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Effect of microdrops deformation on electrical and rheological properties of magnetic fluid emulsion

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A R T I C L E I N F O

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The magnetic fluid emulsions with low interfacial tension have been studied experimentally. The shape deformation of the dispersed phase microdrops under the action of comparatively weak magnetic field has been observed. The effect of microdrops deformation on the macroscopic properties of the emulsion has been investigated. The anisotropic character of emulsion properties in the presence of external magnetic field has been demonstrated. The emulsion dielectric permeability has been measured as a function of the magnetic field strength, the emulsion concentration, and the angle between electrical and magnetic fields. The influence of the droplets deformation under the magnetic field on the rheological behavior of the emulsion has been observed. The obtained results have been analyzed and discussed.

Anisotropic heterogeneous matter constitutes an important field of basic research and applications. One of the approaches to obtain the materials which can become anisotropic under the external action is based on the use of composite material, whose properties strongly depend on its structural microgeometry. Recently many attempts have been undertaken to create new liquid magnetizable composites based on magnetic fluids that can more effectively interact with external magnetic fields than pure magnetic fluid [1–3]. The microstructure of such composites can be controlled by external magnetic fields. One of the examples of the magnetic fluid composites is a magnetic fluid emulsion. Previously some properties of magnetic fluid emulsions with dispersed droplets aligned in chainlike structures under the action of magnetic field have been studied in several works [4–6]. Another type of magnetic fluid emulsions is the emulsions with low interfacial tension. The droplet shape deformation prevails over the chaining effect in such emulsions under the low magnetic field. The effect of droplet deformation on the macroscopic magnetic [7,8] and optical [9] properties of magnetic fluid emulsions has been previously studied. The rheological properties of the similar system of magnetorheological suspension with drop-like aggregates appeared in magnetic field have been studied in [10]. In this paper we extend the previous studies and investigate the macroscopic electrical and rheological properties of magnetic fluid emulsions associated with the droplet deformation.

A ferrofluid is a colloidal suspension of ultra-fine ferro- or ferromagnetic nanoparticles suspended in a carrier fluid. In our experiments we used a kerosene-based ferrofluid with dispersed magnetite nanoparticles of about 10 nm diameter stabilized with oleic acid. The properties of the ferrofluid are: density is $1600\,kg\,m^{-3}$, dynamic viscosity is 29 mPa s, magnetite volume fraction is 18%, initial magnetic permeability is 4; dielectric permeability is 3.8, and the specific electrical conductivity is 10^{-6} S/m. Ferrofluid emulsion has been produced by dispersing either a ferrofluid in a nonmagnetic liquid or a nonmagnetic liquid in ferrofluid. FH 51 aviation oil immiscible with the ferrofluid was selected as the nonmagnetic liquid. Its density is $776\,kg\,m^{-3}$, the dynamic viscosity is 14.5 mPa s, the dielectric permeability is 2.2, and the specific electrical conductivity is 10^{-10} S/m. The main reason to use this oil is that the interfacial tension at the interface between it and the ferrofluid is quite low ($\sigma \approx 10^{-6}$ N/m). The radii of the emulsion droplets are varying from 1 to 5 µm, so the ferrofluid can be considered as continuous liquid magnetizable medium. The mean radius of the emulsion microdrops was $R \approx 3$ µm. No stabilizing agents were used in the preparation of the emulsions.

The structural state of the emulsion was examined under an optical microscope. It was found that the emulsion microdrops become ellipsoidal aligned along the same axis under the action of external magnetic field. Because of low interfacial tension, under the action of comparatively weak magnetic field significant deformation of droplets takes place (Fig. 1).

The specific electrical conductivity λ and dielectric permeability ε of the emulsions were studied using the bridge method. To determine the dielectric permeability and specific conductivity, the emulsion under study was placed into a cell with copper electrodes. The distance

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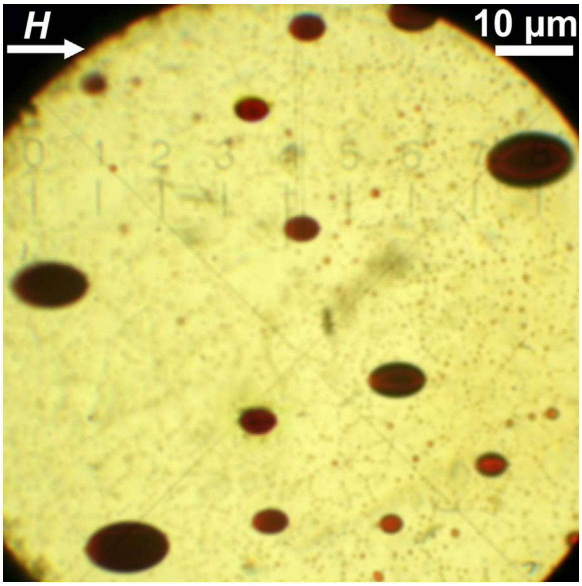

Fig. 1. The layer of emulsion of magnetic fluid drops in oil under the action of constant uniform magnetic field produced by the Helmholtz coils (H≈1 kA/m).

between electrodes was 2.5 mm. The interior of the cell is a rectangular parallelepiped with the dimensions 30×40×2.5 mm. Then the cell capacity and its active conductivity were measured using the parallel equivalent circuit. The measurements used the 100 kHz measurement signal. The dielectric permeability ε, and specific conductivity λ were calculated from the expressions: $\varepsilon=(C-C_p)/(C_0-C_p)$; $\lambda=G/A$, where C_0, C are the capacities of the empty and emulsion filled cells, C_p is the parasitic capacity calculated using the calibration liquid, G is the active conductivity of the emulsion filled cell, A is the constant of cell predetermined using the standard 0.01 aqueous solution of potassium chloride. To study the effect of the magnetic field on the measured values, the emulsion filled cell was placed into the constant uniform magnetic field created by Helmholtz coils. The cell was able to rotate around a vertical axis, which allows varying the mutual orientation of the intensity vectors of the external magnetic and measuring electrical fields with respect to each other. It should be noted that the experimental measuring electrical field was weak enough and did not have effect on the structural state of the emulsion under study, that is, the microgeometry of the emulsion is formed only under the effect of the applied external magnetic field.

The dependences of the dielectric permeability and specific electrical conductivity of magnetic fluid emulsion on the magnetic field strength and direction and on the dispersed phase concentration were studied. It turned out that the dielectric permeability and electrical conductivity of emulsions depends on the applied magnetic field strength and direction. Fig. 2 shows the dependences of the emulsion dielectric permeability relative change on the external magnetic field strength H when the magnetic field is parallel and perpendicular to the measuring electrical field for the two dispersed phase volume fractions, φ. Here the emulsion dispersed phase has been presented by magnetic fluid droplets and the dispersion medium has been presented by oil. Fig. 2 shows that, under effect of the magnetic field whose direction coincides with that of the electrical measuring field, the dielectric permeability grow compared with the initial ones. At the orthogonally related directions of the fields the emulsion dielectric permeability shows less pronounced decrease. The dependences of the specific electrical conductivity relative changes of the emulsion exposed to the magnetic field are of similar character.

To reveal the anisotropic character of the macroscopic electrical properties of magnetic fluid emulsion exposed to the magnetic field, the dielectric permeability of emulsion has been measured as a function of the angle α between the directions of the external magnetic field and

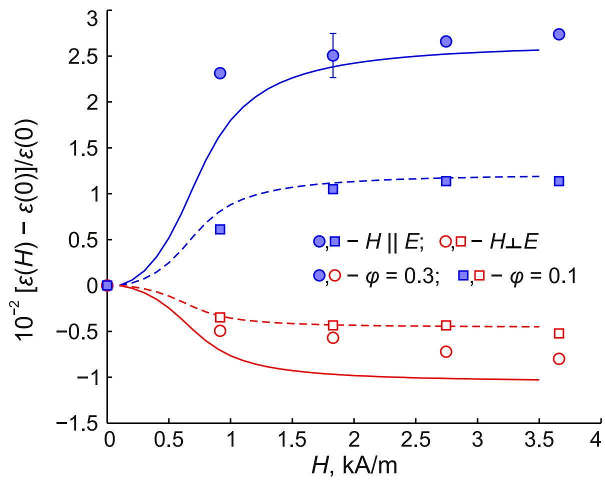

Fig. 2. Dependence of relative change of dielectric permeability of magnetic fluid emulsion on magnetic field strength. Dots are experiments; lines are calculations. Filled symbols: magnetic field strength parallel to electrical field strength; open symbols: magnetic field strength perpendicular to electrical field strength. Circles correspond to emulsion volume fraction 0.3; squares correspond to emulsion volume fraction 0.1.

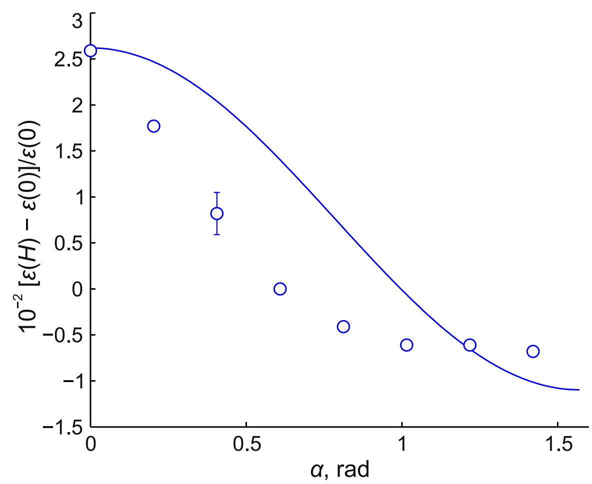

Fig. 3. Dependence of relative change of dielectric permeability of magnetic fluid emulsion on angle between the directions of electrical and magnetic fields. Dots are experiments; line is calculations.

electrical measuring field (Fig. 3). The measurements have been performed for the emulsion of magnetic fluid droplets in oil with volume concentration φ=0.4 at external magnetic field strength H=1.8 kA/m.

Fig. 4 shows the dependences of the relative change of dielectric permeability of emulsion on the dispersed phase (magnetic fluid) volume fraction with exposure to the magnetic field oriented parallel and perpendicular to the electrical (measuring) one. Measurements are performed at external magnetic field strength H=3.7 kA/m. It is seen that the effect of the magnetic field on the dielectric permeability becomes more pronounced with the volume fraction increasing within the studied concentrations range. The specific electrical conductivity dependence on the emulsion volume fraction has the analogous character.

Rheological studies were performed at 20 °C with a cone-and-plate viscometer that allows the applied stress to be independently controlled. The cone diameter was 70 mm and the angle 0.3°. The gap between the plate and the cone point was set to 25 μm. A constant uniform magnetic field was applied perpendicular to the shear plane by means of a pair of coils surrounding the cone and plate. Examples of the stress against strain rate variations, measured at different values of magnetic field, are shown in Fig. 5 for the emulsion of magnetic fluid in