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Dielectric Properties of Magnetic Liquids in High Electric Fields

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In this work, dielectric properties of magnetic fluids composed of magnetite particles dispersed in transformer oil and subjected to a uniform magnetic field were investigated at the high alternating electric field intensities in the range of 0.5–2.5 MV/m. Dielectric stability of the magnetic fluid with the particle volume concentration $\Phi = 0.0019$ was observed. The magnetic fluid with the concentration $\Phi = 0.019$ showed the significant changes of permittivity and dielectric losses, too.

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1. Introduction

Using of magnetic fluids (MF) as insulating mediums in transformers can improve their thermal and dielectric properties [1, 2]. It is known that the permittivity of magnetic liquids is dependent on the presence of magnetic field, that is called magnetodielectric effect. This effect is caused by the reorientation of magnetic particles and the formation of the chain-like clusters of magnetic particles [3]. We suppose that the creation of clusters is also caused by the influence of high electric fields. The motivation of this work is to investigate the dielectric stability of magnetic fluids as a function of high electric field intensity in the presence of magnetic field which usually occurs in transformers. The results of the investigation of the magnetodielectric effect in the high applied electric fields in a magnetic fluid with magnetite particles dispersed in a transformer oil and the dielectric loss factor as a function of the electric field intensity are reported.

2. Experimental

The magnetic fluid composed of transformer oil ITO 100 and Fe_3O_4 particles of approximately spherical shape coated with oleic acid was prepared. Magnetic particles were obtained by chemical precipitation of ferrous and ferric salts by NH_4OH. Oleic acid (as a surfactant) and ITO 100 were added after washing and water removing at the temperature 70°C. Volume concentrations, average diameter and standard deviation of magnetic particles were determined from vibrating sample magnetometer (VSM) measurements. The dependences of magnetic moment of samples on magnetic field were measured in the range of 0 to 600 mT at room temperature. Permittivity and loss factor were measured by the Schering bridge Tettex 2818 at frequency 50 Hz. A capacitor was obtained with the help of parallel plate Cu electrodes placed in the container with a magnetic liquid. The electrodes were 1 cm in diameter and their distance was 0.8 mm. Capacity and loss factor of the capacitor were measured as a function of the applied electric field intensity in the range of 0.5 to 2.5 MV/m. The experimental error of capacity measurements was ±1%. Permittivity of magnetic fluids was determined from capacity as

$$\varepsilon_{\mathrm{r}} = \frac{C}{C_0},$$

where C is the capacity of the capacitor with a magnetic fluid and C_0 is the capacity of the same capacitor filled by gas. Two permanent NdFeB magnets were used to apply homogeneous magnetic field up to 40 mT.

3. Results and discussion

The magnetization curves are shown in Fig. 1. The volume concentrations of magnetite particles in samples were $\Phi = 0.0019$ and 0.019. Average diameter

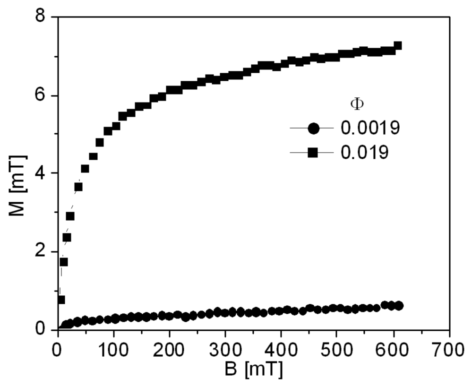

Fig. 1. Magnetization M of samples of magnetic liquid in dependence on applied magnetic field B.

of magnetite particles was $D_m = 9.1$ nm and standard deviation $\sigma = 0.38$. They were determined by the method of Chantrell et al. [4].

The investigations showed that the permittivity of the magnetic liquid of the lower concentration $\Phi = 0.0019$ was weakly dependent on the electric field intensity in the studied range, but the permittivity of the magnetic fluid of the higher concentration significantly increased with increasing electric field intensity in the electric fields in the range of 0.5 to 2.5 MV/m (Fig. 2).

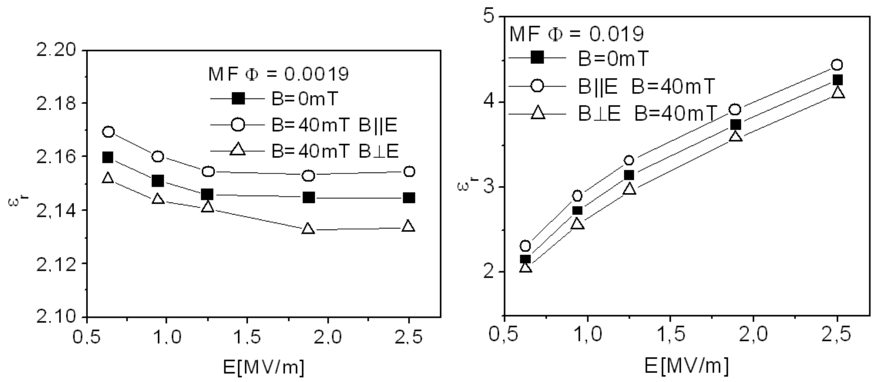

Fig. 2. Dependence of permittivity ε_r of magnetic liquid on electric field intensity E in zero and non-zero applied magnetic field.

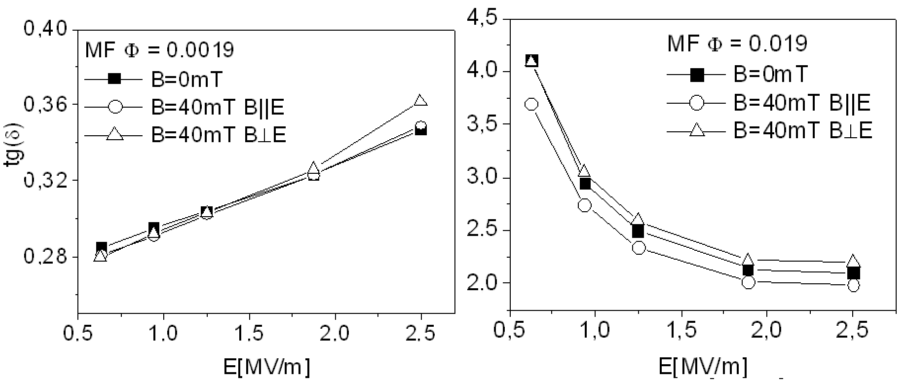

Fig. 3. Dependence of loss factor $\tan(\delta)$ of magnetic liquid on electric field intensity E in zero and non-zero applied magnetic field.

It is known that magnetite particles covered with oleic acid as a surfactant are electrically charged by adsorbed ions and counterions (opposite charged to ions absorbed by particle) from the surrounding atmosphere may be attracted to them [5]. We assume that the increase in the permittivity as a function of the electric field intensity was caused by the larger concentration and the particles aggregation in high electric fields. The increase in permittivity absented in the liquid with $\Phi = 0.0019$. The decrease (in the case of $\boldsymbol{B} \perp \boldsymbol{E}$) and increase (in the case of $\boldsymbol{B} \parallel \boldsymbol{E}$) in permittivity in the applied magnetic field was observed that is known as magnetodielectric effect [3]. As it is shown in Fig. 3, the loss factor slowly increased at $\Phi = 0.0019$ and decreased with increasing electric field intensity at the higher volume concentration of magnetic particles.

4. Conclusions

Magnetodielectric effect in magnetic fluids was confirmed in the high electric fields 0.5–2.5 MV/m. It has been shown that the permittivity of the magnetic fluid with the small volume concentration of magnetic particles $\Phi = 0.0019$ was nearly constant in the range of the investigated electric field intensity, while the dependence on the electric field intensity was significant in the magnetic fluid of the ten times higher concentration, where the permittivity changed twice. Losses were independent of the magnetic field and dependent on the electric field intensity weakly at the concentration $\Phi = 0.0019$, while significant dependence was observed at the concentration $\Phi = 0.019$ as in the case of permittivity dependence for the same concentration. The increase in the polarization seems to indicate that aggregation effects were presented in the magnetic fluid with the high volume concentration of particles in the high electric fields.

Acknowledgments

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