Production, Characterization and Glycerine Analysis of Soybean Oil and Its Biodiesel

I. I. Ogedengbe* and E. I. Bello

Department of Mechanical Engineering, Federal University of Technology, Akure, Nigeria.

Authors’ contributions

This work was carried out in collaboration between both authors. Author EIB conceived and designed the study and undertook the literature searches. Author IIO performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Both authors contributed to the introduction, results and discussion. Both authors read and approved the final manuscript.

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ABSTRACT

Aims: To examine the viability of Soybean Oil as a feedstock for Biodiesel production by carrying out its characterization and examining its thermodynamic properties to see if they are within ASTM limits.

Study Design: Place and Duration of Study-The production was conducted in the Department of Mechanical Engineering of the University while the characterization of the Biodiesel was conducted at the Postgraduate Research Laboratory. Samples of Glycine ma (L.) merril were obtained from a local market in the Akure town of Ondo State, Nigeria in October of 2014.

Methodology: Oil Extraction-The oil was extracted using soxhlet extractor, but before extraction the soybeans were crushed in a blender to increase the area exposed to the petroleum ether solvent. The extraction flask was dried in an oven at 105°C and the weight was measured after cooling. 2.5 g of soybean was poured into the flask and leached for 5 hours after which extraction flask was removed from the mantle heater after all the petroleum ether was removed with rotary evaporator and the oil was oven dried at 105°C for one hour to remove any water present. The flask was finally cooled to room temperature in a desiccators and the weight of the flask and dried oil was again measured.

*Corresponding author: E-mail: ikeoire@gmail.com, iiogedengbe@futa.edu.ng;
Transesterification and Glycerine Analysis Process: 50 mg of the extracted oil was esterified 5 times at 95°C with 3.5 ml of the 0.5 M KOH of dried methanol. The mixture was neutralized using 0.7M HCL. 3 ml of 14% boron trifluoride in methanol was added and the mixture was heated for 5 minutes at 90°C to achieve completed methylation process. The fatty acid methyl esters were thrice extracted from the mixture with redistilled methanol. The content was concentrated to 1mL for gas chromatography analysis and 1 µL was injected into the port of the Gas Chromatograph analyzer.

Results: most of the pertinent parameters for the determination of validity were found to be within ASTM limits, namely: Flash Point (135°C / 130°C min); Kinematic Viscosity (4.80 / between 1.9 - 6); Cetane number (55 / 47 min); Copper Strip Corrosion (1 / 3 max); %Carbon Residue (0.12 / 0.050); %Sulphated Ash (0.044 / 0.020).

Conclusion: Given the obviously good numbers associated with the study relative to ASTM standards, Soybean is a viable source of Biodiesel. However, further study could explore the use of Soybean chaff and other waste matter obtainable from it rather than the entire crop.

Keywords: Soybeans oil; biodiesel; characterization; fatty acids.

1. INTRODUCTION

The world’s weather pattern is changing drastically as manifested by the increase in global temperature, extensive flooding and drought in several countries. This has brought into the forecourt the need for alternative fuel to fossil diesel that is environmentally friendly and yet globally available [1,2,3,4,5]. Research efforts have homed on vegetable oil and several types have been tested. The greatest hindrance being the high viscosity and poor cold weather characteristic of vegetable oil which necessitates a conversion to other forms of which biodiesel has been the most adaptable to diesel engine [6]. Among the vegetable oils that have been tested is soybean oil. Soybean (Glycine ma (L.) merril) is a legume plants that can grow in a wide range of soils, with optimum growth in moist alluvial soils with a good organic content. Soybeans, like most legumes perform nitrogen fixation by establishing a symbiotic relationship with the bacterium Bradyrhizobium japonicum. It can reach a height of around 1 m (3ft), and take between 80-120 days from sowing to harvesting [1]. With an average protein content of 40% and oil content of 20%. It is an important source of high quality, inexpensive protein and oil. Soybean has the highest protein content of all food crops, and is second only to groundnut in terms of oil content among food legumes. Food products from soybean include baby food, cereal, diet foods, imitation meats, processed meats, soy sauce, tofu and miso, salad dressings and margarine, cooking oil, candy, and baked goods. Soybean is used in pet foods and as the leading source of protein meal for livestock in the US. Industrial uses for soybeans include wallboard and plywood, medicines, soaps and disinfectants, pesticides, fertilizers, candles, linoleum, varnish, fire extinguisher fluid, and paint. The oil contains triglyceride and is being considered as a potential source of oil for biodiesel production.

2. METHODOLOGY

This is in two phases – oil extraction and characterization. These are presented subsequently.

2.1 Oil Extraction

The oil was extracted using soxhlet extractor, but before extraction the soybeans were crushed in a blender to increase the area exposed to the petroleum ether solvent. The extraction flask was dried in an oven at 105°C and the weight was measured after cooling. 2.5 g of soybean was poured into the flask and leached for 5 hours after which extraction flask was removed from the mantle heater after all the petroleum ether was removed with rotary evaporator and the oil was oven dried at 105°C for one hour to remove any water present. The flask was finally cooled to room temperature in a desiccators and the weight of the flask and dried oil was again measured. The oil content was determined using equation (1).

\[ \text{Oil Content} \% = \frac{\text{Weight of oil extracted}}{\text{weight of soybean seeds used}} \] (1)

2.2 Transesterification and Glycerine Analysis Processes

50 mg of the extracted oil was esterified 5 times at 95°C with 3.5 ml of the 0.5 M KOH of dried methanol. The mixture was neutralized using
0.7M HCL. 3 ml of 14% boron trifluoride in methanol was added and the mixture was heated for 5 minutes at 90°C to achieve completed methylation process. The fatty acid methyl esters were thrice extracted from the mixture with redistilled methanol. The content was concentrated to 1 mL for gas chromatography analysis and 1 µL was injected into the port of the Gas Chromatograph analyzer.

2.2.1 Characterization methods

The properties of the oil and biodiesel were measured as follows:

2.2.1.1 Cloud point

The cloud point was determined using a cloud points meter equipped with a total-reflection type waveguide sensor having an incidence channel, an emergence channel and a detection surface.

2.2.1.2 Flash point

The sample was dried in the laboratory to remove traces of water moisture in the sample. The dried sample was poured into the cup of the tester to the mark and it was followed by the replacement of the cup and the cup cover with the left hand pointing towards the left front corner of the test unit. Stirrer driver drive was fitted into the tester properly and it was followed by the connection of the resistance thermometer probe. Flame and the pilot light were carried out by lighting and the draught screen was closed. The tester was put on and the heater temperature was regulated and switch for the stirrer was on simultaneously with the tester for homogeneity. The flash occurs when a large flame was observed on the cup and the temperature at which this occurs was recorded as the flash point for the sample. The test was conducted for the oil and biodiesel.

2.2.1.3 Kinematic viscosity

A wide tube capillary viscometer was used for the measurement. It was placed in a thermostatically controlled constant temperature water bath at the test temperature of 40°C. The sample flow time was measured to 0.2 second, the time required for the meniscus to pass from the first time mark to the second was used for calculating the viscosity.

2.2.1.4 Cetane number analysis

The cetane number was determined using the regression equation derived from the analysis of the fuel samples with a wide variety of ignition qualities that was made by mixing different kinds of biodiesels and different kinds of fatty acid methyl ester (FAME) reagents. The value was confirmed using the distillation characteristic of the oil and biodiesel.

2.2.1.5 Water/residue analysis

This was done with the aid of a centrifuge. The samples were shake thoroughly before filling the two centrifuge tubes to the 50 mL mark. 50 mL of the water saturated xyline was added to each of tube followed with 0.2 mL of the emulsifier solution. The tubes were stoppered and inverted severally for mixing which was later placed in the water bath at 60°C for 30 minutes. The content was shake and placed in the opposing cups of the centrifuge and spun for 10 minutes at the rate of 1500 rpm. The combined volume of the water and residue at the bottom of the cup was read and recorded. The cup with the content without agitation was returned to the centrifuge cup and spun for another 10 minutes at the same rate. The process was repeated until the combined volume of water and residue became constant for two consecutive readings.

2.2.1.6 Iodine value

In determining this, 0.25 g of the oil sample was dissolved in the 20 ml carbon tetrachloride in 100 ml volumetric capacity flask. The Wiji’s solution was added to the content of the flask. It was stoppered and allowed to stand for two hours in darkness at the room temperature. 20 ml of the potassium iodide solution was added and the mixture was titrated against sodium thiosulphate solution using the starch indicator. The same procedure was repeated for the blank and the iodine value was calculated using equation (2)

\[
\text{Iodine Value} = \frac{12.69 N (V_2 - V_1)}{W}
\]  

(2)

2.2.1.7 Acid value

To ascertain this, 0.40g of the oil sample was dissolved in the 5.0 ml in 1:1 mixture of ethanol diethyl ether in 100 ml flask. The mixture was homogenized and allowed to stay on the bench until the indicator was added. The acid value was calculated using equation (3)
Acid Value = $\frac{56.1 \times N \times V}{W}$  \hspace{1cm} (3)

2.2.1.8 Carbon residue

In order to obtain this value, 1.0 g of the sample was placed in a crucible and subjected to destructive distillation. The residue undergoes cracking and coking reactions during a severe heating. At the end of the heating, the test crucible containing carbonaceous residue was cooled in a desiccators and weighed. The residue remaining was calculated as a percentage of the original sample, and reported as Conradson carbon residue.

2.2.1.9 Copper strip corrosion test

The copper strip corrosion test (ASTM D 130 in ASTM D 6751; ISO 2160 in EN 14214) was used for the determination of the corrosiveness of copper in the samples. It involved dipping a strip of copper into the samples contained in Koclier K25330 copper strip test bath for 3 hours at 50°C after which the corrosive effects of the samples on the strip was observed and the pattern formed is compared with ASTM copper strip corrosion colour chart standard to ASTM method D130/1p 154 and specified according to the copper strip rating system ASTM D190. The bath was mechanically agitated to insure test point to test point uniformity.

2.2.1.10 Distillation characteristics

The vacuum distillation temperature was determined according to the ASTM D1160 Method using the reduced pressure advanced distillation curve apparatus. This consists of a distillation unit and a vacuum pump. The distillation pressure was set between 1 kN/m2 and 83 kN/m2 and the uncertainty for each measurement was less than 1°C. The distillation temperatures were set to correspond to 10%, 50% and 90% of the biodiesel distilled and condensed.

2.2.1.11 Free glycerin analysis

The method was based on the modified ASTM D7637 by cold oxidation of the glycerol content of the oil sample with sodium metaperiodate in a strong acidic medium. The formaldehyde and formic acid produced in the reaction were used to measure the glycerol content by titration with standard sodium hydroxide solution at pH 8.1 0.10. The quantitative determination of the glycerin levels by the titrimetric method was expressed as percentage.

2.2.1.12 Total glycerin analysis

The glycerol content is the quantity of glycerol expressed as a percentage (m/m). Cold oxidation of the glycerol by sodium periodate was carried out in a strongly acid medium. Titration of the formic acid (produced by the reaction) with a standard solution of sodium hydroxide was done using a pH meter.

2.2.1.13 Methanol

The amounts of methanol in the samples were determined using a rotary evaporator method at the distillation temperature of methanol. The sample was placed in the flask and the rotary evaporator dipped in the water bath and the system was operated to recover the methanol.

2.2.2 Mineral analysis

The ash content of the sample was determined by using the modified AOAC official method 942.05, 2006 as follows:

2.2.2.1 Ash content

To determine the ash content, 1.0 g of the sample was burnt in a muffle furnace pot at 550°C for 4 hours and allowed to cool in a desiccators. The process was repeated until a constant weight was obtained. The 0.1g of the ash samples were digested by adding 30 mL of nitric acid in a borosilicate beaker and placed on a hot plate in a fume cupboard. After cooling, the process was repeated by adding 20 mL of nitric acid and then allowed to cool to room temperature. The mixture was filtered into the 250 mL capacity borosilicate container. The filtrate was made up to the mark with the deionized water and then analysed in Atomic Absorption Spectrophotometer analysis. Standards of Calcium, Magnesium, and Potassium and Sodium solutions of 0.2, 0.4, 0.6, 0.8 and 1.0 mg/L were from each of the heavy metals solution of 1000 mg/L stock solutions of the analytes. The set of standard solutions and the filtrate of the digested samples were analysed by UNICAM 929 London, Atomic Absorption Spectrophotometer powered by the SOLAAR software. The detection limit of the metals in the sample was 0.0001 mg/L. Calcium, Magnesium, and Potassium and
Table 1. Loading of gas chromatography analyzer

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Fatty acid profile</th>
<th>Glycerine analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Injection temperature</td>
<td>Split injection</td>
<td>Split injection</td>
</tr>
<tr>
<td>Split ratio</td>
<td>20:1</td>
<td>20:1</td>
</tr>
<tr>
<td>Carrier gas</td>
<td>Nitrogen</td>
<td>Helium</td>
</tr>
<tr>
<td>Flow rate</td>
<td>-</td>
<td>1.0 ml/minute</td>
</tr>
<tr>
<td>Inlet temperature</td>
<td>250°C</td>
<td>60°C</td>
</tr>
<tr>
<td>Column type</td>
<td>HP INNOWax</td>
<td>Elite-Biodiesel M</td>
</tr>
<tr>
<td>Column dimension</td>
<td>30 m x 0.25 mm x 0.25 µm</td>
<td>14 m x 530 µm x 0.16 µm film</td>
</tr>
<tr>
<td>Oven Initial temperature</td>
<td>Initial temperature @ 60°C</td>
<td>Initial temperature @ 60°C for 2 minutes.</td>
</tr>
<tr>
<td>Oven program 1</td>
<td>First ramp @12°C/minute for 20 minutes, maintained for 2 minutes.</td>
<td>First ramp @10°C/minute to 200°C.</td>
</tr>
<tr>
<td>Oven program 2</td>
<td>Second ramping @ 15°C/minute for 3 minute, maintained for 8 minutes.</td>
<td>Second ramping @ 8°C/minute to 300°C constant at 5 minutes.</td>
</tr>
<tr>
<td>Detector</td>
<td>Flame Ionization Detector</td>
<td>Flame Ionization Detector</td>
</tr>
<tr>
<td>Detector temperature</td>
<td>320°C</td>
<td>380°C</td>
</tr>
<tr>
<td>Hydrogen Pressure</td>
<td>22 psi</td>
<td>-</td>
</tr>
<tr>
<td>Compressed air</td>
<td>35 psi</td>
<td>-</td>
</tr>
<tr>
<td>Pressure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydrogen Flow rate</td>
<td>-</td>
<td>45 mL/minute</td>
</tr>
<tr>
<td>Compressed air Flow rate</td>
<td>-</td>
<td>450 mL/minute</td>
</tr>
</tbody>
</table>

Sodium cathode lamps were used for the analysis of the respective mineral ions in the standards and the filtrate of the samples. Gas mixtures were used in the generation of the flame. Calibration curve for each of metal analysis were obtained and equation and the correlation coefficient obtained.

2.2.2.2 Sulphur

A 5 mL of the sample was poured in a disposable sample cell/holder and inserted into a Horiba Sulphur-in-oil Analyzer model SLEA-20 and analyzed. The results were read in percentages and converted to part per million.

2.2.2.3 The fatty acid profile

The fatty acid profile and rate of transesterification by glycerine analysis of the oil, B100 and the standard samples of free fatty acid were determined using the HP 6890 Gas Chromatography analyzer that used HP ChemStation Rev A 09.11 [1206] software for data collection and analysis. The loading procedures are as in Table 1.

3. RESULTS AND DISCUSSION

The fatty acid profile of the oil and biodiesel are shown in Fig. 1.

Table 2 shows the properties of the samples (oil and its biodiesel) and all subsequent discussion on characterization refers to the table.

3.1 Parameter Analysis

3.1.1 Density

The density reduced from 0.9180 g/ml for the oil to 0.886 g/ml for the biodiesel, which is within the ASTM limits for biodiesel and diesel. Density is important because it affects fuel properties that vary with the mass of fuel.

3.1.2 Cloud point

This is the temperature at which the fuel becomes cloudy in preparation for solidification it reduces from 10.20°C to -2.80°C after transesterification. The biodiesel can hence be used where the temperature is just below the freezing point of water.

3.1.3 Flash point

This is temperature when the vapour arising from the fuel sample-‐upon been heated, is high enough for the vapour to flash when exposed to a standard source of ignition. It affects the safety in handling and storage of the fuel. It reduced from 314°C for the oil to 135°C for the biodiesel, which is higher than the flash point of diesel and thus make it a safer fuel.
Table. 2. Properties of soybeans oil and its biodiesel

<table>
<thead>
<tr>
<th>S/N</th>
<th>Parameter</th>
<th>Oil</th>
<th>Biodiesel</th>
<th>ASTM limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Density (g/ml)</td>
<td>0.918</td>
<td>0.886</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Cloud Point (°C)</td>
<td>10.20</td>
<td>-2.80</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Flash Point (°C)</td>
<td>314</td>
<td>135</td>
<td>130 minimum</td>
</tr>
<tr>
<td>4</td>
<td>Kinematic Velocity (@ 40°C (mm²/s))</td>
<td>34.50</td>
<td>4.80</td>
<td>1.9 – 6</td>
</tr>
<tr>
<td>5</td>
<td>Lower Heating Value (kJ/kg)</td>
<td>-</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Cetane Number</td>
<td>45</td>
<td>55</td>
<td>47 minimum</td>
</tr>
<tr>
<td>7</td>
<td>Water and Sediment (%)</td>
<td>0.790</td>
<td>0.064</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Acid Number (mgKOH/g Oil)</td>
<td>15.00</td>
<td>0.22</td>
<td>0.08 maximum</td>
</tr>
<tr>
<td>9</td>
<td>Iodine Value (gI₂/100g)</td>
<td>114.20</td>
<td>65.40</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Oxidation Stability (Hrs)</td>
<td>40</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Sulphated Ash (%)</td>
<td>0.072</td>
<td>0.044</td>
<td>0.020</td>
</tr>
<tr>
<td>12</td>
<td>Carbon Residue (%)</td>
<td>0.48</td>
<td>0.12</td>
<td>0.050</td>
</tr>
<tr>
<td>13</td>
<td>Copper Strip Corrosion</td>
<td>4</td>
<td>1</td>
<td>3 maximum</td>
</tr>
<tr>
<td>14</td>
<td>Free Glycerin (%)</td>
<td>0.452</td>
<td>0.017</td>
<td>0.020</td>
</tr>
<tr>
<td>15</td>
<td>Total Glycerin (%)</td>
<td>1.315</td>
<td>0.098</td>
<td>0.240</td>
</tr>
<tr>
<td>16</td>
<td>Methanol (%)</td>
<td>0.007</td>
<td>0.102</td>
<td></td>
</tr>
</tbody>
</table>

3.1.4 Kinematic viscosity

This is a measure of the resistance of fuel to flow and affect parameters such as flow rate, power required for pumping and fuel spray from the nozzle. The kinematic viscosity of the oil was high at 34.50 mm²/s but reduces to 4.80 mm²/s after transesterification, which is within the limits for biodiesel.

3.1.5 Heating value

This is the amount of heat released in KJ when a kg of the fuel is burned. The values did not change much after transesterification and are about 10% lower than that of diesel. The heating value of the biodiesel is lower because the oxygen in biodiesel occupies about 10% of the volume and has lower heating value than the carbon and hydrogen present.

3.1.6 Cetane number

This is a measure of the easy with which the fuel can be ignited, the rate of pressure rise during combustion, the completion of combustion and noise level. The cetane number increased from 45 to 55 both of which are within the limits for biodiesel.

3.1.7 Water and sediments

Fuel contains naturally occurring water and the remains after water washing. Sediments also occur naturally and as a result of reaction between elements. It can also result from the degradation of the fuel. Water is detrimental to the fuel system as it can solidify and inhibit fuel flow, it can also result into corrosion in the fuel system. They must therefore, be reduced as much as possible. The value reduced from 0.79% to 0.064% after transesterification.

3.1.8 Iodine value

This is a measure of the degree of saturation and dryness quality of the fuel. Unsaturated fuel can easily react with other element thus creating storage stability problem. The fuel can also easily polymerize to form deposits. The value reduced from 114.20 to 65.40 gI₂/100g which is quite low compare to other biodiesel fuels.

3.1.9 Acid value

This is a measure of the amount of potassium hydroxide required to neutralize the free fatty acids present in one g of the sample. High amount in the fuel promotes the formation of deposit in the system. The value reduced from 15 to 0.22 mgKOH/g of oil.

3.1.10 Sulphated ash

This is the residue of alkaline catalyst after the sample was carbonized and the product treated with sulphuric acid and heated to a constant weight. The test enables the
metallic components of the samples remaining in the product of combustion. The value reduced from 0.072% to 0.044% after transesterification.

### 3.1.11 Carbon residue

This test enables the determination of the remnant when samples are subjected to thermal degradation. It is a measure of the tendency for coke or carbon formation the carbon residue reduced from 0.48% to 0.12% after transesterification.

### 3.1.12 Copper strip corrosion test

The test is used for assessing the corrosive effects of biodiesel on copper components in fuel systems. The oil has a value of 4 on a scale with maximum value of 5 making it very corrosive because of the high content of unsaturated fatty acids but it reduced to 1 for the biodiesel that has the same effect as fossil diesel. The degree of tarnish on the corroded strip correlates to the overall corrosiveness of the fuel sample.

### 3.1.13 Distillation characteristics

The distillation characteristics are shown in Fig. 2. In is clear that the oil and biodiesel distilled at higher temperatures than the diesel tested. The oil also distilled at a higher temperature than the biodiesel. The rate of distillation is steeper for diesel than the oil and biodiesel.

### 3.2 Metal Analysis

Fig. 3 shows the metal elements detected in the fuel samples. The highest value detected in the oil was potassium followed by sodium, magnesium and calcium. In the biodiesel, the elements reduced considerably because parts of the metals have been removed with the glycerol during the transesterification and the subsequent washing processes.
Fig. 2. Distillation characteristic of soybean oil, its diesel and diesel fuel

Fig. 3. Alkaline elements in oil and biodiesel

Fig. 4. Variation of MGE, DGE and TGE with retention time for biodiesel
We deduce the information in table 3 from Fig. 4.

We also see from Fig. 4 that the Mono- and Di-fatty acids are not only more transient than the Triglyceride but also reached a lower peak amount in the transesterification process. Eventually, even the Triglyceride dies out eventually (in the characteristic wavy pattern), showing that the transesterification completely converts fatty acids to biodiesel.

Also from the analysis of the Soya Bean oil presented in the Fig. 5, we deduce the information in Table 4.

We see from Table 2 that unlike the Biodiesel fatty acid, the peak values in each type of fatty acid are higher in the Soya Bean oil and occurs at a lower time (except for DGE). We also see that the TGE transient dies out more rapidly and with lower amplitudes of oscillation immediately after the peak value. A similar trend is observed in MGE and DGE where there is much less frequency of variation within the range of the retention time, compared to Biodiesel B100 oil.

4. CONCLUSION

Soybeans oil can be converted to biodiesel whose properties are within the ASTM limits for biodiesel. The oil and biodiesel are unsaturated and consists mainly of linoleic acid. The mineral contents are also within the limits for biodiesel as juxtaposed with ASTM standards. From the study conducted, soybean oil is seen to be a viable alternative when it comes to selecting feedstock to be used in a biodiesel synthesis process.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

4. Ong HC, Masjuki HH, Mahlia TMI, Silitonga AS, Chong WT, Leong KY. Optimization of biodiesel production and engine performance from high free fatty acid Calophyllum inophyllum oil in CI