

## Production and Characterisation of Biobased Transformer Oil from *Jatropha Curcas* Seed

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**Abstract:** Biobased transformer oil was produced from *Jatropha curcas* seed oil. The oil was extracted from the seed using soxhlet extractor. The oil obtained from the *Jatropha* seed was degummed by washing down the fat with warm water and any water present was removed by  $MgSO_4$ . The physiochemical characteristics of the refined oil were obtained as follows: the saponification value was  $155 \text{ mg KOH g}^{-1}$  oil, peroxide value was  $7.20 \text{ meq g}^{-1}$  oil, iodine value was  $51.27 \text{ g } 100\text{g}^{-1}$  oil, free fatty acid was  $0.0718 \text{ mg KOH g}^{-1}$  oil, neutralisation number (acid value) was  $0.1428 \text{ mg KOH g}^{-1}$  oil, kinematic viscosity was  $82 \text{ cst}$ , oil share rate was  $8.2\%$ , density was  $0.725 \text{ g ml}^{-1}$ , boiling point was  $124^\circ\text{C}$ , specific gravity was  $0.8480$ , flash point was  $150^\circ\text{C}$ , cloud point was  $14^\circ\text{C}$ , pH was  $5.15$  and the dielectric strength was  $22 \text{ kV}$ . The above values obtained for the refined oil were found to be equivalent to that of the ASTM D Standards, hence the refined *Jatropha curcas* oil can be used in place of the conventional transformer oil since it is easily biodegradable and safe for the environment due to its low acid content.

**Keywords:** Biobased transformer oil, Soxhlet extractor, *Jatropha curcas* seed, ASTM standard

### 1. INTRODUCTION

*Jatropha curcas* is an ornamental, medicinal and multipurpose shrub belonging to the Euphorbiaceae family. The exact origin of *Jatropha curcas* is still a subject of debate, but generally it is known to have come from Mexico and other states of Central America and there is a growing agreement to that.<sup>1</sup> It is widespread throughout arid and semi-arid tropical region of the world. *Jatropha curcas* has since spread to the Caribbean, Africa and warmer parts of Asia. It is a drought-resistance and perennial, living up to 50 years and growing on marginal soil.<sup>2</sup>

*Jatropha curcas* is a poisonous, semi-evergreen shrub or small tree, reaching a height of 6 m (20 ft). It is resistant to a high degree of aridity, allowing it to be grown in deserts. The seeds contain 27–40% oil (average: 34.4%) that can be processed to produce a high-quality biodiesel fuel, usable in a standard diesel engine. The seeds are also a source of the highly poisonous toxalbumin curcin.<sup>3,4</sup>

The Portuguese learned about *Jatropha's* medicinal properties in the 16th century and later established commercial plantations for soap and lamp oil production on the cape verdian Islands and Guinea Bissau.<sup>1</sup> Later, *Jatropha* genotypes adopted in western Africa were spread across the Portuguese colonies in Africa (Mazambique and Angola) and into Asia (India, China and Indonesia). *Jatropha curcas* now grows pan-tropically from Brazil to the tropical islands of Fiji.<sup>4</sup>

*Jatropha* has about 175 species in the world and is known by nearly 200 names indicating its occurrence in various countries.<sup>5</sup> The leaves are large and light-green to green colour, and the seeds of the matured *Jatropha curcas* are brown in colour. Dormancy is induced by fluctuations in rainfall and temperature or light. Common names for this species include Barbados nut, black vomit nut, curcas bean, *kukui haole*, physic nut, purge nut, *purgeer bontji* and purging nut tree.<sup>6</sup> Additionally, the species is known as *Bindazugu* in Hausa, *Lapa-lapa* in Yoruba and *Wuluidu* in Igbo.<sup>6</sup>

The seeds are matured when the capsule changes from green to yellow. The seeds contain around 20% saturated fatty acids and 80% unsaturated fatty acids and they yield 25–40% oil by weight. The seed is black and oval in shape. In addition to seeds, *Jatropha* contains other chemical compounds such as saccharose, raffinose, stacylose, glucose, fructose, galactose and protein. The oil is largely made up of oleic and linoleic acids. Furthermore, the plant also contains curcasin, arachidic, myristic, palmitic and stearic acid, and curcin.<sup>4</sup>

The oil can provide fuel for local uses and lamps. The *Jatropha* oil can also be used to produce high quality soaps. Additionally, the oil is used as fuels for jet, transformer and high hydrocarbon. The seed oil of the plant has been used as an ingredient in the treatment of rheumatic conditions itch and parasitic skin diseases, and in the treatment of fever, jaundice and gonorrhoea, as well as a diuretic agent and mouth wash.<sup>7-9</sup> It has also been used as a source of fuel for stimulating hair growth and making candles and soap.<sup>6</sup> The oil and aqueous extract from oil has been used in the control of insect pests of cotton including bollworm and on pests of pulses potato and corn.<sup>7</sup>

Transformer oil or insulating oil is usually 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. Its functions are to insulate, suppress corona and arcing, and to serve as a coolant. The oil helps cool the transformer. Because it also provides part of the electrical insulation between internal live parts, transformer oil must remain stable at high temperatures for an extended period. To improve cooling of

large power transformers, the oil-filled tank may have external radiators through which the oil circulates by natural convection. Very large or high-power transformers (with capacities of thousands of kVA) may also have cooling fans, oil pumps and even oil to water heat exchangers.<sup>3</sup>

Transformer oil forms a very significant part of the transformer insulation system and has the important functions of acting as an electrical insulation as well as coolant to dissipate heat losses. Transformer oil will be obtained by fractional distillation and subsequent treatment of crude oil. Transformer oil consists of organic compounds namely paraffins, naphthenes, aromatics and olefins. All these compounds are hydrocarbons, so transformer oil is a pure hydrocarbon mineral oil.<sup>4-6</sup>

This paper was aimed at producing transformer oil that is non toxic, non-flammable, readily biodegradable and also produces transformer oil that can extend and enhance transformer life or the ability to carry higher loads during peak demand periods without leading to premature insulation failure. The result obtained was compared with the ASTM standard to determine if the bio-based oil can be used as replacement for the conventional transformer oil.

## **2. EXPERIMENTAL**

*Jatropha curcas* seeds were collected from the Agronomy Department of the Institute of Agricultural Research, Ahmadu Bello University, Zaria. The dried seeds were dehulled. The dehulled seeds were then crushed into fine particles with the aid of mortar and pestle.

### **2.1 Oil Extraction and Degumming**

Oil from the grinded *Jatropha curcas* seed was obtained using a soxhlet extractor, the solvent used was acetone and 500 g of the powdered *Jatropha curcas* seed was used.

### **2.2 Characterisation of Oil**

#### **2.2.1 Determination of saponifaction value (Sv)**

2 g of the oil was placed in a 250 ml conical flask and 25 ml of 0.5 M ethanol potassium hydroxide solution was added. A reflux condenser was attached and the flask content was refluxed for 30 min on a water bath with continuous swirling until it simmered.<sup>7</sup> The excess potassium hydroxide was titrated with 0.5 M hydrochloric acid using phenolphthalein indicator while still

hot. A blank titration was carried out under the same condition and the saponification value was calculated.

$$S_v = (B - S / \text{Weight of sample}) \times 28.5 \quad (1)$$

where  $B - S$  is the volume of HCL used, with

$B$  = blank titre

$S$  = real titre value

### 2.2.2 Peroxide value (Pv)

1 g of the oil was placed in a 250 ml conical flask and 30 ml glacial acetic acid/chloroform (3.2 v/v) was added. The contents were shaken until they dissolved. Saturated potassium iodide solution (1 ml) was added followed by the addition of 0.5 ml starch indicator solution.<sup>7</sup> This was titrated with 0.1 M  $\text{Na}_2\text{S}_2\text{O}_3$  until the dark blue colour just disappeared. Blank determination was carried out without adding oil.

$$Pv = [(R \times B) \times \text{molarity of } \text{Na}_2\text{S}_2\text{O}_3] / (\text{Weight of sample}) \quad (2)$$

where

$R$  = real titre value determined

$B$  = blank titre value

### 2.2.3 Iodine value (Iv)

1 g of the oil was placed in a 250 ml conical flask followed by 30 ml of Hanus solution and the flask, the contents mixed and 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.<sup>7-9</sup> This was titrated against 0.12 M  $\text{Na}_2\text{S}_2\text{O}_3$  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.

$$Iv = [(B - R) \times \text{molarity of } \text{Na}_2\text{S}_2\text{O}_3 \times 12.69] / (\text{Weight of sample}) \quad (3)$$

where

$B$  = blank titre value

R = titre value of real determinants

#### 2.2.4 Free fatty acid (%FFA)

A titration set up was prepared. Here, 2 g of oil was placed in a 250 ml conical flask and warmed, which was followed by addition of two drops of phenolphthalein indicator. The content was then titrated with 0.14 M potassium hydroxide solution while shaking vigorously until a permanent light pink colour was observed.<sup>7-9</sup> The end point was recorded and used to calculate the free fatty acid.

The percentage free fatty acid calculated using the formula below:

$$\% \text{FFA} = (\text{titre} \times M) / (\text{Weight of sample of oil used}) \quad (4)$$

where M = Molarity of the base (KOH)

#### 2.2.5 Acid value determination

The relationship between acid value and percentage free fatty acid was established as follows:<sup>9</sup>

$$\text{Acid value} = [(V-b) \times N \times 56.1] / W \quad (5)$$

$$\text{Percentage free fatty acid} = [(y \times N) / W] \times 28.2 \quad (6)$$

where

W = weight of sample in g

V = titration value for sample in ml

B = titration value for blank in ml

N = normality of KOH

#### 2.2.6 Viscosity determination

Digital electronic viscometer was used for the viscosity test. The digital electronic viscometer measures fluid viscosity at a given shear rate. Viscosity is a measure of a fluid's 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.<sup>7-9</sup>

### 2.2.7 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.

$$\text{Density} = (\text{Mass of oil}) / (\text{Volume of oil weight}) \quad (7)$$

### 2.2.8 Boiling point determination

The oil was placed in a container with an inserted thermometer and heated to the time the first bubble was observed. The temperature was noted, the experiment was repeated twice and the average temperature calculated.

### 2.2.9 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 with formula shown below.

$$\text{Specific gravity} = (W_3 - W_2) / W_1 \quad (8)$$

where

$W_3$  = weight of container and oil

$W_2$  = weight of empty container

$W_1$  = weight of equal volume of water

### 2.2.10 Determination of flash point

An improvised method was used to determine the flash point. A conical flask (150 ml) was filled with 2 ml of oil and heated at as low constant rate on the hot plate. The flash point was obtained when application of a test flame causes the vapour above the oil to ignite.<sup>7-9</sup>

### 2.2.11 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 into 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.<sup>7-9</sup>

#### **2.2.12 Determination of pH**

The pH is the degree of the acidity of the oil. The pH meter's electrode was lowered into a buffer solution, with the temperature 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. Next, it was then dipped into the test tube containing the oil and the pH on the screen of pH meter was recorded.<sup>7-9</sup>

#### **2.2.13 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, the kV was recorded as the breakdown voltage.<sup>7-9</sup>

The Breakdown Analyser 100 dielectric oil tester was used for the dielectric test. This analyser breaks down voltage from DC to AC.

#### **2.2.14 Determination of pour point**

A manual method was used to determine the pour point. The oil was cooled inside a cooling bath to allow the formation of paraffin wax crystals. At about 9°C above the expected pour point, and for every subsequent 3°C, the test tube was removed and tilted to check for surface movement. When the specimen does not flow when tilted, the test tube was held horizontally for 5 s. It does not flow and 3°C was added to the corresponding temperature and the result was the pour point temperature.<sup>7-9</sup>

### **3. RESULTS AND DISCUSSION**

In most plants, seed oil contains phosphatides in the form of lecithin. A large part of those phosphates was removed by water degumming. It was observed that once these phosphatides were removed in the form of lecithin, no further appearances of gums or waxes in the oil took place and this resulted in the

production of oil with a good colour and without taste or smell. The oil remains fit for storage and transportation for a long time (2–3 years).<sup>11</sup>

It was also observed in a previous study that the phosphatides, if present in the oil, did not combust completely in engine and therefore results in carbon deposits and thickening of lubrication.<sup>12</sup> This problem can therefore be solved by removing phosphatides by degumming as shown in the present study. The obtained by-product of this process (lecithin) has a wide range of commercial applications. Industrially produced lecithin (mainly as by-product) from petroleum refinery can be used in food and beverages, medicine, cosmetics, tobacco, lubricant, gasket and cork products, urethane polymer, and soap production.

Table 1: Characteristics of the prepared *Jatropha curcas* seed oil.

Property	Value
Saponification value	155 mg KOH g <sup>-1</sup> oil
Peroxide value	7.20 meq g <sup>-1</sup> oil
Iodine value	51.27 g 100 g <sup>-1</sup> oil
Free fatty acids	0.0718 mg KOH g <sup>-1</sup> oil
Acid value	0.1428 mg KOH g <sup>-1</sup> oil
Viscosity	8.2 cst
Boiling point	124°C
Specific gravity	0.8480
Flash point	150°C
Cloud point	14°C
pH	5.2
Dielectric strength	22 kV
Pour point	4°C
Density at 27°C	0.725 g cm <sup>-3</sup>

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 is, thus the more fluid. The iodine value was found to be 51.27 g 100 g<sup>-1</sup> oil as shown in Table 1. The value is below 100 and as such the oil can be classified as non-dry oil. This value also represents the decrease in unsaturation of oil,<sup>12</sup> which is beneficial in the sense that the lower the unsaturation of oils and fats, the greater will its oxidation stability be.

It was noticed that oil with high iodine, cloud and pour point values exhibits poor cold performance. Oxidation of lipids is a major cause of their

deterioration, and hydroperoxide formed by the reaction between oxygen and the unsaturated fatty acids are the primary products of these reactions. Hydroperoxide has no flavour or odour but breaks down rapidly to form aldehydes, which have disagreeable flavour and odour.<sup>13</sup>

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 1 g of fat. *Jatropha curcas* oil with low saponification value of 155 mg KOH g<sup>-1</sup> oil as shown in Table 1 was found better because oil with high saponification value causes exhaust emissions during burning of the engine.<sup>14</sup>

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. Furthermore, the oil of this seed was found to have a saponification value of 155 mg KOH g<sup>-1</sup> as shown in Table 1. High value of acid can indicate the presence of oxidation products in the oil bath; this can cause corrosion and sludge in your system.<sup>11</sup>

Peroxide value is a measure of extent of glycerides constituent decomposition by lipase action, which is added by light, air and moisture. It is also an indication of the level of rancidity of the oil. In the present study peroxide value of *Jatropha curcas* oil was found to be 7.20 meq g<sup>-1</sup> oil as shown in Table 1 indicating that the oil is still good and it has low level of rancidity. A low peroxide value, as seen in the present study, increases the suitability of the oil for a long-time storage due to a low level of oxidative and lipolytic activities. Refining of oils can result in considerable decrease of peroxide value of various oils. This low value of 7.20 meq g<sup>-1</sup> shows the efficiency of the refining process of this study and this makes the oil ideal for consumption and storage.<sup>14</sup>

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. *Jatropha* seed oil with viscosity of 8.2 cst as shown in Table 1 is close to that of diesel fuels. 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. A low viscosity of 8.2 cst for *Jatropha* oil is good in this aspect. The operating temperature greatly affects the viscosity of a fluid though the viscosity of the *Jatropha* seed oil was taken at 27°C. 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.<sup>15</sup>

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 contaminants; 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.<sup>10</sup>

Dielectric strength possesses a good correlation with the turbidity of oils; low turbidity represents better dielectric strength. Most crude forms of oils have 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.<sup>15</sup>

A higher density means more mass of fuel per unit volume. In this case, the vegetable oil has a higher density compared to crude oil. *Jatropha* seed oil has a density of  $0.725 \text{ g cm}^{-3}$ , which is high. The higher mass of oils would give higher energy available for work output per unit volume.<sup>11</sup>

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.<sup>11</sup> The flash point of *Jatropha curcas* seed oil was found to be  $150^\circ\text{C}$  (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.<sup>11</sup> The limit expected for most applications is  $100^\circ\text{C}$ . The appearance and the relative density are in agreement with the standard limit. With a flash point of  $150^\circ\text{C}$ , *Jatropha curcas* oil can prevent auto ignition and fire hazard at high temperatures during transportation and storage. Oils with flash point above  $66^\circ\text{C}$  are considered as safe oils.<sup>10</sup>

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 where the amount of wax from a solution is sufficient to gel the oil. In other words, it is the lowest temperature where the oil can flow. The cloud point for *Jatropha curcas* oil is 14°C (Table 1), which means that the oil can perform satisfactorily even in cold climatic conditions. The higher cloud point can affect the engine performance and emission adversely under cold climatic conditions.

The pour point of 4°C for *Jatropha curcas* oil is low. In general, a higher pour point often limits the area 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 vegetable oil and it loses its flow characteristics. Wax can block the filters and fuel supply line. Under these conditions, fuel cannot be pumped through the machine. Therefore, the pour point should be low so that oil can remain flowing even at low temperature.<sup>1</sup>

Table 2: Transformer oil specifications of the ASTM standard.

Property	Value
Density at 29.5°C (min-max)	0.55–0.89 g cm <sup>-3</sup>
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 <sup>-1</sup> 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 of KOH g <sup>-1</sup> oil
Peroxide value (min-max)	5–10 meq g <sup>-1</sup> oil
Iodine value (min-max)	55–120 g 100 g <sup>-1</sup> oil
Cloud point	7–15°C
Free fatty acid	0.01–0.08 mg KOH g <sup>-1</sup> oil

Table 3: The properties of diesel, *Jatropha* oil and transformer oil.

Property	Diesel	<i>Jatropha</i> oil	Transformer oil
Flash point (°C)	65	150	140
Pour point (°C)	-6	4	-7
Cloud point (°C)	5	14	7
Viscosity (cst) at 27°C	2.86	8.2	9.3
Specific gravity at 27°C	0.792	0.8480	0.89
Density (g ml <sup>-1</sup> )	0.8162	0.725	0.89
Dielectric strength (kV)	20	22	24

#### 4. CONCLUSION

The results obtained from the characterisation of the refined *Jatropha curcas* seed oil shows that the seed oil is of good quality, because there is a reasonable agreement between the values obtained and the ASTM specifications. The chemical and electrical tests, especially the acidity and the break down voltage are the most important specifications for transformer oil, all of which correspond to the ASTM specifications. Transformer oil spill or leak has always been a challenge, particularly the cleanup and remediation aspects. As a result, environmentally friendly oil can be use as substitutes in transformers and transmission lines, thereby reducing losses and minimising remedial procedures in case of oil spills.

A biodegradable transformer oil represents significant potential savings for utilities because it should simplify the clean up and remediation procedures. However, the real savings are realised in case of leakage or spill. This is particularly true for utilities in environmentally sensitive areas where spills or leaks can be a threat to marine life. The new transformer oil could also represent a large and profitable market for *Jatropha curcas* farmers.

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