ASSESSMENT OF CALABASH SEED OIL AS BIOBASED INSULATING FLUID FOR POWER TRANSFORMERS

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ABSTRACT

The research on the production of transformer oil from biodegradable oil is the focus of this work. Biobased transformer oil was produced from calabash seed oil. The oil was extracted from the seed, then was purified using a modified Dijkstra and Opstal purification method. After the produced purified oil was degummed. The oil characteristics obtained are: the density - 0.85 g/cm^3, boiling point 126°C, specific gravity 0.813, flash point 164°C, cloud point 10°C, pour point 4°C, pH 5.23, saponification value 157 mg KOH/g oil, peroxide value 7.22 meq/g oil, iodine value 52.23 g 100/g oil, free fatty acids 0.072 mg KOH/g oil, acid value 0.142 mg KOH/g oil, kinematic viscosity 8.8 cst, and the dielectric strength 24 kV. The results obtained for the purified calabash oil meet the requirements of ASTM Standards. It was concluded that the purified calabash seed oil can be used in place of the conventional transformer oil because it is easily biodegradable and safe for the environment due to its low acid content.

Keywords: biobased transformer oil, purified calabash seed oil, biodegradability.

INTRODUCTION

The constant search for sustainable economic development demands the coherent use of resources and energy, including investment on renewable materials and greener processes [1]. 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 the cooling of the transformer. Because it also provides part of the electrical insulation between internal live parts, the 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. A transformer is static electronic equipment that transforms voltages and transfers energy via inductive coupling. Inner transformers are filled with insulating oil for heat transfer and insulation [2]. Petroleum-based insulating fluid such as mineral oil is the most commonly used transformer insulating fluid transformers [3]. Mineral oils have been used for over a hundred years in power transformers to ensure electrical insulation and cooling. However, these oils are mainly obtained from petroleum products, a non-renewable resource that involves various political and socio-economic issues. In the last half of the last century, synthetic hydrocarbon fluids, silicone, and ester fluids were introduced, but, at that time, their use was limited [4]. Furthermore, mineral oils are non-biodegradable, high flammable (due its low flash point) and dangerous for the environment, since spills from leaks and equipment failure can contaminate the water and the soil [5 - 7].

Based on the aforementioned, the development of alternative fluids is receiving great attention, in particular vegetable insulating oils, produced from renewable sources. Compared to mineral oils, bio-based oils are considered eco-friendly, since they are completely biodegradable, pollution-free, non-toxic and free of polychlorinated biphenyls (PCB), which also simplifies the leaking protection and further disposal. Furthermore, the relatively higher flash and fire points compared to mineral oils, makes the vegetable oils extremely safe, as it is classified as a Less-Flammable Dielectric Liquid, which requires no fire mitigation system and prevents the costly replacements caused by fires. Consequently, the vegetable insulating fluids are not considered dangerous by international authorities such as Environmental Protection Agency (EPA) and Occupational Safety and Health Administration (OSHA) [8 - 10].

The dielectric breakdown voltage is the most significant parameter of insulating oil. This is sensitive to impurities such as gas or air bubbles and excessive moisture in the insulating fluid [5]. Nevertheless, using natural ester as a transformer insulating oil can maintain high dielectric breakdown voltages at relatively high moisture levels because it creates hydrogen bonds with the water molecules [11, 12]. Furthermore, these oils are not corrosive to copper and increase the insulation life of Kraft paper, since they present ability to absorb moisture of the paper and protect cellulose from thermal aging. Taking into account all these properties, vegetable oils can increase the transformer overloading capability, its performance, its useful life, and can decrease its rates of failure. Jeong et al., [13] wrote that its use requires no or just minor modification sand, it is compatible with the existing electric power infrastructure. Nevertheless, vegetable oils have some disadvantages, like higher viscosity and lower oxidative stability, when compared to mineral oils. Additionally, their price is subject to significant oscillation caused by the food market, since, generally, the feedstock is also used as edible oils [6, 14].

The common edible vegetable oils like palm oil, groundnut oil, etc., is already expensive, their utilization for transformer oil production would further increase the cost of production, hence raise their prices of the transformer oil and will also aid the food crises. Calabash also known as lagenaria siceraria is a creeping plant which produces large spherical fruits commonly found in Nigeria. It is used as containers and storage vessels by some rural settlers in Nigeria [15]. The center is filled with seeds that contain oil. They are wildly harvested, cold-pressed and filtered to obtain clear oil. Developing countries like Nigeria have a comparative advantage for its production because of the availability of virgin land, favourable climatic conditions for agriculture and lower costs of labour [16]. In spite of this potential of calabash seed oil, no studies have addressed the use of this oil as insulating fluids for power transformers. The existing works focus their studies on the characterization of specific properties and there is no concern about the industrial oil production. In this context, the objective of this work was to develop a new bio-based insulating fluid based on calabash seed oil, for power transformers use, since the oil obtained after its processing presents a lower viscosity than commercial vegetable fluids available associated to a low acid number and a high dielectric breakdown value, besides the advantages already cited. The processed oil was characterized and compared according to the American Society for Testing and Materials (ASTM) standard requirements for new insulating vegetable oils.

EXPERIMENTAL

Experimental procedure

The calabash (Lageneria sinceraria) seeds were obtained from Ogbomoso, Nigeria. The fruits were broken and the seeds were sorted out, dehulled, ground into powder and the oil was extracted using soxhlet extraction method with n-hexane as a solvent. A modified Dijkstra and Opstal purification method used by Abdelmalik et al., [17] was adopted for the purification of the sample to obtain the refined calabash seed oil sample. A 200 ml solution of calabash seed oil (CSO) sample was heated in a 500 ml conical flask to 70°C and 8 vol. % of 64 vol. % aqueous citric acid solution was added gently and mixed thoroughly with a magnetic stirrer for 15 min. An amount of 4 ml of 8 vol. % NaOH solution was gently added and the mixture stirred at 400 rpm for 15 min. The mixture was then dried in vacuum oven at 85°C for 30 min to reduce the water content. An amount of 2 g of silica gel was added to the mixture at 70°C and agitated for 30 min at 300 rpm to prevent the settling. Fuller's earth was then added and continuously stirred for 30 min at 8 wt %. The sample was then filtered with filter paper in vacuum oven at 85°C.

Degumming

The method of Evangelista et al., [9] was used where crude oil obtained from the extraction is mixed with phosphoric acid (85 wt. %), in a proportion of 0.4 g of this acid to 100 g of oil, at 70˚C for 10 minutes. Then, a hot water is added and mixed for 10 minutes. After which, the mixture is centrifuged for phase separation. The aqueous whitish bottom phase, containing gums, phosphatides and proteins, insoluble in the oil when hydrated, are discarded.

Characterization of Biotransformer Oil

Some of physicochemical properties of the oil (iodine value, saponification value, and acid value) are determined using methods described by the association of Official Analytical Chemists (AOAC), 2000. Properties such as kinematic viscosity, pour point, flash point, and cloud point of the biodiesel are ascertained following ASTM D445, ASTM D97, ASTM D93, and ASTM D25100-8, respectively.

Determination of Oil Colour

The colour of the oil is determined by an observation using several independent competent individuals. Oil colour is correlated using colour charts as used by Okolie et al., [18].

Determination of Saponificaton Value (SV)

Saponification value indicates the presence of normal triglycerides, which can be used for the production of liquid soap and shampoo. AOAC, [19] is used for determining the saponification value. The step is repeated for a blank which did not contain oil sample (y) as used by Bhandarea and Naikb [20].

Determination of pH

The pH is the degree of the acidity of the oil. The pH meter's electrode is lowered into a buffer solution, at 50°C using a temperature regulator. The instrument is then calibrated at a buffer of pH 7.

The electrode is then removed from the buffer and rinsed with distilled water. Next, it is dipped into the test tube containing the oil and the pH on the screen of pH meter is recorded as used by Akbar et al. [21].

Determination of Density

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

$$\text{Density} = \frac{\text{Mass of oil}}{\text{Volume of oil weight}} \quad (2)$$

Determination of Specific Gravity

An empty container is weighed. The container is filled with water and weighed. The container is then filled with the same volume of oil as that of the water and weighed. The specific gravity is calculated with Equation 3 as shown below:

$$\text{Specific gravity} = \frac{(W_3 - W_2)}{W_1} \quad (3)$$

where W_3 is weight of container and oil; W_2 is weight of empty container; W_1 is weight of equal volume of water.

Flash point

ASTM D93 [22] Test Method was employed. The temperature at which the flash occurred is recorded for each sample, respectively, as their flash points.

Determination of Cloud and Pour Point

The ASTM D2500 [23] was used to test the cloud point of the produced biodiesel. The pour point is the lowest temperature at which the oil flows [24]. The samples are cooled and the test tubes containing the sample are bended at intervals to check for flow of oil until no flow of samples is observed. The temperatures of the samples at that point are recorded as their pour point. The cloud point is the highest temperature at which the oil begins to solidify [24].

Free Fatty Acids (% FFA)

The free fatty acids (%FFA) and acid value were determined and analyzed by methods described by IS-EN ISO 660 [25].

Viscosity Determination

Brookfield Viscometer with the appropriate spindle was used to measure the viscosity of the liquid sample in accordance with ASTM D445 [26].

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 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) ASTM D1816 standard [27]. The oil sample is placed between two electrodes with a 2.5 mm gap. A constant increasing voltage is applied until the oil discharges at a certain kV, which is recorded as the breakdown voltage.

RESULTS AND DISCUSSION

The calabash seeds yielded a good quantity of oils at extraction. There was reduction of FFA of the oils after purification. The produced purified calabash seed oil (PCSO) was characterized and the results obtained were compared with the ASTM standard as shown in Table 1. In most seed oil the phosphatides are in form of lecithin. A great portion of those phosphates was removed by water degumming. It was also detected that when these phosphatides were removed in the form of lecithin, there is no presences of gums or waxes in the oil resulting in the production of oil with a good colour, no taste or smell.

A higher density means more mass of fuel per unit volume. In this case, the biotranformer oil from PCSO has a higher density compared to conventional transformer oil. The PCSO has density of 0.85 g cm^{-3}, which is within the ASTM specification. Raja et al. [28] wrote that higher mass of oils would give higher energy available for work output per unit volume. Viscosity is a significant property of transformer oil in view of the fact that it affects the operation of fuel injection equipment, predominantly at low temperature when an increase in viscosity affects the fluidity of the fuel. The PCSO viscosity of 8.8 cst as shown in Table 1 is close to that of ASTM specification. It should be noted that as the oil temperature increases, its viscosity decreases and the lower the oil viscosity, the easier it is to pump and atomize. This shows that there is an inverse relation between viscosity and temperature. Bashi et al. [29] wrote that for a smooth oil operation in electrical equipment, the temperature needs to remain around the mild range. The 8.8 cst for PCSO is good in this aspect. Rafiq et al. [6] also wrote that in electrical power transformers, the insulating fluid also promotes heat dissipation, usually by natural convection. Thus, oils with lower viscosities can enhance heat dissipation efficiency, which can in-

Table 1. Transformer oil specifications of the ASTM standard.

PROPERTIES	PCSO	ASTM Specification
Density at 29.5°C (g/cm^3)	0.85	0.55-0.89
Viscosity at 27°C (cst)	8.8	9.3-27
Cloud point (°C)	10	7-15
Pour point (°C)	4	–8 - (–6)
Flash point (°C)	164	140-155
Acid value (mgKOH/g oil)	0.142	0.01-0.03
Dielectric strength (kV)	24	25-40
Boiling point (°C)	126	120-230°C
pH	5.23	5.5-8.2
Specific gravity at 20°C	0.813	0.89-0.91
Saponification value (mgKOH/g oil)	157	150-244
Peroxide value (meq/g oil)	7.22	5-10
Iodine value (g100/g)	52.23	55-120
Free fatty acid (mgKOH/g oil)	0.072	0.01-0.08

crease the transformer capacity and lifetime, in addition to more operational safety.

The standards used for low temperature performance of oil are cloud and pour points. Cloud point is the lowest temperature at which the oil can flow. The cloud point for PCSO is 10°C as shown in Table 1, this is an indication that the oil can perform satisfactorily in cold climatic conditions. The pour point for PCSO is 4°C, and it is very low although it is higher than the ASTM specification. In general, a higher pour point often limits the application of oils as fuels for transformer in cold climatic conditions. Achten et al. [30] wrote that pour point should be low so that the oil can remain flowing, even at low temperature. This is because when the ambient temperature is below the pour point, wax precipitates in the oil and it loses its flow characteristics causing the wax to block the filters and fuel supply line.

Flash point is a significant specification for safety during transport, storage and handling [28]. The temperature at which oil produces a certain vapour that mixes with air and forms an ignitable mixture, resulting in a momentary flash is called flash point. In order to prevent the risk of fire that might result in accidental ignition a minimum flash point is specified. The flash point of PCSO was found to be 164°C as shown in Table 1, which is slightly higher than the ASTM value. The value obtained is good in preventing accidental ignition. This flash point has revealed that the oil can safely be used even where the temperature is very high.

Iodine value is a measure of the unsaturation level and the reactivity of the oil. High iodine value signifies greater degree of unsaturation. The iodine value for PCSO was found to be 52.23 g 100 g^{-1}oil as shown in Table 1. The value is lower than 100 and the oil can be classified as non-dry oil and slightly lower than minimum ASTM requirement. This value also represents the decrease in unsaturation of oil [31], which is an advantage since the lower the unsaturation of oils and fats, the greater is the oxidation stability. Saponification value is a measure of the alkali reactive groups in fats and oils and is helpful in predicting the type of glycerides in an oil sample. A higher saponification value indicates that there is a greater portion of low molecular mass fatty acids [8]. The Saponification value of PCSO was found to be 157 mgKOH/g oil as shown in Table 1 and is within the ASTM specification. High value of acid can indicate the presence of oxidation products in the oil bath which can cause corrosion and sludge in a system [28]. Peroxide value is a measure of extent of glycerides constituent decomposition by lipase action, which is added by light, air and moisture. Peroxide value is also an indication of the level of rancidity of the oil. The peroxide value of PCSO was found to be 7.22 meq g^{-1} oil as shown in Table 1 indicating that the oil is still good and it has low level of rancidity. The value obtained is within the ASTM specification. A low peroxide value 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 therefore obtained makes PCSO ideal for usage and storage [32].

Dielectric strength is used to define an electric insulating material. The dielectric strength of insulating oil is a measure of the oil to withstand electric stress without failure. Contaminants like water, conducting particles and sediments reduce the dielectric strength of insulating oil. Dry and clean oil has an inherently high dielectric strength but is not an indication of the absence of contaminates; it only shows that the amount of contaminant present between the electrodes is not large enough to affect the average breakdown voltage of the oil [33]. The dielectric strength of 23 kV of PCSO was very close to the minimum requirement of ASTM specification.

CONCLUSIONS

The present work presents the results on the development of a new vegetable insulating fluid for power transformers based on Purified Calabash seed oil. The characteristics of the purified Calabash seed oil shows that the seed oil is of good quality, since there are some reasonable agreement between the values obtained and the ASTM specifications. Transformer oil spill or leak has always been a great task, especially the cleanup and remediation phases. Consequently, environmentally friendly oil can be used as substitute in transformers and transmission lines, thereby reducing losses and minimizing remedial procedures in the event of oil spills. The use of biodegradable transformer oil will signifies probable savings for utilities because it should simplify the cleanup and remediation procedures. However, the real savings are realized 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 calabash farming.

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