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Dielectric spectroscopy of oil

Streszczenie. (Spektroskopia dielektryczna w badaniach oleju). *Rozwój techniki pomiarowej i komputerowej pozwalają na stosowanie coraz bardziej skomplikowanych metod badawczych. Artykuł dotyczy zastosowania metod spektroskopii dielektrycznej w badaniach olejów elektroizolacyjnych poprzez pomiar odpowiedzi prądowej będącej reakcją na pobudzenie napięciem stałym. Wykonane zostały analizy prądów relaksacji izotermicznej. Obiekty badań były mierzone w różnych temperaturach i przy różnych wartościach natężenia pola elektrycznego.*

Abstract*. Development of measuring engineering and computer allowed using more complicated method. Paper deals with utilization of dielectric spectroscopy of oil. Measurement of current response excitation with direct voltage impulse is analyzed. Isothermal relaxation current analysis was done. Test objects were measured in different temperature and electric field.*

Słowa kluczowe: spektroskopia dielektryczna, transformator, olej, diagnostyka.
Keywords: dielectric spectroscopy, transformer, oil, diagnostics.

Introduction

Insulation system of electrical power transformer is based on mineral oil now. This article reports measuring of some dielectric parameters of natural ester fluids and inhibited oil ITO 100. Esters have lower oxidation resistance and that is why we measured raw samples of them without any additive. Experimentation using natural ester fluids as dielectric coolant began around the same time as the early mineral oil trials [1]. They proved less desirable than mineral oil due to inferior oxygen stability and higher pour point, relative permittivity and viscosity values especially in lower temperatures.

Today not only performance and financial cost are keys for material selection. Overall environmental and total life costs are parts of the analysis. For lower health and environmental requirements materials used for power transformers should:

- be biodegradable,
- be nontoxic,
- produce by-products with acceptable low risk thermal degradation,
- be recyclable, reconditionable, and readily disposable,
- not be listed as a hazardous material by the EPA or OSHA.

In 1892, experiments with liquids other than mineral oils included ester oils extracted from seeds. None made operational improvements over mineral oil and were not commercially successful. A particular problem with seed-oil-based coolants was their high pour point and inferior resistance to oxidation relative to mineral oil based insulation system.

Except for occasional applications in capacitors and other specialty applications, renewed interest in ester-based dielectric fluids did not occur until after the infamous PCB issue arose in the 1970s. By then, there was a mature synthetic organic ester industry serving other markets.
However, modern transformer design practices, along with suitable fluid additives and minor design modifications, compensate for this characteristic. The application of natural esters in transformers achieves a balance of desirable transformer and external environmental properties not found in other dielectric fluids. An attractive source of natural esters is edible seed oils. Used mainly in foodstuffs, these agricultural commodity oils are widely available and, unlike mineral oil, are derived from renewable resources – a question of nowadays [2].

We made experiment on raw vegetable oil in various temperatures.

Theoretical background

Recent state of insulation system diagnostics is based on observing of electro – physical changes in material. There is not any method that can determine the state of insulation material itself. The set of methods has to be used to reach the complex view to material properties. Generally electrical methods can be divided according to applied voltage or current as AC and DC methods. Not so far ago DC methods measured current flowing through insulation material. The resistance or polarization indices were calculated in past.

When applying external direct voltage forming an internal electrical field inside the material, the total current shown in Fig. 1 consists of several components. While charging with direct voltage currents from the geometrical capacity, absorptive and steady current are present. There is not steady current during discharging, because there is no external electrical field.

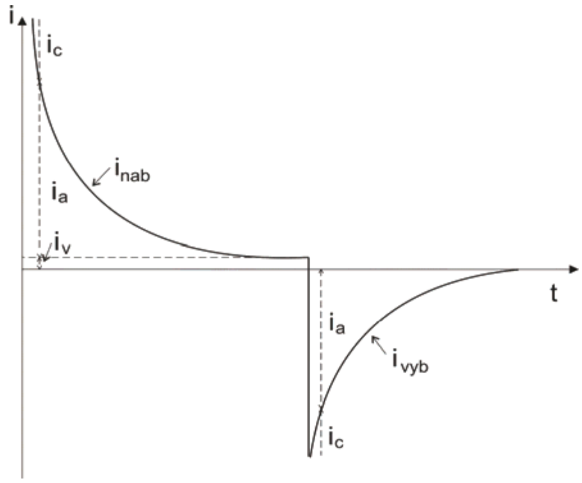

Fig 1. Charging and discharging currents

$$i_{nab}(t) = i_c(t) + i_a(t) + i_v(t) \quad (1)$$

where: $i_{nab}(t)$ - total current, $i_c(t)$ - geometrical capacity current, $i_a(t)$ - absorption current, i_v - steady current.

Geometrical capacity current is so fast, that it can be neglected (about 10^{-12}s). Then the total current can be described as:

$$i_t(t) = i_s + i_a(t) \quad (2)$$

For a macroscopic description of current responses the equivalent Maxwell-Wagner model can be used for dielectric materials. The equivalent model of the insulating material shown in Fig.2 is based on n independent Debye's polarization processes. Each process has its own time constant of stabilization τ_i and maximum of elementary current I_{mi}, and by observing its changes we can obtain information about the state of insulation electro-physical structure and its changes [3].

$$i_t(t) = i_s + \sum_{i=1}^{n} I_{mi} \exp\left(\frac{-t}{\tau_i}\right) \quad (3)$$

$$i_s = \frac{U_0}{R_0} \quad (4)$$

$$I_{mi} = \frac{U_i}{R_i} \quad (5)$$

$$\tau_i = R_i . C_i \quad (6)$$

$$i_t(t) = \frac{U_0}{R_0} + \sum_{i=1}^{n} \frac{U_0}{R_i} \exp\left(\frac{-t}{R_i C_i}\right) \quad (7)$$

Then calculation is made and all parameters is known, it is possible to calculate one minute polarization index:

$$P_1 = \frac{I_{15}}{I_{60}} \quad (8)$$

and ten minute polarization index:

$$P_{10} = \frac{I_{60}}{I_{600}} \quad (9)$$

where I_{15}, I_{60} and I_{600} are currents at 15, 60, and 600 seconds after charging.

There is a big advantage that calculation is carried out on data without disturbances after digital filtering due to replacing model. If exactly on calculated time noise exists, model doesn't accept it according its ratio.

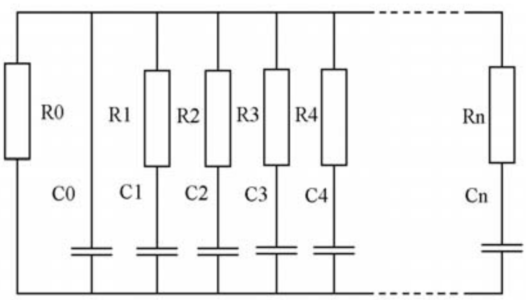

Fig. 2. The Maxwell-Wagner replacing model

Measuring

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.

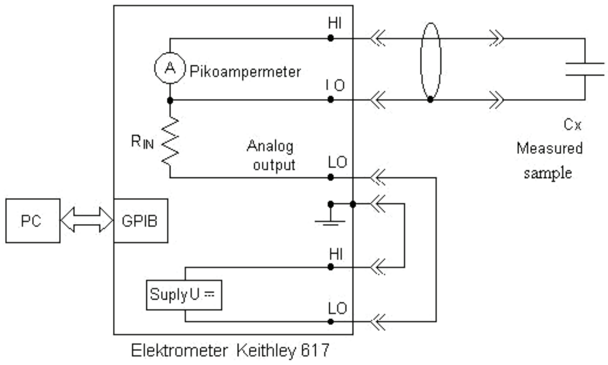

Fig. 3 Measuring equipment

Inhibited transformer oil ITO 100 was analyzed first. Current responses on 100 V direct voltage were observed. As oil is quite homogenous material, one elementary Debye's process was decided. There is amplitude of elementary current varied on temperature in the Figure 4 and for vegetable oil in the Figure 6

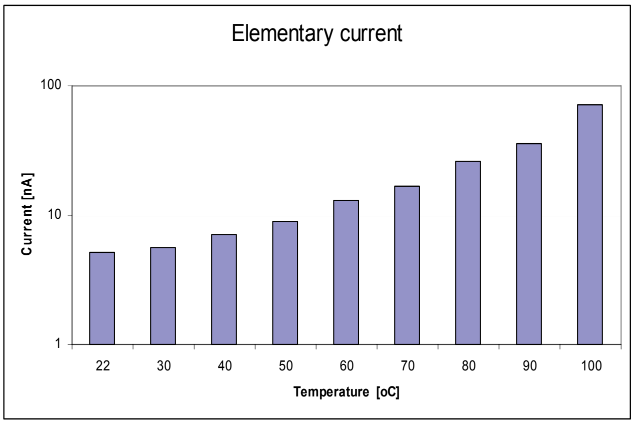

Fig. 4. Influence of temperature on elementary current responses

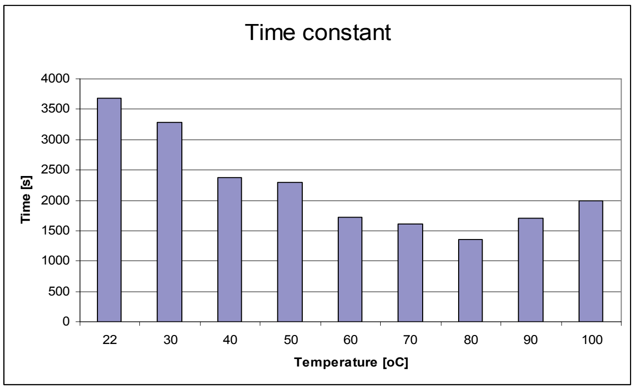

Fig. 5. Time constant of stabilization of ITO 100

Time constant describe time of stabilization of elementary polarization process. The influence temperature on time for inhibited oil ITO 100 is in the Figure 5 and for vegetable oil on Figure 7. The conductivity current at infinity time was calculated. There is comparison of vegetable oil and synthetic oil ITO100 in the Figure 8. There are 1 and 10 minute polarization indices for vegetable oil in the Figure 9. It is evident that temperature influence is small. It is a surprise. Ten-minute polarization index is always higher than one-minute. There are 1 and 10 minute polarization indeeces for inhibited oil ITO 100 on Fig. 10. It is evident that temperature has higher influence on values than it is in the case of vegetable oil.

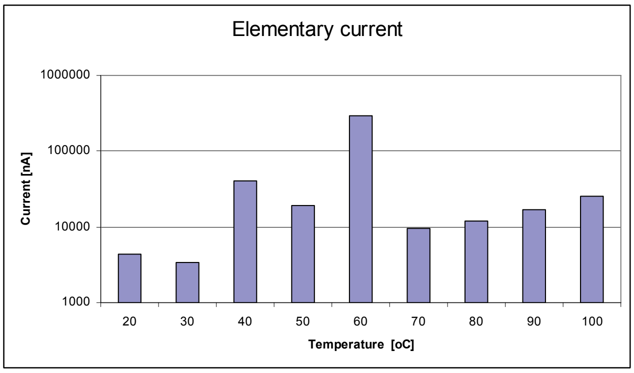

Fig. 6. Elementary current of vegetable oil

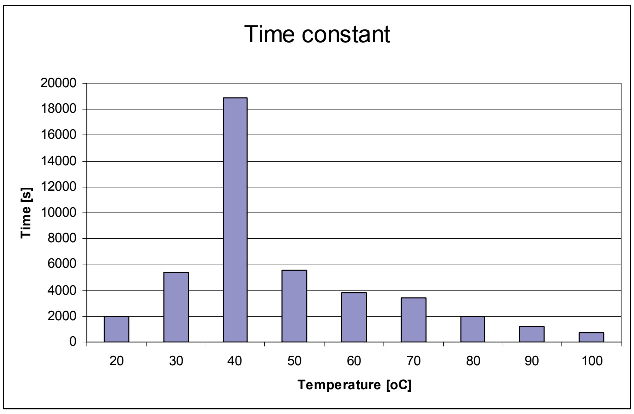

Fig. 7. Time constant of stabilization of vegetable oil

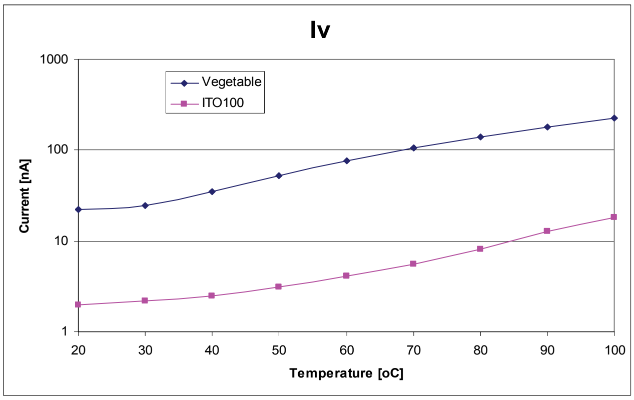

Fig. 8. Conductive current of vegetable and ITO100 oil at temperature

Conclusion

This is the initial work for complex diagnostic parameter measurements of raw vegetable oil and comparison to inhibited oil ITO 100. Samples were achieved directly from manufacturer. Current responses under various temperatures were observed. Total current and conductive current are magnified around ten-times from 20 °C to 100 °C in the case of both oil. Differences between raw natural esters and synthetic oil in insulation behavior (conductive current) are around 10 times too. But it is necessary to add that vegetable oil samples were without any additives. Polarization indices of vegetable oil varied not too much In the case of inhibited oil the variation is higher. It is can't be said that there is direct relation to temperature. We measured breakdown voltage, capacitance and dissipation factor too, but it is a contents of other paper.

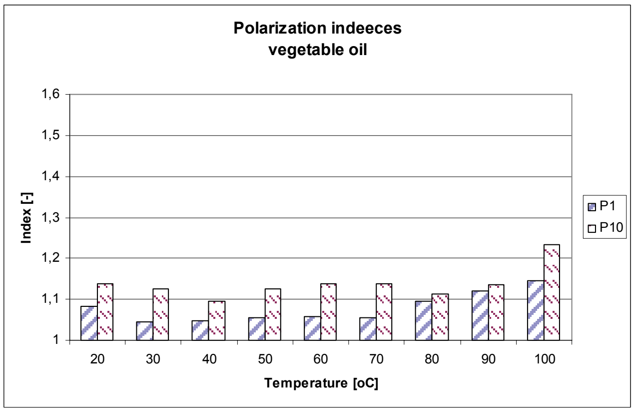

Fig. 9. Polarization indices of vegetable oil

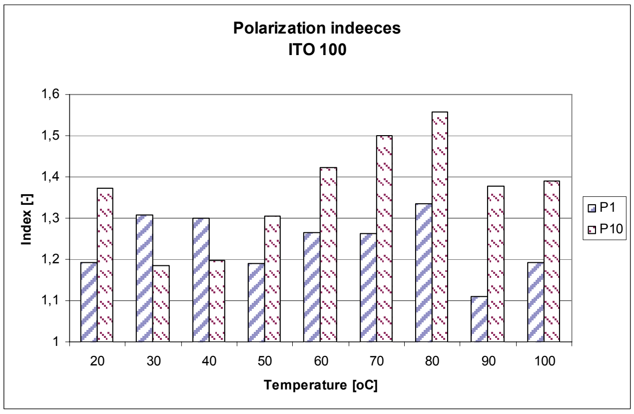

Fig. 10. Polarization indices of ITO 100 oil

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