COMPARISON OF MINERAL OIL WITH NATURAL AND SYNTHETIC OILS

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Abstract: This work describes the application of natural insulating fluids in electrical engineering, allocation by to the types of chemical structures. For the selection are described below essential parameters determining the proper choice for insulating liquids with satisfactory environmental requirements and sufficient oxidative stability. This work deals with experimental measurements of rheological and dielectric properties in the frequency domain. For the found results of the experiments were calculated activation energy of selected oils.

Keywords: Activation energy, Archimedes law, conductivity, dielectric constant, loss number, FAME, fatty acids, methyl laurate, methyl oleate, methyl stearate, Midel, natural ester, rapeseed oil, renolin.

1. INTRODUCTION

1.1. MINERAL AND NON-MINERAL OILS AS INSULATING LIQUIDS

Worldwide are in distribution systems electrical transformers filled with an insulating liquid. E.g., in 1998 there were used in the U.S. 30 million. This fluid has to be electrically insulated well, 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 advantage 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 this time, the persistently increasing ecological requirement for the use of natural oils (esters of higher fatty acids). All countries haven't their own mineral oil deposits. These countries include, among else, Brazil, Argentina, Paraguay, India and Pakistan. These countries are engaged in growing crops, which can be used for the production of natural oils. Applicable crops are: canola, sunflower, flax, soybean, olive, poppy and other. Natural oils are natural esters with different fatty acid composition. Fig. 1 shows fatty acids in the most of oils.

1.2. NATURAL AND SYNTHETIC ESTERS

Synthetic esters are usually liquid polyol esters (POES) with the required dielectric properties. Their biodegradability is better than that of mineral oils. The railways and other special applications began since 1984 to use these esters in transformers. The advantage of synthetic esters is their excellent thermal stability and low temperature setting. The seven main types of these esters include: diester, phthalate, trimellitate, pyromellitate, dimer acid ester, polyols, and polyoleates. The fundamental disadvantage of synthetic esters is their high price. A significant factor is the requirement to use alternative and regrown plants in large quantities in farming grown [1].

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. Unsaturated fatty acids in the liquid exhibit lower oxidative stability and lower values of dynamic viscosity [1].

The experiment used a shorter name for methyl esters of acids such for example as lauric acid to methyl ester is methyl laurate used name.

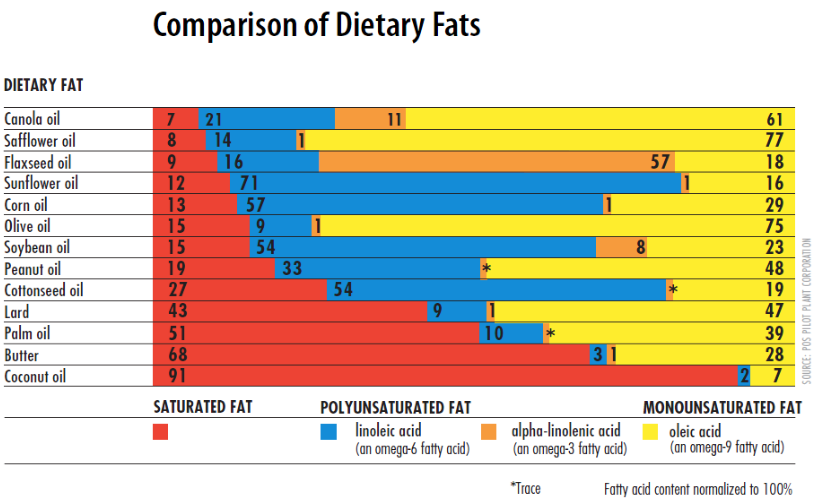

Figure 1: Comparison of Dietary Fats [2]

1.3. RHEOLOGICAL AND DIELECTRICAL PROPERTIES

Important rheological properties use in electrical engineering are viscosity and density, which affect the behavior of liquid in dependence to changes in operating temperature. If these parameters are taken into account, it can lead to poor lubrication of moving parts, loss or leakage liquid from the transformer. Viscosity is a measure of fluidity of liquids can be divided into two types: kinematic and dynamic. Kinematic viscosity is influenced by gravitational force and its conversion to dynamic it is necessary to know the density of the liquid at a given temperature. The density of liquids can be measured in standard laboratory conditions.

For the correct selection of electrical insulating liquids is necessary to know these dielectric properties: dielectric constant and loss number. 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.

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. The mobility of free carriers affects the viscosity, which is a rheological parameter. The relationship between conductivity and dynamic viscosity can be described Walden's law [3].

2. EXPERIMENTAL PART

2.1. RHEOLOGICAL PROPERTIES

For find the density the density of different types depending on the temperature of oil were the following oils: synthetic ester (Midel 7131), natural (rapeseed oil), silicone (Luko Oil Silik M 350), methyl ester rapeseed oil (FAME) and one mineral Renolin Eltec T. The waveform in Fig. 2 is showing the density in dependence on temperature in the inverse temperature interval from 250 to 370 K. The lowest values were found in mineral oils and methyl ester rapeseed oil.

The principle of density measurements using principle Archimedes' law takes into account the gravity and buoyancy force acting on the plunger (calibrated glass weights) with a defined volume (V_{pl}). For calculate the density is necessary to know the weight of the plunger calibrated (calibrated glass weight) weighed in air (m_A) and immersed in liquid (m_L). The density of the liquid can be calculated according to equation:

$$\rho = \frac{m_A - m_L}{V_{pl}} \tag{1}$$

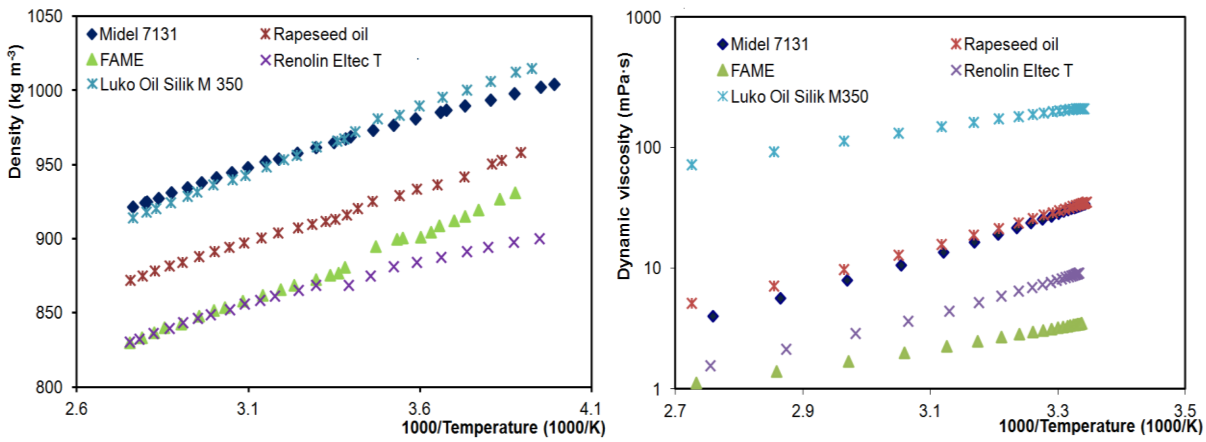

Figure 2: Plot of density and dynamic viscosity *vs.* reciprocal temperature for different oils

2.2. DIELECTRICAL PROPERTIES

For study the dielectric properties were selected samples FAME and rapeseed oil methyl ester for comparison with the two fatty acids found in rapeseed oil. Measurements were performed using LCR meter Agilent 4284 and electrode system for liquid samples Agilent 1642. The highest values of relative permittivity reached and lowest FAME 3.24 and lowest methyl laurate 2.94 (Fig. 3). Loss number of these samples resulted in at least rapeseed oil, the FAME samples of methyl laurate and stearate loss and the number declined with increasing frequency.

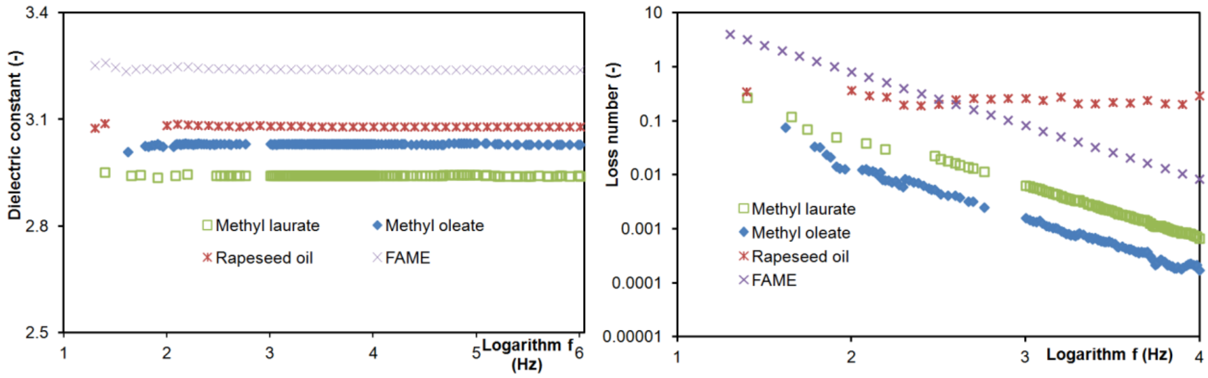

Figure 3: Frequency dependence of dielectric constant and loss number

2.3. CONDUCTIVITY AND ACTIVATION ENERGY

The external electric field in insulating liquids may cause the ions, but the state can also occur when the ion captures the molecule, forming a single unit. Effect of temperature can cause separation of ions from the molecule to overcome some potential barriers to energy Ea, called the activation energy. For calculate the activation energy can be used temperature dependence of ionic conductivity according to the equation:

$$\sigma = \sigma_0 e^{-\frac{E_A}{kT}} . \qquad (2)$$

To Fig. 4 can see rapeseed oil. The highest conductivity is of 15 nS/m at frequency 1 MHz is shown in rapeseed oil. Conductivity values of the other samples are given for frequency of 10 kHz. The second highest conductance 4 nS/m had FAME. Methyl esters had the lowest conductivity of these values: methyl laurate 0.087 nS/m and methyl oleate 0.097 nS/m For methyl conductivity values were at frequencies above 30 kHz useless because the values are close to the threshold of resolution LCR meter Agilent 4284 instrument, that were loss factor lower than 0.00001 (-).

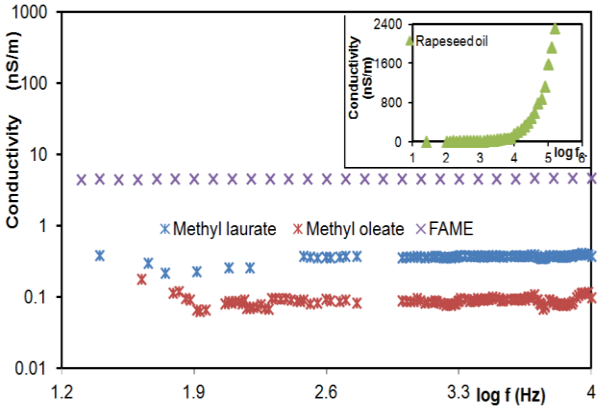

Figure 4: Conductivity of methyl esters, FAME and rapeseed oil vs. Logarithm frequency

In Table 1 is see the comparison of the activation energy E_A calculated for different types of oils: synthetic MIDEL 7131, rapeseed oil, silicone oil (Luko Oil Silik M 350), rapeseed oil methyl ester (FAME) and mineral oil RENOLIN Eltec T. The highest value of activation energy of 30.3 MJ/kmol was calculated for oil MIDEL 7131 and the lowest 14.8 MJ/kmol for FAME. In the second column are calculated to compare the activation energy of methyl esters of three acids found in rapeseed and other oils. The rapeseed oil with methyl oleate occurs in approximately 60% of the composition and its activation energy was determined 22.8 MJ/kmol. Rapeseed oil had the activation energy of 26.3 MJ/kmol. The difference is due to other fatty acids contained in oil. Representation of the ratio of fatty acids in natural oils differ in genetic intervention in the growing of plants, both the composition of the soil in which plants were grown. The proportion and type of fatty acids influences the solidification temperature, which is not common in natural oils significantly below 0 ° C as in mineral and synthetic oils.

The activation energy E_A of different types of oils		**The activation energy of fatty acids**	
Midel 7131	30.3 MJ/kmol	Methyl laurate	30.2 MJ/kmol
Rapeseed oil	26.3 MJ/kmol	Methyl oleate	22.8 MJ/kmol
Luko Oil Silik M 350	14.6 MJ/kmol	Methyl stearate	8.7 MJ/kmol
Fame	14.8 MJ/kmol		
Renolin Eltec T	24.1 MJ/kmol		

Table 1: Size of the activation energy for different oils and three compounds of natural esters

3. CONCLUSION

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. Experimental measurement of rheological and dielectric properties of various types of oils evaluated the differences between species, as known fact that mineral oils are less dense. For individual types of oils has been calculated activation energy. The activation energies were also calculated for the three methyl esters of fatty acids found in natural oils (Fig. 1). The highest conductivity 15 nS/m was found in rapeseed oil and 4 nS/m FAME. The lowest conductivity was methyl esters: methyl oleate and 0.097 nS/m and methyl laurate 0.087 nS/m.

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REFERENCES

[1] McShane, C. P. , Vegetable-oil-based dielectric coolants, Industry Applications Magazine, IEEE, vol. 8, pp. 34-41, May-Jun 2002. Waukesha, WI, USA.

[2] ditfatpadFINAL.pdf [online]. [cit. 2012-02-28] Dostupné z www: <http://www.canolainfo.org/quadrant/media/downloads/pdfs/ditfatpadFINAL.pdf>

[3] MENTLÍK, V. Dielektrické prvky a systémy. 1. Vydání, Praha : BEN - technická literatura, 2006. 240 s. ISBN 80-7300-189-6.