DIELECTRIC PROPERTIES OF NATURAL OILS FROM DIFFERENT OILSEEDS

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Abstract: This paper describes analysis of perspective, ecological and environmentally-friendly electrical insulating liquids for electrical engineering. In the experimental part, dielectric properties of the most common vegetable oils were analyzed and compared with frequently used non-inhibited mineral oil (TrafoN): soybean oil, sunflower oil, rapeseed oil, peanut oil and two types of olive oils (extra virgen and pomace). Dielectric properties were measured using the high-resolution Novocontrol Alpha-A Frequency Analyzer in the frequency range 1 Hz – 1 MHz in the temperature interval 243 K – 363 K.

Keywords: activation energy, biodegrability, conductivity, dielectic constant, frequency dependence, temperature dependence, insulating liquids, mineral oil, methyl oleate, natural oil, olive oil, peanut oil, rapeseed oil, soybean oil, sunflower oil.

1 INTRODUCTION

1.1 MINERAL OILS AS INSULATING LIQUIDS

Insulating oil must have to function as a liquid insulating material (minimum conductivity), functioning as a heat transfer medium and to be stable against oxidation for many years. Mineral oils are transformer oil refined from petroleum. Mineral oils are mixtures of various alkanes and as such they are unique from each supplier and may vary by electrical, chemical and physical properties. To determine the tolerance allowed values was created to technical standards for insulating liquids, etc. so that the oil producers comply with the uniform tolerance parameter oils have to satisfy [1].

Mineral oil is used as a dielectric in transformers, but also in cables and capacitors. The ad-vantage of mineral oils in comparison with types of oils is their high resistance to aging. Transformer oil required low viscosity oils. For the correct selection oil we have to choose appropriate profile of the transformer and transformer oil with stable properties and experimentally verified rheological properties which may affect heat transfer, leakage or lack of oil in the transformer. For all types of mineral and non-mineral transformer oils, one needs to know in particular the following parameters: kinematic viscosity, density, flash point, pour point, breakdown voltage, relative permittivity, loss number and oxidative stability. The most important parameters of transformer oils include long-term stability of parameters that affects the reliability of equipment and especially the costs of operating transformers in distribution systems. At the moment, inhibited oil replace uninhibited oil previously used. All countries haven't their own mineral oil deposits. These countries include among else Brazil, Argentina, Peru, Chile, Paraguay, India, Pakistan. These countries are engaged in growing crops, which can be used for the production of natural oils. Applicable crops are: rapeseed, sunflower, flax, soybean, olive, poppy, corn and other. Natural oils are natural esters with different fatty acid composition. Fig. 1 shows fatty acids in the most of oils [1].

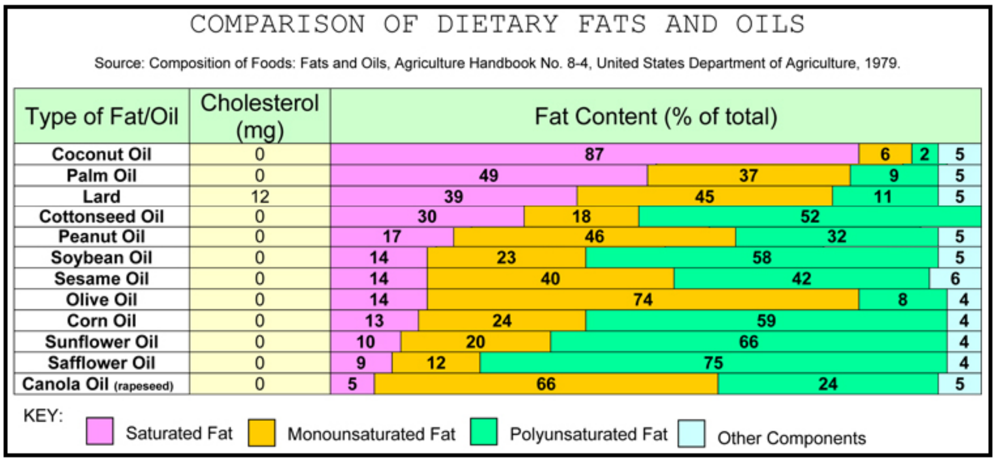


Figure 1: Comparison of Dietary Fats [2]

1.2 NATURAL OIL AND OILSEEDS

Natural esters and primarily rapeseed oil were previously considered unsuitable, especially due to low oxidative stability. Regrown and satisfactory materials for the production of natural esters are the seeds of oilseed crops grown commercially in farming. Liquids made from these seeds are composed of triglycerides. Triglyceride is a molecule of glycerol with three molecules bound him to fatty acids (Fig. 2). Unsaturated fatty acids in the liquid exhibit lower oxidative stability and lower values of dynamic viscosity [1].

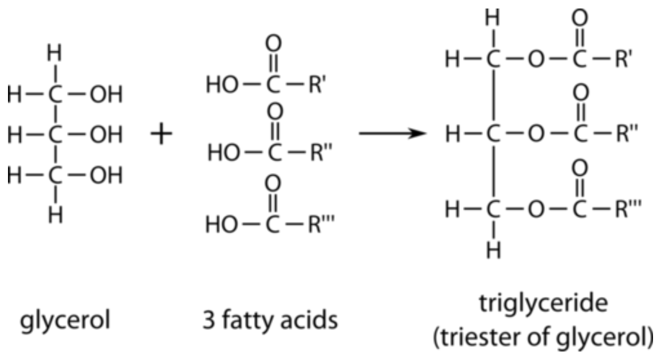


Figure 2: General triglyceride structure [3]

1.3 DIELECTRICAL PROPERTIES OF LIQUID

For the correct selection of electrical insulating liquids is necessary to know these dielectric properties: dielectric constant and loss number (Fig.3 and Fig. 4). Another relevant parameter is the influence of temperature on the change of parameters. Oils are tested in laboratory conditions using various accelerated aging tests in order to monitor changes in parameters over time. The changes are mainly influenced by the oxidative stability of oil.

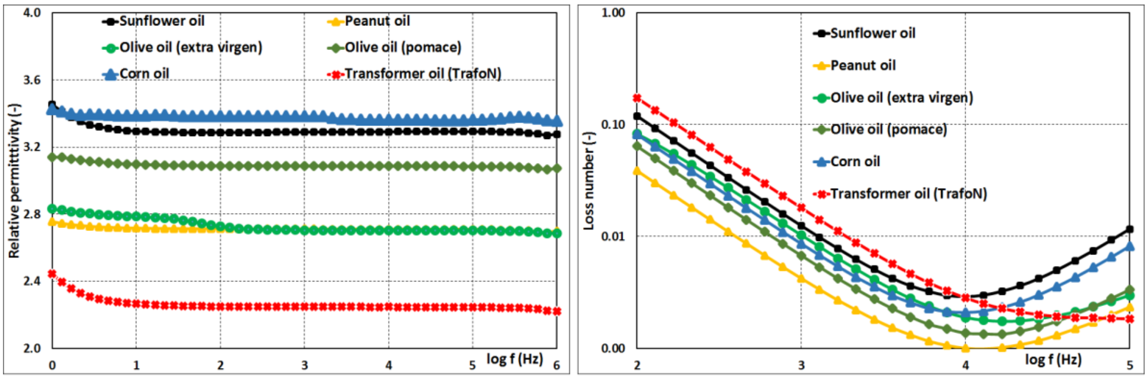
Oil aging process are exacerbated their insulating properties, with the associated parameters, such as relative permittivity and loss number. The values of the relative permittivity of oil defined so, that the how many times capacitance of the capacitor increases when used in place of vacuum oil. The oil aging process influences the chemical composition and decrease of values of relative permittivity. The loss number increases as the usual components are added conductivity polarization losses (oxidative aging, occurrence of humidity, etc.). For these reasons it is necessary to observe these parameters for finding a suitable analogue of natural oil behind a mineral, which is oxidatively more stable.

The conductivity of liquid insulators is influenced by concentration of free carriers of electric charge that may be due to ionization of neutral molecules, molecular dissociation own liquid, dissociation of molecules of matter, electron emission from the cathode in strong electric fields and thermal excitation of electrons. Temperature dependence of the mobility of free carriers of electric charge causes a strong dependence of conductivity on the temperature of insulating liquid. Technically pure liquids with conductivity in the order of 10^{-11} to 10^{-12} S/m [4].

2 EXPERIMENTAL PART

2.1 DIELECTRICAL PROPERTIES

For study the dielectric properties were selected samples natural oils (sunflower, peanut, two types of olive oils, corn oil) for comparison with mineral oil TrafoN (N = non-inhibited). Measurements were performed using Novocontrol Alpha-A and electrode system for liquid samples Novocontol cell 1308. The samples of natural oil show higher values of relative permittivity compared with mineral oil. The highest values of relative permittivity (at 10 kHz) reached corn oil (ε_r = 3.86) and sunflower oil (ε_r = 3.29) and lowest value of relative permittivity mineral transformer oil TrafoN 2.25 (Fig. 3a). For parameter loss number (Fig. 3b) it is reversed (to 10 kHz) has a higher values mineral oil compared to mineral oil.



a) b)

Figure 3: Frequency dependence of: a) relative permittivity of natural oils and transformer oil with temperature 283 K as parameter, b) loss number of natural oils and transformer oil with temperature 283 K as parameter

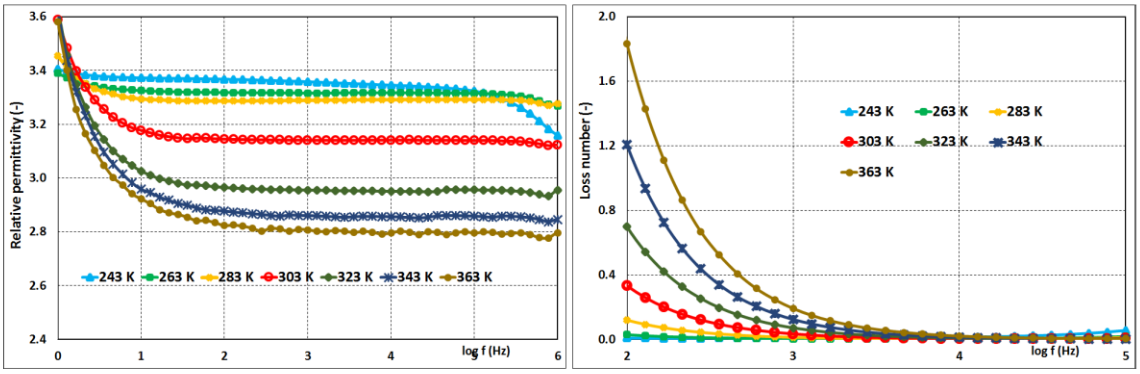


Figure 4: Frequency dependence of sunflower oil: a) relative permittivity of sunflower oil with temperature as parameter, b) loss number of sunflower oil with temperature as parameter

Fig. 4 shows changes in temperature spectrum of relative permittivity of sunflower oil (Fig. 4a) and changes in temperature spectrum of loss number of sunflower oil (Fig. 4b). The Fig. 4 shows, that increasing temperature causing an decrease in the values of relative permittivity and increase values of loss number.

2.2 CONDUCTIVITY AND ACTIVATION ENERGY

Dielectric constant (permittivity $\varepsilon_r = \varepsilon'$) (1) is defined as a ratio of capacity of an empty electrode system C_0 (Novo-control BDS 1308 with silica spacers) → C_0 = 27.82 pF) fully filled by air and capacity C_x when liquid is filled in the electrode system.

$$\varepsilon' = \frac{C_X}{C_0} \quad . \tag{1}$$

In case dielectric losses are solely due to conductivity contribution the acquired results should be better analyzed in the framework of the conductivity formalism. Conductivity σ and dielectric loss ε'' are related to each other (2) as

$$\sigma = \omega \varepsilon_0 \varepsilon'' \ , \tag{2}$$

where ω is angular frequency and ε_0 is permittivity of free space (ε_0 = 8.854 x 10^{-12} F/m).

The highest conductivity is of 1 nS/m at frequency 1 kHz is shown in mineral oil (TrafoN). The second highest conductivity 0.69 nS/m had natural sunflower oil. Other samples of natural oils had these values: olive oil (extra virgin) 0.57 nS/m, corn oil 0.47 nS/m, olive oil (pomace) 0.37 nS/m and peanut oil 0.23 nS/m.

The activation energy E_A is the height of the energy barrier hampering a transition of an electron, another elementary particle, atom, molecule or segment from one local energy minimum to another. The activation energy was calculated under the assumption that the temperature dependence of conductivity satisfies Arrhenius equation (3):

$$\sigma = Ae^{-\frac{E_A}{RT}} \ , \tag{3}$$

where A is a frequency factor (S/cm), R is gas constant (R = 8.314 x 10^{-3} kJ/(mol K)) and T is temperature (K). The calculations activation energies E_A were performed in accordance with the equation (3) addition of all values except the frequency factory A and activation energy E_A, and formed a system of two equations with two unknowns (A, E_A).

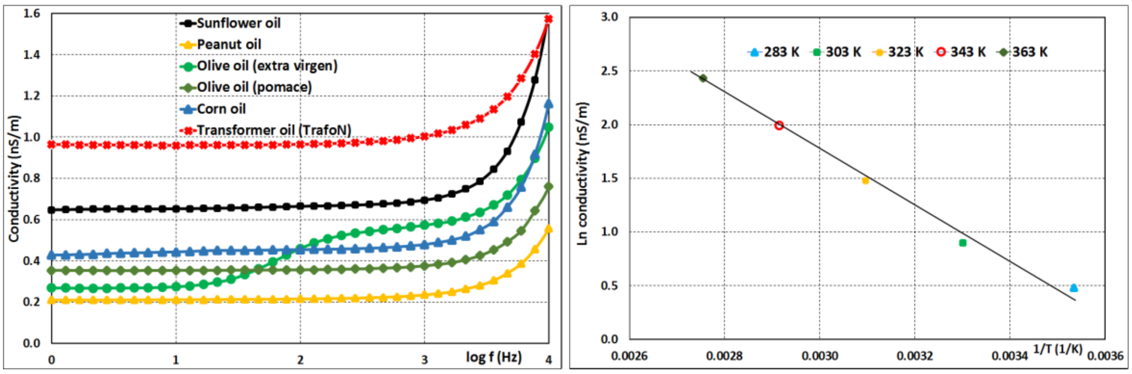


Figure 5: a) Conductivity of natural oils (sunflower, peanut, two types of olive oils, corn oil) and transformer oil with temperature T = 283 K as parameter, b) Ln conductivity of sunflower oil with temperature (from 283 K to 363 K)as parameter

3 DISCUSSION

Properties natural oils can vary genetically propagated species, but also growing place in the same regions on the grounds that is conducted sowing field on one every four years of higher returns. Mineral oils from the same raw material may have different composition parameters from a different manufacturer. In the Czech Republic can not growing rice and palm trees, so it is better for us growing oilseeds such as sunflower, canola and corn. Locally grown crops reduce its cost and improve availability. At this time can also be be imported from abroad coconut and palm kernel oil. These imported oil, but disagree grow ecologically (cutting down forests, threats of space for exotic and wild animals).

In Table 1 is see the comparison of the activation energy E_A calculated for different types of oils (six natural oils (+ methyl ester) versus one mineral oil): sunflower, peanut, olive oils (extra virgen), olive oils (extra virgen), corn oil, soybean oil, methyl oleate and mineral oil TrafoN. The highest value of activation energy of 31.6 MJ/kmol was calculated for natural oil – soybean oil and the lowest value 20.1 MJ/kmol for methyl oleate.

4 CONCLUSION

The size of the activation energy of insulating liquids describes a possibility starting of degradation mechanisms delivery such a large energy, which causes, that particles overcome the energy barriers. That energy which causes a transition particles to a different energy band is called activation energy. By supplying the activation energy required size will cause that particles in the oil leaves the stable state, thereby causing the formation of degradation processes oily structure.

Therefore it is necessary to examine the size of the activation energies of various oils, because the greater this energy, thus the higher the chemical stability the examined oils. The chemical resistance (oxidation stability) affects a change in dielectric parameters (relative permittivity, loss number and other). The main finding, that the highest value E_A has soybean oil and therefore is most chemically resistant oil. Worst stability of has methyl ester (methyl oleate), and therefore is least resistant to aging.

The activation energy E_A of different types of oils			
Sunflower oil	29.1 MJ/kmol	Corn oil	26.3 MJ/kmol
Peanut oil	29.8 MJ/kmol	Soybean oil	31.6 MJ/kmol
Olive oil (*extra virgin*)	27.0 MJ/kmol	Transformer oil (*TrafoN*)	30.2 MJ/kmol
Olive oil (*pomace*)	25.8 MJ/kmol	Methyl oleate (methyl ester)	20.1 MJ/kmol

Table 1: Size of the activation energy for different natural oils and mineral oil

ACKNOWLEDGEMENT

This work was supported by the Internal Grant Agency of Brno University of Technology, grant No. FEKT-S-17-4626“.

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