Magnetodielectric anisotropy in magnetic fluids in temperature interval from 20 °C to 80 °C

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Abstract

Substitution of transformer oil as insulator medium by magnetic fluid in transformers requires observation of electric properties of magnetic fluids at temperatures higher than 20 °C. That´s why important physical quantities were measured at temperature in interval from 20 °C to 80 °C. The magnetodielectric anisotropy was studied at the same temperature region. Two important quantities have been measured: specific electric conductivity and dielectric breakdown strength of magnetic fluids at volume concentrations from 0,185 % to 2 %. So the behavior of magnetic fluids as insulator medium could be observed at working conditions of transformers.

Abstrakt

Náhrada transformátorového oleja ako izolačného média magnetickou kvapalinou v transformátoroch si vyžaduje skúmanie elektrických vlastností magnetických kvapalín pri teplotách vyšších ako 20 °C. Z toho dôvodu odporúčame merať fyzikálne veličiny v interval teplôt 20 °C do 80 °C. Magnetodielektrická anizotropia bola skúmaná v tej istej teplotnej oblasti. Zamerali sme sa na dve veličiny: mernú elektrickú vodivosť a elektrickú pevnosť magnetickej kvapaliny o objemovej koncentrácii 0,185 % do 2 %. Takže správanie magnetickej kvapaliny ako izolačného media mohlo byť pozorované pri pracovných podmienkach transformátora.

INTRODUCTION

The application of magnetic fluids as insulator medium in transformers of high voltage has not been done sufficiently deep so far. The structure of magnetic fluids themselves shows that magnetic fluids are complex material consisting of three components: nonpolar component – inhibited transformer oil as carrier liquid, polar component – oleic acid as surfactant and solid magnetite nanoparticles of average diameter 10 nm. The still completed measurements of electric properties have showed fair-sized differences of observed fluid particularly when observed medium is placed into combined electric and magnetic fields at two different orientations of used fields (**E**||**H, E**⊥**H**).

The goal of this work was observation of magnetodielecric anisotropy of both dielectric breakdown strength (E_b) and specific electric conductivity [1] of magnetic fluids based on transformer oil and observation temperature dependences of important quantities characterizing electric properties of magnetic fluids. The experiments have proved the presence of electrophoretic conductivity in magnetic fluids, too.

THEORY

Complex physico-chemical character of the magnetic fluids requires investigation of their properties:

- in DC and AC electric fields,
- in weak (below 10^6 V.m^{-1}) and strong electric fields (above 10^7 V.m^{-1}),
- in "clean" - nonpolar insulating liquids, in polar liquids with surfactant and in pigmented liquids by colloidal nanoparticles.

Based on the elementary Ohm's law in differential form $di = \gamma(E)dE$, after a detailed analysis we get this equation:

$$\gamma = n_0 q b_i = \frac{n_0 q \delta^2 \upsilon}{6kT} \exp\left(\frac{-W_a}{kT}\right) \qquad (1)$$

where b_i is the ion mobility, that is also exponentially dependent on temperature T and it can be expressed as:

$$b_i = \frac{\upsilon_i}{E} = \frac{q \delta^2 \upsilon}{6kT} \exp\left(\frac{-W_a}{kT}\right) \qquad (2)$$

where δ is the distance of potential holes, υ is the frequency (eg. 10^{12}-10^{13} s^{-1}) and W_a is the activation energy.

The coefficient b_i in mineral oils, when weak electric fields are applied, reaches value of $10^{-8}\,m^2.s^{-1}.V^{-1}$ and in strong fields it increases to $10^{-7}\,m^2.s^{-1}.V^{-1}$ (mobility of negatively charged ions). When DC field (voltage) is applied on a magnetic fluid containing nanometer sized particles of ferrites then it is expected that electrophoretic conductivity occurs in the inter-electrode space, which is defined as follows:

$$\gamma_k = \xi \frac{\varepsilon^2 r n_k}{6\pi\eta} \qquad (3)$$

where ξ is the electrokinetic potential, η is the dynamic viscosity, ε is the electric permittivity and r is the particle radius. Electrical conductivity of liquid insulating material is often associated with the viscosity η of the liquid, that is dependent on temperature, which can be expressed as:

$$\eta = \frac{6kT}{\gamma^3 \upsilon} \exp\left(\frac{W_a}{kT}\right) \qquad (4)$$

The equation (4) is a part of Walden's law that is applicable on nonpolar (or weakly-polar) liquid insulators in the form:

$$\gamma\,\eta = const. \qquad (5)$$

Relationship between the specific electrical conductivity and electrical stability can be found from modelling of heat transition, when we come out from the model of a dielectric (insulator) placed between two plane parallel electrodes. After creation of differential equations that corresponds to balance state of energy, we get the equation [3]:

$$-\lambda \frac{dT}{dz}\Big|_{z+dz} + \lambda \frac{dT}{dz}\Big|_{z} = \gamma E^2 dz \qquad (6)$$

where λ is the coefficient of thermal conductivity of dielectric material (oil), γ is the equivalent conductivity of liquid media. The maximum intensity of electric field at a generated temperature can be reached by another solution of the differential equation (6).

EXPERIMENT AND RESULTS

The specific conductivity measurements have been carried out with help of closed small container that was armed with permanent magnets that were source of homogeneous magnetic fields of value from 0 to 40 mT with possibility to change orientation of electric and magnetic fields (**E∥H, E⊥H**). The comparing of voltage decrement on measured resistor (magnetic fluid) with normal resistor on base of Ohm´s law was used for determination of specific conductivity. The experimental set up is illustrated in fig.1 [1].

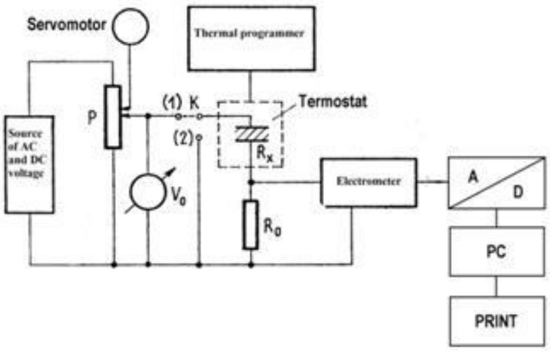

Fig. 1 Experimental set up for specific conductivity measurements

The experiments have been carried out with magnetic fluids of volume concentration of magnetite particles from 0,185 % to 2 % at DC voltage from 200 V to 1000 V. The course of dependencies $\gamma = f(T)$ with U as parameter showed the validity of equation (1). The magnetodielectric anisotropy was more distinct at higher values of voltage.

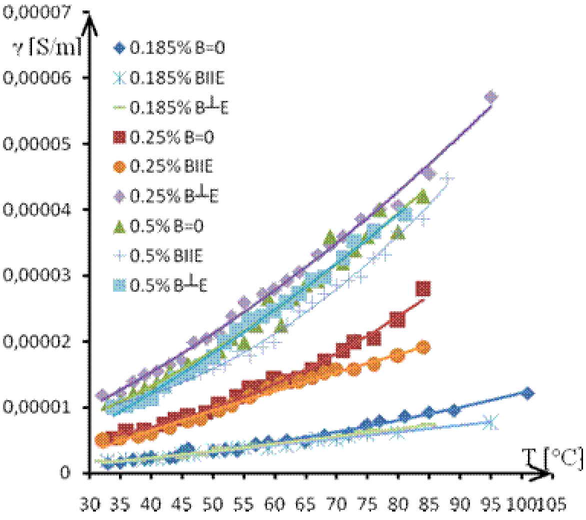

Fig. 2 The dependencies of specific conductivity on temperature at voltage of 200 V

The measurements of dielectric breakdown strength, i.e. dielectric stability of magnetic fluids were carried out on the base on the STN norm. The sample of magnetic fluids was placed into small container that was armed by Rogowski´s electrodes and permanent magnets (NdFeB). Magnetic fluids temperature was controlled by ultra thermostat.

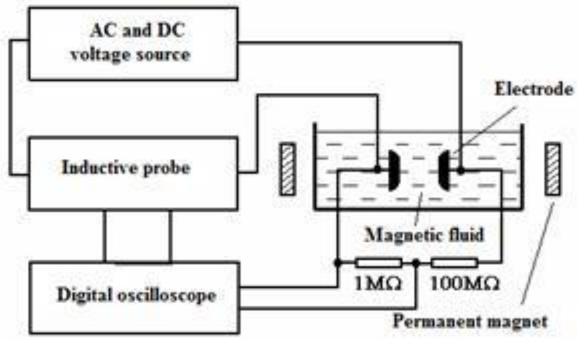

Fig. 3 Experimental set up for dielectric breakdown strength measurements [4]

Electric field intensities were higher than 10^7 V.m^{-1}, i.e. experiments were carried out in strong electric field. The course of dependencies in fig.4 corresponds to the same dependency for pure mineral oil that contains small amount of water (0,02 %) at low temperature. Water at higher temperature changes from state of emulsion solution to molecular state and so dielectric breakdown strength reaches lower values. This decrease is caused by increasing of magnetic fluid conductivity. The observed maximum of dependency at perpendicular orientation of magnetic and electric fields shifts to lower temperatures.

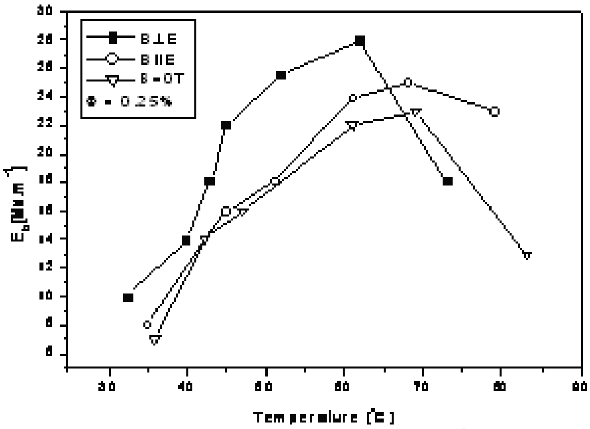

Fig. 4 Dielectric breakdown strength vs. temperature for magnetic fluid with a low volume concentration of magnetite particles (0,25 %)

CONCLUSIONS

It is interesting that on dependencies of conductivity on temperatures at various volume concentrations (mainly at higher values) of magnetite particles in magnetic fluids could be observed stair-like formations that were loaded down on exponential dependency of specific conductivity for observed medium. It could be assumed that observed formation are caused by arrangement effect of magnetite particles in magnetic fluids that is dependent on temperature. This hypothesis is supported by courses of specific conductivity dependencies on temperatures in magnetic fluids that have been measured at constant voltage of 100 V, during 200 sec at given temperatures.

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