Asian Journal of Engineering and Applied Technology
ISSN: 2249-068X (P) Vol.12 No.1, 2023, pp.51-54

DOI: https://doi.org/10.51983/ajeat-2023.12.1.3685

Potential Characterization of Bush Mango Oil for Application in Transformer Insulation

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(Received 20 April 2023; Revised 7 May 2023; Accepted 30 May 2023; Available online 5 June 2023)

***Abstract* - In recent times, the suitability of some oils from edible fruits as a replacement for mineral oils used in transformers has been proven in different literature. The use of edible oils as transformer insulation fluid gives rise to the concept of green insulation in transformers. Research in the use of edible oil in the production of transformer oil has been one of the major researches in high voltage engineering. The existence of paucity of knowledge on the use of bush mango oil as dielectric fluid in transformers led to the idea of this research work. Therefore, this study focuses on the investigation of the suitability of using Irvingia Gabonensis Oil (IGO) for insulation in power transformers. From the series of analyses conducted, it has been established that the Irvingia Gabonensis (Bush Mango) oil is not suitable for transformer insulation oil. This is because the biobased green oil produced presented characteristics that are not suitable to match the standards recommended by the International Electrochemical Commission (IEC) and the American Society for Testing and Materials (ASTM).**
***Keywords:* Transformer, Oil, High Voltage, Insulation, Bush Mango**

I. INTRODUCTION

From the beginning of the large blast of electric power discovery, oil has commonly been used in transformers. However, mineral oils (MOs) are widely used in insulation applications in transformers [1]. The continuously increasing demand for electricity has triggered a changing situation in the level of power system voltage, especially with increasing socio-economic activities. As the world is moving towards decarbonization and environmental sustainability, the quest for the replacement of MOs for human safety and environmental sustainability is continuously soaring. From this perspective, research efforts toward bringing alternative solutions to the environmentally challenging MOs have been a welcome development in the last few decades. There are some associated environmental risks of some MOs due to their non-biodegradable nature. The application of potentially viable alternative fluids to MOs in the insulation of transformers is obviously a productive and reasonable task. Utilization of MOs such as gasoline-based fuels have been reported to be characteristically non-suitable from the environmental perspective. A lot of research activities on the use of alternative edible vegetable oils for transformer insulation have been conducted across different parts of the world. Oils used for insulation purposes must have a sublime cooling tendency and good dielectric properties. The sources of edible vegetable oils are renewable with biodegradable characteristics. Some commonly known vegetable-based like soybean oil, sunflower oil, canola oil, castor oil, rapeseed oil, coconut oil, and palm oil [2-4] have been investigated for the possibility of their application as transformer oil. They are generally non-toxic, biodegradable, and less flammable than petroleum-based MOs.

Oils are basically used in transformers to insulate the system from arcing, prevention of corona discharge and remove heat (coolant) from the system. A good transformer oil does reliably prevent the core and winding of the system. In addition, transformer oil has the potential to thwart the oxidation of the paper insulation made from cellulose paper by acting as a blockade between the cellulose and the atmospheric oxygen. In order to protect a transformer from destruction, the level of oxidation must be minimized. In operations of high-voltage equipment, the need for insulation obviously cannot be jeopardized. Therefore, this study investigated the suitability and the short-time dielectric characteristics of Bush mango oil for application as transformer oil. The sample utilized refined oil extracted from the Irvingia Garbonensis fruits shown in Figure 1. The oil was extracted from the seed by solvent extraction using the method of Soxhlet extractor. This method was adopted due to its high chance of oil yield based as presented in previous studies [5-6].

II. MATERIALS AND METHODS

A. Materials: Irvingia Gabonensis Oil

A raw kernel of Irvingia Gabonensis purchased from a local market in Nasarawa was used for the experiment. The Irvingia Gabonensis fruits from which the oil is extracted are shown in Figure 1. The Laboratory reagents such as Hydrogen peroxide, sodium hydrogen-trioxocarbonate, potassium hydroxide, sodium chloride, methanol, boron trifluoro diethyl-etherate, acid anhydride, acetic acid, and others obtained from Ness Chemical Nigeria Limited were used for the experiment. After gathering the research samples and the required chemical reagents for the extraction of the oil. The standard extraction procedure of the Soxhlet experimental design presented in reference [7] was then used to extract the oil. The amount of oil extracted is computed by the expression in Eq. (1) [8]. The Irvingia gabonensis oil has been extracted for local consumption in different parts of Africa. The oil contains 91.4 % and 8.6 % of neutral and polar fat respectively in its crude content.

$$Percentage\ of\ oil\ yield = \frac{weight\ of\ oil\ extracted\ (g)}{weight\ of\ sample\ used\ (g)} \times 100\% \qquad (1)$$

Fig. 1 Irvingia Gabonensis fruits

B. Experimental Approaches

The experimental investigation of the physiochemical properties of the IGO to establish the suitability of the properties of the oil as transformer insulation fluid was carried out. The experimental measurements include dielectric breakdown voltage, dielectric constant, losses factor, flash point, viscosity and others. The sample of the oil used was refined, bleached and deodorized to the level of unsaturated low-fat content by the addition of stearine.

III. EXPERIMENTAL RESULTS

The results obtained from the experiments conducted for the IGO, and the standards recommended by the ASTM are not satisfied. In terms of oil yield from the extraction process, the result was quite satisfactory. Then followed by the purification processes to reduce the Free Fatty Acid (FFA) content. It was observed that refined oil cannot be used as the replacement of traditional mineral oils used in transformers even though it is not harmful to the environment like many others that have been investigated in some previous studies. Compared with the conventional characteristics of ASTM standard transformer oil, the experimental results obtained are presented in Table 1.

A. Breakdown Voltage

The dielectric strength also known as the breakdown voltage of an oil was conducted by using the transformer oil dielectric strength tester kit shown in Figure 2. A standard breakdown voltage of 30kV is essential for an oil to be used suitably for insulation in power transformers. A dielectric strength test is conducted to assess the insulation characteristics. The breakdown voltage is a measure of the voltage that is needed to maintain the reliable operation of the transformer. The presence of water, acid and other potential chemical and nonchemical impurities. The presence of contaminants will decrease the dielectric strength of the transformer oils faster than expected. Traditionally, the dielectric strength of transformer oils decreases with the passage of time due to the prevailing weather conditions of the location where the transformer is installed. Hydration is one of the main sensitive factors affecting transformer oils, especially in regions with high field strength. The presence of a suspected quantity of moisture can drastically affect the dielectric strength of oils in transformers due to the contaminated effect of the moisture. It is therefore important that oils suitable for application in transformers must have low moisture content and be free from impurities. However, the variation of the oil's breakdown voltage with the fat content was studied. The fat content varied from 1.0 to 30.0% based on temperature considerations. It was observed that while the voltage increases with temperature, at the fat content of 15%, 18%, 23% and 30%, the breakdown voltages are less than 30 kV. It was also observed that the lower the fat content of the oil, the higher the chances of approaching a breakdown strength greater than the required standard of 30 kV.

Fig. 2 Automated electric distribution transformer oil dielectric strength tester kit

B. Viscosity

Transformer oil with high-quality characteristics must be formulated with low viscosity. The experiment conducted showed that the viscosity increased with the fat content of the oil. In order to obtain a low viscosity in transformer oil, the fat content of the oil must be reduced. From Figure 3, a value of the oil viscosity of 23.2 cst was obtained for 5% fat content which is entirely different from the acceptable value of 296 based on the standard recommended by the International Electrochemical Commission (IEC) for suitable transformer oil. In transformer insulation, the viscosity of an oil is a crucial property. It affects the operational condition of fuel injection equipment based on the prevailing working temperature. Transformer oils are required to be flexible enough to perform to their expectations. At low temperatures, transformer oils have high viscosity while at high temperatures the reverse is the case. However, an optimum temperature is required to maintain a reasonable viscosity to give a chance of effective performance to the oils. From the experiment conducted, at 25°C the viscosity obtained for the oil is 7.2 cst which is below the range of 9.3-27 specified by the ASTM as shown in Table I. An optimum temperature of transformer oil provides sustainable cooling and convection.

TABLE I COMPARATIVE ANALYSIS OF RESULTS OBTAINED WITH THE ASTM STANDARDS

Sl. No.	Oil properties	Extracted IGO	ASTM specifications
1	Density at 29.5°C (g/cm3)	0.91	0.55-0.89
2	Flashpoint (°C)	117	140-155
3	Acid value (mgKOH/g oil)	0.15	0.01-0.03
4	Dielectric strength (kV)	22	25-40
5	Boiling point (°C)	116	120-230°C
6	Viscosity at 25°C	7.2	9.3-27
7	pH	4.23	5.5-8.2
8	Free Fatty Acid (FFA)	0.098	0.01-0.08
9	Peroxide value	12.22	5-10
10	Specific gravity at 20°C	0.76	0.89-0.91
11	Cloud point (°C)	18	7-15
12	Saponification value (mgKOH/g oil)	134	150-244
13	Pour point (°C)	18	7-15

C. Flashpoint

The flashpoint of a transformer oil represents the working temperature at which the oil vaporizes to yield a flammable mixture with air. Higher flash point temperatures are desirable in transformer oils because they reduce the chances of fire incidents due to light hydrocarbons. Heat due to electrical stress can results to fire in the transformer. Traditionally, the flashpoint temperature of transformer oil is expected to be greater than 140^{0}C but going by the result shown in Table 1 is quite low. Internal faults in transformers and service conditions may reduce the flashpoint of a transformer thereby putting the system at the risk of fire disaster. In the experimental analysis, the flashpoint obtained was 1170C at the fat content of 1.0%, which is a lower value than the specification by the ASTM standard. According to El- Sayed *et al.,* [9], the handling, transportation and storage of transformer oil, the characteristic Flashpoint is an important consideration. The lower flashpoint of the oil examined in this study than the specified value by the ASTM is a pointer that the oil may likely not be able to reduce the chance of accidental fire outbreak in the equipment.

D. Cloud and Pour Point

The performance of transformers oils must be investigated in a study of this kind especially at different temperatures. Low and high-temperature scenarios have a great impact such that the cloud and pour point are used to evaluate the performance of oils at low temperatures. Variations in regional temperatures affect the performances of different transformer oils. A cloud point is the lowest possible temperature at which a transformer oil exhibits a cloudy characteristic when the oil cooled down slowly due to low temperature. On the other hand, the pour point is the temperature at which an oil is solidly frozen without movement. Low-temperature pour point is perilous for circuit breakers and transformers. The results of the cloud and pour point of the oil investigated in this study are presented in Table I. Conventionally, it is desirable for a transformer oil to have a low pour point to ensure the continuity of flow of the oil even at low-temperature conditions [10].

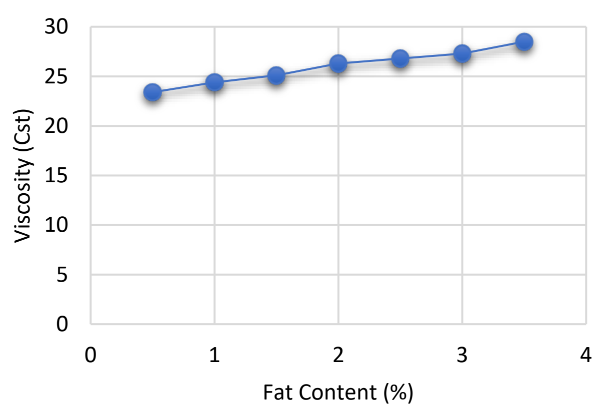

Fig. 3 Viscosity as a function of the fat content of oil used

E. Dielectric Constant

In the experiment, ASTM D924 transformer oil relative permittivity or dielectric constant tester was used. The dielectric constant of a transformer oil which is a nondimensional physical value is also known as relative permittivity. Under normal circumstances, the relative permittivity of transformer oil is in the range of 2.1-2.4. It is however important to know that the value can be altered during the working processes of the transformer especially when the cellulose insulation is impregnated with oil. Contamination of transformer oil with water, oxidation products, and gases has detrimental effects on the oil with consequential degradation of the quality of the oil. The results obtained herein from the oil under consideration established that the relative permittivity is a function of fat content at different temperature ranges. The trend observed was that the higher the fat content the greater the relative permittivity of the oil. This effect may be attributed to the dipole characteristic with the tendency to increase the electrical susceptibility and dipole density which have the potential to increase the dielectric constant. In addition, an increase in temperature increases the relative permittivity of the oil.

IV. DISCUSSION OF RESULTS

The breakdown voltage, viscosity, flashpoint, dielectric constant, and other characteristic properties of the oil as the function of the fat content and temperature were investigated in this study. The values obtained for all the aforementioned parameters indicated that the bush mango oil is not suitable for use as transformer insulation fluid. This submission is based on the conspicuous deviation of the values obtained from the measurements compared to the standards recommended by the ASTM and IEC. Based on the comparative analysis of the oil with the properties of mineral and silicone-based transformer oils, the Bush Mango oil is obviously not suitable for use as an alternative insulating fluid transformer in its raw and refined form. However, further investigation is required especially for the classical refined version of the oil with reduced fat content. From realistic experimental evidence, it can be adjudged that all the properties investigated in the framework are functions of the fat content and temperature condition of the oil.

V. CONCLUSION

In the current work, the results of the utilization of a bush mango seed oil-based for utilization in power transformers are presented. The results obtained show some series of deviations from the expected documented quality of oils suitable for use in transformers based on standard criteria. The purpose of this study is to examine the possibility of producing new environmentally friendly oil as an alternative fluid for transformer insulation. The oil insulation properties of breakdown voltage, viscosity, flashpoint, dielectric constant, and others were investigated with reference to the fat content and temperature of the oil. It was found that the fat content of the oil has a great impact on the parameters investigated. It is consequently observed that a reduction in the fat content of the oil has a great impact on the applicability of the oil for the purpose of insulation in power transformers based on the ASTM and IEC standards. Mineral oils are commonly used as transformer-insulating oils and their leakage and spillage could be harmful to the natural environment. The quest for mitigation of negative environmental impacts brought the idea of suitable and sustainable alternatives. Over the years, the suitability of many edible vegetable oils for application in power transformers has been investigated and some have proven to be a realistic substitute. Since edible transformer oils are non-toxic oils, therefore, any possible spillage has no harm to the environment, especially in ecologically vulnerable locations. In addition, they are usually less expensive than the mineral oils.

ACKNOWLEDGMENT

This work is supported by the Tertiary Education Trust Fund (TETFUND) under the Institution-Based Research (IBR) project of the research funding to the Federal Polytechnic Nasarawa.

REFERENCES

[1] O. Adeolu and I. Adejumobi, “Breakdown voltage characteristics of castor oil as alternative to transformer insulation oil,” *International Journal of Scientific Engineering and Research (IJSER),* Vol. 2, No. 4, pp. 31-37, 2014.

[2] F. Sitinjak, I. Suhariadi and L. Imsak, “Study on the characteristics of palm oil and it's derivatives as liquid insulating materials,” in *Proceedings of the 7th International Conference on Properties and Applications of Dielectric Materials (Cat. No. 03CH37417), IEEE,* Vol. 2, pp. 495-498, 2003.

[3] M. H. Roslan, N. A. Mohamad, T. Y. Von, H. M. Zadeh and C. Gomes, “Latest developments of palm oil as a sustainable transformer fluid: A green alternative to mineral oils,” *Biointerface Res. Appl. Chem,* Vol. 11, No. 5, pp. 13715-13728, 2021.

[4] N. K. Mohd, L. Wen-Huei, N. A. s. Abu Hassan and Y. Shoot-Kian, “Potential application of palm oil products as electrical insulating medium in oil-immersed transformers,” *Environmental Progress & Sustainable Energy,* Vol. 40, No. 6, pp. e13728, 2021.

[5] L. T. Zoué, M. E. Bédikou, B. M. Faulet, J. T. Gonnety and S. L. Niamké, “Characterisation of a highly saturated Irvingia gabonensis seed kernel oil with unusual linolenic acid content,” *Food science and technology international,* Vol. 19, No. 1, pp. 79-87, 2013.

[6] E. Bello, A. Fade-Aluko, S. Anjorin and T. Mogaji, “Characterization and evaluation of African bush mango Nut (Dika nut) (Irvingia gabonensis) oil biodiesel as alternative fuel for diesel engines,” *J. Petro. Technol. Alter. Fuels,* Vol. 2, pp. 176-180, 2011.

[7] M. C. Menkiti, C. M. Agu and T. K. Udeigwe, “Extraction of oil from Terminalia catappa L.: Process parameter impacts, kinetics, and thermodynamics,” *Industrial Crops and Products,* Vol. 77, pp. 713-723, 2015.

[8] C. Agu, A. Agulanna, C. Kadurumba, P. Nnaji, E. Udokporo and M. Menkiti, “Characterization, kinetics and thermodynamics of epoxidation-esterification of Irvingia gabonensis kernel oil methyl ester,” *Heliyon,* Vol. 8, No. 5, pp. e09520, 2022.

[9] E. El-refaie, M. R. Salem and W. A. Ahmed, “Prediction of the characteristics of transformer oil under different operation conditions,” *World Academy of Science, Engineering and Technology,* Vol. 53, pp. 764-768, 2009.

[10] S. Bashi, U. Abdullahi, R. Yunus and A. Nordin, “Use of natural vegetable oils as alternative dielectric transformer coolants,” *Journal-The Institution of Engineers*, Vol. 67, No. 2, 2006, pp. 4-9.