DIELECTRIC ANALYSIS OF NATURAL OILS

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SUMMARY

This article deals with monitoring of electrical properties in natural ester fluids and method dielectric spectroscopy. The paper describes properties such as the dielectric permittivity ε_r *and dissipation factor tan*δ *of different types of oils. Dielectric spectroscopy has been developed towards a powerful tool for diagnosis of insulating systems and used two methods: the analysis of relaxation current (PDC, Polarisation and Depolarisation Current), analysis of the dissipation factor tan*δ *over a wide frequency range (FDS, Frequency Domain Spectroscopy). Test objects were measured in different temperature.*

Keywords: *electrical properties, natural ester fluids, transformer, dielectric spectroscopy.*

1. INTRODUCTION

For diagnostics on insulations systems of power network equipments such as power transformers, dielectric analysis plays maybe the most important role. This article reports measuring of some dielectric parameters of natural ester fluids and two methods are existing for this purpose: measurement and analysis of the relaxation currents in the time domain (PDC, Polarisation and Depolarisation Current), of the dissipation factor tanδ in the frequency domain (FDS, Frequency Domain Spectroscopy).

Insulation system of electrical power transformer is based on mineral oil now. The popularity of mineral transformer oil is due to availability and low cost, as well as being an excellent dielectric and cooling medium. Ever since the world oil reserves were tapped in the 1940s, petroleum products have become widely available. Petroleum-based products are so vital in today's world that we cannot imagine a time we may not have them easily available. Transformers and other oil-filled electrical equipment use only a tiny fraction on the total petroleum consumption, yet even this fraction is almost irreplaceable [1].

There are two reasons why we should be seriously thinking of alternate natural sources of insulating fluids:

- transformer oil is poorly biodegradable. It could contaminate our soil and waterways if serious spills occur,
- petroleum products are eventually going to run out, and there could be serious shortages even by the mid-twenty-first century.

Natural ester fluids was considered the most likely candidate for a fully biodegradable insulating fluid. Natural ester fluids is a natural resource available in plenty amount; it is a fairly good insulator, and is fully biodegradable [1].

2. MEASUREMENT DIELECTRIC PROPERTIES OF NATURAL ESTER FLUIDS

Investigations were focused on the measurement of the based electrical properties of natural ester fluids. As natural ester fluids were used two types of fluids: sunflower oil and colza oil. The following samples were measured:

- sample 1.1 - non-filtrated sunflower oil,
- sample 1.2 - non-filtrated sunflower oil, stayed in the bottle for 2 months,
- sample 1.3 - non-filtrated sunflower oil, stayed in the bottle for 3 months,
- sample 2 - non-filtrated sunflower oil, stayed in the bottle for 3 months, without air gap,
- sample RACIOL - filtrated colza oil,

2.1. Measurement dissipation factor and dielectric permittivity

Dissipation factor tanδ and dielectric permittivity ε_r were measured by Schering fully automatically bridge fy.TETTEX AG type 2818 with the frequency of 50Hz. Samples were placed in electrode system Tettex 2903/AT, temperature was controlled by Tettex 2965/ZH from 20°C to 100°C. The HV bridge has had a guaranteed sensitivity of dissipation factor better than $\pm 2 \cdot 10^{-4}$ and capacitance better than ±0.05%. The applied voltage was changed from 0.1kV up to 2.0kV by step 0.2kV. First measurement was measured at a room temperature. After that the temperature was increased up to 100°C by step 10°C.

For each temperature level was made the voltage dependence of dissipation factor and dielectric constant.

Dielectric permittivity is calculated according to equation (1):

$$\varepsilon_r = \frac{C_x}{C_0} \tag{1}$$

Where C_x is the capacity of the natural ester fluids measurements and C_0 is the capacity calculated of empty vessel without oil.

Fig. 1 and Fig. 2 shows the influence of the temperature on the dielectric permittivity of oil different type. Characteristic curves have similar dependences on the temperature. Curves of sunflower and colza oil falling down from value 3.2 at the room temperature to 2.8 at 100°C.

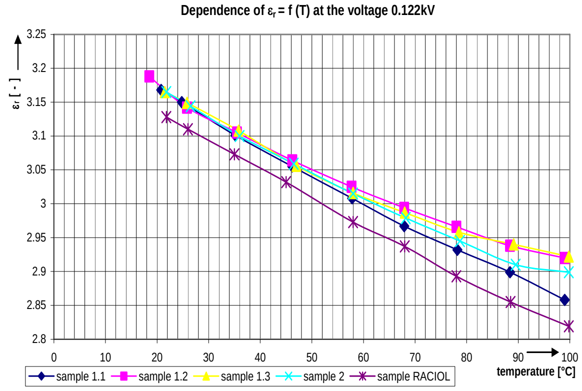

Fig. 1 Dielectric permittivity as a function of temperature for different oil samples at the voltage 0.122kV.

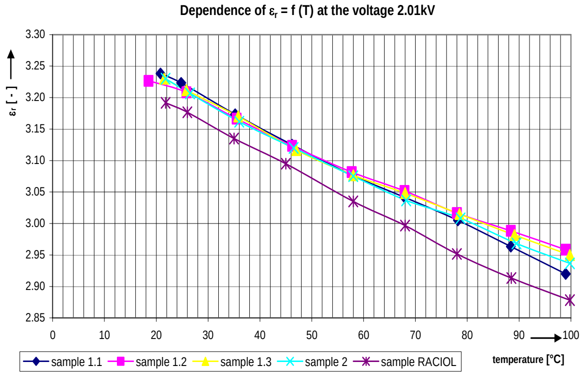

Fig. 2 Dielectric permitivity as a function of temperature for different oil samples at the voltage 2.01kV.

Temperature dependences of dissipation factor of different natural ester fluids for one voltage level 0.122kV are shown in Fig. 3 and voltage dependences of dissipation factor at 20°C are shown in Fig. 4. It is possible to see the difference between two types of natural ester fluids. Filtrated oil has lower dissipation factor than non-filtrated oil.

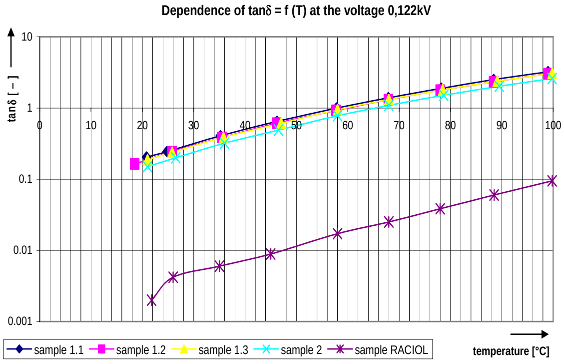

Fig. 3 Dissipation factor as a function of temperature at the voltage 0.122kV.

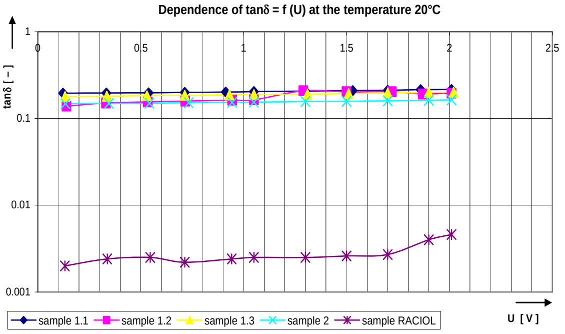

Fig. 4 Dissipation factor as a function of voltage at the temperature 20°C.

3. DIELECTRIC SPECTROSCOPY OF NATURAL ESTER FLUIDS

The polarisation processes inside the oil-paper insulation structure can be modeled by a parallel arrangement of branches each containing a series connection of resistor and capacitor as shown in the circuit of Fig. 5 (RC network model of dielectric) [2-3]. These dipoles, represented as R_i-C_i, are randomly distributed, and have associated time constants given by $\tau_i = R_i . C_i$. Apart from the polarization current, conduction current flows in the insulation in the presence of an electric field. The conduction current in the insulation is due to the insulation resistance R_0 as shown in Fig. 5. C_0 represents the geometric capacitance of the insulation system.

The dielectric measurements can be performed either in “time-domain” or in “frequency-domain”:

- In time-domain, a step voltage is applied to the test sample and the response of the dielectric material is analysed.
- In frequency-domain, a sinusoidal voltage of variable frequency is applied and the response of the dielectric is determined from the amplitude and phase of the current flowing through the test sample.

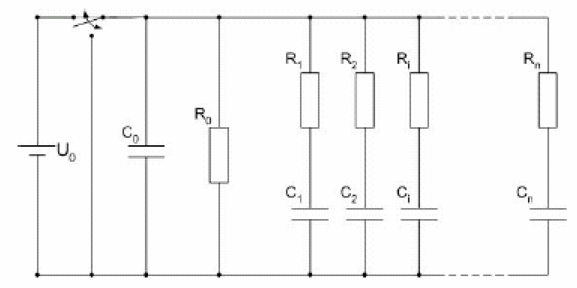

Fig. 5 Equivalent circuit to model a linear dielectric material (the Maxwell-Wagner model) [2-3].

3.2. Time domain Polarisation Measurements

If an insulation system (Fig. 5) with geometrical capacitance C_0 (measured capacitance divided by ε_r, the relative permittivity of the composite insulation system), composite conductivity σ and dielectric response function *f(t)* is exposed to a step voltage of magnitude U_0, the polarisation current through the insulation system can be calculated according to equation(2) [3]:

$$i_{pol}(t) = C_0 \cdot U_0 \cdot \left[\frac{\sigma}{\varepsilon_0} + f(t) \right] \tag{2}$$

Once the step voltage is removed and the insulation system is shorted to ground, the depolarisation current can be written as [3]:

$$i_{depol}(t) = -C_0 \cdot U_0 \cdot \left[f(t) - f(t+t_p) \right] \tag{3}$$

Where t_p is the duration of the time during which the voltage had been applied to the test object. If the polarisation time is sufficiently long, so that $f(t+t_p) \approx 0$ the response function is proportional to the depolarisation current.

$$i_{depol}(t) = -C_0 \cdot U_0 \cdot f(t) \tag{4}$$

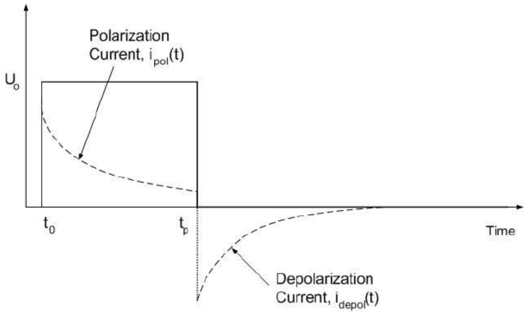

Fig. 6 Principle of relaxation current measurement [3].

From these two equations (2) and (4) of the polarisation and depolarisation currents the dielectric response function *f(t)* and the composite conductivity σ can be determined.

Fig. 6 shows the nature of the polarisation current after applying a DC voltage U_0 and of the depolarisation current during the short circuit. The polarization current was measured with the frequency of 50Hz in the time domain.

3.3. Frequency Domain Dielectric Spectroscopy (FDS)

On the theoretical background of the RC network model of dielectric (Fig. 5) and time domain polarisation measurements (Fig. 6) can be calculated of the dissipation factor and the complex capacitance in relation to frequency. It is possible to distinguish between the different polarizations mechanisms in the frequency spectra. A frequency range between 1mHz to 1kHz is most commonly used [2].

3.3.1. Dissipation Factor

When a sinusoidal voltage is applied across an insulation, a current will flow with a certain phase angel φ. The dissipation angle δ describes the angle between the complex conductance Y_C and the imaginary axis. If $\varphi = 90°$ that means angle $\delta = 0$ degree, the insulation material would have no loss. The tangent of the angle δ is called the "dissipation factor".

$$\tan\delta = \frac{\mathrm{Re}\,al\ part\ of\ \mathrm{Im}\,pedance}{\mathrm{Im}\,aginary\ part\ of\ \mathrm{Im}\,pedance} \tag{5}$$

The admittance $\overline{Y}$ of the RC model of dielectric according to (Fig. 5) is [2]:

$$\overline{I}(\omega) = \overline{Y} \cdot \overline{U}(\omega) \tag{6}$$

$$\begin{aligned} \overline{Y} &= \frac{1}{R_0} + j\omega \cdot \varepsilon_{r0} C_0 + \sum_{i=1}^{n} \frac{j\omega C_i}{1 + j\omega R_i C_i} \\ &= \frac{1}{R_0} + \sum_{i=1}^{n} \frac{(\omega R_i C_i)^2}{R_i (1 + (\omega R_i C_i)^2)} + j\omega [\varepsilon_{r0} C_0 + \sum_{i=1}^{n} \frac{C_i}{1 + (\omega R_i C_i)^2}] \end{aligned} \tag{7}$$

Then the dissipation factor can be easily derived out of the admittance according to equation (7):

$$\tan\delta = \frac{\mathrm{Re}\{\overline{Y}\}}{\mathrm{Im}\{\overline{Y}\}} = \frac{\dfrac{1}{R_0} + \sum_{i=1}^{n} \dfrac{(\omega R_i C_i)^2}{R_i (1 + (\omega R_i C_i)^2)}}{\omega \varepsilon_{r0} C_0 + \sum_{i=1}^{n} \dfrac{\omega C_i}{1 + (\omega R_i C_i)^2}} \tag{8}$$

3.3.2. Complex Capacitance

The expression for the capacitance is:

$$C = \varepsilon \cdot \frac{A}{w} \tag{9}$$

Where A is the plate area of the capacitance, ε is the permittivity and w is distance between two plates.

Real and imaginary components of the complex permittivity [4]:

$$C(\omega) = C'(\omega) - jC'(\omega) = (\frac{A}{w}) \cdot (\varepsilon'(\omega) - j\varepsilon''(\omega)) \qquad (10)$$

C'(ω) corresponds to the ordinary capacitance, while the imaginary component C''(ω) represents the dielectric loss component. The tangent of the loss angle δ the dissipation is given by the relation:

$$\tan\delta = \frac{C'(\omega)}{C''(\omega)} \qquad (10a)$$

3.4. Relation between Time and Frequency Domains

The information obtained in either frequency or time domain is theoretically equivalent if the dielectric material can be described as a linear system (Fig. 5) and complex permittivity can be calculated by the Fourier transformation as [5]:

$$\hat{\varepsilon} = \varepsilon' - j\varepsilon'' \qquad (11)$$

$$\hat{\varepsilon} = \varepsilon_\infty + (\varepsilon_s - \varepsilon_\infty)\int_0^\infty \varphi(x)e^{(-j\omega)}dx \qquad (12)$$

Where ε_∞ is the optical permittivity, ε_s is the static permittivity, φ(x) is the function regress given of polarisation current.

The other paper describes principle time domain polarisation current measurement and conversion of polarisation current into dissipation factor tanδ (complex permittivity ε″) by the Hamon approximation [5].

$$\varepsilon'' = \frac{i(t)}{2\pi f C_0 U_c} \qquad (13)$$

Where i(t) is the measured polarisation current of a dielectric, U_c is the test voltage, C_0 is the capacity calculated of empty vessel without oil.

The test voltage was 100V DC and was controlled with the instrument 100V DC supply. Current responses to DC voltage were measured. Measuring instrument electrometer Keithley 617 was controlled by PC and connected with PC through IEEE 488.2 interface. Control software was written in Hewlett-Packard Virtual Engineering Environment (HP VEE). Calculation was done in Matlab. Samples were placed in electrode system Tettex 2903/AT, temperature was controlled by Tettex 2965/ZH from 20 °C to 100 °C.

Electrometer Keithley 617 can measure currents down to 10^{-16} A and it is suitable for these purposes. Measurements were done under temperatures varied from 20 °C to 100 °C. Measuring equipment was connected to liquid test chamber.

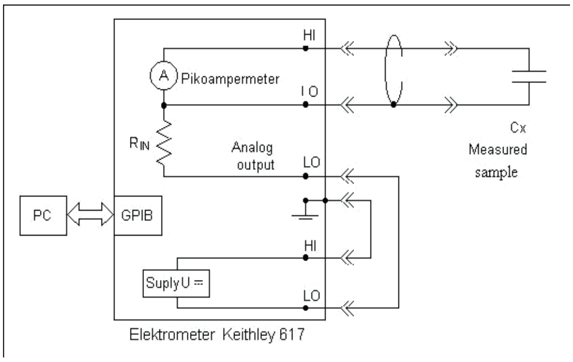

Fig. 6 Measuring equipment.

Fig. 7 show the nature of the polarization current after applying a DC voltage U_0 and Fig. 7 show the conversion of polarization current into complex permittivity ε″ by the Hamon approximation [5].

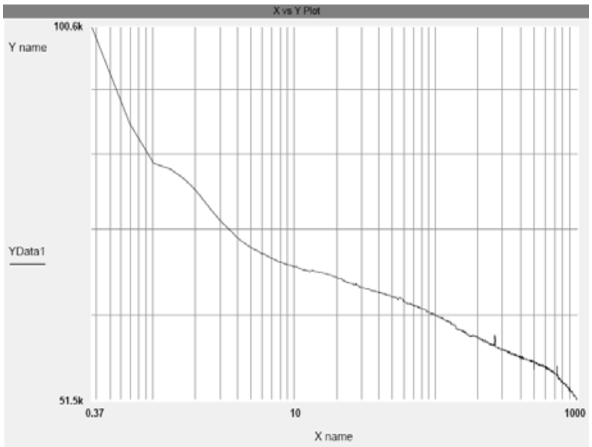

Fig. 7 Polarisation current as a function time domain for sample RACIOL at the temperature 50°C.

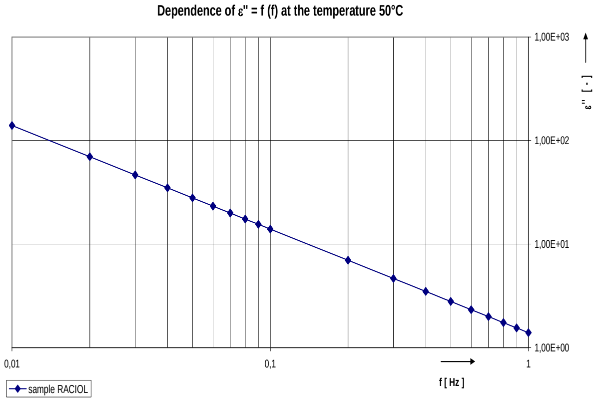

Fig. 5 Complex permittivity as a function of frequency domain for sample RACIOL at the temperature 50°C.

4. CONCLUSION

First investigations of electrical and dielectric properties of natural ester fluids were made. As natural ester fluids were used two types of fluids: sunflower oil and colza oil. Samples were achieved directly from manufacturer. But it is necessary to add that natural ester fluids samples were without any additives. The results show that natural ester fluids are possible to use in practice. It appears that filtrated colza oil is better than non-filtrated sunflower oil. It has higher value of dissipation factor and dielectric constant (not very good). In the second part was describes principle time domain polarisation current measurement of natural ester fluids and conversion of polarisation current into dissipation factor tanδ (complex permittivity ε'') by the Hamon approximation. We need to make more measurements to say that natural ester fluids are ready for using in practice. There are more important properties to study.

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BIOGRAPHIES

Peter Semančík was born in Prešov, Slovakia, in 1983. In 2006 he graduated (MSc.) with distinction at the department of Electric Power Engineering of the Faculty of Electrical Engineering and Informatics at Technical University in Košice. Since 2006 he is an internal PhD. Student at the faculty. His research interests are in the Thermal degradation of insulating systems.

Roman Cimbala was born in Košice, Slovakia, in 1962. He graduated in electrical power engineering, field of generation and transmission of electrical energy, Faculty of Electrical Engineering and Informatics, Technical University Košice in 1986. He received the Ph.D. degree electric power engineering from Slovak Technical University in Bratislava in 1994, and associate professor degree from Technical University Košice in power engineering diagnostics in 1998.

From 1986 to 1990 he served as a Research Assistant at Department of High Voltage Engineering. Since 1990 he is a teacher. From 1991 to 1995 and in 2003 he was the head of this department. Now he is a head of High Voltage Division of Department of Electric Power Engineering at same University. Now he is a vicedean of the Faculty. He is a member of Working Group “Insulation Diagnostics” and invited member of Working Group “Electrostatics”. He is a member of Slovak Commission for Technical Normalization, Slovak Association for Technical Diagnostics.

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Iraida Kolcunová was born in Kotlas, Russia, in 1955. She graduated from the Department of High Voltage Engineering, the Faculty of Power Engineering at the Moscow Power Engineering Institute in 1979. She received the PhD degree from Slovak Technical University in Bratislava in 1993. She became an Associate Professor of Electric Power Engineering at the Faculty of Electrical Engineering and Informatics at the Technical University of Kosice in 2000.

Since 1979 she has been working at the Technical University, first as a research worker in High Voltage Laboratory, now as a teacher at the Department of Power Engineering.

She deals with degradation of insulating materials and measuring of partial discharges in high voltage equipments. She is lecturing on Diagnostics of High Voltage Equipments and High Voltage Engineering.