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Production and Characterisation of Biodiesel from Palm Kernel Oil

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ABSTRACT

Growing energy challenges to meet future demands and sustain environmental health has necessitated the search for more renewable energy options to sustain human activities. This study investigated the production of biodiesel by transesterification of palm kernel oil (PKO) from the typical wild type 'akwu ojukwu' palm tree (Elaeis guineensis) of the Dura variety. Pure (100% v/v) biodiesel and its blends (10, 20, 30 and 50% v/v biodiesel) with petroleum diesel were characterised for the following properties: relative density, kinematic viscosity, flash point and pour point using standard laboratory techniques. The properties of the pure biodiesel and its blends were compared with diesel from the Nigerian National Petroleum Corporation (NNPC) and some international standards for biodiesel characteristics. The study revealed that for every 1 L of this variety of PKO and its additives, at least 0.87 L (87%) of biodiesel was produced; and most blends with 20% biodiesel and lower have desired properties for relative density, kinematic viscosity, flash point and pour point, hence possible use in diesel engines. The study has widened the frontiers of biodiesel fuel access and recommended the exploitation of the abundance of this crop-based fuel in Nigeria in ways that strengthen energy security, meet competitive needs for PKO, promote environmental sustainability and enhance the livelihood of PKO producers.

1. INTRODUCTION

Growing human population and its associated energy needs to sustain economies are driving the exploration and exploitation of fossil fuels. However, the use of fossil fuels exceeds their regeneration. Consequently, there is fast depletion of their natural reserves, and this challenges the prospects for their continuous usage in the future (United Nations, 2020; IEA, 2021). Besides the challenges of the availability of these resources faced in the future, their continuous usage emits pollutants into the environment. These pollutants usually stem from

huge dependence of the transport sector, and agriculture ventures on diesel engines and their utilisation of diesel fuel (Chukwu *et al.*, 2015; Akujor *et al.*, 2022). These emissions such as carbon dioxide (CO_2), oxides of nitrogen (NO_x), sulphur (SO_x), among others undermine the productive capacity of the environment and has interconnected impacts that impede the achievement of human goals and aspirations (Perera, 2018; Bertrand, 2021; Anukwonke *et al.*, 2022).

Following these interconnected challenges aligned to fossil fuels usage and diesel in particular, research attention is being directed towards renewable energy sources, hence reducing the proportion of non-renewable energy use (Wang *et al.*, 2015; Hood, 2016; Tambe *et al.*, 2022). This approach is a tenet in achieving sustainability in energy and is being integrated in various sectors in human energy needs. One of such sectors is the automobile industry, where agriculture-based sources of oil, such as animal fats, vegetable and waste cooking oils are being developed in biodiesel production for use in internal combustion engines (Demirbas *et al.*, 2016; Balasubramanian and Steward, 2019). These agriculture-based sources of fuels are mainly produced from crops such as soya bean, sunflower, rapeseed, canola, and oil palm. Among these crop-based sources of oils, the oil palm (*Elaeis guineensis*) is the most important vegetable oil globally, producing two different types of oils: palm oil and palm kernel oil (PKO), equating to more than 39% of world production of vegetable oils (Global Palm Oil Conference, 2015).

Like other bio-oils, there is growing interest in using palm kernel oil for biodiesel development. However, the high viscosity of raw vegetable oils challenges the prospect for their direct use in diesel engines (Bello *et al.*, 2015; Tarbuka *et al.*, 2017). This high viscosity has been attributed to high iodine and low cetane number. These are discouraging factors for any biofuel as they cause reduced atomisation of fuel, ignition delay and a subsequent reduction in efficiency in mechanical power production compared with those found in diesel fuel tests. To curb these challenges, transesterification is used – a process which reduces the viscosity of vegetable oils to a desired level similar to that of petroleum diesel. In this process, the fat or oil is reacted with an alcohol, like methanol, in the presence of a catalyst to produce glycerol and methyl esters or biodiesel.

The process of transesterification breaks down the three-dimensional networks in bio-oils into less complex small straight-chain molecules similar to those of petroleum diesel (Azeez *et al.*, 2016; Tarbuka *et al.*, 2017). The produced biodiesel through transesterification can be blended with petroleum diesel and used in diesel engines (Barabás and Todoruț, 2011). Besides the challenges of reducing viscosity in crop-based fuels, there is also the challenge of meeting competing needs (e.g. food, medicine and other raw materials) of crop-based biofuels sources (Geletu and Poto, 2019; Kurowska *et al.*, 2020). Therefore, identifying appropriate blends of biodiesel and petroleum diesel are essential in promoting the use of bio-oils and reducing competing needs.

While the production and use of biodiesel or its blends guarantee environmental health and sustains human progress, it is important that their content should mimic desired petroleum diesel properties that will accommodate little or no diesel engine modification, and yield desired engine performance (Azeez *et al.*, 2016). Thus, the efficiency of any biodiesel is tested in how close or similar they express these petroleum diesel properties, which include density, kinematic viscosity, cetane number, cold-flow, flash point, specific gravity, heat content, pour point, Sulphur content, ash content among others.

In biodiesel research, the different species and varieties within the same species of plants of crop-based bio-oils express varying biomass, different feedstock cellulose, lignin and hemicellulose content (Machado *et al.*, 2022). These affect the resulting bio-oil chemical composition and varying molecular chain properties. These properties define the quality of the bio-oil, required treatments and its subsequent use in diesel engines (Ansari *et al.*, 2019).

In *Elaeis guineensis,* the *Tenera* (high breed) variety of this species is characterised with thinner shell and thicker mesocarp. This is common in industrial scale production of palm oil, and subsequently production of PKO, which is commercially marketed and used for biodiesel production (Alamu *et al.*, 2008; Bello *et al.*, 2015). However, the typical wild variety called 'akwu ojukwu', a name from "Igbo" extraction, South-east Nigeria, similar to the normal oil palm of *Dura variety* of *Elaeis guineensis*, has not been specifically used with methanol for biodiesel production. While "akwu ojukwu and normal oil palm of *Dura variety* are characterised with thick shell and thin mesocarp, the difference between it and other palm nuts is that, other types have shades

of black and reddish yellow colour, while "akwu ojukwu" ripens without developing any black spot. This variety of palm nut is dominant in Central and West Africa, including Nigeria. Thus, the variation in species makeup and the implication of its contents and bio-oil quality are essential considerations in biodiesel production and use. This study, therefore, investigated the production of biodiesel from the typical wild type of *Elaeis guineensis*, "akwu ojukwu" and testing the fuel properties of using the pure biodiesel and its different blends with petroleum diesel. Addressing this gap will advance the frontiers of bioenergy development in the automobile industry, strengthen energy security, enhance energy mix and sustain environmental health.

2. MATERIALS AND METHODS

2.1. Materials and Equipment

Palm kernel oil from 'akwu ojukwu' was obtained from a wild farm located at Umuorie village, Naze, Owerri North Local Government Area (LGA), Imo State, Nigeria. The materials and equipment that were used in the study included 70 L reactor powered by 1.5 kW electric motor equipped with electric heater and thermostat, stove, stainless steel pot, 30 L plastic washing pail bucket with a tap at the base, pH meter, measuring cylinder of different sizes, sensitive weighing balance, 50 mL burettes and pipettes, and beakers of different sizes. In addition, a hydrometer, plastic containers, thermometers, sodium hydroxide pellets, methanol, isopropyl alcohol, concentrated acid, phosphoric acid and a filter were also used.

2.2. Production of Biodiesel from Palm Kernel Oil by Transesterification

2.2.1. Determining the quantity of sodium hydroxide (NaOH) catalyst used

The palm kernel oil was pre-treated by heating to remove water and other impurities which hinder transesterification. A gram (1 g) of NaOH was diluted in 1 L of distilled water to yield a diluted solution of NaOH. A solution of palm kernel oil (1 mL of PKO in 10 mL of isopropyl alcohol) was produced. The produced NaOH was introduced into the burette and titrated against the solution of PKO until the pH of the PKO solution rose to about 8.5. Each mL of NaOH used in the titration was considered as 1g and for x mL used for titration, the amount of NaOH was x g. Thus, 1mL of NaOH is needed to neutralize 1 L of PKO, and a further 3.5 g of NaOH was required to crack the molecules of PKO. Thus, for 1 L of PKO used, the amount of NaOH and the catalyst required =(x+3.5) g.

For y L of PKO used for biodiesel production, amount of NaOH and catalyst = (x+3.5) y g

2.2.2. Production of the biodiesel

Biodiesel was produced from the palm kernel oil using the adopted method of direct-base catalyst transesterification (Bello *et al.,* 2015; Yunus Khan *et al*., 2018). Here, the titration method was employed. After determining the quantity of NaOH catalyst that was used, the y litres of pre-treated PKO was heated in the reactor to about 60 ^{o}C. Values of y ranging from 5 to 40 L were tried. During the heating of the PKO, the (x+3.5) y g of NaOH pellets was measured and dissolved in high grade quality methanol of 0.175y litres to produce a solution referred to as sodium methoxide. The heated PKO in the reactor was agitated and after 10 minutes, the sodium methoxide was carefully added to the PKO while heating and mixing continued. The heating temperature was maintained using a thermostat. The mixture was thick and murky at first but became thinned out as the mixing continued. After mixing vigorously at a speed of 850 rpm for about 2 hours, straw yellow ester began appearing on the top of the mixture. After the mixing and heating were stopped, the mixture was allowed to settle in the separating funnel overnight and covered to avoid contamination. In the following morning, two layers were observed: the translucent liquid (ester or biodiesel) on the top and the sticky layer (glycerol) at the bottom. The biodiesel was siphoned out while the glycerol was discharged through the drain tap.

2.2.3. Washing and drying the biodiesel

The siphoned biodiesel was poured into a washing bucket containing a tap at the base and washed with pipe borne water through stirring. After 4 hours, the water used for washing was drained out through the tap. At the initial stage of washing, the drained water was very cloudy. However, after intermittent washing, the wash water became clear. The pH of the wash water was also tested intermittently until it was about 6.9 to 7.1, and

the washing was discontinued. At the end of the washing, and because of the slightly acidic nature of pipe borne water, the highly alkaline biodiesel was neutral (pH=7.0). Clear biodiesel on top was decanted into a stainless steel pot and heated. Care was taken so that large drops of water were not allowed to enter the pot as this could cause series of explosions. The heating was completed after steaming and cracking noise ceased, indicating that there was no water in the biodiesel. Three attempts of biodiesel were produced. Each attempt of the fuel was allowed to cool to room temperature and was then ready for use.

2.3. Characterisation of the Biodiesel and Experimental Determination of Properties

The samples of biodiesel produced, and the petroleum diesel obtained from Nigerian National Petroleum Corporation (NNPC) mega station at Owerri, Imo State were characterised for the following proportions (blends) of fuel:

10%/90% (v/v) biodiesel/petroleum diesel

20%/80% (v/v) biodiesel/petroleum diesel

30%/70% (v/v) biodiesel/petroleum diesel

50%/50% (v/v) biodiesel/petroleum diesel

100% (v/v) biodiesel from PKO

The pure biodiesel and its blends were tested for relative density (specific gravity), kinematic viscosity, flash point and pour point using standard biodiesel analytical methods (Van Gerpen *et al.*, 2004). The relative density (specific gravity) was determined using the density bottle, a device for revealing the specific gravity of liquids-the ratio of the weight/density of a liquid to the weight/density of an equal volume of water. The determination required a density bottle, water and weighing balance. The density bottle was cleaned and dried properly. It was weighed with the stopper using the weighing balance and filled with water and weighed again after drying the outside of the bottle properly. The weight of the water alone was deduced. The water was poured out and the last drop was washed with the 10% blend of biodiesel. The density bottle was then filled with the 100% biodiesel and the various blends. For each of the biodiesel and its blends, the specific gravity was deduced.

The kinematic viscosity was determined using rotational viscometer – a viscosity measuring device designed to give a direct value of liquid dynamic viscosity. The thermal bath was filled with water. The viscometer was set up with a cup containing the biodiesel positioned in the thermal bathe with the rotating spindled immersed inside the biodiesel. The temperature was set at 45 ^{o}C using the thermostat and allowed to reach thermal stability. The spindle was switched on to rotate and the value of the viscosity of the biodiesel was displaced and recorded. This process was repeated for the various blends and the 100% (v/v) biodiesel.

The flash point, the lowest temperature at which oil gives off enough vapour that ignite for a moment when tiny flame is brought near it, was determined using Pensky Marten;s apparatus. Besides the apparatus, match box, thermometer, and filter paper were used. Benzene was used to clean all parts of the apparatus. The oil cup was filled with 100% biodiesel up to the mark. The lid of the oil cup was fixed, and the thermometer and stirrer were fixed in their respective opening. The flame exposure device was also fixed on the top. The test flame was lighted and adjusted to about 4 mm in diameter. The apparatus was heated, and the temperature of the biodiesel increased by 5 to 6 ^{o}C per minute as the stirrer was continuously rotated. For every 1 ^{o}C rise in temperature, test flame was introduced into the biodiesel vapour through the opening. When the test flame caused a distinct flame in the interior cup, the temperature at which this occurred was recorded. This temperature was the flash point and the process was repeated for the other blends.

The pour point, the lowest temperature at which fuel stops flowing to the pump. It was determined using the Automatic Pressure Pulsing Method. Under ASTM (2001), the pure biodiesel and its blends were heated and then cooled by a Peltier device at a rate of 1.5±0.1 °C/min. A pressurized pulse of compressed gas was imparted onto the surface of each sample at either 1 °C or 3 °C intervals. Each sample was continuously monitored for movement using multiple optical detectors. The lowest temperature at which surface movement was detected on the sample was indicated and recorded as the pour point.

The tested properties were compared with that of NNPC diesel and other recommended international standard for biodiesel fuel (Barabás and Todoruț , 2011). These standards used for the comparison with the produced biodiesel were European Union, United States, Australia, India, Japan and South Africa.

3. RESULTS AND DISCUSSIONS

3.1. Yield of Biodiesel

For the three attempts of biodiesel production, the volume of biodiesel produced from its associated volume of PKO, methanol and other additives after drying is summarised (Table 1). Using one-sample T-test at $p<0.01$, the experiment showed that the mean volume of the three attempts of biodiesel obtained from 16.00 L of PKO, 2.00 L of methanol and 10.55 L of other additives was 14.01±0.02. This showed that for every 1 L of PKO and its additives, at least 0.87 L (87%) of biodiesel was produced. The proportion of the volume of biodiesel generated from the PKO is similar with those of the studies by Aladetuyi *et al.* (2014) and Alamu *et al.* (2008) where more than 80% of biodiesel was produced from 1 L of PKO. In order to achieve maximum yield, the quality of PKO, quality and quantity of chemicals, operating time and mixing speed are essential variables to be considered. For example, at a mixing speed of 400 rpm during the start of the experiment, no separation was observed between the biodiesel and glycerol. When the speed was increased up to 850 rpm, separation occurred after 2 hours. This agrees with studies that a consideration of the optimum independent variables that define maximum yield are essential in biodiesel production (Hasan *et al.*, 2017; Chukwuezie *et al.*, 2018). Therefore, the abundance of 'akwu ojukwu' oil palm and its subsequent production of PKO in Nigeria can be transformed through transesterification in suitable conditions for biodiesel production.

Table 1: Volume of biodiesel produced from methanol and other additives

Attempts	Volume of PKO (L)	Volume of methanol (L)	Volume of other additives (L)	Volume of biodiesel produced after drying (L)
1	16.00	2.00	10.55	14.06
2	16.00	2.00	10.55	14.00
3	16.00	2.00	10.55	13.98

3.2. Biodiesel Characterisation

Table 2 shows the properties of biodiesel and its various blends, and also that of petroleum diesel obtained from Nigerian National Petroleum Corporation (NNPC).

Table 2: Properties of biodiesel blends and petroleum diesel.

Properties	NNPC diesel	Biodiesel/petroleum diesel (v/v)				
		10%/90%	20%/80%	30%/70%	50%/50%	100%
Specific gravity at 15 ^oC	0.87	0.87	0.87	0.88	0.88	0.90
Kinematic viscosity at 40 ^oC (mm^2/s)	4.90	5.60	6.02	6.21	5.90	7.65
Flash point (^oC)	126.70	127.20	126.70	127.70	134.10	178.70
Pour point (^oC)	< -26.00	< -26.00	< -26.00	< -26.00	-1.10	10.00

The study found that the specific gravity at 15 ^oC increased from 0.8720 to 0.9001 and is aligned with increasing proportion of biodiesel in the blends. The increased specific gravity with increased amount of biodiesel is associated with the relatively more complex structural networks of biodiesel when compared with petroleum diesel. This specific gravity of fuel is related to other fuel parameters like cetane number, aromatic contents, viscosity and distillation characteristics (Bello *et al.*, 2015; Tarbuka *et al.*, 2017). The NNPC diesel has a specific gravity of 0.8709. It is recommended to mix petroleum diesel with biodiesel of mixtures between 5-20% biodiesel (Barabás and Todoruț, 2011). It further specifies that specific gravity between 0.860 to 0.900 at 15 ^oC corresponds to several international standards (ISO, 1996; ISO, 1998; ASTM , 2005) for efficient diesel engine performance. The lower the specific gravity, the better the engine performance. Increasing specific gravity of diesel fuel is associated with heavier aromatic hydrocarbons due to poor refining (Igbani and Lucky, 2015). Increase in specific gravity enhances emission of particulate matter and smoke. This undermines engine power and fuel consumption efficiency, hence a discouraging factor for any biofuel. To curb this challenge, the

specific gravity must be controlled within a narrow range. Therefore, the specific gravity of the produced fuel is recommended in diesel engine.

Similarly, the study also found that the kinematic viscosity also generally increased from 5.6 to 7.65 mm^2/s at 40 ^oC and is aligned with increasing proportion of biodiesel in the blend. This is also because of the relatively more complex structural networks in biodiesel when compared to the petroleum diesel. The NNPC diesel has kinematic viscosity of 4.9. Several international methods and standards (such as ISO, 1994; ASTM, 2006, 2017) have recommended kinematic viscosity for fuels for use at 40 ^oC to be between minimum of 1.9 to maximum of 6.0 mm^2/s. This means that the blends of the biodiesel produced below 20% biodiesel are suitable to meet international standard for kinematic viscosity and sustain diesel engine performance. The flash point was also found to increase from 127.2 to 178.7 ^oC in relation to increasing proportion of biodiesel in the blends. This is because the relatively more complex structural content with increasing proportion of biodiesel requires more energy (expressed in temperature) for distintegrating the relatively more complex networks. The determined flash point was very close to that of NNPC diesel, and it is also within the prescribed range by several international methods and standards (ISO, 2004; ASTM, 2008) wherein a minimum flash point of 93 ^oC have been recommended. The higher the value, the better the fuel, and it is based on the premise that the flash point is essential for safe handling and storage of fuel. This is quite impressive for the produced fuel property in using higher proportions of biodiesel in blends. However, increasing biodiesel proportion in blends is a discouraging factor to kinematic viscosity and specific gravity. Consequently, it is essential to identfy more productive synergies in the fuel properties that can accommodate less harmful tradeoffs in the diesel engine performance.

Furthermore, the pour point was found to be less than -26 ^oC for 10 to 30% blend of biodiesel, -1.1 ^oC for 50% biodiesel blend and 10 ^oC for pure (100%) biodiesel. The pour point for NNPC diesel was also less than -26 ^oC. According to European standard, EN (2003) for using biodiesel as a heating oil, the pour point should have a maximum limit of 0 ^oC. This means that, excluding the pure (100%) biodiesel, the blends of 10 to 50% biodiesel produced from 'akwu ojukwu' can be acceptable for use in diesel engines.

The tested properties of biodiesel produced from 'akwu ojukwu' PKO were also similar with those of the properties of other crop-based fuels that have been recommended (Alamu *et al.*, 2008; Aladetuyi *et al.*, 2014). Therefore, exploiting 'akwu ojukwu' for biodiesel production in Nigeria is a feasible option for sustainable energy development in the automobile industry.

4. CONCLUSION

Exploring new sustainable energy frontiers in the automobile sector constitute an essential tenet in transportation research and development of society. The findings from this study showed that the produced biodiesel from palm kernel oil from the typical wild type 'ackwu ojukwu' palm tree (*Elaeis guineensis)* has the potential for use in diesel engines when blended with petroleum diesel. However, selecting the appropriate biodiesel and petroleum diesel blend (v/v%) will require identifying more productive synergies in the fuel properties that can accommodate less harmful tradeoffs in the diesel engine. Therefore, the abundance of this crop-based fuel in Nigeria can be exploited in ways that will enhance energy security, reduce ecological footprint, satisfy other needs of PKO and improve the livelihood of oil palm producers.

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6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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