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Electrical Analysis of Corn Oil as an Alternative to Mineral Oil in Power Transformers

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***Abstract*—**In insulation and cooling of power transformers various liquids are used. Mineral oils have wide availability and low cost. However, they have a poor biodegradability potential and lower fire point in comparison with other insulating liquids. Use of a liquid having high biodegradability is important due to environmental consideration. This paper investigates edible corn oil as an alternative to mineral oil. Various properties of mineral and corn oil like breakdown voltage, dissipation factor, relative dielectric constant, power loss and resistivity were measured according to different standards.

***Keywords*—**Breakdown voltage, corn oil, dissipation factor, mineral oil, power loss, relative dielectric constant, resistivity.

I. Introduction

MINERAL oil is the most preferred insulating liquid since nearly 100 years since it has a good insulating performance, a thermal cooling capability and low cost. However, mineral oils recycling process is difficult and oil resources are predicted to be finished in near future. Thus, the necessity to investigate of alternative insulating liquid is revealed. Environmental friendly oil investigations are ongoing to be used as insulating fluid in high voltage power equipment. It is important to find a new kind of alternative insulating oil because various vegetable oils grow in Turkey.

In [1], dielectric properties of olive oil as an alternative to mineral insulating liquid were investigated. Chemical treatments to the filtered sample were applied and thus acidity of olive oil was reduced. Mineral oil and olive oil were compared in terms of breakdown voltage, flash point and viscosity values. Results indicated that olive oil might be a good alternative for mineral oil. In [2], edible soybean oil, rice oil and sunflower oil were compared with commercial natural ester Biovolt A. It was determined that rice oil meets all limit values specified by the ASTM D6871 standard.

In our previous study, breakdown voltage of mineral oil was analyzed according to distinct temperature and moisture content. The breakdown voltage increased with temperature rise from 30°C to 110°C. The reason for this increase stems from the fact that the moisture content inside oil decreases with rising temperature [3].

In this study, corn oil is investigated electrically as an alternative insulating liquid to mineral oil. Firstly, breakdown voltage of mineral and corn oil was measured by IEC 60156 standard. Then, dielectric dissipation factor, relative dielectric constant and power loss of these oils were measured and plotted according to distinct frequency and voltage by ASTM D924 standard. Furthermore, resistivity of both of the oils was calculated and plotted with respect to different frequency and voltage.

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II. Natural Ester Fluids

Investigations of natural esters as heat transfer fluids in power transformers began in early 1990s and it has been used in the industry since 1999 [4]. Natural esters are produced from oil of plant seeds and have a triglyceride structure as shown in Fig. 1. Here, R_1, R_2 and R_3 indicate the fatty acid chains that are seen in the same or different forms [5]. Chain structure of naphthenic oil is shown in Fig. 2.

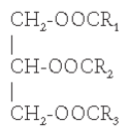

Fig. 1 A triglyceride structure

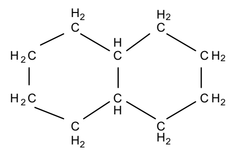

Fig. 2 Chain structure of naphthenic oil

Physical and chemical properties of ester liquids are dependent on the ratio of saturation and unsaturation of fatty acids. Ester oils having high percentage of monounsaturated fatty acids (oleic acid) exhibit better oxidation stability. The fatty acids ratio of analyzed corn oil is given in Table I.

TABLE I
Fatty Acid Composition of Corn Oil-Typically

Properties	Quantity
oil	100 ml (91 g)
saturated fatty acids (g)	11.5
monounsaturated fatty acids (g)	25.3
polyunsaturated fatty acids (g)	54.2

g= gram, ml= milliliter

III. Experimental Study

In our study, APAR 60UX mineral oil and edible corn oil were subjected to aging in a stainless vessel at 90 °C for 18 hours. In this way, moisture ratio in the oil was reduced. Test system in Yildiz Technical University high voltage laboratory was used for measurements, which were performed according to IEC 60156 standard for breakdown voltage and ASTM D924 standard for relative dielectric constant and dielectric dissipation factor [6], [7]. Resistivity of both of the oils was calculated for distinct frequencies and voltages.

Measurements were performed by Omicron CPC100, which allows analysis at variable voltages and frequencies. Fig. 3 shows experimental setup for measurement of tan delta, relative dielectric constant and power loss.

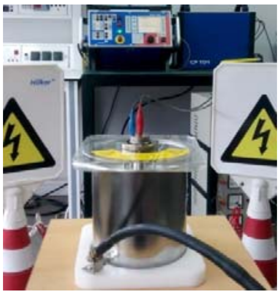

Fig. 3 Experimental setup for measurements

A. Breakdown Voltage

Gap between electrodes were set to 2.5 mm and six measurements were performed in total with voltage rise rate of 2kV/s according to IEC 60156 standard. Breakdown voltage was calculated as average value of these measurements. Breakdown voltage measurements are given in Table II.

TABLE II
BREAKDOWN VOLTAGE VALUES OF THE OILS

Insulating oils	Breakdown voltage (kV)	Standard deviation
apar 60UX	51.60	9.203
corn oil	52.73	8.994

kV= kilovolt

In literature, the acceptance value for breakdown voltage is determined as 30kV/2,5mm [8]. As seen in Table II, corn oil meets this limit value.

B. Dielectric Dissipation Factor (Tan Delta)

When a sinusoidal voltage is applied to perfect capacity, the phase angle between current and voltage is 90°. However there is not any material that has a perfect capacity in power systems. The phase angle between current and voltage in actual capacitance is less than 90°. Deviation angle of 90 ° is shown as 'δ' and defined as 'loss angle'. Tangent of angle (tan δ) is called as dissipation factor. Tan delta is expressed as in (1).

$$\tan\delta = (\omega \cdot R \cdot C)^{-1} \tag{1}$$

Tan delta provides important information about utility of oils in service. Therefore, tan delta of oil was investigated with respect to frequency and voltage considering ASTM D924 standard. Fig. 4 shows measurements with respect to frequency performed at 10kV. In addition, measurements with respect to voltage performed at 50 Hz are shown Fig. 5.

As seen in Figs. 4 and 5, tan delta of corn oil is higher than mineral oil in all frequency levels. The limit value of tan delta for natural ester fluids is specified as 0.20% at 25°C according to ASTM D6871 standard. This limit value is met by corn oil between 175Hz to 400Hz.

C. Relative Dielectric Constant

Relative dielectric constant is the ratio between capacitance of oil filled test cell to the capacitance of empty cell. It is known that complex dielectric constant is defined in (2).

$$\varepsilon^* = \varepsilon' - j\varepsilon'' \tag{2}$$

Reel term of complex dielectric constant can be expressed as:

$$\varepsilon' = \varepsilon_r = \frac{C_x}{C_0} \tag{3}$$

where C_x is capacitance of oil filled test cell and C_0 is capacitance of empty cell. In this study, we measured C_0=62.295*10^{-12} Farad.

Dielectric constants of mineral oil and corn oil in 1kV-12kV range were 2.19 and 3.12, respectively. Fig. 6 shows change of relative dielectric constant with respect to frequency.

In literature, relative dielectric constant of commercial ester fluids is between about 2.9 and 3.2 [9]. Thus, use of corn oil is suitable in terms of relative dielectric constant.

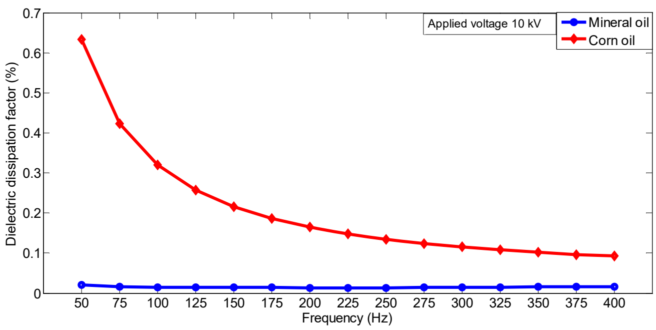

Fig. 4 Change of tan delta with frequency for mineral oil and corn oil

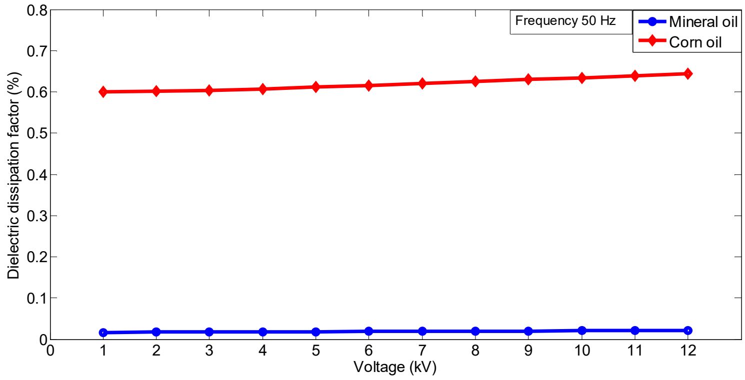

Fig. 5 Change of tan delta with voltage for mineral oil and corn oil

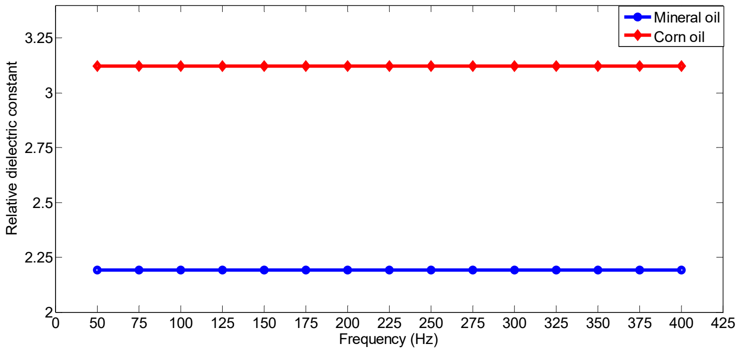

Fig. 6 Change of relative dielectric constant with frequency for mineral oil and corn oil

D. Dielectric Power Loss

When a dielectric material is subjected to stress, active power loss resulting in heat form is observed. Although power loss is low, it is important in terms of energy efficiency. Loss in unit volume is found by dividing dielectric loss to volume of dielectric material. It is known that loss in unit volume is expressed with (4). Loss in dielectric material is also expressed with (5).

$$p = P \cdot V^{-1} = E^2 \cdot \omega \cdot \varepsilon \cdot \tan\delta \tag{4}$$

$$P = \omega \cdot C \cdot U^2 \cdot \tan\delta \tag{5}$$

From above it is seen that dielectric power loss is proportional with frequency, capacitance and tan delta. Measurements were performed for two conditions according to voltage and frequency increase. Fig. 7 shows alteration of voltage with respect to frequency for mineral and corn oils.

The power loss increases exponentially with rising voltage as can be seen in Fig. 8. The power loss in corn oil is more than that of mineral oil.

E. Resistivity

It is desired that oils have a resistivity as high as possible. Resistivity also is inverse electric conductivity. Therefore, we calculated resistivity of oils considering:

$$\tan\delta = \frac{\sigma}{\omega \cdot \varepsilon} \tag{6}$$

$$\rho = (\tan\delta \cdot \omega \cdot \varepsilon)^{-1} \tag{7}$$

where σ is the electric conductivity, ε is dielectric constant of oil, ω is angular frequency and ρ is resistivity.

Resistivity of mineral and corn oil was measured in 1kV-12kV range and 50Hz-400Hz range. Results showed that the resistivity of both oil decreased with rising frequency and voltage.

Fig. 9 shows alteration of resistivity according to frequency. Resistivity of mineral oil is higher than that of corn oil in all frequency ranges.

Fig. 10 shows change of resistivity with respect to voltage. It is seen that resistivity of corn oil is lower than that of mineral oil.

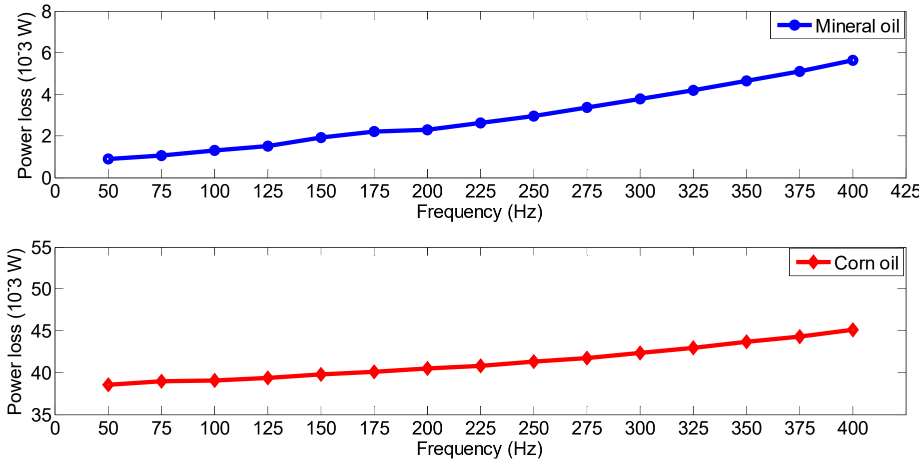

Fig. 7 Change of power loss with frequency for mineral oil and corn oil

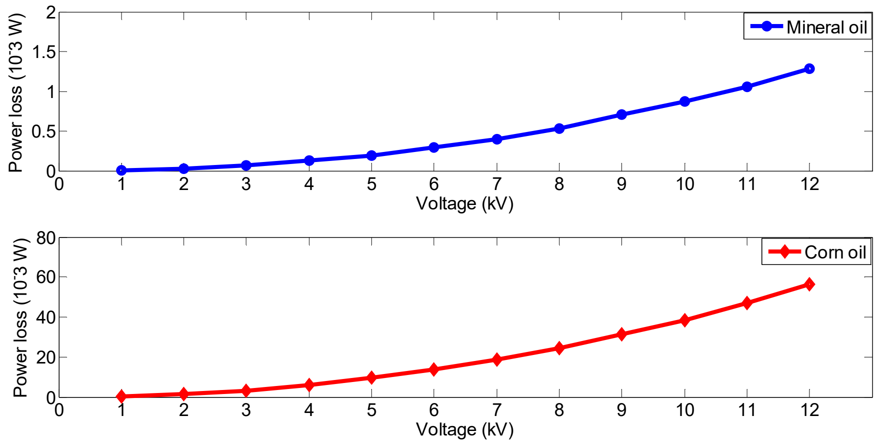

Fig. 8 Change of power loss with voltage for mineral oil and corn oil

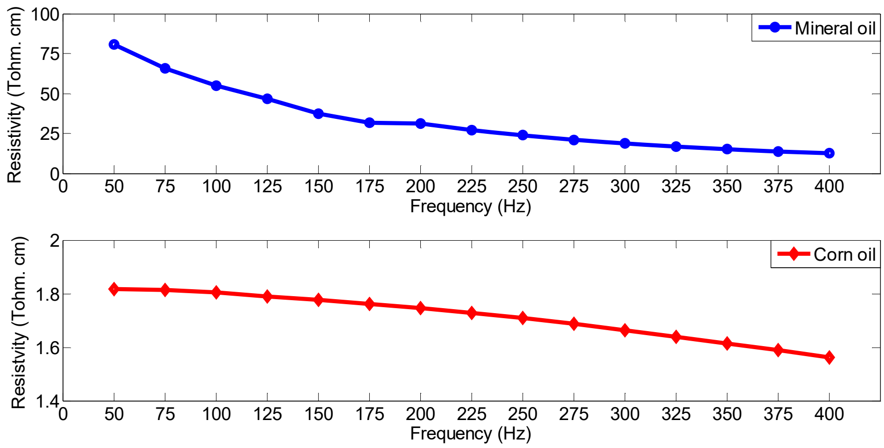

Fig. 9 Change of resistivity with frequency for mineral oil and corn oil

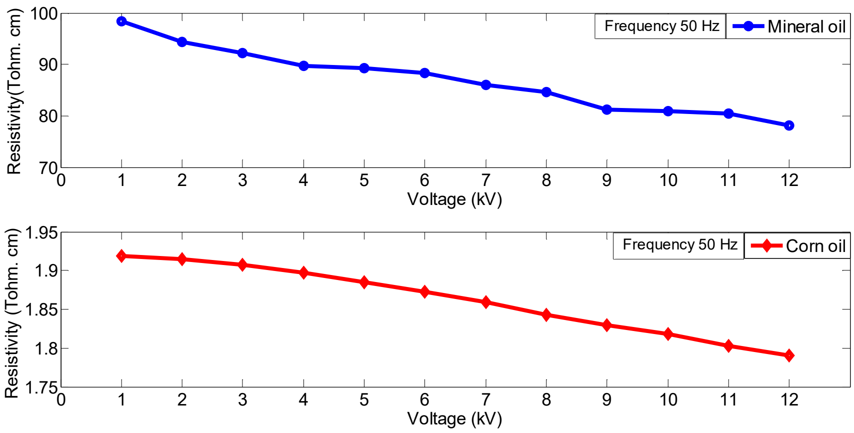

Fig. 10 Change of resistivity with voltage for mineral oil and corn oil

Acceptance value of resistivity in insulating liquids is determined as $1 \cdot 10^{12} \Omega$cm in [8], [10]. Use of corn oil is suitable in terms of resistivity for all measured voltage and frequency values.

IV. Conclusion

In this paper, the properties of mineral oil and edible corn oil including breakdown voltage, tan delta, relative dielectric constant, power loss and resistivity were investigated according to distinct frequency and voltage values.

Measurements demonstrated that while tan delta increased with respect to voltage, it had a tendency to decrease with respect to rising frequency. Relative dielectric constant was not affected from alteration within measured voltage and frequency ranges. Power loss increased with rising frequency and voltage. Resistivity of the oils decreased with respect to frequency and voltage.

The harmonic component of voltage should be reduced in order to minimize dielectric dissipation factor and power loss.

It is seen that use of edible corn oil in transformers is suitable considering breakdown voltage, dielectric constant and resistivity. Filtering process and chemical treatment may cure tan delta of corn. By this way, corn oil might be a good candidate for use in transformers.

References

[1] M H. Abderrazzaq, F. Hijazi, “Impact of Multi-Filtration Process on the Properties of Olive Oil as a Liquid Dielectric”, *IEEE Trans.on Dielectrics and Electrical Insulation,* vol.19, no.5, pp. 1673-1680, Oct. 2012.

[2] H.M. Wilhelm, M.B.C Stocco, L. Tulio, W. Uhren and S.G. Batista, “Edible Natural Ester Oils as Potential Insulating Fluids”, *IEEE Trans.on Dielectrics and Electrical Insulation,* vol.20, no.4, pp. 1395-1401, August 2013.

[3] C. Kocatepe, O. Arikan, E. Taslak, C.F. Kumru, “Breakdown Voltage Analysis of Insulating Oils under Different Conditions” *Electric Power and Energy Conversion Systems (EPECS), 2013 3rd International Conference on, IEEE,* 2013, pp. 1-4.

[4] Cigre Working Group A2-35, "Experiences in Service with New Insulating Liquids," in Brochure 436, October 2010.

[5] T.V. Oommen, “Vegetable Oils for Liquid-Filled Transformers”, *Electrical Insulation Magazine, IEEE*, vol.18, no.1, pp.6-11, Jan.-Feb. 2002.

[6] IEC 156, *Insulating Liquids-Determination of Breakdown Voltage at Power Frequency-Test Method*, IEC, Second ed., Switzerland: IEC, 1995.

[7] ASTM D924-08, *Standard Test Method for Dissipation Factor (or Power Factor) and Relative Permittivity (Dielectric Constant) of Electrical Insulating Liquids*, West Conshohocken, PA, USA: ASTM, 2008.

[8] M. Kohtoh, G. Ueta, S. Okabe and T. Amimoto, “Transformer Insulating Oil Characteristic Changes Observed Using Accelerated Degradation in Consideration of Field Transformer Conditions”, *IEEE Trans.on Dielectrics and Electrical Insulation,* vol.17, no.3, pp. 808-818, June 2010.

[9] I. Fernandez, A. Ortiz, F. Delgado, C. Renedo and S. Perez, “Comparative Evaluation of Alternative Fluids for Power Transformers”, *Electric Power Systems Research*, vol. 98, pp. 58-69, 2013.

[10] ASTM D1169-11, *Standard Test Method for Specific Resistance (Resistivity) of Electrical Insulating Liquids*, West Conshohocken, PA, USA: ASTM, 2011.

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