PRODUCTION AND CHARACTERIZATION OF BIO-DIESEL FROM VITEX OIL

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DECLARATION

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CERTIFICATION

This is to certify that this project was carried out by Ahmad Abdullahi Tanko and submitted to the Department of Chemical Engineering Federal University of Technology Minna Niger State in partial fulfillment of the requirement for the award of Bachelor of Engineering (B.Eng) Degree in Chemical Engineering.

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Dedication

This work is dedicated to the Almighty Allah, who created the universe and taught mankind what he knew not. And also to the entire Alhaji Tanko Family

I sincerely want to thank the members of my family Eng'r T.T Mohammed, Fatima Alhaji Abdumimini (San Turaki) and Rabi Shehu (Sarkin Yaki) and my cousins, Ustaz Aminu, Bello AZ, Usman Abubakar, Asiya, Dr Aminu and Mairo Hamza, and other too numerous to mention for their encouragement financially, morally and otherwise.

A lot of thanks goes to the entire members of the department of chemical engineering staff, most especially Eng'r M.D Abdullahi and Eng'r Mukhtar Abdul Kadir for their individual and collective contribution towards making my dream for becoming an engineer a success.

Those mention and those not mentioned I pray that the almighty God will favour you in all your doings thanks.

Let me conclude by thanking the almighty Allah the lord of the world for everything.

ABSTRACT

This is a research work conducted on the production of bio-diesel from vitex oil. It is aimed at providing an alternative to fossil fuel; hence diversify the use of vitex. Batch trans-esterification of the crude vitex oil using methanol and sodium hydroxide as catalyst was use to achieve this at a reaction temperature of 40^0C - 45^0C. Analysis on the bio-diesel produce showed it has a density of $0.867 g/cm^3$ viscosity of 18.68, flash point of 54, cetane index of 54. The values falls within the specification for diesel fuel (ASTM), which indicate that the bio-diesel produce can serve as a better alternative to petroleum diesel. In conclusion base-catalyzed trans- esterification process is an effective method for the production of bio-diesel from vitex oil.

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CHAPTER ONE

Introduction

Diesel fuels play an important role in the industrial economy of the country. The global petroleum diesel fuel consumption is over 900mt/year of which 45-65% depending on the country is used by the transportation sector. It's use in transportation contributes over 25% of global green house (GHG) emission (Dalai, 2004). These data show that the fuel run major part of the transport sector and their demand is steadily increasing with rising cost of conventional fuel and concern on the environment, alternative diesel fuel are being considered, in this context. Synthetic diesel from biomass (known as bio- diesel) can be a viable option as it is already in practice in South Africa, India. Europe and the U.S.A.

Vegetable oil (edible and non-edible) are widely available from various sources. And the glyceride present in the oils can be considered as viable alternative for diesel fuel. Bio-diesel which is synthesized from vegetable oil is a realistic alternative for diesel fuel because it provides a fuel from renewable resources and has lower emissions compared to petroleum diesel. It is biogradable and contributes minimal amount of net green house gases and zero sulphur emission to the atmosphere more specifically, bio-diesel cuts down on the amount of carbon dioxide, hydrocarbons and particulate matter released into the environment. The conversion of vegetable oils to bio-diesel is done through transerterification reaction.

Needs for Bio-Diesel

Bio-diesel reduce CO_2 emissions the primary cause of green house effects, by up to a 100% its emission are 20 to 40% lower than those from low sulphur diesel, and 10 to 29% lower than those from ultra low sulphur diesel. (Hiraga, 2003)

The sources of petrol-diesel pollutions are hazardous to the environment. The need to reduce global warming and increase sustainable energy has lead to a search for alternative fuel source, producing bio-diesel from vitex oil serves as an alternative to the nearly depleted and costly petrol diesel.

Scope of Work

This work researches into the possibilities of producing bio-diesel from vitex oil and determination of the properties of the bio-diesel produced. It also seek to find out the amount of bio-diesel and glycerin obtainable from a given volume of vitex oil at different temperatures and the economic analysis of the process.

Aims and Objectives

This research is aimed at finding an alternative, less hazardous and cheap fuel to petroleum diesel. It also aimed at bridging the gap between agriculture and industrialization and hence providing alternative uses for vitex.

CHAPTER TWO

2.0 Survey of Literature

2.1 Definition

Bio-diesel is defined as the mono-alkyl esters of fatty acid derived from vegetable oil or animal fats. In simple terms, bio-diesel is a product you get when a vegetable oil or animal fat is chemically reacted with alcohol to produce a new compound that is known as fatty acid alkyl esters.

There are at least three ways to run a diesel engine on bio-fuel using vegetable oils, animal fats or both. All three work with fresh and used oils.

- Using the oil just as it is usually called SVO fuel (straight vegetable oil)
- Mix it with kerosene (paraffin) or petroleum diesel fuel, or with bio-diesel.
- Convert it to bio-diesel (transesterification)

2.1.1 Mixing

If you are mixing SVO with petroleum or kerosene you are still using as fossil fuel. It is cleaner than fossil diesel. But not clean enough, many would say. Still for every gallon of vegetable oil you use that's one gallon of fossil fuel saved, and that much less carbon in the atmosphere.

Various mixtures are used 10% vegetable oil and 90% petrol diesel oil or 50/50 mix some people just use it that way. Start up and go. Others still need at least pre-heating and probably a two tank system too-tank system Like SVO. The same goes for mixture of vegetable oil and bio-diesel.

Mixtures are poor compromise. But they do have advantages in weather. Some kerosene or diesel mixed with bio-diesel lowers the temperature at which it start to get and mix with biodiesel will do the same for an (SVO) system.

2.1.2 Straight Vegetable Oil

Unlike bio-diesel, with SVO you have to modify the engine. The best to fit a full single-tank SVO system with different injectors and glow plugs injectors pump, adjustment, fuel preheating, temperature control and euter folters.

There are also two-tank system which only pre-heat the oil, to make it thinner. You have to start the engine on ordinary petroleum diesel or bio-diesel in one tank to warm it up then switch back to petrol or bio-diesel before you stop the engine.

2.2 Bio-Diesel

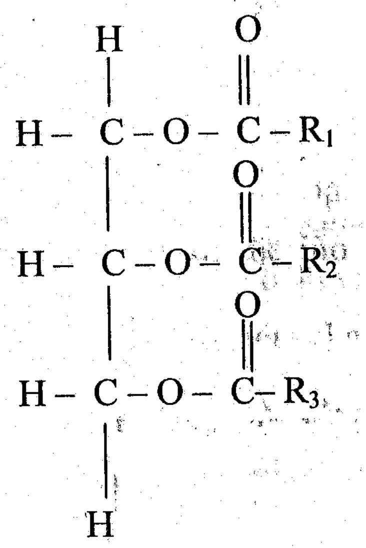
Bio-diesel has some clear advantages over SVO; it works in any diesel engine without any conversion or modification to the engine or the fuel system, just put it in and go, it also has better cold-weather properties than SVO (but as good as petrol- diesel).

Bio-diesel is a clean safe ready to use alterative fuel, where as its fair say that many SVO system are still experimental and need further development.

2.2.1 The Chemistry of Bio-Diesel

It is not necessary to be a chemist to understand where bio-diesel comes from and how it is used, however it is useful to review some of the fundamental chemical principles that are behind bio-diesel so that its properties can be understood.

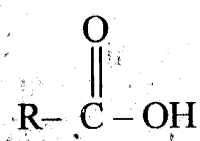
All vegetable oil and animal fats consist primarily of triglyceride molecules as shown schematically below:



Structure of triglycerol

R_1, R_2 and R_3 represent the hydrocarbon chain of the fatty acid elements of the triglyceride.

Note that there is a three carbon chain called the glycerol backbone that runs along the left side of the molecule. Extending a way from this backbone are the three long fatty acid chains in their free form, the fatty acid chains in their free form, the fatty acids have the configuration below.



Fatty acid configuration

Where R is a hydrocarbon chain of greater than 10 carbon atoms.

The properties of the triglyceride and the bio-diesel fuel will be determined by the amounts of each fatty acid that is present in the molecules.

Fatty acids are designated by two numbers: first number denotes the total number of carbon atoms in the fatty acid and the second is the number of double bonds. For example 18:1 designates oleic acid which has 18 carbon atoms and one double bond.

2.3 How to Make Bio-Diesel

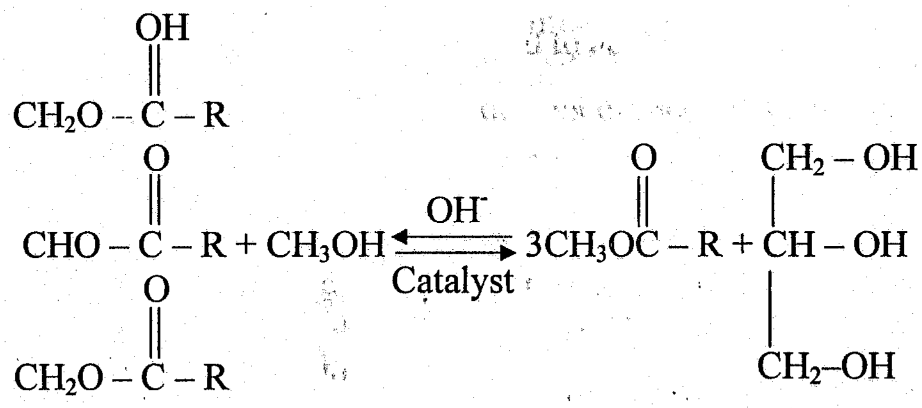
Making bio-diesel is a simple process to power our vehicles, we need to reduce the viscosity of the vegetable oil. Basically the vegetable oil need to be mixed given time to settle, then drained: there are literally millions of different ways this can be done.

Vegetable oil is a tri-glyceride, that's three vegetable molecules or esters, attached to one molecule of glycerin. Glycerin is what makes vegetable oil thick and sticky. To make bio-diesel, we want to remove the glycerin and replace it with an alcohol this is the process of transesterification. The alcohol we use is methanol.

To initiate the bio-diesel reaction we need a catalyst, by adding strong base for this reaction we use sodium hydroxide (NaoH). Also known as lye the amount of lye is constant when using new vegetable oil, but use cooking oil varies due to the amount of free fatty acids (FFAs) from heating the oil. To determine the amount of FFAs. We perform a titration

2.4 Transesterification of Vegetable Oil

In the transesterification of vegetable oils. A triglyceride reacts with an alcohol of a strong acid or base. Producing a mixture of fatty acids alkyl-ester and glycerol



Glyceride Alcohol Ester Glycerol

Equation of Transesterification of vegetable oils. The overall process is a sequence or three consecutive and reversible reactions in which di-and monoglylcerides are formed as intermediates. The stoichiometric reaction requires 1 mol of a triglyceride and 3 mol of the alcohol. However an excess of the alcohol is used to increase the yield of the alkyl ester and allows its phase creation from the glycerol formed.

Several aspects including the type of catalyst (alkaline or acid) alcohol/ vegetable oil molar ratio, temperature purity of the reactants (mainly water content) and free fatty acid content have an influence on the course of the transesterification.

2.5 Characterization of Bio-Diesel

It is necessary to compare the properties of bio-diesel produced with that of fossil fuel. These properties including, density, refractive index, viscosity, specific gravity, flash point, pour point and other like sulphur content copper stripe corrosion, ash content water content and cetane number standard method of analysis, as prescribe by the (ASTM) American Standard for testing method is required to achieved this (ASTM-D 1985).

2.6 Advantage of Base Catalyzed Over Acid

❖ The base catalyzed transesterification of vegetable oils proceeds faster than the acid catalyzed reaction.

❖ Alkaline catalyst are less corrosive than compounds, industrial process usually favour base catalyzed such as alkaline metal, alkoxide and hydroxide.

2.7 Sources of Raw Materials

Vitex

This large genus is distributed through out the tropics and sub-tropics the fruit are broadly ellipsoid or almost circular with the enlarged catyx forming an open source at the base, or a cup with shallow teeth. These drupes are fairly fleshy often turning black when fully ripe, surrounding a hard stone containing 1 -4 seeds.

There are about a dozen spears of vitex in Nigeria, some of them only shrubs. Some of the species are:

- ✓ Vitex simplicifolia.
- ✓ Vitex chryso carpa
- ✓ Vitex doniana (sweet)
- ✓ Vitex grandifolia
- ✓ Vitex terruginea
- ✓ Vitex rivularis

Vitex doniana (sweet)

This is the most abundant and widespread Vitex in savannah regions, recognized by it long stalked glabarous leaves with the leaflets usually rouded at the apex.

Hausa; dunya; Fulani; gabbihi; Yoruba; ori nla; Igbo; ucha kura

N. Nig – Sokoto, Kebbi, Zamfara, Kano (Dangora), plateau (Jos, Maragutu), Bauchi, Ilorin (Magebde)

W. Nig. Oyo (Shepetari). Abeokuta (Olokemeji).

E. Nig – Enugu (Udi) Ogoja

Widespread in tropical African

2.8 Extraction of Oil From Vitex Seed

The yield of Vitex seed contains about 48%. This shows that the oil content of the seed is much, thus there is need to develop process of extraction of this oil for both domestic and industrial uses.

There are two (2) methods of extraction.

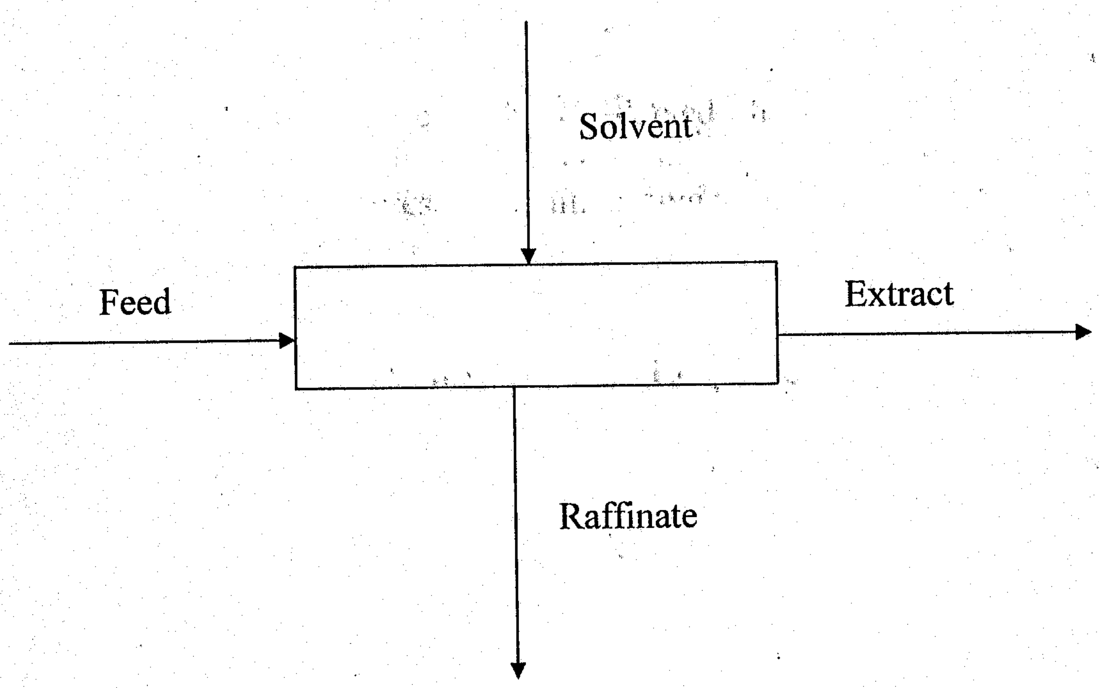
1. Mechanical screw pressing.
2. Solvent extraction.

2.8.1 Mechanical Screw Pressing

This process can be likened to the squeezing of the oil mechanically from the nut. The seeds are put in the screw process after the necessary pre-treatment and oil is squeezed or pressed out. This process is simple and can be done locally at home using domestic apparatus such as pistil and mortar.

2.8.2 Solvent Extraction

This involves the use of a solvent to extract the oil from the seed. It is also referred to as leaching. Any organic solvent can be used, but it is advisable to use with low boiling point such as hexane for easy removal extraction, the solvent is used to wash the seed down allowing the oil to dissolve in it and pour as the rafinate which the extract is collected at the other end.



The raffinate is then heated to about 90^0 to remove the solvent (Faust, 1998)

2.9 History of Diesel

The name "Diesel" was deducted from the man who first demonstrated his compression ignition engine at the world's exhibition in Paris in 1898.

Rudolph Diesel used vegetable oil to power this engine which were later called diesel engines. In 1920 an alteration was made to those engines which enable them to use petroleum diesel.

The alteration became necessary as the use of vegetable oil, not only released toxic waste but also formed scums which affected the engines life span. Henry Ford in his invention in 1908 modified this automobiles to use ethanol.

CHAPTER THREE

3.0 Materials and Research Methodology

The materials used in this research are basically the vitex seed from which the oil is extracted.

3.1 Apparatus and Reagent

3.1.1 List of Apparatus and Equipments Need

Table 3.1.1 list of the apparatus and equipment needed.

Apparatus/Equipments	Uses
(a) Reactor	This is made of glasses, with a capacity of about 2 litres (for experimental purposes) attached to the lid is a stirrer which is connected to an electronic motor, the motor is then connected to a direct current source (battery) and the rate of agitation can be increased or decreased by varying the number of batteries.
(b) Electronic weighing balance	Used for weighing the sample oil
(c) Water bath.	Used during bio-diesel reaction to heat the reactants to desired temperature.
(d) Thermometer	Used to measure temperature
(e) Conical flask	This is where the bio-diesel reaction was carried out.
(f) measuring cylinder:	Used to measure volume of reactants
(g) Pensky martins flash	Used to measure flash point of the bio-diesel
(h) Viscometer	Used to measure the viscosity of the oil
(i) Stop watch	Used for timing

3.1.1 List of Reagents Used

- Methanol, CH_3OH
- Sodium hydroxide, NaOH
- Crude vitex oil extracted

3.2 Methodology

Vitex seeds sample was hand picked from Yauri farm land behind the main town in to a basket.

3.2.2 Sample Preparation

(a) **Drying**

The seeds were sun dried for about 13-14 days (almost two weeks). Hence the seeds are enclosed inside a hard cover shell. After which sample was finally dried in the oven for about 3 hours.

(b) **Winnowing**

The seeds are separated from the shell back and other unwanted materials like leaves, stone and sand particles were equally removed by winnowing.

3.3 Moisture Content Determination

This is the amount in percent of volatile matter in soap for instance water content.

Method:

In order to determine the percentage moisture content in the value oil, 48.15g of oil sample was weighed in a moisture pan, the weight of the pan and the oil was taken and put inside an oven for 3 hours. At about 45^0C.

After every 1 hour, the sample was cooled and weighed again until the weight before and after was approximately equal.

The percentage loss in water content was determined.

Calculation:-

$$\frac{w_1 - w_2}{w_1} x100$$

3.4 Extraction of Oil From Vitex Seeds

For the purpose of this research, the local mechanical screw pressing method was used, and the procedure is as follows:

- The prepared seeds sample was weighed using weighing balance.
- The seeds were crushed in a mortar into a paste form (cake)
- Water at 60^0C was added and mixed with the paste prior to oil extraction.
- The resulting mixture was packed into a porous sieve cloth, then placed into bowl.
- Subsequently it was squeezed and oil was collected.

3.5 Production of Bio-Diesel From Vitex Oil

1.75g of NaOH crystals (Lye) was weighed and dissolved in 100ml of mathanol'. The mixture is stirred vigorously for about 15 minutes until the lye dissolved in methanol (alcohol) to form sodium methoxide.

The extracted oil (0.5 litre) was heated over a water bath to about 40-45^0C. However, sodium methoxide was then added slowly to the heated oil, and the mixture was vigorously stirred and left for about two hours maintaining the temperature 40^0C - 45^0C.

After 2 hours, the stirring is discontinued and the reaction is left to settle for about 16 hours. It was observed that the phases, the bio-diesel which is higher on top with glycerin which is darker and heavier below.

The bio-diesel is the siphoned from the mixture for further analysis.

3.6 Characterization of Bio-Diesel

The following analysis was carried out on the resulting bio-diesel in order to compare its properties with that of fossil fuel.

3.6.1 Density

To obtain the density the following procedure was carried out.

- A clean dry beaker was weighed and the weight recorded as M_2
- The Bio-diesel was put in the beaker and weighed, the weight recorded as M_1. The density is the determined by the equation below:

$$\rho = \frac{M_1 - M_2}{V}$$

Where ρ = density

M_1 = weight of beaker + bio-diesel

M_2 = weight of beaker

V = Volume of bio-diesel

3.6.2 Viscosity

To determine the viscosity of the bio-diesel the cannon ten the viscoumeter was employed, with procedure as follows:

- The bio-diesel is put in the viscoumeter till it reaches the mark above the upper bulbs.
- The time taken for the memiscus or the bio-diesel to fall between the upper and the lower mark of the bulb is then recorded.

The viscosity is then calculated from the equation below:

Viscosity = time taken

3.6.3 specific Gravity

The specific gravity of the bio-diesel was determined by taking a known volume of the fuel and weighing it, also the same volume of water by taking the ratio of the fuel to that of water.

3.6.4 Pour Point

The bio-diesel is poured into the test jar to the appropriate level. The cork to which the thermometer is inserted tightly closed. The test jar, the position of the cork is adjusted tightly so that the thermometer fits the cork tightly.

The thermometer and the cork is coaxial and the thermometer bulb is immersed such that one end of the capillary is 3mm below the surface of the oil. The oil is heated without stirring to 48^0C and maintained at this temperature. The fuel was then cooled to 35^0C in water bath. The ring is placed around the testing jar, 25mm from the bottom. The test jar was put into the an ice jacket. After preliminary heating the sample was cooled at specific rate and examined at interval of 30^0C for flow characterization. The least temperature at which movement of the bio-diesel was observed and recorded as the point.

3.6.5 Sulphur Test

The sulphur content of the bio-diesel produced was determined using ASTM D2 622 method. The sample is placed in an x-ray beam and the intensity of the sulphur x-ray fluorescence was measured.

3.6.6 Copper Strip Corrosion Test

The ASTM D130 detection of coppers corrosion from petroleum products by the copper strip tarnish test method was used. A polished copper strip was immersed in the bio-diesel sample for 3 hours at 100^0C and then removed and washed. The condition of the copper surface was qualitatively rated by comparing it with standard.

3.6.7 Ash Content

The bio-diesel was weighed and a known weight placed in a crucible, ignited and allowed to burn. The carbonaceous residue is heated further in a furnace to convert all the carbon to carbon dioxide and all the mineral salt to oxides (ash). The ash is cooled an weighed.

3.6.8 Cetane Index

Cetane index of diesel fuel is a measure of the tendency of the fuel to ignite spontaneously. In the cetane index scale, high values represent fuels that ignite readily and therefore perform better in a diesel engine. It was calculated using the equation below:

$$Cee = 45.2 + (0.0892)(T_{10}) + [0.151 + (0.0901) B [T_{50N}] + 0.0523 - (0.420)(B)] + [0.00049][T_{10N}]^2 - [T90N]^2 - (107)(B) + 60 (B^2).$$

Where Cee = calculated cetan index

D = Density at 15^0c DN = D – 0.85, B = $[e^{(-3.5)}]-1$

T_{10N} = 10% recovery temperature, T_{10}-215

T_{50} = T_{50} – 260, T_{90N} = 90% recovery temperature

T_{90N} = T_{90} – 310 [astm,d]

3.6.9 Refractive Index

This was determined by using the refractometer. A drop of the fuel was spread evenly all over the watches and readings taken through the peep hole.

3.6.9.1 Flash Point

This is the lowest temperature at which a fuel can form an ignitable mix with air. In order words it is the minimum temperature at which there is enough evaporated fuel in the air to star combustion.

The method used in this case is the Penky-Martens apparatus consists of a small cup containing the bio-diesel, it is gradually heated while its being stirred continuously in order to distribute the heat uniformly. At regular intervals, an open flame is directed into the cup, at the flash point, the content of the cup was ignited.

CHAPTER FOUR

4.0 Result

Tabular representation of the result of the analysis conducted on the sample (vitex seed) and bio-diesel produced from it are shown below.

Table 4.1 determination of moisture content of the seed

MC (%)	X_1	X_2
48.150	40.0000	27.0000
33.3300	40.0000	30.0000
21.2100	40.0000	33.0000
11.1100	40.0000	36.0000

Where

M = percentage moisture content

X_1 = weight of dry sample

X_2 = original weight of the grinded germ before drying.

Table 4.2: percentage of oil extraction from the vitex seed

Parameter	Vitex seed (g)
Weight of seed	1452
Weight of extracted oil	892
Weight of cake	532
Weight loss (due to error)	28

Table 4.3: Determination of Viscosity of Transerterified Vitex Oil (Bio-diesel) at 29^{0}c

Spindle number	Spindle speed	Reading	Factor	Viscosity (mp)
4	20	1.8	100	18
4	50	0.5	40	20
4	100	0.9	20	18
Average				18.67

Table 4.4 Determinatio of flash point of the vitex Bio-Diesel

Bio-diesel	Flash point (^{0}C)
Vitex diesel	54

Table 4.5: Determination of the Density of the Bio-Diesel

Parameter	Value
Weight measuring cylinder	600g
Measured volume of oil	250cm^3
Weight of measured oil +cylinder	817g
Weight of oil	217g
Density	0.868g/cm^3

Table 4.6: Determination of Cetane Index of the Vitex Bio-Diesel

Bio-Diesel	Cetane Index
Vitex Diesel	54

Table 4.7: Summary of Characterization Results with Standard

Parameter	Vitex Bio-Diesel	Automotive Gas Oil (AGO)
Viscosity	18.67	12.5 – 17.5
Flash Point	54	50 – 55
Density g/cm^3	0.868	0.82 – 0.88
Cetane Index	54	48 – 52

CHAPTER FIVE

5.0 Discussion of Result

Bio-diesel was produced from vitex (crude) using base catalyzed transesterification process. Temperature of the reacting mixture influenced the rate of conversion at temperature close to $40^0C - 45^0C$ and a higher yield of bio-diesel was recorded. This is contrary to the literatures that yield increases as the temperature approaches the boiling point of alcohol.

The result of characterization presented in table 4.7 shows that viscosity is 18.67 this is higher than standard values of 12.5 – 17.5 for petrol diesel and bio-diesel respectively. The higher value of viscosity could be due to the fact that the oil was unrefined and contain some impurities which made it difficult for it to ignite readily. It is advantageous since it is easy to handle incase of crash. The bio-diesel shows that flash point and density of bio-diesel produced are 54 and 0.868 respectively which falls within the standard rang of 50 – 55 and 0.82 – 0.88 for petroleum diesel and 0.88 for bio-diesel this indicates that the bio-diesel produced will have better lubricating effects on engine part of compression ignition engines. The cetene number calculated using the equation recommended by ASTM D4737 is 54, this signifies that the bio-diesel produced has high anti-knocking properties.

5.1 Conclusion

Bio-diesel was produced from vitex oil and evaluated. The analysis showed that the bio-diesel produced is sulphur free, has a high cetane rating (less knocking), higher lubricating effect than petrol-diesel and will cause no corrosion on pipes. Thus the bio-diesel can effectively serve as an alternative to petrol-diesel without modification to diesel engines and the environmental and ecological advantages of the bio-diesel should be given more emphasis rather than its economic importance for new. Therefore the base catalyzed trans-esterication process using methanol is an effective method for bio-diesel production.

5.2 Recommendation

1. Further work is recommended in testing the bio-diesel in existing internal combustion engines (diesel fuel injection systems).

2. Agriculturists should intensify their effort in improving the variety of the species in order to obtain higher oil yields for vitex.

3. Large plantation of these plant species should be encouraged in order to exploit them for bio-diesel production.

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APPENDIX

Determination of moisture content

$$m = \frac{x_1 - x_2}{x_2} \times 100$$

m = percentage moisture content

x_1 = weight of dry sample

x_2 = original weight of grinded ger before drying

1st day

$$m_1 = \frac{40 - 27}{27} \times 100$$

$m_1 = 48.15\%$

2nd day

$$m_2 = \frac{40 - 30}{30} \times 100$$

$m_2 = 33.33\%$

3rd day

$$m_3 = \frac{40 - 33}{33} \times 100$$

$m_3 = 21.21\%$

$$m_4 = \frac{40 - 36}{36} \times 100 = 11.11\%$$

CHARACTERIZATION RESULT

1. Density Calculated Thus

$$P = \frac{m_1 - m_2}{V}$$

Weight of measuring cylinder 600g

Measured volume of oil $250cm^3$

Weight of measured oil + cylinder 817g

Weight of oil = 817.13 – 600 = 217g

$$\text{Density} = \frac{217}{250} = 0.868 g/cm^3$$

$= 0.868g/cm^3$

2. Viscosity

Readi	Factor	Viscosity (mp)
1.8	100	18
0.5	40	20
0.9	20	18

$$\text{Average} = \frac{18+20+18}{3}$$

$= 18.666$

≈ 18.67

3. Cetane Index

It was calculated using the equation below

$Cee = 45.2 + (0.0892)(T_{10N}) + [0.15 + (0.901)(B)][T_{50N}] + 0.0523 - (0.420)(B)] + [0.00049][T_{10N}] - [T_{90N}]^2 - (107)(B) + 60(B)^2$

$D = 0.868$

$DN = (D-0.85) = 0.8680 - 0.85 = 0.0180$

$B = [e^{[-3.5][DN]}] -1 = [e^{[-3.5][0.0180]}] -1 = -6.106 \times 10^{-2}$

$T_{10N} = T_{10} - 215 = 255 - 215 = 40$

$T_{50N} = T_{50} - 260 = 282 - 260 = 22$

$T_{90N} = T_{90} - 310 = 335 - 310 = 25$

ASH CONTENT

Wright of bio-diesel = 450g

Weight of ash recovered = 0.015g

$$= \frac{0.015}{450} \times 100$$

0.0033%

Cee = 45.2 + 0.0892 (40) + [0.1510 + (0.901 x – 6.10 x 10^{-2})] (22) + [0.0523 – (0.420 x -6.106 x $^{10-2}$)] (25) + 0.00049 [$(40)^2$ – $(22)_2$] + (107 x -6.106 x $^{10-}$ ^{2}) + 60 (-6.106 x $10^{-2})^2$] = 45.2 + 3.3568 + 3.322 + 7.719 + 0.54684 – 6.5334 + 2.22369 x 10^{-1} = 54.046 = 54