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Investigation of the Potential of African Oil Bean Seed as a Feedstock for Biodiesel Production using Iron (Iii) Oxide

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ABSTRACT: Biodiesel which is the diesel fuel derived from renewable sources such as plant oils and animal fats, holds a significant potential as a sustainable alternative to conventional fossil fuels. However, the cost of its production has remained a major obstacle to the widespread production and commercialization of this globally established renewable alternative energy source. This study investigated the potential of African oil bean seed as a viable feedstock for biodiesel production using iron (iii) oxide as catalyst. In carrying out this research, oil was extracted from African oil bean seed by the Soxhlex solvent extraction method using N-hexane, and converted into biodiesel with Iron (iii) oxide as a catalyst through base-catalyzed transesterification process. The oil and biodiesel yields were found to be 38% and 92% respectively. The result of the biodiesel characterization through determination of its physicochemical properties revealed that the biodiesel has these values; viscosity (1.67mm^2/s), specific gravity (0.898), density (0.9 g/cm^2), saponification number (174.8 mg KOH/g), free fatty acid (0.5%), iodine value (17.56 gI_2/100g), cloud point (10.2), pour point (9.5), flash point(223.5^{o}C), cetane number (108.3), calorific value (47,4 MJ/kg). The values are within the acceptable range prescribed by ASTM D6751for biodiesel, except the high cetane number, cloud point, pour point, which can be reduced with appropriate additives. This biodiesel compared well with the hydrocarbon diesel fuel. Furthermore, the percentage oil and biodiesel yields were high, thereby confirming African oil bean seed and Iron (iii) oxide as a viable feedstock, and cheap catalyst respectively, for biodiesel production.

KEYWORDS: biodiesel, physiochemical-properties, transesterification, seed oil, saponification, solvent extraction, base-catalysis, edible oil

1.0 INTRODUCTION

The growing global concern for environmental sustainability and the increasing energy cost have spurred extensive research into the discovery of alternative energy sources. Biodiesel is a renewable and eco-friendly fuel [1][2] [3], that has gained global prominence recently, as a viable alternative to the traditional fossil fuels. The use of biodiesel not only reduces greenhouse gas emissions but also provides an opportunity to utilize edible plant oils, such as African oil bean seed oil, which could contribute significantly to sustainable energy production [14]. Biodiesel which is the diesel fuel derived from renewable sources such as plant oils and animal fats, holds a significant potential as a sustainable alternative to conventional fossil fuels. It is considered an environmentally friendly alternative to conventional diesel fuel due to its lower carbon footprint and the reduced emissions of harmful pollutants [2]. However, the cost of production of this widely acknowledged viable alternative to hydrocarbon diesel has become a major impediment to the commercialization of this renewable energy source. This has led scientists and other researchers alike to seek for ways of producing biodiesel in a cost-effective manner. A number of strategies that have been identified for reducing, the cost of biodiesel production includes identification of high oil yielding feedstocks, Utilization of the most efficient catalyst for a particular feedstock, improved production technology and optimization of process parameters. The biggest obstacle working against the commercialization of biodiesel production in most developing countries is the chemical reagents such as N-hexane, alcohol and catalyst, which are usually imported at a very high cost. Hence, the development of cheaper reagents and more economical production technologies as well as the identification of cheap, suitable, oil-rich feedstock is essential for commercialization of biodiesel. Furthermore, the choice of catalyst has been reported to wield significant influence on the production efficiency, environmental impact of the production process and production cost [16]. According to TutorChase [21] catalyst functions to alter the mechanism of a reaction by providing an alternative reaction pathway with a lower activation energy. This they do by forming temporary bonds with the reactant molecules, and creating an intermediate

species that is more reactive [21]. It has become necessary to use catalyst in the transesterification of the triglycerides in vegetable oils and animal fats into biodiesel and glycerol, because these triglycerides which the main raw material for biodiesel are reported to have complicated structure, and are comparatively inactive molecules. The large size of the triglycerides molecules makes them comparatively stable. Hence, in order to start the transesterification reaction, the catalyst is needed to aid in breaking the bonds in the triglycerides, and thereby increasing their reactivity during the process [21]. Catalysts are crucial to the biodiesel production process because they accelerate the transesterification reaction and have an impact on the final product's quality [11] [22]. Acids, enzyme catalysts, and base materials (alkalis) are examples of frequently used catalysts in transesterification process. It has been reported that the reaction efficiency as well as the overall economics of producing biodiesel are influenced by the choice of catalyst [14][16][22][23]. The current conventional homogeneous catalysts such as sulphuric acid, sodium hydroxide, potassium hydroxide that are commonly used for conversion of feedstock oils and fats with high FFA into biodiesel are uneconomical, and pose environmental challenges, since the product require washing. Atadashi et al. [23] observed that because of the high cost of refined feedstocks and difficulties associated with the use of homogeneous alkaline catalysts to transestrify low quality feedstocks for biodiesel production, the quest for the development of various heterogeneous catalysts is now on the increase. Strong bases like potassium hydroxide (KOH) or sodium hydroxide (NaOH) are frequently utilized in base-catalyzed transesterification [20], while Acid-catalyzed esterification involves the use of acids such as sulfuric acid (H_2SO_4) or hydrochloric acid (HCl) [16] [29]. A homogeneous catalyst is a catalyst that exists in the same phase as the reactants which it is catalyzing [24]. However, it has been reported that the strong acids or bases which are examples of homogeneous catalysts can be extremely reactive and caustic during the biodiesel synthesis process, and often poses serious concerns about the safety of workers and equipment. However, some of the strategies aimed at solving these problems involve the use of either through the use of cheap, but effective less strong base like iron (iii) oxide or acidic catalyst, or through the use of heterogeneous catalyst such as solid and enzymes catalysts [23]. This necessitates additional safety measures and maintenance procedures, resulting in additional operational complexity and cost. This makes the application of some homogeneous catalysts in the production of biodiesel difficult and costly. Furthermore, homogeneous catalytic processes often require elevated temperatures and pressures to achieve satisfactory reaction rates and yields, leading to higher energy consumption and operational costs compared to heterogeneous catalysis. This can also lead to a reduction in the overall economic viability of biodiesel production and increase its carbon footprint [26]. This research aims to contribute to the on-going research at providing solutions to some of the problems mitigating against the large-scale production of biodiesel. Specifically, this work seeks to explore the feasibility of using African oil bean oil as a biodiesel feedstock, by producing biodiesel from oil bean seed kernel using cheap and readily available waste material known as iron oxide as catalyst. Iron oxide, with its abundance, low cost, and environmentally friendly characteristics, could serve as a potential catalyst for biodiesel synthesis. When it comes to the manufacture of biodiesel using transesterification method, homogeneous catalysis typically produces high ester yields in short reaction times, but the products must be purified to remove the residual catalyst, though the waste-water resulting from washing the products can be environmentally damaging. Orege et al., [27] observed that one important technology that has allowed the biodiesel industry to advance significantly is catalysis. For a long time now, homogeneous catalysis has been the most common catalyst for biodiesel production. Since they generate large amounts of biodiesel quickly and affordably, homogenous acid or alkaline catalysts are appealing for transesterification in theory [27],[25]. However, the application of this type of catalyst is usually associated with problems such as water pollution, corrosion of equipment, unnecessary use of wash water, and separation of catalyst-product mixtures, and so on [5][31]. African oil bean (Pentaclethra macrophylla) is an underutilized oilseed crop that is grown in abundance in many African countries. The African oil bean tree usually grows into a large size with long bipinnate compound leaves. It belongs to the Fabaceae family. The common use of the seeds is that they are boiled and allowed to ferment for making Ugba, which can either be eaten alone or used as a condiment for making soup in south-east Nigeria [39]. The oil bean seed currently has little or no industrial uses, though its oil is edible oil. Its oil content and potential for biodiesel production make it an attractive candidate for sustainable energy generation.

2.0 METHODOLOGY

A brief documentation of the methodology for the production and characterization of biodiesel from African oil bean seeds is presented here with the various steps involved, including seed collection, seed preparation, oil extraction, oil transesterification, and biodiesel characterization.

2.1 MATERIALS

2.1.1 Seed feedstock Collection. The feedstock material for this experiment are the seeds of the African oil been tree, which are processed to obtain its oil. Mature seeds of African Oil bean used for the experiment were bought from Obollo-Afor Market in Nsukka Enugu state, south-east Nigeria. This is a seasonal crop that produces matured seeds in large quantities during the dry seasons, though the dried seed can be found in the market all year round. A sufficient quantity of seeds was collected for the conduct of the biodiesel production process and subsequent characterization tests.

2.1.2 Reagents and chemicals

The chemicals and reagents used in this research work for the extraction of oil and biodiesel production were purchased from Joechem Ventures chemical store at 45 Enugu-road Nsukka, Enugu state. They include, N-hexane (99.9%) made by Merck of Germany, for the Soxhlet oil extraction from the pulverized seed. Sulphuric acid, for the acid esterification of the seed oil, Iron oxide (Fe_2O_3) which will serve as the catalyst, analytical grade Methanol and Ethanol (99.9%) produced by Merck Germany for the transesterification of the oil to biodiesel, and distilled water for washing the biodiesel, and Phenolpthlein which served as indicator.

2.1.3 Apparatus and analytical equipment

The major apparatus and analytical equipment used in this research include A (name of) country made Milling machine (for pulverizing the seeds), an Electrical digital precision weighing balance (for weighing), a Magnetic stirrer,(for stirring the reactants), a Measuring cup (1 litre), Measuring cylinder, Conical flask, Hydrometer (for density determination), Soxhlet extractor (for oil extraction), Evaporator oven for drying the produced oil and biodiesel), Automatic viscosity tester (JSR1104, China), Funnel for separation of transesterification products, Thermometer for temperature determination during the oil conversion process. Other materials included: Distillation tool, Burette, Conical flask, Glass column, Heater, knife (for extracting the seed kernel from the shell), and pulverizer (Grinder). Both the Soxhlet and Transestrification processes for the extraction of the African Oil bean Seed Oil (AOBSO) and the Subsequent conversion to Biodiesel respectively were performed at the National Energy Centre Laboratory, university of Nigeria, Nsukka, Enugu State.

2.2 METHODS

The production of biodiesel from the African oil been seed involves a number of stages which are discussed in detailed below.

2.2.1 Seed Preparation: The purchased seeds were sorted and selected based on their maturity and quality, to ensure that they are free from any visible damage or contamination. The seeds were first sun-dried in the open at an average temperature of 38^{o}C for 10 days. Thereafter the shells of the seeds were manually opened using a knife for the seed kernels to be taken out. The useful seed kernel which formed the feedstock (major raw material) was sun-dried. To reduce the moisture content of the extracted seed kernels, the semi-dried extracted seed kernels were further sun-dried for another 10 days at an average temperature of 38^{o}C, 8 hours each day, and weighed after each drying day, until the weight loss became almost insignificant. Figures 2.1a and 2.1b show the sorted African oil bean seed and the pulverized African seed kernel.

Fig.2.1a, Sorted African oil bean seed

Fig. 2.1b, The pulverized African seed kernel

Table [1] shows the weight loss of the extracted seeds of the African oil bean seed during the sun-drying process. The weight of the seeds was recorded daily to determine the moisture contents as it is dried. After drying for about 10 days and 8 hours each day till the mass of the specimen became nearly constant. The dried seed specimen was then taken to the mill for grinding to powdery form, to make it ready for the Soxhlet solvent oil extraction process. The moisture lost from the seeds is calculated based on equ.(1)

Table [1] the weight variations of the seeds during 10 days of sun drying

DAY	weight(kg) variations	Moisture content lost /day (kg)
1	16.16 -14.80	1.34
2	14.80 -13.65	1.15
3	13.65 -12.90	0.75
4	12.90 -12.55	0.35

5	12.55 -11.50	1.05
6	11.50 -10.51	0.99
7	10.51 -9.39	1.12
8	9.39 -8.64	0.75
9	8.64 -8.29	0.34
10	8.29 -8.18	0.12

The initial weight of sample before sun-drying = 16.16kg
Total moisture lost during 10 days of sun drying = (1.32 + 1.15 + 0.75 + 0.35 + 1.05 + 0.99 + 1.12 + 0.75 + 0.34 + 0.12) kg =7.96kg
Total mass available for grinding after 10 days of sun drying = (16.16 – 7.96)kg = 8.18 kg (1)

2.2.2 Oil Extraction and Concentration Procedure. The dried seeds were pulverized using a milling machine and subsequently, a given amount of the pulverized seed was used for the Soxhlet solvent oil extraction process. The oil was then extracted using the Soxhlet solvent oil extraction method with N-hexane as the solvent. For the Soxhlet solvent oil extraction process, a round bottom flask containing analytical grade N-Hexane (99%) was fitted with a reflux condenser to the top. This was placed in a heating mantle at 65∘C and the liquid condensate dripped into the thimble which contained the pulverized sample [30]. The extract sipped through the pores of the thimble and filled a syphon tube in an operation that lasted for 6 hours. The extracted oil was collected and stored in suitable containers for further processing. The extract was later subjected to heat at a temperature of 65^{o}C to recover the solvent, through centrifugation and later to evaporation processes at 100^{o}C, in a rotary evaporator (R00102439, 50W/15A) to eliminate moisture, leaving behind the extracted oil. To improve the quality of the extracted oil, further purification steps, such as refining and filtration, were implemented on the oil to remove impurities, water, and any remaining solvent traces. The oil extraction procedure is shown in figure [2.2]. The flask was then allowed to cool and the percentage yield was determined. Thereafter, the refractive index, viscosity, saponification values, acid value, iodine value, free fatty acid value, specific gravity, and other relevant properties of the oil were determined using AOAC (1997) [18].

Fig 2.2 The Soxhlet oil extraction from the milled African oil bean and the purification processes

A solvent extraction procedure was used to extract the oil. The powdered African oil bean was wrapped in Whatman filter paper and put into the thimble and the thimble was placed in a 1 litre capacity flask containing 700 milliliters of N-hexane of the Soxhlet extractor. Because the n-hexane has an ideal boiling point of 78°C, the flask was then heated to a temperature of 79°C with this temperature maintained for a whole six-hour reflux period. At the end of the six-hour reflux period, the excess n-hexane in the oil and n-hexane mixture was removed, and the oil containing a small quantity of n-hexane was placed inside a centrifugal evaporator, for the remaining n-hexane solvent to evaporate. The extracted oil left after the evaporation process was collected and poured into a sealed airtight container. A total of 2.66 kg of oil was produced from the 7 kg of the pulverized African oil bean tree seed, at the end of the oil extraction process.

2.3 Catalyst Preparation

The Iron oxide catalyst used in this experiment is a homogenous catalyst. This catalyst was prepared by 8g of Fe_2O_3 was weighed out and added to 125ml of methanol and left in a tightly closed container overnight to dissolve properly. This mixture was stirred thoroughly to facilitate the formation of the solution of Iron (iii) methoxide. It is the formed Iron (II) methoxide solution which was used as the catalyst. Figure 2.3 shows the ground iron (iii) oxide catalyst.

Fig. 2.3 Iron oxide (Fe_2O_3) catalyst

2.4 BIODIESEL PRODUCTION

The production of biodiesel from vegetable oils and animal fats using the transesterification method can be by either alkali-transesterification (base-catalysis), acid-transesterification (acid-catalysis) or by Lipases (enzyme catalysis) process. Transesterification is the chemical process of converting glycerol esters that constitute vegetable oils into another ester such as the alkyl monoesters that compose biodiesel [6]. In general, it is the process of exchanging the organic functional group R^{II} of an ester with the organic group of an alcohol [7]. The transesterification process usually involves a number of steps. And the number of steps involved in the biodiesel production process is dependent upon the type of the triglyceride conversion method adopted.

2.4.1 Oil Pretreatment/Acid Esterification of the oil

The extracted oil was subjected to acid esterification because the free fatty acid test on the oil was above 1%, in compliance with the ASTM D6751 standard [15]. Hence, after the extraction of the oil from African oil bean tree (Pentaclethra macrophylla) seed, the free fatty acids of the seed oil were determined and found to be 3.25% but it is expected to be ≤ 1%, because high FFA leads to low yield [1] [15][16]. To reduce the FFA percentage of the extracted seed oil (AOBSO), 400ml of the oil was preheated to 50^{o}C in a 650ml round bottom flask containing a mercury in glass thermometer and placed on the hotplate of a magnetic stirrer rotating at 250 rpm. 100ml of Methanol was mixed with 10ml of sulfuric acid (the catalyst) in a beaker and brought to the same temperature of 50^{o}C afterwards. The mixture of acid and methanol were added gradually to the preheated oil at the constant temperature of 50^{o}C and the reaction allowed to agitate on the stirrer for 1 hour. After this agitation for an hour, the reaction product mixture was poured into a separating funnel and left for 6 hours to allow for the settlement of the impurities. At the end of the resting time, the content of the funnel was found to have separated into three layers comprising water at the bottom, pretreated oil in the middle and methanol at the top layer [14]. The mixture was carefully separated by tapping of the water first, thereafter the oil, and finally the methanol. After this, the test for the FFA of the oil was carried out again. The process of FFA reduction was continued until the FFA content of the oil was reduced to ≤ 1% (FFA = 0.52). The pretreated oil was then poured into a beaker and dried in an oven maintained at a temperature of 100°C until all the residual water evaporated away, leaving the African oil bean seed oil extract ready for biodiesel conversion through transesterification and other analysis.

2.4.2 Transesterification Process

The oil-to-biodiesel conversion process was carried out by the use of homogenous base-catalyzed transesterification reaction method was used as described by Umer et al. [32]. The pretreated African oil bean tree seed oil was converted into biodiesel by the transesterification reaction in the presence of Iron oxide catalyst. The ratio of methanol to the oil sample used was 6:1, the quantity of Iron oxide (Fe_2O_3) used was 1% weight of the sample. Freedman et al.[33] reported that the optimal yield of biodiesel (90-97%) was achieved during transesterification of triglycerides to methyl esters at methanol to oil ratio of 6:1 and validated by Patil and Deng.[34]. The transesterification process was carried out using the batch method. In this method, 6g of the catalyst, Iron oxide was weighed out and mixed with 600 ml of methanol in the chemical reactor vessel- a 1000 mL round bottomed flask equipped with thermostat and mounted on a magnetic stirrer machine hotplate rotating at 250 rpm, and raised to a temperature of 60^{o}C, the optimal temperature for these type reaction as reported by Ma and Hanna, [35]. As increasing the reaction temperature above the boiling point of methanol, has been found to speed up saponification until alcoholysis is concluded [13]. A 100 ml of the preheated seed oil was then added gently, while maintaining the required reaction temperature of 60^{o}C, and for a time of two hours, the reaction time of 120 minutes was identified by [36] for optimal biodiesel yield of above 90%. Furthermore, after the agitation for two hours, the reaction product mixture was poured into a separating funnel and allowed to stand and settle for 24 hours, enabling the segregation of the reaction products into two layers, with the upper light layer containing the Biodiesel, and the denser glycerin layer occupying the

bottom part. The glycerin layer was tapped off, and thereafter, the Biodiesel, with the methanol recovered from the methanol-water mixture through distillation. The transesterification process was carefully controlled to achieve optimal conversion efficiency.

$CH_2COOR_1CH_2CH_2COOR_1CHOH+CH_2COOR_2+3CH_2CH_2OH$

$CH_2CH_2COOR_2+CHOH+CH_2COOR_3CH_2CH2COOR_2CH_2COOR_2CH_2OH$

(glycerides) + (alcohol) ⟶ (ethyl esters) + (glycerin)

Fig. 2. 4 The Transesterification process of oil conversion to biodiesel [36]

2.4.3 Separation and Decantation of Biodiesel

As earlier mentioned, the reaction mixture was allowed to settle for 24 hours, to enable the segregation of bye-products of the transesterification reaction into two layers; a pale liquid layer at the top layer of the separatory funnel, the biodiesel and the lower layer containing glycerin which settled at the bottom of the funnel. Each of the solutions was either tapped off or decanted into two different containers.

Fig 2.5 Segregation of the biodiesel from the glycerin after transesterification.

2.4.4 Purification of the Biodiesel

In order to purify the Biodiesel produced, Acetic acid was added to it, followed by warm, distilled water to remove impurities [4] [11]. The purification of the biodiesel involved washing the produced biodiesel with warm distilled water to remove impurities such as unreacted methanol, glycerin, particles of the catalyst (Iron oxide), and any soap formed during the process, from the biodiesel. The ester or biodiesel obtained are usually washed thrice with warm distilled water to remove sediments and impurities including the residual catalyst. Complete removal of the catalyst from the ester could be made certain by determining the amount of the catalyst in the glycerin phase and the total catalyst removed from the ester or biodiesel phase. The sum of these components of the catalyst will account for all of the Iron oxide that was used in the reaction as catalyst. In this experiment, 35mL of distilled water was added to the separatory funnel containing the produced biodiesel and gently swirled for approximately one minute while being maintained at a temperature of 60°C and thereafter allowed to settle. The distilled water will dissolve the unreacted methanol, glycerin, and any soap formed during the reaction. The bottom layer containing the reaction sediments and impurities was then tapped off from the funnel while the leftover biodiesel was poured into a clean, dry graduated beaker. Furthermore, the produced biodiesel which contained some sediment was thereafter, filtered by passing it through filter paper, to remove the sediment. This filtration process is necessary in order to improve the quality of the biodiesel, and ensure its efficient performance in CI engine as well as prolong the life of the injection system of the engine [11]. The purified ester (biodiesel) was thereafter poured into a 250 mL beaker, placed in an oven set at 100°C and dried for 2 hrs. Finally, the volume of the biodiesel was determined and percentage yield calculated.

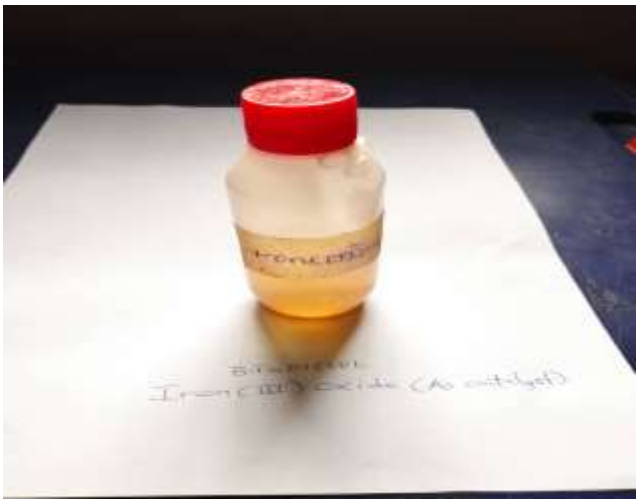

Fig 2.6 Biodiesel produced from African Oil Bean Tree Seed Oil using (Fe_2O_3) catalyst

2.5 OIL AND BIODIESEL YIELD DETERMINATION

A given quantity of the material feedstock was collected and processed to obtain oil of a given quantity which was subsequently processed, yielding a given amount of biodiesel. The methods for the determination of the oil and biodiesel yield percentages are discussed below.

2.5.1 Oil yield determination

Mass of dry seed kernel = I kg
Mass of seed residue after oil extraction =L kg
Mass of Oil extracted from the seed = (I- L) kg
Oil yield percent = (I – L)/I x100 **(2)**

2.5.2 Biodiesel yield determination

Mass of the extracted dry and purified oil used = M kg
Mass of glycol+ sediments =N kg
Mass of the biodiesel obtained after conversion M kg of oil extracted from the seed = (M-N) kg
Biodiesel yield percent = (M – N)/M x100 **(3)**

2.6 CHARACTERIZATION OF THE OIL AND PRODUCED BIODIESEL

The samples of the produced biodiesel were thereafter subjected to various characterization tests based on ASTM standards to determine its properties, quality and suitability for use as a diesel fuel. The following parameters were investigated and analyzed.

2.6.1Physicochemical Properties of Oil: To comprehend the chemical and physical attributes of the extracted seed oil (AOBSO), an assessment was conducted. This evaluation was aimed at determining the condition of the oil in order to make informed decisions about the need for any necessary additional treatment prior to commencing the Biodiesel production process or not [16].

i) **specific gravity (Sg)**

The specific gravity measurement on the oil was conducted utilizing a carefully cleaned 50 ml density bottle. The process entailed weighing an empty thoroughly cleaned 50 ml density bottle and noting the weight. Then filling the bottle with the test samples and recording their weight. Subsequently, the bottle was emptied and refilled with water, and its weight was recorded again. The formula for calculating specific gravity is presented as follows:

$$SG = (w_1 - w_0) / (w_2 – w_0) \quad (4)$$

Where, w_1 signifies the combined weight of the density bottle and the sample, w_2 indicates the combined weight of the density bottle and the water, and w_1 represents the weight of the empty density bottle.

ii) Viscosity: The major goal of the transesterification process of oil conversion to biodiesel is basically to reduce the viscosity of the oils. The viscosity of oils and even biodiesel often determines the applicability of any fuel in diesel engines or otherwise, as it creates one of the key challenges to efficient fuel flow, fuel spray, fuel atomization, fuel-air mixing, early injection, increased maxi mum pressure and temperature in the combustion chamber, continuous combustion, and steady power production in engines [16]. The viscosity of the feedstock oil for biodiesel can indicate the ease or difficulty of its conversion to biodiesel as well as the biodiesel quality and production efficiency [10][13][16]. The kinematic viscosity of biodiesel was determined using an automatic viscosity tester (JSR1104, China).

iii) Acid value: This is the number of NaOH required to neutralize the free fatty acid present in 1.0 gm of the oil sample [17]. The acid content of the oil was determined using the approach outlined by Egan et al. [20], with modifications derived from IUPAC [18]. For this, a combination of diethyl ether and ethanol (25 ml) was combined with 5 grams of African oil bean tree seed oil. The mixture was subjected to titration using 0.1 N ethanolic KOH solution, with 5 drops of phenolphthalein added to serve as an indicator. The volume (V) of 0.1 N ethanolic KOH used in the titration was recorded, and the mixture was continuously agitated until a shift from coloration to a colourless to pink mixture occurred. The total acidity of the oil, expressed in mg KOH/g, was calculated using Equation (5) as follows:

$$\text{Acid Value} = 56.1 \times N \times V / W \quad (5)$$

Where; W is the weight of the oil sample in g of the test portion, and V is the volume expressed in ml of 0.1 N solution of ethanolic KOH. Titer value, N, is the concentration of Potassium hydroxide KOH.

iv) Free fatty acid value: The acid value is a measure of the amount of free fatty acids present in an oil sample. It is an important parameter that indicates the quality of the oil. Higher acid values indicate a higher concentration of free fatty acids, which can lead to increased acidity and potential corrosion in engines and fuel systems. Therefore, a lower acid value is desirable as it signifies a higher quality biodiesel with reduced corrosive properties. Regular monitoring and control of acid value oil are crucial to ensure the optimal performance. Determination of % free fatty acid (FFA) The % FFA of the hydrolysis of the seed oil was determined according to AOAC as described in, [17] and [18]. Approximately 50 mL of isopropanol was poured into the flask, and about 0.5 mL phenolphthalein added, and thereafter neutralized with the addition of 0.02 N sodium hydroxide (NaOH) until a permanent pink colour appeared. The neutralized isopropanol was then added to 5 g of FFA, stirred gently and thereafter transferred into an Erlenmeyer flask, followed by the addition of about 0.5 mL of phenolphthalein. The mixture was monitored closely and immediately the first permanent pink colour appeared, 0.02N NaOH was added to neutralize the mixture. The percentage FFA was calculated by using the equation (6).

$$\% \text{ FFA} = (28.2 \times N \times V)/ W \quad (6)$$

Where: V = Volume in ml of 0.5N NaOH required for titration in ml, W = Weight of oil sample in g, N= Normality of the NaOH

v) **Saponification number (SN):** The saponification value (SV), which is also known as the saponification number, indicates the quantity of potassium hydroxide (KOH) needed to saponify (or convert to soap) 1 g of oil. The saponification value of an oil sample is a measure of the chain length (or average molecular weight) of all the fatty acids in the oil**.** A small saponification value or number indicates the presence of long-chain fatty acids on the glycerol backbone in an oil sample, while a high saponification value indicates triacylglycerols with shorter fatty acyl chains [16].The saponification number of the oil was determined using the Titration technique based on ISO 3657 [18]. The process involved dissolving the oil in a solution of ethanolic KOH. Approximately 2 grams of the oil were weighed and introduced into a conical flask containing 25 milliliters of 0.1 N ethanolic KOH solution. This mixture was placed on a magnetic stirrer and gently maintained at boiling state for 1 hour. Thereafter, drops of the indicator phenolphthalein were added to the mixture and set up in a reflux condenser, and subjected to titration using 0.5 N HCl. The titration process was carried out until the pink color from the indicator disappeared. Following this, a blank titration was conducted using the same quantity of KOH solution under identical conditions and for the same period of time. The saponification number was calculated using Equation (7) below.

$$\mathbf{SN = 56.1 \times N \times (V_0 - V_1) / W \quad (7)}$$

Where, W represents the oil weight in grams, N stands for the concentration of the HCL solution, V_1 denotes the volume of utilized HCL solution in milliliters, and V_0 signifies the volume of HCL solution employed for the blank measurement in milliliters.

vi) Iodine value (IV): The iodine value of the oil extract was assessed according to the guidelines outlined in ISO 3961[18]. A quantity of approximately 0.4 grams of the oil was introduced into a conical flask that contained 20 milliliters of CCl_4, to facilitate the dissolution of the oil. Subsequently, 25 milliliters of iodine monochloride reagent were cautiously added to the mixture within a fume chamber, with the use of a safety pipette. The flask was securely covered with a stopper and vigorously swirled. The mixture was then kept in darkness for 2.5 hours. Afterwards, 20 milliliters of a 10% aqueous potassium iodide solution and 125 milliliters of water were added. The resulting mixtures were subjected to titration using 0.1 N sodium-thiosulfate solutions until the disappearance of the yellow color. The titration process continued even after the inclusion of a few drops of 1% starch indicator and drops of sodium thiosulfate, with continuous vigorous shaking until the blue color of the mixture vanished. The same procedure was equally employed for the blank assessment. The iodine value (IV) was computed using Equation (8) as below:

$$\mathbf{IV = 12.69 \times N \times (V_2 - V_1) / W \quad (8)}$$

A higher iodine value indicates a higher degree of unsaturation in the fatty acids, which can affect the oxidative stability and susceptibility to degradation of biodiesel. Biodiesel with a high iodine value may be more prone to oxidation, leading to the formation of harmful byproducts and potential engine performance issues. Therefore, a lower iodine value is generally preferred as it signifies a higher quality biodiesel with better oxidative stability and resistance to degradation. Monitoring and controlling the iodine value is crucial to ensure the long-term stability and performance of biodiesel fuel.

vii) **Peroxide Value: To determine the peroxide value of the oil extract,** 1 gram of the oil sample was dissolved in a mixture of glacial acetic acid and chloroform in a proportion of 2:1. The solution was allowed to stand in darkness for 1 minute to make for complete dissolution. Subsequently, 1ml of a potassium iodide solution with a concentration of 10% was introduced into the mixture and left in darkness for another minute. 5 ml of distilled water, was later added to the solution until the pink color as a result of the potassium iodide solution gradually disappeared. Thereafter, 2 ml of a starch indicator solution (composed of 10% starch) was added making the solution to transform into a blue-black color. The resulting mixture was used for titration with a 0.02 N sodium

thiosulfate solution. The peroxide value (PV) for the oil was subsequently determined using Equation (9), below:

$$PV = 100 (V_1 – V_2) N / W \quad (9)$$

Where, V_1 represents the volume of thiosulfate used in the sample, V_2 stands for the volume of thiosulfate in the blank, W denotes the weight of the utilized oil, and N signifies the normality of the sample.

A higher peroxide value indicates a higher concentration of peroxides, which can lead to the degradation of biodiesel and the formation of harmful byproducts. High peroxide levels can negatively impact the stability, storage life, and performance of biodiesel produced from the oil. Therefore, oil with a lower peroxide value is generally preferred as it yields a higher quality biodiesel with better oxidative stability and freshness.

2.6.2 Physicochemical Properties of Biodiesel

The biodiesel produced from the AOBSO was analyzed for its physicochemical properties using standard methods such as the ASTM D4052 for specific gravity, ASTM D8045 for acid value, ASTM D5558 for saponification value, ASTM D4607 for iodine value and free fatty acid using standard methods [37].

i) Specific gravity: The exact methodology employed for the determination the specific gravity of the extracted oil above was also applied for the determination of the specific gravity of the produced biodiesel. specific gravity value is relevant to the quality of any biodiesel, as it provides information about its purity, composition, and potential presence of impurities or contaminants. Deviations from the expected specific gravity value may indicate the presence of water, unreacted chemicals, or other substances that can affect the performance and stability of biodiesel.

ii) **DENSITY**

The density of the biodiesel is generally related to the energy content of a fuel. it is defined as the mass of a material per unit volume of the material. The density of the biodiesel was determined using Equ.(10)

Specific gravity of biodiesel sample (x) = 0.897

Specific gravity of water (y) = 0.999

$$\text{Density } (\frac{x}{y}) \quad (10)$$

ii) Viscosity: The major goal of the transesterification process of oil conversion to biodiesel is basically to reduce the viscosity of the oils. The viscosity of oils and even biodiesel often determines the applicability of any fuel in diesel engines or otherwise, as it creates one of the key challenges to efficient fuel flow, fuel spray, fuel atomization, fuel-air mixing, early injection, increased maxi mum pressure and temperature in the combustion chamber, continuous combustion, and steady power production in engines [16]. The viscosity of the feedstock oil for biodiesel can indicate the ease or difficulty of its conversion to biodiesel as well as the biodiesel quality and production efficiency [10][13][16].

iii) Acid value: The acid value of biodiesel was determined with ASTMD664.The acid value is a measure of the amount of free fatty acids present in a biodiesel sample. It is an important parameter that indicates the quality of biodiesel. Higher acid values indicate a higher concentration of free fatty acids, which can lead to increased acidity and potential corrosion in engines and fuel systems. Therefore, a lower acid value is desirable as it signifies a higher quality biodiesel with reduced corrosive properties. Regular monitoring and control of acid value are crucial to ensure the optimal performance and longevity of biodiesel fuel.

iv) **Free fatty acid value:** The percentage of the FFA value of the produced biodiesel was determined using the procedure adopted for the determination of the percentage free fatty acid for the AOBSO using equation) (6) as above. The free fatty acid value is a measure of the amount of free fatty acids present in the biodiesel sample. It is an important parameter that indicates the quality of the biodiesel. Higher acid values indicate a higher concentration of free fatty acids, which can lead to increased acidity and potential corrosion in engines and fuel systems. Therefore, a lower acid value is desirable as it signifies a higher quality biodiesel with reduced corrosive properties. Regular monitoring and control of acid value are crucial to ensure the optimal performance.

v) Saponification number (SN): The methodology adopted for determining the Saponification number for the OBSO was applied to assess the saponification value of the generated biodiesel. Higher saponification value indicates a higher average molecular weight of the fatty acids, which can affect the viscosity and combustion characteristics of biodiesel. It can also impact the cold flow properties and stability of the fuel. Therefore, a lower saponification value is generally preferred as it signifies a higher quality biodiesel with better fuel properties.

vi) Iodine value (IV): The iodine value of the oil extract was determined based on the ISO 3961 guidelines of 1989. A quantity of approximately 0.4 grams of the oil was introduced into a conical flask that contained 20 milliliters of CCl_4, to facilitate the dissolution of the biodiesel. Subsequently, 25 milliliters of iodine monochloride reagent were cautiously added to the mixture within a fume chamber, with the use of a safety pipette. The flask was securely covered with a stopper and vigorously swirled. The mixture was then kept in darkness for 2.5 hours. Afterwards, 20 milliliters of a 10% aqueous potassium iodide solution and 125 milliliters of water were added. The resulting mixtures were subjected to titration using 0.1 N sodium-thiosulfate solutions until the disappearance of the yellow color. The titration process continued even after the inclusion of a few drops of 1% starch indicator and drops of sodium thiosulfate, with continuous vigorous shaking until the blue color of the mixture vanished. The same procedure was equally employed for the blank assessment. The iodine value (IV) was computed using Equation (8) as below:

$$IV = 12.69 \times N \times (V_2 - V_1) / W \quad (8)$$

A higher iodine value indicates a higher degree of unsaturation in the fatty acids, which can affect the oxidative stability and susceptibility to degradation of biodiesel.

Biodiesel with a high iodine value may be more prone to oxidation, leading to the formation of harmful byproducts and potential engine performance issues. Therefore, a lower iodine value is generally preferred as it signifies a higher quality biodiesel with better oxidative stability and resistance to degradation. Monitoring and controlling the iodine value is crucial to ensure the long-term stability and performance of biodiesel fuel.

vii) **Peroxide Value: To determine the peroxide value of the biodiesel,** 1 gram of the sample was dissolved in a mixture of glacial acetic acid and chloroform in a proportion of 2:1. The solution was allowed to stand in darkness for 1 minute to make for complete dissolution. Subsequently, 1ml of a potassium iodide solution with a concentration of 10% was introduced into the mixture and left in darkness for another minute. 5 ml of distilled water, was later added to the solution until the pink color as a result of the potassium iodide solution gradually disappeared. Thereafter, 2 ml of a starch indicator solution (composed of 10% starch) was added making the solution to transform into a blue-black color. The resulting mixture was used for titration with a 0.02 N sodium thiosulfate solution. The peroxide value (PV) for the biodiesel was subsequently determined using Equation (9), below:

$$PV = 100 (V_1 – V_2) N / W \quad (9)$$

Where, V_1 represents the volume of thiosulfate used in the sample, V_2 stands for the volume of thiosulfate in the blank, W denotes the weight of the utilized oil, and N signifies the normality of the sample.

A higher peroxide value indicates a higher concentration of peroxides, which can lead to the degradation of biodiesel and the formation of harmful byproducts. High peroxide levels can negatively impact the stability, storage life, and performance of biodiesel. It can also contribute to engine deposits, fuel filter clogging, and potential engine damage. Therefore, a lower peroxide value is generally preferred as it signifies a higher quality biodiesel with better oxidative stability and freshness. Regular monitoring and control of peroxide value are essential to ensure the optimal performance and longevity of biodiesel fuel. Proper storage and handling practices can help minimize peroxide formation and maintain the quality of biodiesel.

viii) Cloud Point (CP) Measurement: About 10 ml of the produced biodiesel sample was poured into a clean 50 ml beaker. The beaker was then placed inside a refrigerator and regularly observed. The temperature at which a slight haze initially became visible in the biodiesel sample was recorded. This recorded temperature was designated as the cloud point.

ix) Pour point (PP) determination: Pour point is the lowest temperature at which a liquid fuel or lubricant will flow under specific conditions**.** About 10 ml of the produced biodiesel sample was introduced into 50 ml clean beaker. The beaker was then positioned within a refrigerator to allow the biodiesel to solidify. Once solidified, the beaker was taken out from the refrigerator. As the biodiesel sample began to thaw and revert to liquid form that temperature was noted as the pour point.

x) Determination of Flash Point (FP): To determine the flash point, approximately 10 ml of the produced biodiesel was poured into a conical flask equipped with a thermometer and gradually heated on a hot plate. An ignition source was brought close to the top of the container holding the biodiesel sample. The lowest temperature at which the vapor above the liquid ignited was recorded as the flashpoint. The flash point of biodiesel is relevant to its quality as it determines its susceptibility to ignition and potential fire hazards. A higher flash point indicates a higher resistance to ignition, which is desirable for safe storage, transportation, and handling of biodiesel. Regulatory standards often specify minimum flash point requirements for biodiesel to ensure safe usage. Biodiesel with a lower flash point may pose a higher risk of ignition and should be handled with caution.

xi) Determination of calorific value (Heating Value): The Higher Heating Value (HHV) of both the oil extracted from African oil bean seeds and the resulting biodiesel was computed using Equation (11), as proposed by Demirbas [13]:

$$HHV = 49.43 - 0.041 (SN) + 0.015 (IV) \quad (11)$$

A higher calorific value indicates a higher energy content in the biodiesel, which translates to more efficient combustion and greater heat output. Biodiesel with a higher calorific value can provide more energy per unit volume or weight, resulting in improved fuel efficiency and potentially better engine performance.

xii) Determination of cetane number (Cn): The cetane number for the biodiesel was obtained from an empirical formula presented by [8], which was based on the saponification number and iodine value of the biodiesel:

$$CN = 46.3 +(5458 / SN) - 0.225 (IV) \quad (12)$$

A higher cetane number signifies a shorter ignition delay, meaning the fuel ignites more quickly and efficiently. The cetane number is relevant to the quality of biodiesel as it affects engine performance, combustion efficiency, and emissions. Biodiesel with a higher cetane number tends to have better cold-starting properties, smoother combustion, reduced noise, and lower emissions of pollutants like nitrogen oxides (NOx) and particulate matter. Regulatory standards often require a minimum cetane number for biodiesel to ensure proper engine operation and compliance with emissions regulations. Therefore, monitoring and controlling the cetane number is crucial to ensure the quality and performance of biodiesel fuel in diesel engines.

3.0 RESULTS AND DISCUSSION

The results and discussion of the production and characterization of biodiesel from the oil extracted from the seed kernel of African oil bean tree (Pentaclethra macrophylla), Ukpaka seed are now presented in this section, detailing the analysis and findings of this experimental journey targeted at identifying new feedstock and catalyst for

a cost-effective production of biodiesel from underutilized agro-crop. The ultimate goal being to ensure widespread commercialization of biodiesel, which has been globally acclaimed to be more eco-friendly than the fast-depleting fossil diesel fuel.

3.1 RESULTS

When dealing with oil containing high free fatty acids like the Ukpaka seeds, the effectiveness of a base catalyst in improving the biodiesel yield from a given quantity oil has been reported to be enhanced by the application of the two-step transesterification method. This involves the acid-esterification step, and then followed by the base-catalyzed transesterification step. The results of all the tests aimed at determining the major physiochemical properties of the oil extract as well as the biodiesel from African oil bean tree seed kernel shown in Tables 3.1 and 3.2 respectively.

3.1.1 Seed moisture content

Weight of sample (g) = 16.16 kg
Weight of dry seed (x) =8.18kg
Loss in weight (g-x) = 7.96 kg
% moisture content of seed ($\frac{g-x}{g}$ X $\frac{100}{1}$) = 49.26% (13)

3.1.2 Oil yield percent

Percentage oil yield from 7kg of seed kernel used during the oil extraction
From equ.(14), the oil yield percent was obtained as follows;
Mass of dry seed kernel used = 7 kg
Mass of seed kernel residue =4.34 kg
Mass of Oil extracted from the seed = 2.66 kg
Oil yield percent = [(7 – 4.34)/5] x100 **= 38% (14)**

3.1.3 The physiochemical properties of the oil extract from African oil bean seed

The dry oil extracted from the African oil bean seed was subjected characterization analysis to determine its physicochemical properties. The result of the oil characterization tests is presented in Table 3.1 below.

Table 3.1 The physiochemical properties of the oil extract from African oil bean seed.

S/N	Property	Results	ASTM	Method
1	Density g/cm^3 @ 40^{o}C	0.90		
2	Specific gravity @ 40^{o}C	0.90		
3	Viscosity mm^{2}s^{-1} @ 40^{o}C	3.5		
4	Free fatty acid % @ 40^{o}C	3.25		
5	Acid value, mg KOH/g @ 40^{o}C	0.64		
6	Saponification value mg/KOH/g @ 40^{o}C	185		
7	Iodine value gI_2/100g @ 40^{o}C	85		
8	Peroxide value (meq. O_2/kg oil)	5.9		
9	Cloud point (^{o}C)	10.5		
10	Pour point (^{o}C)	9.7		
11	Flash point (^{o}C)	229		
12	Cetane number	108.5		
13	High heating value MJ/kg	49		
14	Colour	Brown		

3.1.4 Biodiesel production using iron(iii) oxide Catalyst

i) Biodiesel yield percent

Percentage biodiesel yield from 2kg of seed oil used
The biodiesel yield percent was obtained as follows;
Mass of dry seed oil used = 2 kg
Mass of glycol and other sediments =0.16 kg
Mass of biodiesel obtained after oil conversion = 1.84 kg
Percentage biodiesel yield = [(2 – 0.16)/2] x100 **= 92%**

ii) Water and Sediment Content

Weight of biodiesel sample before oven drying (g) = 1.88 kg
Weight of dry biodiesel matter (x) = 1.84 kg
Loss in weight (g-x) = 0.04kg
% moisture content($\frac{g-x}{g}$ X $\frac{100}{1}$) = [(1.88-1.84)/1.88]x10 = 2.13%

iii) Physiochemical properties of biodiesel from oil extract of African oil bean seed

After the conversion of the extracted oil from African oil been seed into biodiesel using iron (iii) oxide as catalyst, and the subsequent tests aimed at determining the properties of the biodiesel, the results have been summarized in table 3.2, in order to see how they complied with the ASTM D6751 standards for biodiesels and also to enable easy comparison with the properties of the conventional hydrocarbon diesel fuel.

Table 3.2 The physiochemical properties of biodiesel from oil extract of African oil bean seed.

Properties	Conventional Diesel	Results	ASTM Standards	Method
Density g/cm^3	848	0.864		
Specific gravity	845	0.865	0.81 – 0.95	
Viscosity mm^{2}s^{-1}	2.73	1.67	1.9 -6.1	D445
Free fatty acid Mg KOH/g	=	0.5%*		
A cid value, mg KOH/g	0.28	0.79	0.8 max	
Saponification value mg KOH/g	=	79.8		ISO1989
Iodine value gl$_2$/100g	=	17.56		ISO 1985
Peroxide value (meq. O_2/kg oil)	=	4.8		
Cloud point ^{o}C	-2	10.2	-15 -5	D97
Pour point ^{o}C	-9	9.5	-18 - 6	D2500
Flash point ^{o}C	68	223.5	52 – 96	D93
Cetane number	51	108.3	40	D613
High heating value MJ/kg	45.5	47.4	45 – 50	D240

iii) A comparison between the physicochemical properties of African oil bean seed biodiesel and the seed oil

The impact of transesterification oil can be seen from the differences between the values of the physicochemical properties of the oil before conversion and the converted biodiesel. A comparison of the values of the properties of the oil before conversion and that of the produced biodiesel is shown in Table 3.3 below.

Table 3.3 A comparison between the physicochemical properties of African oil bean seed oil biodiesel and the seed oil

S/N	Property	Oil	Biodiesel
1	Density g/cm^3 @ 40^{o}C	0.90	0.864
2	Specific gravity @ 40^{o}C	0.90	0.865
3	Viscosity mm^{2}s^{-1} @ 40^{o}C	3.5	1.67
4	Free fatty acid % @ 40^{o}C	3.25	0.5%*
5	Acid value, mg KOH/g @ 40^{o}C	1.60	0.79
6	Saponification value mg KOH/g @ 40^{o}C	185	79.8
7	Iodine value gl$_2$/100g @ 40^{o}C	19.5	17.56
8	Peroxide value (meq. O_2/kg oil)	5.9	4.8
9	Cloud point ^{o}C	10.5	10.2
10	Pour point ^{o}C	9.7	9.5
11	Flash point (^{o}C)	229	223.5
12	Cetane number	108.5	108.3
13	High heating value MJ/kg	49	47.4
14	Colour	Brown	Light brown

3.2 Discussion

3.2.1 Seed moisture content: In order to minimize the water content of the oil extracted from the seed and ensure minimal interference of water on the catalyst during the biodiesel conversion process, the seed kernels obtained after removing the seed shells were sun-dried for 10 days, 8 hours each day at an average daily temperature of 38^{o}C. At the end of the 10 days drying process, the percentage water content of the seed was determined to be 49.3%. This high seed water content implies that there is need to ensure that the seeds are carefully and properly sun-dried until the mass remains constant, so as to guarantee efficient seed oil extraction and also minimize energy utilization on oven-drying. Large water content of oil for biodiesel production usually contaminates the catalyst and also results in poor oil yield as the greater quantity of the oil will tend towards the formation of soap rather than biodiesel [14] [16].

3.2.2 Oil yield percent: The mass of dry oil extracted from 7kg of seed kernel of AOBSO was determined to be 2.66 kg, giving a percentage oil yield of 38%. This is in agreement with the finding of Ndukwu and Onyeoziri [14]. This high oil yield percent shows that AOBSO could serve as a good feedstock for industrial biodiesel production.

3.2.3 Physicochemical properties of the oil extract from African oil bean seed oil (AOBSO)

The result of the physicochemical tests conducted on the dry oil extract from the AOBSO is presented in Table 3.1. The properties values though with little variation are in close

agreement with the findings of Abel et al.[17]. The physicochemical properties of oils are very important as the have a great impact on the behaviour of the biodiesel fuel produced from the oil [16]. It is also important to state here that the physicochemical properties of seed oils determine the amount of rigour, processing method and the cost incurred during the oil conversion to biodiesel.

3.2.4 Biodiesel performance

i) Biodiesel yield percent: After the transesterification of the AOBSO using iron (iii) oxide as catalyst, the result showed that the quantity of biodiesel obtained from 2kg of the dry oil was 1.84 kg giving 92% oil yield. This result is in line with the findings of reports of some previous authors [14], [17], [36]. It also indicates that the cheap iron (iii) oxide could be a viable catalyst for the conversion of AOBSO to biodiesel.

ii)Biodiesel moisture content: The mass of wet biodiesel obtained after washing with warm distilled water was 1.88kg. However, after oven-drying, the biodiesel produced from the oil obtained from 7kg of the seed kernels, the biodiesel weight was determined to be 1.84kg, giving a percentage moisture content of 2.13%. Biodiesel has the tendency to absorb moisture than hydrocarbon diesel. It has been reported that high moisture content in biodiesel can cause problems such as water accumulation and microbial growth in fuel handling, storage, and transportation[16] [38].

iii) **Physicochemical properties:** The result of the physiochemical analyses on the biodiesel produced from the oil extract of African oil bean seed is presented in table 3.2. A close look on the results indicates that most of the property values are within the ASTM D6751 standards for biodiesel for CI engines. However, it must be pointed out that the values of cloud point, pour point, cetane number and flash point are outside the ASTM standards. The high cloud and pour points indicate that the AOBSO biodiesel will have poor cold flow properties [16]. The high flash point of the produced biodiesel is good because it makes for safe transportation and storage of the fuel. Nevertheless, it is important to mention that the poor cold flow properties of the AOBSO biodiesel could be improved with proper blending with good additives. Moreover, it could be seen that the variations in values between the physicochemical properties of the conventional diesel and that of the AOBSO biodiesel is not very wide. Hence, one can safely say that the behaviour of the biodiesel produced from AOBSO using iron (iii) oxide as catalyst will be close to that of the conventional hydrocarbon diesel, though with less adverse impact on the environment.

iii) Comparison of the physicochemical properties of the AOBSO and AOBSO biodiesel: Table 3.3 shows the effects of transesterification on the AOBSO during conversion to biodiesel. A critical look at the table indicates that transesterification serves to reduce the values of most of the physicochemical properties of the oil. This is in agreement with the findings as reported in Umeh and Okonkwo [16].

4.0 CONCLUSION

The increasing concerns over the depletion of natural resources coupled with the public outcry over the pollution caused to the environment by the combustion of fossil fuels has made imperative the need to explore alternative ecofriendly fuels. Biodiesel which has been acknowledged as a viable alternative to fossil diesel is currently plagued by its cost of production. And this has proved to be a major challenge against its widespread adoption and commercialization. This state of affairs has brought to the front burner, the quest for an efficient and cost-effective strategy for biodiesel production. The study investigated the potential of using Fe_2O_3, as catalyst for the conversion of (AOBSO) to biodiesel by the trans-esterification process. The results of the Physicochemical properties tests of the biodiesel produced from AOBSO based on ASTM standards, compared very well with that of the conventional Biodiesel. The Fe_2O_3 catalyzed biodiesel from AOBSO gave a cetane number of 108.3, while the ASTM standard is 40, and that of the conventional diesel determined to be 51. The result further revealed that the Iron (iii) oxide catalyzed biodiesel has a flash point 123.5^{o}C, which is generally considered safer because it reduces the risk of accidental ignitions and combustion.

REFERENCES

1. A. Demirbas, Biodiesel from vegetable oils via transesterification in supercritical methanol. Energy Conversion and Management, 49(1), 2008, pp.125-130.
2. Elia, M., Licursi, D., & Rossi, S. Life cycle assessment of biodiesel production from rapeseed oil. Journal of Cleaner Production, 52,2013, pp.182-191.
3. Kafarov, V., Advances in biodiesel production: processes and technologies. Boca Raton, FL: CRC Press, 2015.
4. Manohar, S., & Chandrasekhar, K., Biodiesel production from jatropha oil and its characterization. International Journal of Chemical Engineering and Applications, 3(4), 2012, pp. 259-263.
5. Meher, L. C., VidyaSagar, D., & Naik, S. N.,Technical aspects of biodiesel production by transesterification: a review. Renewable and Sustainable Energy Reviews, 10(3), 2006, pp. 248-268.
6. Biodiesel Production Via Acid Catalysis Retrieved online July 15, 2025. https://biodieseleducation.org
7. Wikipedia, Transesterification Retrieved online July 15, 2025. https://en.wikipedia.org
8. Kalayasiri P, Jayashoke N, Krisnangkura K (1996) Survey of seed oils for use as diesel fuels. J Am Oil Chem Soc 73:471–474

9. ARO SCIENTIFIC, Pour Point of Petroleum Products- A Brief Guide, 2024. Retrieved online, June 2024.
10. Foroutan R, Esmaeili H, Mousavi SM, Hashemi SA, Yegaaneh G. The physical properties of biodiesel-diesel fuel produced via transesterification process from different oil sources. Physical Chemistry Research. 2019;7(2):415-424. DOI: 10.22036/pcr.2019.173224
11. Okonkwo PA, Omenihu I. Production and characterization of biodiesel from mango seed oil (MSO). Nigerian Journal of Technology. 2021:598-607. DOI: 10.4314/ njt.40i4.6.2021, 598-607
12. Ajala A, Kanokwon N, Worapon K, Doonyapong W, Suttichai A. Effect of water content in waste cooking oil on biodiesel production via ester transesterification in a single reactive distillation. International Conference on Smart Materials Applications IOP Conf. Series: Materials Science and Engineering. 2019;559:012014. DOI: 10.1088/1757-899X/559/1/012014
13. Leung DYC, Xuan W, Leung MKH. A review on biodiesel production using catalyzed transesterification. Applied Energy. 87, 2010,pp.1083-1095
14. Macmanus C. Ndukwu and C.I Onyeoziri, African oil bean seed as feedstock for bio-oil and biodiesel production and on the effects of thermal pre-treatment on the quality of the bio-oil. Biomass Conversion and Biorefinery, 2020 Doi:10.1007/s13399-020-00754-6
15. Shuman Guo, Zhenzhong Yang, and Yuguo Gao, Effect of Adding Biodiesel to Diesel on the Physical and Chemical Properties and Engine Performance of Fuel Blends, Journal of Biobased Materials and Bioenergy Vol. 10, 1–10, 2016
16. Sunday Ifeanyichukwu Umeh and Peter Anadebe Okonkwo, The Essential Properties of Oils for Biodiesel Production, In Biodiesel Plants – Fueling The Sustainable Outlooks, Intechopen, 2025 DOI: http://dx.doi.org/10.5772/intechopen.1008694
17. Otache Monday Abel, Amagbor Stella Chinelo, Inweh Cynthia and Godwin Kparobo Agbajor, Evaluation of African Star Apple (Chrysophyllum albidum) Seed Oil as a Potential Feedstock for Industrial Application, Asian Journal of Applied Chemistry Research, 7(1): 31-42, 2020; Article no.AJACR.57028.
18. AOAC. Association of official analytical chemists international official methods of analysis. 16th Edition, AOAC, Arlington; 1997.
19. Mushtaq A, Shazia S, Lee K.T, Ahmed Z.A, Haleema S, Muhammed Z, Taibi B.H, Muhammed A.A, Rasool B.T, Distaff thistle oil: a possible new non-edible feedstock for biogas energy. Int J Green Energy 10:2014, pp.1–27
20. Egan H, Kirk R.S, Sawyer R, Pearson's chemical analysis of foods, 8th edn. Churchill Livingstone, London, New York 1981
21. TutorChase, How do catalysts alter the mechanism of a reaction? Retrieved online June 15,2025 www.tutorchase.com
22. M. Mathiyazhagan and A. Ganapathi, Factors Affecting Biodiesel Production, Research in Plant Biology,1(2):01-05, 2011 www.resplantbiol.com
23. I. M. Atadashi, M. K. Aroua, A. R. Abdul Aziz, N.M.N. Sulaiman, The Effects of Catalysts in Biodiesel Production: A Review, journal of industrial and Engineering Chemistry, Vol.19, Issue1, 2013 pp. 14 – 26 https://doi.org/10.1016/j.iec.2012.07.009
24. SENECA NOTES, Homogeneous catalysts, Retrieved online July 20, 2025. www.senecalearning.com
25. A. K. Endalew, Y. Kiros, and R. Zanzi, "Heterogeneous catalysis for biodiesel production from *Jatropha curcas* oil (JCO)," *Energy*, vol. 36, no. 5, 2011, pp. 2693–2700 Doi:10.1016/j.energy.2011.02.010.
26. Bello EI Effects of transesterification on the colour of bio diesel. Sci Agric 13: 2016, 10–13
27. J. I. Orege, O. K. Oderinde, G. A. Kifle, O.O.Ajayi, A.A. Ibikunle, S. A. Raheem, O. Ejeromedoghen, E. S. Okeke, O.M. Olukowi, Recent advances in heterogeneous catalysis for green biodiesel production by transesterification, *Energy Convers. Manag.*, vol. 258(82), 2022 p. 115406 Doi:10.1016/j.enconman.2022.115406.
28. S. Kumar and R. K. Sani, Eds., *Biorefining of Biomass to Biofuels: Opportunities and Perception*, vol. 4. in Biofuel and Biorefinery Technologies, vol. 4. Cham: Springer International Publishing, 2018. doi: 10.1007/978-3-319-67678-4.
29. Prachasanti Thaiyasuit, Kulachate Pianthong , Ittipon Worapun, Acid Esterification- Alkaline Transestrification Process of Methyl Ester Production from Crude Rubber Seed Oil, Journal of Oleo Science 61(2) 2012, pp.81-88
30. Kartika A, Yani M, Ariono D, Evon PH, Rigal L Biodiesel production from Jatropha seeds: solvent extraction and in situ transesterification in a single step. Fuel 106: 2013, pp.111–117.
31. A. E. Atabani, A. S. Silitonga, I. A. Badruddin, T. M. I. Mahlia, H. H. Masjuki, and S. Mekhilef, "A comprehensive review on biodiesel as an alternative energy resource and its characteristics," *Renew. Sustain. Energy Rev.*, vol. 16, no. 4,2012, pp. 2070–2093

32. Umer R, Farooq A, Gerhard K. Evaluation of biodiesel obtained from cottonseed oil. Fuel Processing Technology. 2009;90: 1157–1163.
33. Freedman B, Pryde EH, Mounts TL. Variables affecting the yields of fatty esters from transesterified vegetable oils. Journal of American Oil Chemical Society.1984;61:1638- 43.
34. P. D. Patil and S. Deng, Optimization of Biodiesel Production from Edible and Non-Edible Vegetable Oils, Fuel, 88,2009, pp.1302 – 1306 https://doi.org/10.1016/j.fuel.2009.01.016
35. F. Ma and M. A. Hanna, Biodiesel Production: A Review, Bioresour. Technol, 70, 1999, pp.1-15
36. P. Verma and M. P. Sharma, Review of Process Parameters for Biodiesel Production from Different Feedstocks Renewable and Sustainable Energy Reviews, Vol.62,2016, pp.1063-1071 https://doi.org/10.1016/j.rser.2016.04.054
37. Vegetable Oils and Animal Fats In: Biodiesel. Springer, London. 65–110. DOI:10.1007/978-1-84628-995-8_3
38. B. B. He, J. C. Thompson, D. W. Routt, J. H. Van Gerpen, Moisture Absorption in Biodiesel and its Petro-Diesel Blends, Applied Engineering in Agriculture, 23(1)2007 Doi: 10.13031/2013.22320
39. Wikipedia, Pentaclethra macrophylla Retrieved online July 23,2025. https://en.m.wikipedia.org