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An Investigation on Vegetable Oils as Potential Insulating Liquid

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Abstract**—**While choosing insulating oil, characteristic features such as thermal cooling, endurance, efficiency and being environment-friendly should be considered. Mineral oils are referred as petroleum-based oil. In this study, vegetable oils investigated as an alternative insulating liquid to mineral oil. Dissipation factor, breakdown voltage, relative dielectric constant and resistivity changes with the frequency and voltage of mineral, rapeseed and nut oils were measured. Experimental studies were performed according to ASTM D924 and IEC 60156 standards.

Keywords**—**Breakdown voltage, dielectric dissipation factor, mineral oil, vegetable oils.

I. Introduction

THE insulating liquids are used to provide electrical insulation and thermal cooling in high voltage power equipment such as transformer (power, distribution, traction etc.), circuit breaker, capacitor, cable, bushing and load tap changer etc. The power equipment needs are increasing as a result of increasing electrical demand in the world day by day. Especially, increase in power losses in high voltage system equipment cause to rises in equipment temperature. So, it is particularly necessary to dissipate the generated heat fast, reliable and economically. It is known that some of the electrical faults occur in power transformers arise from weak insulating performance of used oil. Electrical and chemical analysis of the insulating oil can provide information about failures.

Breakdown voltage measurement is a classic test method for analysis of insulating oils. Dielectric dissipation factor so-called tan delta is one of the important parameters to have information about the quality of insulation. Dielectric properties of the oil vary depending on several factors such as temperature, frequency, polarity, voltage level, electrode geometry, particle, moisture etc.

The breakdown voltage and breakdown time of mineral oil were analyzed according to different electrode topology by researcher [1]. Furthermore, the number and size of particles have a major effect on breakdown voltage level of insulating oil. Because, they become polarized particles which exposed to electrical field and come between electrodes to facilitate the beginning of breakdown. Here, the particle effect on breakdown voltage was examined [2], [3].

The publications were analyzed dissipation factor based on temperature and aging of oil [4], [5]. However, only few reports were made about variation of relative dielectric constant, dissipation factor and resistivity with respect to distinct frequency and voltage as an alternative insulation liquid to conventional mineral oil.

In this paper, breakdown voltages of mineral oil, edible rapeseed and nut oil are compared according to the IEC 60156 standard. Then, dissipation factor and relative dielectric constant measurements at certain frequencies and voltage levels are carried out as specified in ASTM D924 standard. In addition, changes in resistivity value with frequency and voltage of both oils are presented.

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II. Insulating Liquids

Insulation liquids can be categorized depending on chemical structures. The main types of dielectric liquids are generally mineral oils, high molecular weight hydrocarbons (HMWH), silicones and ester-based fluids [6].

Mineral oil is referred to as petroleum-based oil and consist of different bonding of the mainly carbon and hydrogen molecules. There are paraffinic, naphthenic and aromatic oil which contain different ratios of components [7]. Classification of the oils according to these rations is given Table I.

TABLE I
CLASSIFICATION OF THE OIL [7], [8]

Paraffin bond carbon (C_p %)	Oil type
42-50	Naphthenic
50-56	Aromatic
56-65	Paraffinic

Mineral oils has been used as an insulation and cooling liquid in power system equipment for more than 100 years because of low viscosity, wide availability and low-cost compared with the other liquids [9].

The mineral oil used in this paper is severely hydrogenated light naphthenic petroleum oil. In Table II, some of the electrical and physical features of this oil are given.

TABLE II
PROPERTIES OF MINERAL OIL-TYPICALLY

Symbol	Properties	Naphthenic oil
g/ml	Density (15ºC)	0.89
mm^2/s	Viscosity (40ºC)	10
°C	Flash point	>145
°C	Pour point	<-45
	Dissipation factor (90 ºC)	<0.005
kV	Breakdown voltage (2.5mm gap)	>30

g=gram, ml=milliliter, kV=kilovolt

Natural esters are produced from oil of plant seeds. 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 analysed rapeseed oil and nut oil are given in Table III.

TABLE III
FATTY ACID COMPOSITION OF RAPESEED AND NUT OIL-TYPICALLY

Properties	Rapeseed oil	Nut oil
	Quantity	Quantity
oil	100 ml (91 g)	100 ml (100 g)
saturated fatty acids (g)	7	8
monounsaturated fatty acids (g)	58	77
polyunsaturated fatty acids (g)	26	15

g= gram, ml= milliliter

III. EXPERIMENTAL STUDY

In the experimental study, APAR 60UX mineral oil and edible rapeseed and nut oils were subjected to aging in a stainless vessel at 90°C for 18 hours. In this way, moisture ratio in the oil was reduced. Thereafter, oils were conserved at 25°C of laboratory environment for measurements. Breakdown voltage (BDV) of these oils was measured according to IEC 60156 standard and dissipation factor and relative dielectric constant measurements were performed as described in ASTM D924 standard [10], [11]. In addition, resistivity of oils was calculated with respect to frequency and voltage.

A. Breakdown Voltage

Nowadays, aging and contamination conditions of oils can be measured by applying physical, chemical and electrical test. Thus, before a fault take places in transformer and other electrical equipment, the necessary measures should be taken. Breakdown voltage test has significance about oil quality.

After oil container was slowly shaken a few times, driblet oil was used for cleaning of test cell. Then, the cleaning oil was drained and the cell was filled with clean oil without producing air bubbles. For purging the oil from air, the cell was closed and waited for 5 minutes until applying test voltage. Gap between electrodes were set to 2.5 mm and six measurements were performed in total with voltage rise rate of 2 kV/s according to IEC 60156 standard. In addition, after each breakdown, it was waited 2 minutes. Breakdown voltage measurements are given in Table IV.

TABLE IV
BREAKDOWN VOLTAGE VALUES OF THE OILS

Insulating oils	Breakdown voltage (kV)	Standard deviation
Apar 60UX	51.60	9.203
Rapeseed oil	74.78	3,110
Nut oil	75.95	2.618

In literature, the acceptance value for breakdown voltage is determined as 30kV/2,5mm [12]. As seen in Table II, all of oils tested meet this limit value. Moreover, rapeseed and nut oils might be an alternative to mineral oil in terms of breakdown voltage.

B. Dielectric Dissipation Factor (Tan Delta) and Relative Dielectric Constant

Dissipation factor provides important information about quality of insulating oil which has been aged and contaminated in service. Dielectric dissipation factor is expressed as in (1):

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

The relative dielectric constant of insulation oil (ε_r) is found by the ratio of oil-filled test cell capacity (C_x) to capacity of empty test cell (C_0) as shown in (2). It is known that the higher dielectric constant is better for more uniformly electric field:

$$\varepsilon_r = \frac{C_x}{C_0} \tag{2}$$

The dissipation factor and relative dielectric constant changes were measured according to the voltage and frequency changes. Fig. 1 shows variation of dissipation factor with respect to voltage for mineral, rapeseed and nut oils. Measurements of dissipation factor with respect to frequency are shown in Fig. 2.

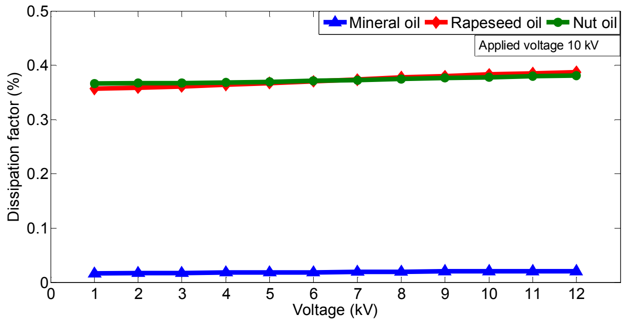

Fig. 1 Change of tan delta depending on voltage

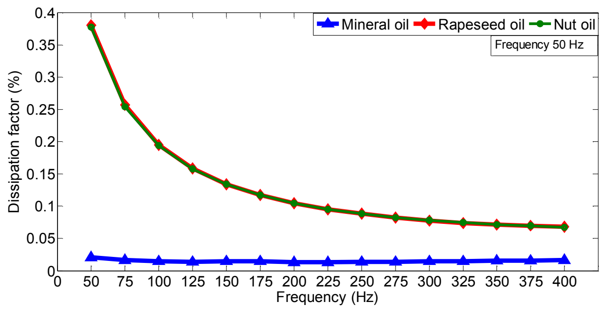

Fig. 2 Change of tan delta depending on frequency

As can be seen in Figs. 1, and 2, while dissipation factor increases with rising voltage, it decreases with rising frequency for all oil types. Dissipation factor of nut and rapeseed oils is found to be quite close. The limit value of dissipation factor for natural ester fluids is specified as 0.20 % at 25°C according to ASTM D6871 standard. This limit value is met by rapeseed oil and nut oil from 100 Hz to 400 Hz.

Relative dielectric constant of mineral oil, rapeseed and nut oil was measured according to distinct voltage. In addition, it was also measured at 50Hz to 400Hz frequency range. It is seen that relative dielectric constant was not affected from change of frequency and voltage. Fig. 3 shows change of relative dielectric constant with respect to voltage.

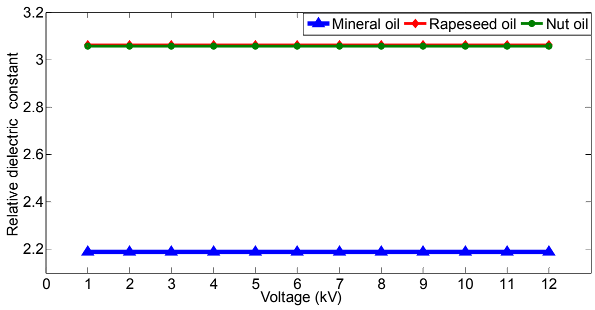

Fig. 3 Change of relative dielectric constant with voltage

In literature, relative dielectric constant of commercial ester fluids is specified between about 2.9 and 3.2 [13]. Relative dielectric constants of rapeseed and nut oil are 3.06 and 3.05 respectively. Thus, use of rapeseed and nut is suitable in terms of relative dielectric constant.

E. Resistivity

It is desired that oils have a resistivity value as high as possible. Resistivity of oils is expressed with (3):

$$\rho = (\tan\delta \cdot \omega \cdot \varepsilon)^{-1} \tag{3}$$

where ε is dielectric constant of oil, ω is angular frequency and ρ is resistivity. Resistivity of mineral oil was calculated in 1kV-12kV voltage and 50Hz-400Hz frequency ranges. Fig. 4 shows variation of resistivity with respect to voltage at 50 Hz. Changes in resistivity according to frequency at 10kV is showed in Fig. 5.

It is seen that resistivity of the oils generally is in a decreasing trend with rising frequency and voltage. Resistivity of mineral oil is higher than those of rapeseed and nut oil. In addition, it is seen that rapeseed and nut oils have quite close resistivity.

Acceptance value of resistivity in insulating liquids is determined as $1 \cdot 10^{12}\Omega$cm in [12], [14]. Use of rapeseed and nut oils is suitable in terms of resistivity for all measured voltage and frequency ranges.

IV. Conclusion

In this paper, breakdown voltages of mineral, edible rapeseed and nut oil were compared. In addition, the properties of their including dissipation factor, relative dielectric constant and resistivity were investigated based on distinct frequency and voltage. It is seen that breakdown voltage of rapeseed and nut oil was quite close together and also higher than that of mineral oil. When dissipation factor of oils was found to increase with increasing voltage, it decreased with increasing frequency from 50Hz to 400Hz. It is seen that dissipation factor of nut oil was closer to rapeseed oil. The relative dielectric constant of the oils was not affected from the change in frequency and voltage. Resistivity of the oils decreased with respect to rising frequency and voltage. In the light of our results, after filtering process and chemical treatment, rapeseed and nut oils might be a good candidate as an insulating liquid in power equipment.

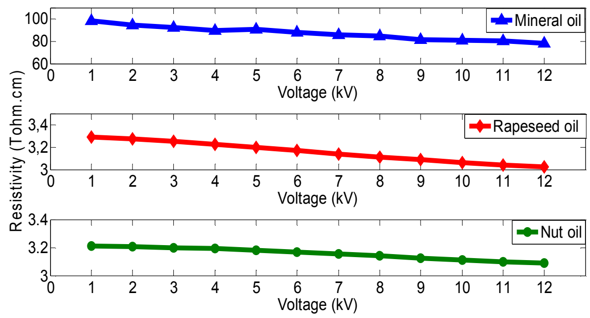

Fig. 4 Change of resistivity with voltage

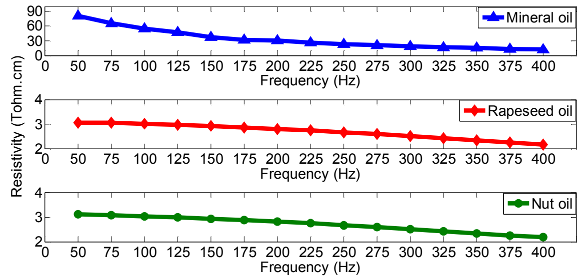

Fig. 5 Change of resistivity with frequency

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