PRODUCTION OF TRANSFORMER OIL FROM CASTOR SEED OIL

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ABSTRACT

In search of solution to the harmful ecological problems due to toxicity and non-biodegradability posed by conventional transformer insulation oil (mineral oil), the production of transformer oil from castor seed oil (vegetable oil) was carried out. The oil was extracted using N-hexane and was refined. The transformer oil was produced by trans-esterification and was characterized using American Society for Testing Material (ASTM) standard test. The solvent employed gave good yield of oil from the seeds. The results of characterization showed that the density 0.987 (g ml^{-1}), viscosity7.01 (cst), Flash Point 253^{o}C and dielectric strength of 24(KV) values, of Castor seed oil as transformer oil produced under optimized conditions met the ASTM standard and was within the acceptable limits as transformer oil. These showed that Castor seed oil is a potential feed stock for production of transformer oil.

Keywords: Solvent Extraction, Bio-based transformer oil, Castor Oil, Trans-esterification, ASTM standard.

1. INTRODUCTION

Castor seed (Ricinus communi) is an oil seed specie that belongs to the Euphorbiaceae family. The common names are castor oil plant, and Palma Christi. It has its origin in Africa but can be found in tropical and subtropical countries of the world. The castor plant is drought-resistant and can thrive in arid conditions. The oil is non-edible as it contains ricin, a poisonous protein substance. The oil content of castor seed has been found to be between 46-55% by weight (Lawson et al, 2010; Efeovbokhan et al, 2012). Often the vegetable oils investigated for their suitability as bio-transformer oil are those which occur abundantly in the country of testing. The environmental properties of the vegetable oil are excellent. Vegetable oils biodegrade quickly and completely, and also exhibit very low or as compared to mineral oils. This is mainly due to the fact that vegetable oil dielectric fluids do not contain halogens, polynuclear aromatics, volatile or semi-volatile organics, or other compounds that can be present in mineral oils or other dielectric fluids (Shah and Tahir, 2011).

Transformer oil or insulating oil is a highly refined mineral oil that is stable at high temperatures and has excellent electrical insulating properties. It is used in oil-filled transformers; some types of high voltage capacitors, fluorescent lamp ballasts, and some types of high voltage switches and circuit breakers,(Shah and Tahir, 2011). Transformer oil produced from mineral oil is non-renewable, non volatile, and non-biodegradable. Transformers form an important part of an electrical network and it is the most expensive equipment in electrical Network. Without them, utility companies would not be able to transmit and distribute electricity generated at remote power stations (Bashi et al, 2006). Distribution transformer selection, whether for residential, commercial, industrial, or utility application, has long-term implications. Transformers can have lives of 15, 30, and even 50 years or more, depending on their design, loading, application, protection, and maintenance, (Shah and Tahir, 2011). Because of the importance of the power transformers in electrical network, taking care of the oil quality is indispensable. The transformer oil, with the main roles of insulating and cooling in power transformers, is similar to the blood in human body and by monitoring its condition the transformer's overall health is determined. Therefore, monitoring and maintaining oil quality is essential in ensuring the reliable operation of oil-filled Transformer (electrical equipment) (Meshkatoddini, 2008).

This paper aimed at producing transformer oil from vegetable oil via castor seed that can extend and enhance transformer life or the ability to carry higher loads during peak demand periods without leading to premature insulation failure.

2. MATERIALS AND METHODS

2.1 Materials and Equipment:

The materials and equipment used in carrying out this work include Castor seeds, Soxhlet Extractor, N-hexane, Methanol, Sodium Hydroxide (NaOH), Condenser, Mortar and Pestle, Porous Container, Heating Mantle, Digital Electrical Weighing Machine, Stopwatch, Measuring Cylinder, Round Bottom Flask, Thermometer, Beakers, Separating Funnel, Retort Stand with Clamps, Digital Electronic Viscometer, Megger Oil Test set, pH Meter etc.

2.2 Methods:

2.2.1 Oil Extraction:

Castor seed Processing - Raw Castor (Ricinus Communi) seeds were bought from a local market in Enugu, Nigeria. The seeds were de-hulled and oven dried for 48hours, after which they were crushed with mortar and pestle into a known particle size of 0.82µm.

Operation of Soxhlet Extractor - 150 ml of normal hexane was poured into round bottom flask. 35 g of the crushed sample was placed in the thimble made of white cotton cloth and was inserted in the centre of the extractor. The soxhlet equipped with a condenser was placed onto a flask containing the hexane. The soxhlet was heated at 60°C. When the solvent was boiling, the vapour moves up a distillation arm and floods the chamber housing the thimble of solid. The condenser ensures that any solvent vapours cools, and drips back down into the chamber housing the solid material. The extract seeps through the pores of the thimble and fills the siphon tube, where it flows back down into the round bottom flask. This was allowed to continue for 30 minutes. It was then removed from the tube, dried in the oven, cooled in the desiccators and weighed again to determine the amount of oil extracted, AOAC, (2016). Further extraction was carried out at 30-minute interval until no weight difference was recorded. At the end of the extraction, the resulting mixture containing the oil was heated to recover solvent from the oil, (Akpan et al , 2006).

2.3 Biotransformer Oil Production by Trans-esterification:

In the biotransformer oil production, the Free Fatty Acid (FFA) content of the extracted oil plays an important role in obtaining the better yield of bio-transformer oil. Depending upon the FFA content of oil, the bio-transformer oil production/ trans-esterification procedures vary. If the FFA levels are too high, saponification reaction will occur with the catalyst; therefore FFA levels should be within 1% (Pandey et al 2011). Esterification of free fatty acid (FFA) aims to eliminate the FFA in the raw oil.

0.5g of the sample was weighed and purred into a conical flask and 3 drops of phenolphthalein indicator was added. This was followed by 20ml of complete ethanol and the mixture was titrated with 0.1N sodium hydroxide until a pink coloration was observed, thus;

$$(FFA\ \%) = \frac{T_r \times N \times 56.1}{W} \quad (1)$$

Where

T_r = Titre value

N = Normality of NaOH

W = Weight of sample used i.e. 0.5 x specific gravity of castor seed oil

The refined oil from Castor seed reacted with methanol in the presence of NaOH to produce methyl esters of fatty acids (transformer oil) and glycerol.

The oil was precisely quantitatively transferred into a flat bottom flask placed on a hot magnetic stirrer. Then specific amount of catalyst (by weight of refined oil) dissolved in the required amount of methanol was added. The reaction flask was kept on a hot magnetic stirrer under constant temperature with defined agitation throughout the reaction. At the defined time, sample was taken out, cooled, and the bio-transformer oil (i.e. the methyl ester in the upper layer) was separated using separating funnel from the by-product (i.e. the glycerol in the lower layer) by sedimentation overnight under ambient condition. The percentage of the bio-transformer oil yield was determined by comparing the volume of bio-transformer oil with the volume of refined oil used.

2.4 CHARACTERISATION OF BIOTRANSFORMER OIL

2.4.1 Acid Value and FFA Determination:

Acid value was established as follows, (Albert, 2012).

$$\text{Acid value} = \frac{(V - b)\ x\ N\ x\ 56.1}{W} \quad (2)$$

Where;

W = weight of sample in g

b = titration value for blank in ml

N = normality of KOH

FFA was characterized and equation (1) used to determine its value in the produced Bio-Transformer oil. The high FFA of the raw Castor oil was first reduced for the oil to be used in the esterification process by the application of Sodium Carbonate, which neutralized the excess FFA before the oil was used.

2.4.2 Determination of Saponification Value (SV):

This was done by weighing 0.2g of the sample into a conical flask. 50ml of 0.5N ethanoic potassium hydroxide was added and heated in a reflux round bottom flask for 30mins. The essence of the reflux was to get a perfect dissolution of the oil sample in the ethanoic potassium hydroxide thereafter. The heated mixture was allowed to cool for another 30mins after which 3 drops of phenolphthalein was added to the mixture, and the latter titrated against a 0.5N hydrochloric acid (HCl) until there was a change from pink to colourless (Kumar and Sharma, 2008; AOAC, (2016). Then a blank (without the sample) solution was also prepared and this titrated until the colour change was observed, hence.

Saponification value (number)

$$= \frac{56.1\ x\ N(V_2 - V_1)}{W} \quad (3)$$

Where

56.1 = Relative Molecular mass of potassium hydroxide

N = Normality of NaOH

V_2 = Titre value of blank

V_1 = Titre value of sample

W = Weight of the sample used

2.4.3 Iodine Value (IV):

1g of the oil was placed in a 250 ml conical flask followed by 30 ml of Hanus solution and the flask, with the contents mixed placed in fume cupboard for exactly 30 min. Potassium iodide solution (10 ml of 15% w/v) was added to the flask washing down any iodide that was found on the stopper (Zaharaddeen et al, 2013). This was titrated against 0.12 M $Na_2S_2O_3$ until the solution became light yellow. Starch indicator (1%, 2 ml) was added and the titration continued until the blue colours just disappeared.

A blank titration was also carried out under the same conditions. The titre value was recorded and used to calculate the iodine value.

$$IV = \frac{(B - R) \text{ x M x } 0.3 \text{ x } 12.69}{W} \quad (4)$$

Where;

B = blank titre value
R = titre value of real determinants
M = Molarity of $Na_2S_2O_3$
W = Weight of sample (g)

2.4.4 Viscosity Determination:

Digital electronic viscometer was used for the viscosity test. The digital electronic viscometer measures fluid viscosity at a given share rate. Viscosity is a measure of a fluids resistance to flow. The principle of operation of the digital electronic viscometer is to rotate a spindle (which is immersed in the test fluid) through a calibrated spring. The viscous drag of the fluid against the spindle deflection was measured by the spring deflection. Spring deflection was measured with a rotary transducer, which provides a torque signal. The measurement range of the digital electronic viscometer was determined by the rotational speed of the spindle, the size and the shape of the spindle rotating, and the full-scale torque of the calibrated spring (Albert, 2012; El- Sayed, 2009).

2.4.5 Density determination:

The weight of a small beaker was determined using an electronic weighing balance. 2 ml of the oil was poured into it and the weight was noted.

Density = (Mass of oil) / (Volume of oil weight) (5)

2.4.6 Determination of Specific Gravity:

An empty container was weighed. The container was filled with water and weighed. The container was then filled with the same volume of oil as that of the water and weighed. The specific gravity is calculated.

$$\text{Specific gravity} = \frac{(W_3 - W_2)}{W_1} \quad (6)$$

Where

W_3 = weight of container and oil
W_2 = weight of empty container
W_1 = weight of equal volume of water

2.4.7 Flash Point:

D93 Test Method was employed. This was determined by measuring 20ml of biotransformer oil into a crucible and a thermometer inserted into the crucible as the crucible was heated gently on a moving flame until the sample was ignited. Then, the temperature was noted and recorded as flash point.

2.4.8 Determination of Cloud Point:

The cloud point is the highest temperature at which the oil begins to solidify. A little quantity of the oil was placed in a test tube and placed on an ice bath and a thermometer fixed. The temperature at which the oil begins to condense was recorded as the cloud point (Albert, 2012; El- Sayed, 2009; Emil, 2009)

2.4.9 Pour Point:

The pour point is the lowest temperature at which the oil flows (Daniel et al, 2006).

D97 Test method for pour point determination was used. The cloud point and pour point cabinet was used. A 10ml sample was kept in a glass tube fitted with a cork and thermometer. The sample was placed in the cabinet until it became solid. The temperature readings were recorded and corrected by a factor of +3 (that is correction factor from calibration from the instrument).

2.4.10 Determination of pH:

pH of oil is the degree of the acidity of the oil. The pH meter's electrode was lowered into a buffer solution. The temperature was then adjusted to 50°C using the temperature regulator. The instrument was then calibrated at a buffer of pH 7. The electrode was then removed from the buffer and rinsed with distilled water. It was then dipped into the test tube containing the oil and the pH on the screen of pH meter was recorded (Albert, 2012; El- Sayed, 2009; Emil, 2009).

2.4.11 Determination of Dielectric Strength of the Oil:

Megger oil test set (OTS 60PB) equipment was used in testing the dielectric strength of the oil commonly referred to as breakdown voltage. The instrument is an automatic machine that can assess the quality of oil based on American Society for Testing and Materials (ASTM). The oil sample was placed between two electrodes with a 2.5 mm gap. A constant increasing voltage was applied until the oil discharges at a certain kV, which was recorded as the breakdown voltage (Albert, 2012; El-Sayed, 2009; Emil, 2009).

3. RESULTS AND DISCUSSION

The Castor seeds yielded a good quantity of oils on extraction with solvent. There was a reduction of FFA of the oils after refining. The results of the characterized raw and bio-transformer Castor seed oils are shown in Table 1.

Table 1: The characterization of Raw Castor and Refined Castor seed bio Transformer oils.

Properties	**Raw Castor seed Oil**	**Castor seed bio-transformer oil**
Specific gravity (g/ml)	0.9910	0.9283
Acid value (%)	7.0125	13.184
Iodine value (g /100g oil)	27.83	53.79
Saponification value (mgKOH/g oil)	130.89	165.22
Ph	7.8	8.91
Free fatty acid (%)	6.31	0.09
Viscosity cst	5.25	7.01
Density g cm^{-3}	0.8935	0.9874
Dielectric Strength kV	21	24
Smoke Point(^oC)	60	68
Cloud Point(^oC)	15	9
Flash Point (^oC)	210	180
Fire Point (^oC)	Nil	Nil
Pour Point(^oC)	-6	-9
Turbidity(NTU)	-	119

Iodine value is a measure of the unsaturation level and the reactivity of the oil. The higher the iodine value, the greater the degree of unsaturation. The iodine value for Castor seed transformer oils was found to be 47.79g (100) g^{-1} oil as shown in Table 1. The value is below 100 and as such the oil can be classified as non-drying oil. This value also represents the decrease in unsaturation of oil (Frank, 2011), which is beneficial in the sense that the lower the unsaturation of oils and fats, the greater its oxidation stability.

Saponification value is a measure of the alkali reactive groups in fats and oils and is useful in predicting the type of glycerids in an oil sample. Saponification value is obtained by determining potassium hydroxide, in mg, required to saponify 1g of fat. Saponification value indicates the average molecular weight of the oil. Measuring saponification value means molecular mass can be obtained. Saponification value is inversely related to mean molecular mass. A higher saponification value indicates that there is a greater portion of low molecular weight fatty acids (Zaharaddeen et al, 2013). The refined Castor seed transformer oils was found to have a saponification value of 11.22(mgKOH/g oil) as shown in Table 1.

Viscosity is the most important property of transformer oil, since it affects the operation of fuel injection equipment, particularly at low temperature, when an increase in viscosity affects the fluidity of the fuel. As the oil temperature increases, its viscosity decreases. High viscosity leads to poorer atomisation of fuel spray and less accurate operation of fuel injection. The lower the oil viscosity, the easier it is to pump and atomise, and achieve finer results. The operating temperature greatly affects the viscosity of a fluid. For example, inside a transformer tank, the temperature varies considerably depending on the loading ambient temperature and it rises excessively especially during faults. Usually at a higher temperature, the viscosity becomes lower. This shows that there is an inverse relation between viscosity and temperature. For a smooth oil operation in electrical equipment, the temperature needs to remain around the mild range (Zaharaddeen et al, 2013). The viscosity of refined Castor seed transformer oil was found to be 7.01 cst, which is very close to conventional transformer oil, though lower.

A high density means more mass of fuel per unit volume. In this case, the bio-transformer oil from refined Castor seed oils has a higher density compared to conventional transformer oil. The refined Castor seed transformer oils has density of 0.9874 g cm^{-3}, which is high. The higher mass of oils would give higher energy available for work output per unit volume, (Raja, 2011).

Flash point is the temperature at which oil produces a certain vapour that mixes with air and forms an ignitable mixture, resulting in a momentary flash or flame under prescribed conditions. A minimum flash point is specified in order to prevent the risk of fire that might result in accidental ignition. Flash point is an important specification for safety during transport, storage and handling (Raja, 2011). The flash points of the bio transformer oil from Castor seed was found to be 250 ^{o}C as shown in Table 1. This value is good in preventing accidental ignition. The flash point has shown that the oil can safely be used even where the temperature is expected to be very high. Oils with flash point above 66°C are considered as safe oils (Zaharaddeen et al, 2013).

Two important parameters for low temperature applications of a fuel are cloud point and pour point. Cloud point is the temperature where wax begins to appear visible when the fuel is cooled, while the pour point is the temperature at which the amount of wax from a solution is sufficient to gel the oil. In other words, it is the lowest temperature at which the oil can flow (Zaharaddeen et al, 2013). The cloud point for bio-transformer oil from Castor seed was found to be 9^{o}C, (Table 1), which means that the oil can perform satisfactorily even in cold climatic conditions. The pour point of -9 °C of bio-transformer oil from Castor seed oil was however, little lower than the conventional transformer oil, but the value is not objectionable. In general, a higher pour point often limits the application of oils as fuels for transformer in cold climatic conditions. Cloud and pour point are criteria used for low temperature performance of oil. When the ambient temperature is below the pour point, wax precipitates in the bio-transformer oil and it loses its flow characteristics. The pour point should be low so that oil can remain flowing even at low temperature (Wouter, 2010).

The dielectric strength of insulating oil is a measure of the oil to withstand electric stress without failure. It is a term used to describe or define an electric insulating material. Contaminants such as water, sediments and conducting particles reduce the dielectric strength of insulating oil. Combination of these tends to reduce the dielectric strength to a greater degree. Clean, dry oil has an inherently high dielectric strength, but this does not necessarily indicate the absence of all contaminates; it merely indicates that the amount of contaminant present between the electrodes is not that large enough to affect the average breakdown voltage of the oil, (Zaharaddeen et al, 2013). The dielectric strength of 24 kV of bio-transformer oil from Castor seed was very close to the conventional transformer oil.

Dielectric strength possesses a good correlation with the turbidity of oils; low turbidity represents better dielectric strength. Most crude form of oils has a very high turbidity and a low breakdown voltage. Further purification of vegetable oils can be carried out which will reduce the turbidity and hence raise the breakdown voltage, (Bashi,2006). The turbidity of 119 (NTU) of bio transformer oil from Castor seed was a clear indication of correlation between turbidity and dielectric strength. The specifications for Transformer oil of the ASTM is shown in Table 2.

Table 2: Transformer oil specifications of the ASTM standard (Ma Zhizai, (2005)

PROPERTIES	VALUES
Density at 29.5°C (min-max)	0.55-0.96 g cm^{-3}
Viscosity at 27°C (min-max)	9.3–27 cst
Flash point (min-max)	140–155°C
Acid number (min-max)	0.01–0.03 mg KOH g^{-1} oil
Dielectric strength (min-max)	25–40 kV
Pour point (min-max)	–8– (–6)°C
Boiling point (min-max)	120–230°C
pH (min-max)	5.5–8.2
Specific gravity at 20°C (min-max)	0.89–0.91
Saponification value (min-max)	150–244 mg KOH g^{-1} oil
Peroxide value (min-max)	5–10 meq g^{-1} oil
Iodine value (min-max)	55–120 g /100 g oil
Cloud point	7–15°C
Free fatty acid (%)	(0.01–0.89)

Table 3 also shows the relationship between the conventional Transformer Oil and the Castor seed Transformer oil

Table 3: The major properties of Castor seed Bio-transformer Oil compared with ASTM limits of conventional transformer oil.

Properties	**Castor Seed Bio-Transformer Oil**	**Conventional Transformer Oil**
Flash point (°C)	180	140
Pour point	-9	–7
Viscosity (cst) at 27°C	7.01	9.3
Specific gravity at 27°C	0.9283	0.89
Density (g ml^{-1})	0.9874	0.89
Dielectric Strength(KV)	24	25

4. CONCLUSION

Based on the results obtained from the various characterization tests carried out on refined Castor oil, the bio transformer oil obtained was in agreement with values of conventional transformer oil of ASTM specifications (Tables 2 and 3). This indicates that Castor seed is a good quality oil seed for bio-transformer oil. The Electrical tests especially the breakdown voltage corresponded to the ASTM specification of transformer oil. The greatest challenge which was transformer explosion, as a result of pressure from accumulated gases in the transformer tank can be remedied with the use of these oils. The bio-transformer oil produced can be a good substitute to conventional transformer oils for it is environmentally friendly. The use of the bio-transformer oils will also remove the fear of depletion because they are from renewable source. The choice for the bio-transformer oil could represent a large and profitable market for Castor seed farmers.

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