MJ/kg}$ ) [26], and sunflower biodiesel ( $40\text{MJ/kg}$ ) [22], but higher than that of peanut oil methyl ester ( $33.6\text{MJ/kg}$ ) [25], karanja oil methyl ester ( $34.0\text{MJ/kg}$ ) [27]. Generally, the calorific value of biodiesel fuel is less than that of fossil diesel ( $42.0\text{MJ/kg}$ ), which may be due to the presence of oxygen molecule in the biodiesel chain [3], and also due to the difference in chemical composition of biodiesel fuel

when compared to diesel fuel [15]. The heat supplied to the engine is influenced by the calorific value of the fuel since heat input to the engine is the product of fuel mass flow rate and the calorific value of the fuel [28].

### 3.4.8 Ash content.

Ash is the residue remaining after heating oil in air under oxidizing conditions at high temperature. Ash forming materials may be present in biodiesel as abrasive solids, soluble metallic soaps and unremoved catalyst [29]. Abrasive solids and unremoved catalyst can contribute to the failure of injector, fuel pump, piston and ring wear, and also engine deposits. Soluble metallic soaps contribute to filter plugging and deposits.

The ash content of *Khaya senegalensis* oil biodiesel was found to be 0.01% (w/w), this value is within the limits specified by both the ASTM D6751-2 and EN14214 standards of < 0.02% (w/w) and is in agreement with the values from other researchers; mahua oil biodiesel (0.01% (w/w)) [15], sunflower oil biodiesel (0.004% (w/w)) [22], cotton seed oil biodiesel (0.0225%) [30], waste frying oil (0.029%) [31].

### 3.4.9 Peroxide value

The peroxide value of *Khaya senegalensis* oil biodiesel measured was 0.225mgeq/kg. This value is higher than the value specified by ASTM D6751-2 standard (< 0.02mgeq/kg), and that of groundnut oil biodiesel of 0.13mgeq/KOH [25].

### 3.4.10 Moisture content

The moisture content of *Khaya senegalensis* oil biodiesel is 0.0355. This value lies within the limits specified by both the ASTM D6751-2 and EN14214 standards of < 0.05% (w/w), but higher than that of jatropha oil methyl ester of 0.02% [32], that of waste cooking oil biodiesel of 0.0190% [31], and that of soapnut oil biodiesel of 86mg/kg [24], but lower than that of rape seed oil biodiesel of 841mg/kg [33].

### 3.4.11 Cetane number

This is an important parameter that affects so many engine parameters including incomplete combustion and harmful exhaust emissions. It is the measure of the ignition quality of a fuel. The cetane number of *khaya senegalensis* oil biodiesel is 54. This value is close to that of cotton seed oil biodiesel 53 [18], rice bran biodiesel 56 [17], mustard seed oil biodiesel 55 [34], jatropha oil methyl ester 52 [35], Waste frying oil 55 [31].

Higher cetane number of biodiesel diesel fuel is a big advantage over fossil diesel in terms of performance and emissions and makes biodiesel fuel engines run more smoothly and with less noise [20]. The higher the cetane number, the shorter is the delay in fuel combustion since fuels with high cetane number ignite faster [24]. Also higher cetane number of biodiesel fuels results in higher intensity of pre-mixed combustion which initiates early combustion and the fuel is burnt early due to the presence of oxygen molecule in biodiesel fuel resulting into higher NO<sub>x</sub> emission level of biodiesel fuel combustion exhaust [36].

## 4.0 Conclusion

The following conclusions may be drawn from the investigation;

1. The viscosity, flash point, acid value, ash content, moisture content and kinematic viscosity of *Khaya senegalensis* biodiesel fuel are within the limits specified by ASTM D6751 standard for biodiesel fuels.

2. The calorific value, the cetane number of *Khaya senegalensis* biodiesel fuel are lower than that of fossil diesel but in agreement with the values obtained from other plants' oil biodiesel fuels.
3. The cloud point, pour point, density, peroxide values of *Khaya senegalensis* biodiesel fuel are higher than that of fossil diesel, but in agreement with the values obtained from other plants' oil biodiesel fuels.
4. Considering the obtained physico-chemical properties of *Khaya senegalensis* biodiesel fuel, it could be concluded that the fuel properties of *Khaya senegalensis* biodiesel fuel is close to those for fossil diesel (D100). Therefore *Khaya senegalensis* biodiesel fuel can be used as a substitute to fossil diesel in compression ignition engines with little modification of the fuel.

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