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INCREASING BIODEGRADABILITY AND ENVIRONMENTAL FRIENDLINESS OF POWER TRANSFORMERS USING SOYBEAN OIL

Benard Akor
Department of Physics, Benue State University Makurdi, Benue State, Nigeria

Abstract: This study analyzes the breakdown voltage of soybean oil and its potential as an alternative to mineral oil in power transformers. Soybean oil was physically and chemically analyzed in the laboratory for its characteristics such as density, viscosity, moisture content, sludge, acidity, flashpoint, and breakdown voltage. The results indicate that soybean oil possesses suitable characteristics for use as a transformer oil, according to the International Electrotechnical Commission (IEC) standard, with the exception of a lower flashpoint compared to the IEC standard. The researchers suggest that soybean oil can be blended with other oils to improve its characteristics and increase its potential as an alternative to mineral oil. Other plant-based oils such as sunflower, coconut, and palm kernel-based oil have also been explored for their environmental friendliness, biodegradability, and affordability. The dielectric strength of soybean oil was observed to be temperature-dependent, with the breakdown voltage decreasing as the temperature increases. Overall, the study concludes that soybean oil shows promise as an environmentally friendly and affordable alternative to mineral oil in power transformers.

Keywords: breakdown voltage, soybean oil, mineral oil, transformer oil, alternative oil, environmental friendliness, biodegradability, affordability, plant-based oils.

INTRODUCTION

High voltage systems like power transformers usually require insulating oil to protect it from chemical attack, internal short circuit, and prevent sludge formation [1-3]. The liquid insulating oils that are commonly used in all power transformers act as a coolant to prevent the transformer from overheating and provide electrical insulation, suppress corona and arching [4]. A good insulating oil is usually associated with qualities such as high breakdown voltage (dielectric strength), good chemical stability, high thermal stability, low dielectric loss factor, good cooling medium and it is reasonably cheap [5-6].

Petroleum-based mineral oils possess all qualities of good insulating oil. However, all mineral oils have gross adverse effects on environment and contaminate soil and water. These effects are observed whenever accident occurs such as tank rupture, leak or explosion and fire. The hazardous effects such as poor biodegradability and lack of environmental friendliness that characterize mineral oils have made scientists all over the world to begin a search for an alternative oil.

Today, sunflower oil is considered 100% environmentally friendly and it is used as insulating oil in some countries [5]. Unfortunately, sunflower oil is very expensive and other alternative oils (vegetable oils) such as soya bean-based oil, coconut oil, palm oil and palm kernel-based oil for their easy availability, biodegradability, environmental friendliness and affordability are explored by scientists [7-9].

The dielectric strengths of both soya bean-based oil and palm kernel oil in their crude states was found to be 39kV and 25kV respectively [10]. These dielectric strengths were very small when compared to the 50kV maximum dielectric strength of the mineral oil. Coconut oil with the small dielectric strength of about 20kV in its crude state can be increased to 60kV when refined [7]. In this work, the breakdown voltage of refined soyabean oil and other physio-chemical characteristics of the oil have been analyzed. The oil sample have been refined and tested for the dielectric breakdown voltage, moisture content, viscosity, and flash point.

1. MATERIALS AND METHODS

The soyabean oil used in this work was extracted and refined at Grand Cereal Oil Company in Jos, Plateau State and thereafter, the physio-chemical properties and breakdown voltage were analyzed in the laboratory. The following instruments were used for the analysis DV-E Brookfield Viscometer and Accessories, Petrotest Machine and accessories – PM-4 model, FUNKE-GERBER Centrifuge Machine, F-STREEM Vacuum Oven, MEGGER 60 KV Oil Tester Machine, Anton-Paar Hydrometer, Density Bottle, Test Tubes and Beakers.

Methods Density Measurement

A cylinder was washed and properly dried. The cylinder was then filled up to 1000 ml with refined soyabean oil. The temperature of the oil in the cylinder was maintained at 40 ℃. The hydrometer was deep into the oil sample in the cylinder and allowed to suspend freely. The readings for the oil's density at temperature of 40 ℃ were taken from the hydrometer and recorded. The temperature of the cylinder containing the oil was increased to 50 ℃ and finally 60 ℃. The density of each oil sample was again taken for the respective temperatures and the results are recorded as shown in Table 1.

Viscosity Measurement

The DV-E Brookfield viscometer machine shown in the Figure 1 was used to measure the viscosity of the oil. A cylinder was filled to 500 ml with of the oil. The temperature of the oil in the cylinder was maintained at 40 ℃. The viscometer machine was powered ON and four spindle were clamped on the rotational axis of the viscometer. The spindle type was set to spindle four (4) and the speed of the spindle at 60 RPM (revolution per minutes). The spindle was deep down into the oil sample under measurement up to the graduated point of the spindle before pressing the menu button to set the spindle rotating. The procedure was repeated for the temperature of 50 ℃ and 60 ℃ and most stable value readings on the DV-E Brookfield viscometer screen were recorded as shown in Table 1 according to the ISO standard [11]. The equation 1 was used to obtained the viscosity values in centistoke

$$Viscosity\ (Cst) = \frac{Viscosity\ reading}{Density} \quad (1)$$

Figure 1: The DV-E Brookfield viscometer used for experimental measurement of oils viscosities.

Measurement of the Oil Flash Point

To measure the flash point, the PM-4 Petrotest flash point machine was powered ON, and oil was poured into the flashing cup to the graduated mark and close with the cover. The cup was clamped into the heating compartment of the machine and a mercury thermometer was inserted into its compartment in the flash cup before pressing the run button for both the heating and spin. The experimental setup is as shown in Figure 2 and the centrifuge cup is depicted in Figure 3. The gas was switched ON and the flash light was ignited. As the temperature was rising, the flash light was deepened to the volatile outlet of the flash cup at an interval of 2 to 3 minutes until the light goes out (flashed). The temperature at which the oil sample flashed was noted immediately on the thermometer and recorded in Table 1.

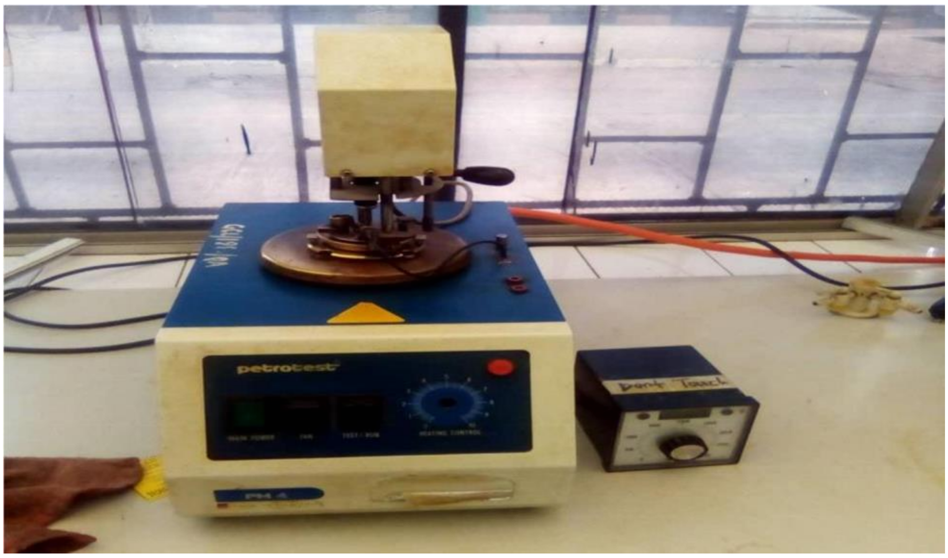

Figure 2: Experimental setup for flash point measurement using the PM-4 Petrotest flash point machine

Figure 3: The flash point cup inside the PM-4 Petrotest flash point machine used for housing the spinning fluid

Determination of the Oil Moisture Content

In order to determine the moisture content, an empty crucible/cup was weighed on a weighing balance and the value was recorded as W_2. 0.5 ml of the oil sample filled into the crucible and recorded as W_1, then the weighed oil sample was placed into a vacuum oven (see Figure 4) operating at the temperature of 120 °C for one hour. The sample was removed and inserted into a desicater for about 5-10 minutes to cool, the cooled sample was then weighed and the recorded value was again taken to be W_3. The percentage moisture content of the oil was calculated using the equation 2:

$$Moisture\ Content\ (\%) = \frac{W_1 + W_2 + W_3}{W_1} \times 100 \qquad (2)$$

The crucible was then filled with 2 ml of the oil and the above procedures was repeated and recorded in Table 1.

Figure 4: The F-STREEM Vacuum Oven for demoisturizing water from the oil samples during the determination of moisture content

Determination of the Oil Sludge

The FUNKE-GERBER Centrifuge Machine shown in Figure 5 was used to measure the amount of sludge in the oil. This was carried out by weighing an empty clean test tube as W_2 and also weighed 20 g of the oil sample into test tube, and then climb the oil sample on the centrifuge machine and powered the centrifuge to set the sample spinning for 15 minutes. The spinning centrifuge machine with the sample on it was stopped, removed the sample and decanted the sample off the test tube completely and again weighed as W_3. The percentage sludge was mathematically calculated using the formula:

$$Sludge\ (\%) = \frac{W^3 - W^2}{W_1} \times 100 \qquad (3)$$

Figure 5: The FUNKE-GERBER Centrifuge Machine used in the determination of sludge

Free Fatty Acid (Acidity) Measurement

To measure the free fatty acid content in the selected oil sample, 0.1 N of caustic soda (NaOH) was prepared as a based on the IEC standard [12]. More than 50 ml quantity of methylated spirit above was measured and two to three drops of phenolphthalein indicator was added to give a light pink colouration. A 50g of the oil sample was again weighed into a beaker and the sample was heated on a heating panel. 50 ml of the mixture of methylated spirit and indicator was added and titrated against 0.1 N of caustic soda (NaOH) until a light pink colouration which is the end point and represent the titrate value was reached. The FFA was calculated using the relationship below:

$$FFA\ (\%) = \frac{T \times N \times 28.2}{W1} \times 100, \quad (4)$$

where T is the titre value reached, N is the normality of NaOH, W_1 is the weight of the oil sample and 28.2 is known as the Oleic constant. The results for the free fatty acid content of the oil are reported in Table 1.

Measurement of the Breakdown Voltage of Oil

To determine the dielectric strength of the oil, 100 ml of the sampled was measured in a measuring cup containing electrode gab of 2.5 mm [13], the oil was filled in the vessel of the MEGGER 60 KV oil tester machine shown in Figure 6. The machine was switched ON and allowed to steam for about 1-2 minutes and five breakdown voltages were taken at given temperature. The average breakdown voltage (BDV) recorded in Table 1 and the average BDV are plotted against the temperature as shown in Figure 7.

Figure 6: The MEGGER 60 KV Oil Tester Machine used for measuring transformer oil dielectric constant

2. RESULTS AND DISCUSSION

The technical specifications for transformer oils and the IEC standards had classified the important properties of the transformer oils as the physical properties, the chemical composition, and most importantly, the electrical properties [14-15]. The physio-chemical properties and breakdown voltage of soyabean oil analyzed in this work and presented in the Table 1.

Table 1: Are the physio-chemical properties and breakdown voltage of soyabean oil

Properties of the oil	This work	IEC 296, 2013
Density, kg/m^3 (40^{o}C, 50^{o}C, 60^{o}C)	0.36, 0.40, 0.44	0.895
Viscosity, cSt (40^{o}C, 50^{o}C, 60^{o}C)	8.56, 7.04, 5.71	13
Sludge	0.00	0.00
Flash point ^{o}C	38	154
Moisture content, mg/kg	0.05	1.5
Acidity, (mNaOH/kg)	0.001	<0.001
Breakdown voltage, kV/2.5 mm	52.6 ± 6.47	50

The physical, chemical and electrical properties measured in this work were compared with the International Electrotechnical Commission (IEC) standard. Some properties such as density, the viscosity, the sludge, the acidity, and the breakdown voltage were within the acceptable limits [16]. However, the flash point was below the IEC standard.

The low viscosity of the soyabean oil implies that the oil can circulate for better heat transfer. The transformer oil has to be mobile, since the heat transfer in transformers occurs mainly by convection currents. As viscosity increases with temperature, it is necessary that viscosity be as low as possible at low temperatures. The viscosity of soyabean oil have shown such an important characteristic. The density of the transformer oil is particularly significance most especially when the transformer is operating in a very low temperature zone. The maximum value to density fixed at 29.5^o C to ensures that water in the form of ice present in oil remains at bottom and does not tend to float on the oil up to a temperature of about -10^o C [16-17]. The density of the soyabean oil was within the IEC acceptable limit and suggests that oil is capable replacement of the mineral oil. The Presence of moisture is harmful since it adversely affects the electrical characteristics of oil and accelerates deterioration of insulating paper. The low moisture content measured from the soyabean oil makes it a good transformer oil.

The flash point is the temperature at which the oil gives sufficient amount of vapour, when mixed with air, formed an ignitable mixture, and gives a momentary flash on application of flame under prescribed condition. A minimum flash point is specified to be 154^{o}C in order to prevent the risk of fire that might result by accidental ignition. The soyabean oil however, showed a small flash point when compared with the standard. The flash point of blended soyabean and palm kernel oils measured by [18] was as high as 242^{o}C. The small flash point recorded in this work may be because the oil was not blended.

The dielectric strength (Breakdown voltage) is the voltage at which the breakdown occurs when the oil is subjected to an electric field under standard test conditions. Five measurements were taken at different temperatures and the results is shown in Figure 1. The result revealed that as the temperature of the oil increases, the breakdown voltage decreases. This result shows that the breakdown voltage is a function of temperature.

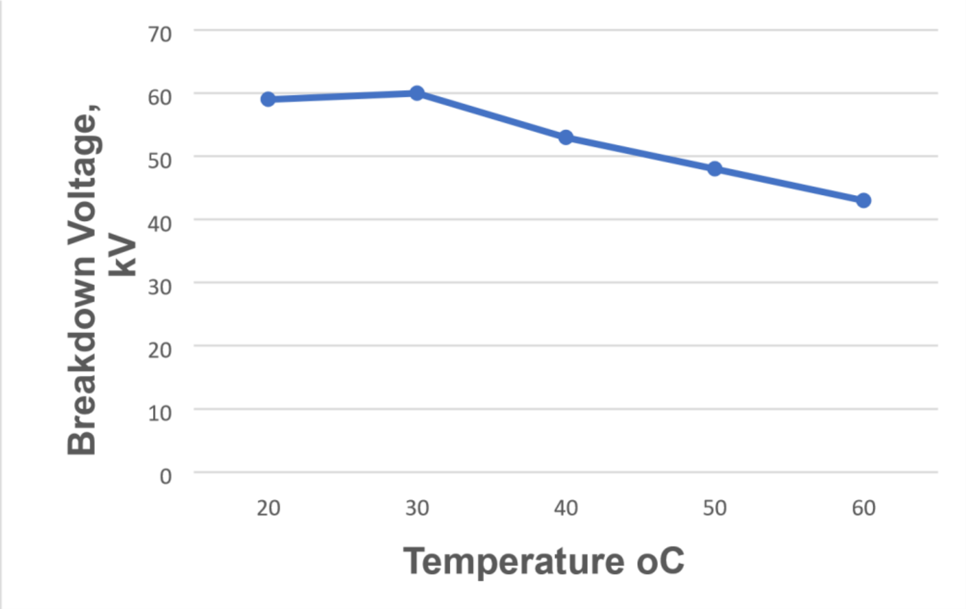

Figure 7: Breakdown Voltage against the temperature

3. CONCLUSION

In this work, some physical, chemical and electrical properties of soyabean oil have been analyzed in order to find a suitable replacement to the usual mineral oil used in transformer. The density, viscosity, sludge, acidity, moisture content, and breakdown voltage of soyabean oil indicated that the oil could be a good replacement of the mineral oil. However, the flash point of the oil was relatively small when compared standard. This property can be made better if the oil is blended with palm kernel oil [18]. The researchers therefore, concluded that the physio-chemical and electric characteristics of refined soyabean oil can be significantly improved if the oil is blended.

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