Ndubuisi, Elizabeth Chinyerem, 2025, 13:3
ISSN (Online): 2348-4098
ISSN (Print): 2395-4752

International Journal of Science, Engineering and Technology

An Open Access Journal

Enhancing Biodiesel Yields from Animal Fat Waste for Sustainable Energy Solutions

Ndubuisi, Elizabeth Chinyerem[1], Achadu, Michael A.[2], Odunna, Evans Chibuzor[3]
University of Port Harcourt, Faculty of Engineering, Department of Petroleum and Gas Engineering[1,3]
University of Port Harcourt, Faculty of Engineering, Department of Chemical Engineering[2]

Abstract- This study focuses on the production and optimization of biodiesel derived from waste animal fat, specifically cow fat (beef tallow). The tallow was processed using a dry rendering method to extract oil, which served as the feedstock for transesterification. To optimize biodiesel yield, various alcohol-to-oil molar ratios (5:1, 6:1, and 9:1) were investigated. The physicochemical properties of the rendered oil were assessed to evaluate its suitability for biodiesel production. The final biodiesel product was characterized and benchmarked against the European Standard Specification for unblended biodiesel (EN14214, B100), with results indicating compliance across key parameters. Gas Chromatography analysis revealed that the biodiesel primarily consisted of saturated fatty acid methyl esters, including pentadecanoic acid 14-methyl ester, methyl stearate, methyl tetradecanoate, methyl 13-methyl tetradecanoate, and 9-octadecanoate methyl ester. The prevalence of these saturated compounds significantly influenced the fuel's properties, notably increasing its cloud and pour points. Among the tested conditions, a molar ratio of 9:1 yielded the highest biodiesel output. Overall, the study demonstrates that beef tallow is a viable and compliant feedstock for biodiesel production when processed under optimized conditions.

Keywords- Chromatography, Biodiesel, Cowfat, Methyl stearate, Pentadecanoic

I. INTRODUCTION

Increasing energy demands, depletion of fossil fuels, and growing environmental concerns, have led to the exploration of alternative and renewable energy sources (Chisti, 2007). Biodiesel, derived from renewable resources such as plant oils and animal fats, offers a viable solution by reducing reliance on finite fossil fuels and decreasing greenhouse gas emissions (Atadashi et al, 2010). Biodiesel is a fatty acid alkyl ester, which is produced by transesterifying triglycerides present in oil or fat with organic solvent such as methanol, ethanol, butanol and even pentanol in presence of homogeneous or heterogeneous catalyst under optimum temperature and time. The sources for triglycerides are: unsaturated vegetable oils, saturated animal fats, discarded or reprocessed greases and edible oil. Biodiesel is a bio-degradable and non-toxic fuel with zero effect on environment and has very low level of CO, SO, hydrocarbon emissions. They have unique characteristics like high oxygen content, high cetane number with no aromatics and zero sulphur content. These properties make this biofuel sustainable and renewable, thus enabling it to be used for combustion and energy-based applications.

Numerous researches have been carried out on biodiesel production from plant seed oils, whereas there are limited researches performed on transesterification of animal fat for biodiesel production. Presently, oils from the corn, soybean, safflower, cottonseed, peanut, sunflower and

rapeseed along with another 350 crops have been identified as potential feedstock with high fat content for producing biodiesel which is suitable for running in diesel engines (Goku et al, 2018). But these feedstocks have turned out to be less cost effective, more time consuming (considering life cycle analysis) and serious concern related to "Food vs. fuel" conflict. However, to reduce the price of biodiesel while competing with the diesel fuel and surviving in market, diverse kind of low-cost feedstocks like; animal fats, recycled greases, used vegetable oil, waste cooking oil, by-products of refining vegetable oil and soap stocks have been identified for low-cost biodiesel production (Haas et al, 2000). Waste animal fats obtained from tanneries, slaughter houses and meat processing units are considered as high potential feedstock for biodiesel production because of its chemical inertness, zero corrosivity, better calorific value and renewable resources. Among these sources, leather tanneries produce 55% of solid wastes during trimming, pre-fleshing, fleshing and shaving operations, which majorly consist of subcutaneous fat wastes (Carraretto et al, 2004). Using these wastes not only reduces the solid waste disposal, but also reduces the overall production cost of biodiesel.

Utilizing waste animal fat as a feedstock for biodiesel production holds significant potential (Du et al, 2011). Waste animal fat is abundantly available from various sources, including rendering plants, slaughterhouses, and food processing industries. Moreover, improper disposal of waste animal fat poses environmental challenges, including water pollution and emission of harmful gases, which have detrimental effects on human health and ecosystems (Nguyen and Khan, 2016). Converting this waste material into biodiesel not only provides an environmentally friendly solution for waste management but also contributes to the production of a sustainable and renewable energy source (Lam and Lee, 2012).

1. Biodiesel Production Techniques

There are several techniques that can be employed to synthesize biodiesel such as:

Direct Blending: This is the direct use of vegetable and waste oils by mixing with a solvent or petroleum diesel in certain proportions. It is problematic because even though the vegetable oils have similar properties to biodiesel, they require modification before they can be used in a diesel engine. This leads to a reduction in oil fuel viscosity and diesel fuel utilization.

Micro Emulsion Method: This method is used to reduce the high viscosity of vegetable oils using solvents such as methanol, ethanol, 1-butanol. Microemulsion is the equilibrium distribution of optically isotropic liquid microstructures with dimensions between 1 and 50nm normally formed by a combination of two immiscible liquids and one or more active substances (Arifin 2009; Parawira 2010). The components of a biodiesel micro-emulsion include diesel fuel, vegetable oil, alcohol, surfactant and cetane improver in suitable proportions. Under vigorous stirring, all of these is turned into a micro-emulsion with lower viscosity. Higher alcohols are used as surfactants and alkyl gnitrates are used as cetane improvers. Micro-emulsion results in reduction in viscosity, increase in cetane number and good spray characters in the biodiesel. However, continuous use of micro-emulsified diesel in engines causes problems like injector needle sticking, carbon deposit formation and incomplete combustion (Parawira, 2010).

Pyrolysis (Thermal Cracking): This entails the thermal decomposition of oils in the absence of air or nitrogen. It results in the breakdown of molecules by heating at temperatures above 450c forming a mixture of chemical compounds and smaller molecules with properties very similar to those of petroleum diesel. In some situations, the process is supported by a catalyst. Typical catalyst used are silicon oxide (SiO_2) and aluminum oxide (Al_2O_3) (Sandeep Singh, 2012). The equipment for thermal cracking and pyrolysis is expensive for modest biodiesel production particularly in developing countries. Furthermore, the removal of oxygen during the thermal processing also removes any environmental benefits of using an oxygenated fuel (Parawira, 2010).

Transesterification: This is the most commonly used method in the production of biodiesel. It is a chemical reaction in which triglycerides present in the fat are converted into fatty acid methyl esters (FAME), the main constituents of biodiesel (Zhang et al, 2003). Catalysts such as sodium hydroxide or potassium hydroxide are typically used to facilitate the reaction (Marchetti et al, 2007). The final products are Alkyl esters (i.e., biodiesel) and Glycerol. However, optimizing specific parameters and conditions for the production process is necessary to achieve high yields and desirable fuel properties (Freedman et al, 1984).

2. Environmental Benefits Of Biodiesel

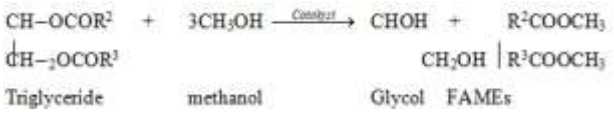
Benefits of biodiesel in comparison to petroleum-based fuel include:

Biodiesel reduces emissions of carbon monoxide (CO) by approximately 50% and carbon dioxide (CO2) by 78% on a net lifecycle basis because the carbon in the biodiesel emissions is recycled from carbon that was in the atmosphere, rather than the carbon from petroleum that was sequestered in the earth's crust (Sheehan, 1998).

Biodiesel contains fewer aromatic hydrocarbons: benzenefluoroethene: 56% reduction; benzopyrenes: 71% reduction (Beer, 1998). These hydrocarbons do not burn completely during combustion. Hence, they are emitted into the atmosphere as fumes from the tailpipes of combustion engines. The fumes are harmful to human health, and are leading causes of respiratory and other airborne diseases. Thus, a fuel with reduced polyaromatic hydrocarbons is a relatively better one.

Biodiesel can reduce by as much as 20% the direct (tailpipe) emission of particles, small particles of solid combustion products, on vehicles with particulate filters, in addition to a low sulphur content (<50 ppm) compared to petro diesel. Particulate emissions are reduced by around 50%, compared to fossil-sourced diesel. Particulate matter (PM) is tiny solid or liquid particles of soot, dust, smoke, fumes, and aerosols. The size of the particles (10 microns or smaller) allows them to easily enter the air sacs in the lungs where they may be deposited, resulting in adverse health effects. PM also causes visibility reduction and is a constituent of air pollutants (Demirbas 2001).

Biodiesel produces between 10% and 25% more nitrogen oxide NOx tailpipe-emission than petro diesel. As biodiesel has low sulphur content, NOx can be reduced through the catalytic converters to less than the NOx emissions from conventional diesel engines. Nonetheless, the NOx tailpipe emissions of biodiesel, (that is) after the use of catalytic converter will remain greater than the equivalent emissions from petro diesel. As biodiesel contains no nitrogen, the increase in NOx emissions may be due to the higher cetane rating of biodiesel and higher oxygen content, which allows it to convert nitrogen rapidly. If methanol is used it is called methanolysis. The methanolysis of triglycerides is as given by the equation in figure 1.



Where FAMEs refer to Fatty Acid Methyl Esters

Figure 1: Methanolysis of triglycerides (Gerpen et al., 2002)

3. Transesterification Mechanism

Transesterification of triglycerides produce fatty acid alkyl esters and glycerol. The glycerol layer settles down at the bottom of the reaction vessel (Gerpen et al., 2004). Diglycerides and monoglycerides are the intermediates in the process. The transesterification reaction is represented by the general equation given below.

Triglycerides +R'OH ↔ Diglycerides + RCOOR

Diglycerides +R'OH ↔ Mono glycerides + RCOOR

Monoglycerides + R' OH ↔ Glycerol + RCOOR'

One key parameter that requires optimization is the alcohol-to-fat ratio. The choice of alcohol and its ratio to the fat significantly affects the yield and quality of biodiesel. Methanol and ethanol are commonly used alcohols in transesterification reactions (Marchetti et al., 2007). Studies have

investigated the influence of different alcohol types and their ratios on the reaction efficiency and biodiesel properties (Mittelbach and Schober, 2003). Optimization of the alcohol-to-fat ratio is necessary to achieve high conversion rates and desirable fuel properties.

Catalysts play a vital role in facilitating the transesterification reaction. Alkaline catalysts, such as sodium hydroxide (NaOH) and potassium hydroxide (KOH), are widely used due to their high activity and low cost (Marchetti et al., 2007). These catalysts promote the conversion of triglycerides into fatty acid methyl esters (FAME), the main components of biodiesel. Acid catalysts, such as sulfuric acid (H2SO4) and hydrochloric acid (HCl), and enzymatic catalysts have also been explored as alternatives to alkaline catalysts (Azocar et al., 2010). The choice of catalyst depends on factors such as feedstock composition, reaction conditions, and desired biodiesel properties.

Optimization of reaction temperature and time is crucial to maximize the conversion efficiency and minimize unwanted side reactions. Studies have investigated the influence of temperature on the transesterification process (Marchetti et al., 2007). Higher temperatures can enhance the reaction rate, but excessive heat can lead to undesirable byproducts and fuel quality degradation. Similarly, reaction time must be optimized to achieve sufficient conversion without excessive energy consumption or prolonged reaction times (Marchetti et al., 2007).

Understanding the kinetics of the transesterification process is important for process optimization and scale-up. Reaction kinetics studies have been conducted to determine the rate constants and reaction mechanisms involved (Gonzalez-Garcia et al., 2009). Mathematical models, such as empirical and mechanistic models, have been developed to describe the transesterification process and predict the biodiesel yield under different reaction conditions (Choi et al., 2010). These modeling approaches help in process design and optimization.

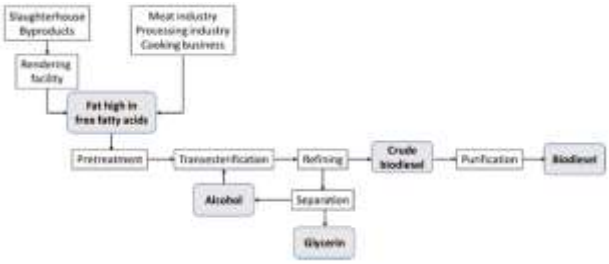


Figure 2: Schematic for the Production of Biodiesel from Waste animal fat (Kirubakaran et al, 2018)

II. MATERIALS AND METHODS

1. Materials

The primary raw material employed in this study was beef tallow fat, which served as the triglyceride source for biodiesel production via transesterification.

Reagents

The reagents used in the experimental procedures included: Potassium hydroxide (KOH) pellets (analytical grade), Methanol solution (99.8%), Phenolphthalein indicator, Isopropanol solution and Distilled water. All chemicals were of analytical grade and used without further purification.

Equipment and Apparatus

The equipment and laboratory apparatus utilized in the course of this study are as follows: Beakers (250 mL), Conical flasks (250 mL), Thermometer, Burette, Retort stand, Pipette, Magnetic stirrer, Electric heating mantle, Sample storage bottles, Water bath, Electronic weighing balance, Oven (for drying), Heating vessel, Separating funnel, Reflux condenser, Stopwatch, Viscometer, Flash and fire point tester, Cloud and pour point apparatus. All equipment was calibrated prior to use to ensure measurement accuracy and consistency.

2. Methods

Collection and Preparation of Raw Material

Raw beef tallow was procured from the Rukpokwu Slaughter Market, an abattoir approved by the Rivers State Government, Nigeria. Upon collection, the tallow was thoroughly washed and allowed to drain using a fine-mesh sieve. It was subsequently sun-dried to reduce moisture content and stiffen the material. The dried tallow was then chopped

into smaller pieces to enhance the efficiency of oil extraction as shown in Figure 3.

Extraction of Tallow Oil

The oil was extracted via the dry rendering method. The prepared beef tallow chunks were introduced into a heating vessel and subjected to medium heat. As the fat melted, the oil was released and collected. Solid residues and protein particles were removed by filtration. The extracted oil was further heated to evaporate residual moisture, thereby yielding refined beef tallow oil suitable for transesterification.

Transesterification Process

Biodiesel was synthesized through the alkaline transesterification of beef tallow oil using potassium methoxide as the active reagent. Potassium methoxide was prepared by dissolving potassium hydroxide pellets in methanol under controlled conditions.

To optimize the methanol-to-oil molar ratio for maximum biodiesel yield, three different molar ratios (5:1, 6:1, and 9:1) were tested. For each experiment, the required stoichiometric quantities of methanol, KOH catalyst, and beef tallow oil were calculated and prepared, as detailed in Appendix A. The reaction mixture was stirred continuously using a magnetic stirrer and maintained at a reaction temperature between 55°C and 60°C using an electric heating mantle. After the reaction period, the mixture was allowed to settle in a separating funnel to enable phase separation. The upper biodiesel layer was decanted and subjected to further purification and characterization.

Figure 3: Raw beef tallow used for transesterification

Characterization of Extracted Beef Tallow Oil

Determination of Percentage Yield of Tallow Oil

This is the quantity of Oil extracted in a specific time relative to the weight of the sample used. It was determined at the end of extraction by applying this equation;

$$\text{Percentage yield} = \frac{\text{WEIGHT EXTRACTED}}{\text{WEIGHT OF SAMPLE}} \text{X} \frac{100}{1}$$

Free Fatty Acid content (FFA)

Free fatty acid content is the measure of rancidity in a sample. The FFA value is the number of milligrams of KOH required to neutralize 1g of the Oil. 1g of the sample of oil was weighed out accurately into a conical flask. Afterwards 5ml of isopropanol was added into the flask. The mixture was slightly heated to properly dissolve the sample after which few drops of phenolphthalein indicator were added. The mixture was titrated with 0.1N potassium hydroxide solution and shook vigorously until the appearance of the first permanent pink colour.

The percentage of free fatty acids was calculated using the formula below.

$$\text{Acid value} = \frac{\text{TITRE VALUE} \times \text{N} \times 56.11}{\text{WEIGHT OF SAMPLE}} \times \frac{100}{1}$$

$$\%\text{FFA} = \frac{\text{AV}}{1.99}$$

Where N = Normality of KOH

Density of Tallow Oil (Gravimetric Method)

The density of tallow oil was measured using the gravimetric method. An empty syringe was weighed using an analytical weighing balance. 10cm3 of oil was then poured into the syringe, and the combined weight measured. The difference between the weight of the syringe plus oil and that of the empty syringe was obtained and recorded as the weight of the oil. The density was obtained by taking the ratio of the weight of the oil and its volume. The density of the biodiesel was obtained in the same way by following steps 1 to 4.

Viscosity of Oil

The viscosity of the tallow oil was measured by the use of a viscometer. The procedure followed is outlined as follows:20 ml of the oil produced was poured into a 50 ml beaker. A spindle with a spindle number of seven was immersed into the oil until the oil level was at the mark on the spindle. It was positioned such that it did not touch the walls of the beaker. The value of the viscosity was then read from the viscometer, and recorded.

Specific Gravity of Tallow Oil

Specific gravity is the ratio of the density of a substance to the density of water. The density of rendered tallow was obtained as 909.4 kg/m3. Hence the specific gravity was determined from this value and the density of water.

The specific gravity was calculated using the formula:

S.G = (Density of tallow oil)/(Density of water)

Pretreatment of Beef Tallow Fat

Beef tallow fat was washed and sun dried till all moisture was removed. The aim of this was to reduce the water content, whose presence reduces the biodiesel yield and creates difficulty in separation and purification of the biodiesel. The oil was extracted and heated further above 110oc to remove moisture.

3. Transesterification of Beef Tallow Oil

The Free Fatty Acid content of the oil was first determined by titration as shown in Figure 4. The value was obtained to be 2.21%. The Production of Biodiesel by transesterification, was carried out in three experiments of varying methanol to alcohol ratios. Ratios of 5:1, 6:1 and 9:1, were evaluated. All other parameters were kept constant. The experimental procedure was the same for all reactions. For the reaction of the 6:1 molar ratio; 50g of the oil was measured and heated at 120oc for 10 minutes to remove moisture. 0.5g of KOH pellets were weighed and dissolved completely in 11.02g of methanol using the heating mantle and magnetic stirrer, to form potassium methoxide solution. The potassium methoxide solution was added to the heated oil slowly and then mixed vigorously for 1 hour. The temperature was kept at 60 °C by carrying out the reaction on a heating mantle with a magnetic stirrer, and fitted with a reflux condenser to prevent escape of methanol. After the reaction, the mixture was poured into a separating funnel and allowed to separate by gravitational settling for 12 hours as seen in Figures 5 and 6, after which the separation between biodiesel and the glycerin was complete. Glycerol layer was drained off from the bottom of the separating funnel leaving only crude biodiesel. The crude biodiesel was then purified by washing with warm distilled water, until the pH of the water was neutral; to remove residual catalyst and excess methanol as shown Figure 7. The same procedure was used to produce biodiesel for methanol to oil ratios of 5:1 and 9:1 where the methanol quantities used were 9.19g and 16.62g respectively. The stochiometric calculations are presented in appendix F.

Figure 4: Reaction of beef tallow to produce biodiesel

Figure 5: Biodiesel and glycerin separation

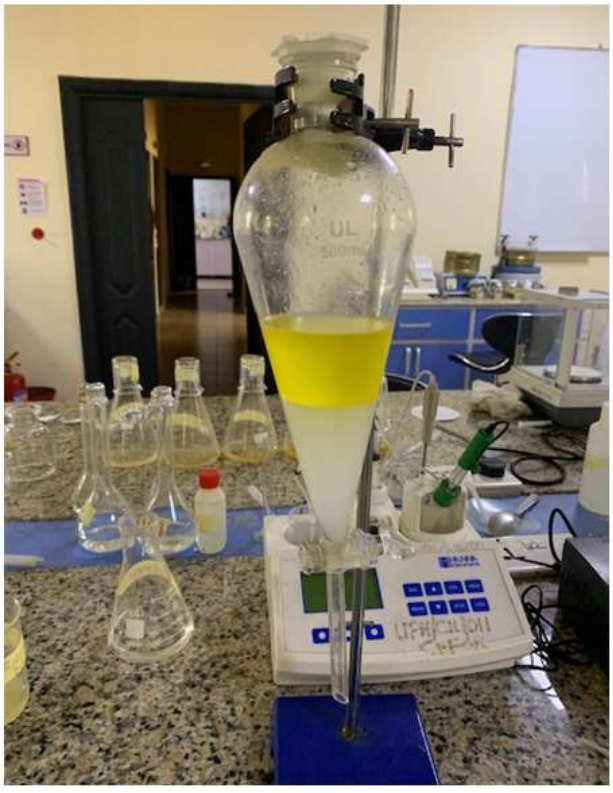


Figure 6: Biodiesel after washing

Figure 7: Produced biodiesel after filtering

4. Biodiesel Characterization

Density Measurement

The density of biodiesel produced was measured similarly, using the gravimetric method. An empty syringe was weighed using an analytical weighing balance and 5cm3 of oil was then poured into the syringe. The combined weight was then measured. The difference between the weight of the syringe plus oil and that of the empty syringe was obtained and recorded as the weight of the oil. The density was obtained by taking the ratio of the weight of the oil and its volume.

Viscosity Measurement

The major aim of transesterification is to reduce the viscosity of a viscous oil to an acceptable standard for use in diesel engines. The viscosities of the biodiesel produced were measured by the use of the viscometer. 20 ml of the biodiesel produced was poured into a 50 ml beaker. A spindle with a spindle number of seven was immersed into the oil until the oil level was at the mark on the spindle. It was positioned such that it did not touch the walls of the beaker. The value of the viscosity was then read from the viscometer, and recorded.

Flash Point and Fire Point

The flash point is an important indicator for fuel production that defines the lowest temperature at which the vapours of the material ignite. Hence this value indicates the safety of the fuel for storage and handling. The Cleveland Open Cup Flashpoint Tester was used to obtain the flash and fire points of the biodiesel produced. The biodiesel was poured into the brass cup to touch the prescribed mark inside the cup and then gently placed into its position until it locked. A thermometer was placed inside the brass cup so that the bottom of the thermometer is one quarter inch from the bottom of the test cup and to the side of the test cup. By placing a lighted match and turning the gas valve gently, the Bunsen burner was ignited together with the injected burner. The biodiesel was constantly stirred and the heating was adjusted to give a temperature rise of the biodiesel at the same time of flashing of 7-8° F per minute. At intervals of say 10 to 15 seconds, the spring lever was turned so that the injector burner was injected into the container. Immediately a distinct flash was seen after turning the nub, the temperature reading of the thermometer was taken and recorded. This gave the closed flash point of the biodiesel.

Cloud Point and Pour Point

Cloud point is defined as the temperature at which a cloud of wax crystals first appears in a liquid when it is cooled under controlled conditions during a standard test. A cloud and pour point apparatus was used for this analysis.

A Pour point apparatus was used to test for the Cloud and pour points of the biodiesel. The procedure is as follows: Crushed ice crystals were used to fill the pour point apparatus. The biodiesel sample was poured into the test jar to the level mark and subsequently closed with the cork carrying the thermometer. The test jar was placed into the jacket at the center of the apparatus and the gasket placed around the test jar to prevent escape of cool air. The temperature at which ice crystals started to form in the sample was noted as the cloud point, while the temperature at which the fluid ceased to flow was noted as the pour point.

Acid Value

This reflects the amount of free fatty acids in a sample. It is the amount of KOH that will be neutralized in 1g of the sample. 1g of the sample of oil was weighed out accurately into a conical flask. Afterwards 5ml of isopropanol was added into the flask. The mixture was slightly heated to properly dissolve the sample after which few drops of phenolphthalein indicator were added. The mixture was titrated with 0.1N potassium hydroxide solutions and shook vigorously until the appearance of the first permanent pink colour.

The percentage of free fatty acids was calculated using the formula below.

$$\text{Acid value} = \frac{\text{TITRE VALUE} \times N \times 56.11}{\text{WEIGHT OF SAMPLE}} \times \frac{100}{1}$$

This method covers the determination of the chemical composition of Carbon atoms in the fuel. A Gas chromatogram was used to conduct this analysis. The sample was injected in the column through an injector and components were separated by column based on their affinity towards the stationary phase of the column. They are afterwards fed to the flame where ionization takes place. An electrode system is located close to the flame which picks up the ionization current which is then amplified and suitably fed to an integrator. The components are identified from their retention times and concentrations are calculated from the pre calibrated method. 50ml of biodiesel sample was transferred into a 125ml

bottle and sealed with a rubber septum. The bottle was placed in an oven (100oC) for a period of 60 minutes. The method was set on the gas chromatogram. After 60minutes had elapsed, the 125ml bottle was taken out of the oven.

III. RESULTS ON BEEF TALLOW ANALYSIS

The experimental results obtained from various analysis carried out on the beef tallow fat are presented below:

Table 1: Physiochemical Properties of Tallow/Oil

Analysis	Result
Colour	yellow
Odour	Characteristic smell
Density (kg/m^3)	909.4
% Oil yield	93%
Free fatty acid (FFA)	2.21%
Specific gravity	0.9094

2. Results on Biodiesel Analysis

Biodiesel Yield Result

The biodiesel yield from the transesterification of the three samples of beef tallow is presented in table 3. The yields estimation are detailed in appendix A.

Table 2: Biodiesel Yields of Varying Methanol to Oil Ratios at Constant Catalyst Conc., Temperature and Time

Sample	Varying Methanol to Oil ratio	% Yield of biodiesel Produced
A	5:1	43.66%
B	6:1	48.832%
C	9:1	64.42%

The fuel properties of the biodiesel were investigated and their average values compared with those of EN14214 (The European Standard Specifications for biodiesel).

The density, viscosity, flash and fire points, cloud and pour points, acid value and the fatty acid composition were evaluated.

3. Characteristics of Beef Tallow Biodiesel and EN14214 Standards

The European Standard Specifications for biodiesel (EN14214) have been developed for unblended FAME biodiesel (B100) while the ASTM Standard Specification (ASTM D6751) establishes specifications for a biodiesel blend feedstock.

Table 3: Characteristics of Produced Biodiesel with EN14214 Standard and Hydrocarbon Diesel

Parameter	Biodiesel	Hydrocarbon Diesel	EN14214 Limits
Density at 15°c (kg/m^3)	838.2	840	860-900
Specific gravity	0.8382	0.840	0.860-0.900
Flash point (°c)	160	52-96	>120
Cloud point (°c)	22	-9	-
Pour point (°c)	17	-13	-
Acid value (mgKOH/g)	0.0757	0.35	<0.5
Viscosity at 40°c (mm^2/s)	5.35mm	5.7	3.5-5.0

4. Chemical Properties of Beef Tallow Methyl Ester

Fatty Acid Profile Using Gc-Ms

A Gas chromatograph and Spectroscopy machine (GC-MS) was used to quantify compounds present in the beef tallow biodiesel. These compounds have been tabulated and presented in table 4. The GC-MS chromatograph result is shown in Figure 8.

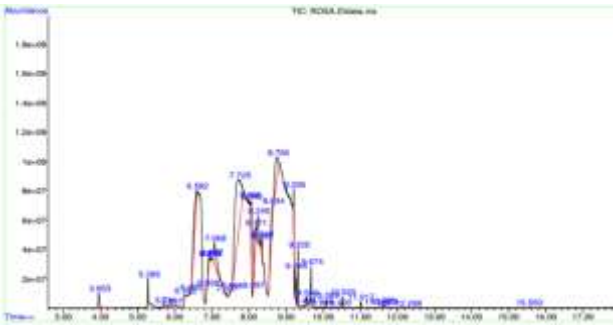


Figure 8: GC-MS chromatograph beef tallow biodiesel sample

Table 4: GC-MS Fatty Acid Methyl Ester Composition

23	9-Octadecanoic acid, methyl ester	$C_{19}H_{36}O_2$	8.634	5.43
24	Methyl stearate	$C_{19}H_{38}O_2$	8.766	9.03
25	Methyl 9-cis, 11-trans-octadecadienoate	$C_{19}H_{34}O_2$	9.206	1.88
26	Methyl 10-trans, 12-cis-octadecadienoate	$C_{19}H_{34}O_2$	9.246	1.71
27	Nonadecanoic acid, methyl ester	$C_{20}H_{40}O_2$	9.320	3.13
28	Methyl 18-methylnonadecanoate	$C_{21}H_{42}O_2$	9.491	0.20
29	Cis-13-Eicosenoic acid, methyl ester	$C_{21}H_{40}O_2$	9.549	0.96
30	Eicosanoic acid, methyl ester	$C_{21}H_{42}O_2$	9.674	3.67
31	Heneicosanoic acid, methyl ester	$C_{22}H_{44}O_2$	9.494	0.08
32	Heneicosanoic acid, methyl ester	$C_{22}H_{44}O_2$	10.069	0.44
33	Methyl 11-docosenoate	$C_{23}H_{44}O_2$	10.400	0.05
34	Docosanoic acid, methyl ester	$C_{23}H_{46}O_2$	10.520	0.93
35	Tricosanoic acid, methyl ester	$C_{24}H_{48}O_2$	11.017	0.54
36	15-Tetracosenoic acid, methyl ester	$C_{25}H_{48}O_2$	11.463	0.07
37	Tetracosanoic acid, methyl ester	$C_{25}H_{50}O_2$	11.606	0.25
38	Octadecanoic acid, 2,3-dihydroxypropyl ester	$C_{21}H_{42}O_2$	11.663	0.11
39	Pentacosanoic acid, methyl ester	$C_{26}H_{52}O_2$	12.298	0.05
40	Cholesterol	$C_{27}H_{46}O$	15.550	0.17

Peak no	Identified Component	Formula	Retention time (min)	Area %
1	Decanoic acid, methyl ester	$C_{11}H_{22}O_2$	3.953	1.94
2	Dodecanoic acid, methyl ester	$C_{13}H_{26}O_2$	5.285	1.74
3	Methyl 11-methyl-dodecanoate	$C_{14}H_{28}O_2$	5.731	0.71
4	Tridecanoic acid, methyl ester	$C_{14}H_{28}O_2$	5.896	0.19
5	Tridecanoic acid, 12-methyl ester	$C_{15}H_{30}O_2$	6.262	0.41
6	Tridecanoic acid, 12-methyl ester	$C_{15}H_{30}O_2$	6.405	0.28
7	Methyl tetradecanoate	$C_{15}H_{30}O_2$	6.582	8.21
8	Methyl 13-methyltetradecanoate	$C_{16}H_{32}O_2$	6.868	0.54
9	Methyl 13-methyltetradecanoate	$C_{16}H_{32}O_2$	6.914	1.22
10	Methyl 13-methyltetradecanoate	$C_{16}H_{32}O_2$	6.948	0.14
11	Methyl 13-methyltetradecanoate	$C_{16}H_{32}O_2$	6.977	0.22
12	Methyl 13-methyltetradecanoate	$C_{16}H_{32}O_2$	7.068	6.62
13	Pentadecanoic acid, methyl ester	$C_{16}H_{32}O_2$	7.377	0.21
14	9-Hexadecanoic acid, methyl ester, (z)	$C_{17}H_{32}O_2$	7.508	0.46
15	Pentadecanoic acid, 14-methyl-, methyl ester	$C_{17}H_{34}O_2$	7.725	36.83
16	Hexadecanoic acid, methyl ester	$C_{17}H_{34}O_2$	7.988	0.16
17	Hexadecanoic acid, methyl ester	$C_{17}H_{34}O_2$	8.045	3.32
18	Hexadecanoic acid, 15-methyl ester	$C_{18}H_{36}O_2$	8.097	0.16
19	Hexadecanoic acid, 15-methyl ester	$C_{18}H_{36}O_2$	8.171	2.72
20	Hexadecanoic acid, 15-methyl ester	$C_{18}H_{36}O_2$	8.240	3.46
21	Hexadecanoic acid, 15-methyl ester	$C_{18}H_{36}O_2$	8.303	0.31
22	Heptadecanoic acid, methyl ester	$C_{18}H_{36}O_2$	8.343	1.44

4.5 Discussion of Results

Biodiesel was produced from beef tallow oil via transesterification in this study. The production process was optimized by varying three molar ratios of alcohol to oil mixture (5:1, 6:1, 9:1) to determine the optimum ratio for beef tallow transesterification at a constant temperature of 60oc and time of 60minutes.

The extraction of oil from beef tallow gave an appreciable percentage yield of 93% within an extraction time of 45 mins. The quality of oil was enhanced by reducing the moisture content. This was carried out by sun drying the tallow feedstock prior to utilizing the dry rendering method for oil extraction. The oil was analyzed for physical and chemical parameters. The free fatty acid of the tallow oil was recorded to be 2.21%, which is within the acceptable range of free fatty acid value for transesterification. Therefore, the oil samples were trans esterified using methanol, with potassium hydroxide catalysts to produce fatty acid methyl ester – biodiesel. All transesterification reactions were carried out for 60 minutes at 600c temperature.

Percentage Yield

The percentage yield is a percent ratio of the actual yield to the theoretical yield. Percentage yield of biodiesel describes the actual yield of biodiesel produced, in ratio with the amount of oil used in the reaction, expressed as a percent value. The biodiesel yields for the three molar ratio samples were compared and presented in table 2. As seen from the table, the yield of biodiesel increased as the methanol to oil ratios increased. At 9:1 molar ratio, the yield obtained was 64.42%; hence 9:1 is the methanol to oil ratio that gave the highest yield. The yield of biodiesel from beef tallow oil was observed to reduce for lower methanol to oil ratios. This can be attributed to the fact that even though the stochiometric molar ratio of alcohol to oil for transesterification is 3:1, the reaction is reversible and higher molar ratios are required to increase the miscibility and enhance the contact between the alcohol molecule and triglyceride. In practice, to shift the reaction toward completion, the molar ratio should be higher than that of the stochiometric ratio. Therefore, it is needed to increase the concentration of reactant such as alcohol amount, so that the reaction will be more favourable to produce biodiesel.

The percentage yield of a transesterification reaction is dependent on a number of factors, and is unique to every reaction.

Density

Density is the weight of a unit volume of fluid. It can also be defined as the mass per unit volume of any liquid at a given temperature. The density of the biodiesel produced was measured to be 838.3 kg/m3 at 15oc. According to the European Standard Specification for biodiesel, an acceptable range of biodiesel density at 15oc is 860-900kg/m3, while the density of conventional diesel at same temperature is 840kg/m3. The biodiesel density was found to be within the acceptable range for B100 according to the standard.

Viscosity

Viscosity is a measure of the internal fluid friction or resistance of oil to flow, which tends to oppose any dynamic change in the fluid motion. As the temperature of oil increases, its viscosity decreases, and it is therefore able to flow more readily. It is an important parameter that shows the lubricity of the fuel.

The viscosity of the produced biodiesel was measured at 40oc to be 5.35mm2/s, which is slightly higher than the stipulated standard of 5.0mm2/s.

Acid value

This reflects the amount of free fatty acids in a sample. It is the amount of KOH that will be neutralized in 1g of the sample. At high concentrations free fatty acids can cause corrosion of the fuel supply system of the engine. The acid value of the biodiesel was measured to be 0.0757mgKOH/g. The EN14214 Standard says that the acid value should be below 0.5mgKOH/g., this confirms that the acid value of the biodiesel is well within range of the EN14214 standards.

Flash Point and Fire point:

Flash point is the temperature at which the fuel becomes a mixture that will ignite when exposed to a spark or flame, and higher flash point indicates a safer fuel. The flashpoint for the produced biodiesel was measured to be 160oc. The European Specification Standard for flash point dictates a value above 120oc. Biodiesel has a higher flash point compared to petroleum diesel whose flashpoints is within a range of 52-96oc, making biodiesel less prone to ignition and a safer fuel.

Cloud Point and Pour point

Cloud point is defined as the temperature at which a cloud of wax crystals first appears in a liquid when it is cooled under controlled conditions during a standard test and the Pour point describes the lowest temperature that a volume of liquid fuel will solidify and not flow. The cloud point of the biodiesel was measured to be 22oc, while the pour point was measured to be 17oc. The cloud point and pour point properties are noted to be location and season dependent, hence do not have comparable data ranges according to the EN14214 standards.

GC-MS Analysis

The GC-MS was used to quantify compounds present in beef tallow biodiesel. The GC-MS chromatograph shows 40 peaks of identified component of methyl esters and trace elements such as cholesterol. From figure 8, it can be seen that the five highest peaks with the largest areas have components that were contributed by: Pentadecanoic acid 14-methyl ester, Methyl stearate (stearic acid, methyl ester), Methyl tetradecanoate (myristic acid, methyl ester), Methyl 13-methyl tetradecanoate and 9-Octodecanoate acid, methyl ester. These compounds are long chain hydrocarbons that are saturated, and this characteristic has a direct effect on fuel properties. The high saturated fatty acids of beef tallow biodiesel have high cloud and pour points, which hamper its applicability in winter seasons. This was observed from the cloud and pour point analysis carried out on the biodiesel sample, which were obtained to be 22 and 17oc respectively. This presents a tendency of the fuel to crystallize at low temperatures, which can limit the use of this fuel in cold climates. Also, the high saturated fatty acids of the biodiesel, are advantageous because the saturated compounds have high cetane numbers and less propensity to oxidise. This means that, properties such as cetane number, oxidation stability and heat of combustion will increase with an increase in the number of carbon atoms but decreases with an increase in number of double bonds. A fuel with compounds that are fully saturated has better oxidation stability and cetane number but poor cloud and pour points.

IV. CONCLUSION

This study presented the production of fatty acid methyl ester – biodiesel from waste beef tallow oil. Physicochemical properties of the oil were evaluated to determine its viability as a feedstock for biodiesel production. The reaction process was optimized to determine the alcohol to oil ratio that

would produce the best yield at a constant temperature and catalyst concentration.

The biodiesel produced was characterized and the physicochemical properties compared to the European Standard Specifications for B100 biodiesel and with hydrocarbon diesel. The biodiesel was confirmed to meet the standard specifications and showed advantages over hydrocarbon diesel.

Acknowledgments
We would like to express our sincere gratitude to the Africa Center of Excellence, the World Bank,University of Port Harcourt for providing the necessary grant and access to their laboratory facilities, which enabled us to conduct the analyses for this study.

Disclosure of conflict of interest
There is no conflict of interest.

REFERENCES

1. Atadashi, I. M., Aroua, M. K., & Abdul Aziz, A. R. (2010). High quality biodiesel and its diesel engine application: A review. Renewable and Sustainable Energy Reviews, 14(7), 1999-2008.
2. Chisti, Y. (2007). Biodiesel from microalgae. Biotechnology Advances, 25(3), 294-306.
3. Du, W., Liu, D., Zhang, E., & Liu, Y. (2011). Synthesis and characterization of biodiesel produced from soybean oil and animal fat. Journal of Chemical Technology & Biotechnology, 86(9), 1212-1219.
4. Lam, M. K., & Lee, K. T. (2012). Utilization of sludge for energy recovery: pyrolysis kinetics. Bioresource Technology, 128, 576-581.
5. Nguyen, D. T., & Khan, M. A. (2016). Overview of renewable biobased materials for environmental applications. In Handbook of Environmental Materials Management (pp. 1-25). Springer.