ELECTRICAL AND MAGNETIC PROPERTIES OF MAGNETIC FLUID

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Abstract: *the magnetic fluid based on magnetite has been obtained by chemical co-precipitation method. Magnetite particles of the obtained magnetic fluid were examined by using X-ray diffraction analysis (XRD) and transmission electron microscopy (TEM). The electrical conductivity and magnetic susceptibility of magnetic fluids have been studied depending on concentration of disperse phase. The variation of the electrical conductivity of the samples depending on temperature was measured. Also the relative changes of the specific electrical resistance studied depending on magnetic field. The results of the experiments were compared with existing theories.*
Keywords*: magnetic fluid, chemical co-precipitation, colloidal particles, volume concentration, specific electrical conductivity, specific electrical resistance, magnetic susceptibility, Quince's method.*

ЭЛЕКТРИЧЕСКИЕ И МАГНИТНЫЕ СВОЙСТВА МАГНИТНОЙ ЖИДКОСТИ

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Аннотация: *магнитная жидкость на основе магнетита была получена методом химического соосаждения. Частицы магнетита полученной магнитной жидкости были изучены с помощью рентгеноструктурного анализа (РА) и просвечивающей электронной микроскопии (ПЭМ). Электропроводность и магнитная восприимчивость магнитных жидкостей были изучены в зависимости от концентрации дисперсной фазы. Были измерены изменения электропроводности образцов в зависимости от температуры. Также относительные изменения удельного электрического сопротивления изучены в зависимости от магнитного поля. Результаты экспериментов сравнивались с существующими теориями.*
Ключевые слова: *магнитная жидкость, химическое соосаждение, коллоидные частицы, объемная концентрация, удельная электрическая проводимость, удельное электрическое сопротивление, магнитная восприимчивость, метод Квинке.*

1. INTRODUCTION

Magnetic fluids are colloid disperse system stabled of ferromagnetic or ferrimagnetic nanoparticles in carrier liquid. For stabilization the colloidal particles of magnetic fluid and prevention the formation of aggregates the surfactant is used [1]. Generally surfactant molecules have a polar "head" and a non-polar "tail" (or vice versa) [2]. One of the ends is adsorbed to the particle, and the other is attached to the molecules of the carrier liquid, forming a normal or reverse micelle around the particle respectively [3]. Magnetic fluids due to the uniqueness of their properties are widely used in various fields of science and technology. For example these fluids can be used in ultrasonic flaw detection, in chemical industry as catalyst for chemical reactions in engineering as sealants, for separation of nonmagnetic materials in mining industry, in the field of radio electronics [4]. In medicine, magnetic fluids are used against cancer as medicinal preparations and for testing gastrointestinal diseases as contrast substances [5]. For the above mentioned reasons, in this article it is aimed to study the electrical and magnetic properties of magnetic fluids.

2. Methods and materials of experiment.

In order to prepare the magnetic fluid, firstly colloidal particles of this liquid were synthesized, then these particles apply a layer of surfactant [6]. The magnetite nanoparticles were synthesized by the chemical co-precipitation method [7]. The salts hydrated iron chloride ($FeCl_3 \cdot 6H_2O$), iron sulfate ($FeSO_4 \cdot 7H_2O$) and sodium hydro-oxide ($NaOH$) are the basic materials used for the synthesis. The solutions 100 ml of 0,25M $FeSO_4 \cdot 7H_2O$ and 100 ml of 0,5M $FeCl_3 \cdot 6H_2O$ were dissolved in 200 ml of distilled water and filtered. 100 ml of 0.9M KOH solution was added to the filtered solution and mixed well with magnetic stirrer. Dark yellow solution instantly turns into a black suspension. The synthesized precipitate of magnetite was separated in the field of the permanent magnet and washed with distilled water until neutral pH. After the last washing, the oleic acid as surfactant and olive oil as carrier liquid were added and mixed 3 hours until heating at 80°C in the volume ratio 1:6. Magnetic fluids with ten different volume concentrations of nanoparticle were prepared. The volume concentrations of samples were determined using the following formula:

$$C = \frac{\rho - \rho_{cl}}{\rho_m - \rho_{cl}} \quad (1)$$

Here, ρ, ρ_{cl}, ρ_m – are density of magnetic fluid, crier liquid and magnetite[7].

3. Results and discussion

By the transmission electron microscope (TEM) was examined the size and shape of the disperse phase (Fe_3O_4) of the magnetic fluid. Fig.1 shows the TEM image of the nanoparticles. The diameter nanoparticles were in the range from 10 to 25 nm. Fig.2 shows distribution on size nanoparticles. From fig.2 it can be seen that the main part of the particles was 15 nm.

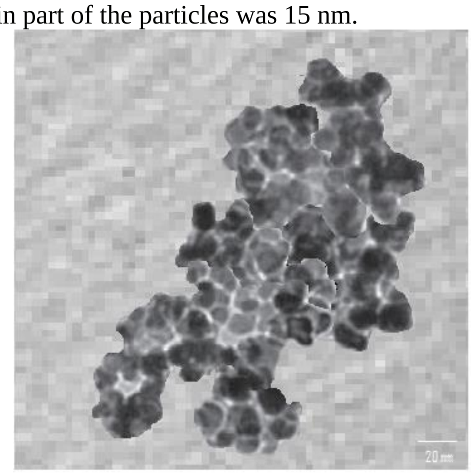

Fig. 1. TEM image of Fe_3O_4 magnetic fluid

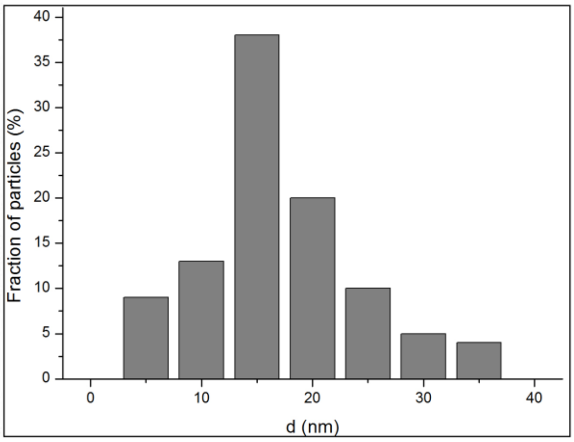

Fig. 2. Size distribution of magnetite nanoparticles

The structural characterization and the average size of magnetite particles were determined using X-ray diffractometer PHYWE – XR 4.0 with a copper tube Cu Kα, λ = 0.14596 nm at 35 kV and 1 mA collected in the range of 2θ =20 – 70° [8]. Fig.3 shows the XRD patterns for Fe_3O_4 powder. From fig.3 it can be seen that there were 6 different peaks at 2θ = 30.5°, 35.7°, 43.5°, 54.1°, 57.4°, 63 °. The average crystallite size D was determined from Scherer's equation:

$$D = \frac{K\lambda}{\beta \cos\theta} \quad (2)$$

Here – *K* is the dimensionless shape factor of particle, it is 0,89 for magnetite, λ – is the X-ray wavelength, β – is the half maximum intensity width of the peak the width of the half maximum intensity of the peak, θ – the diffraction angle. The average crystallite size of the Fe_3O_4 was about 21 nm.

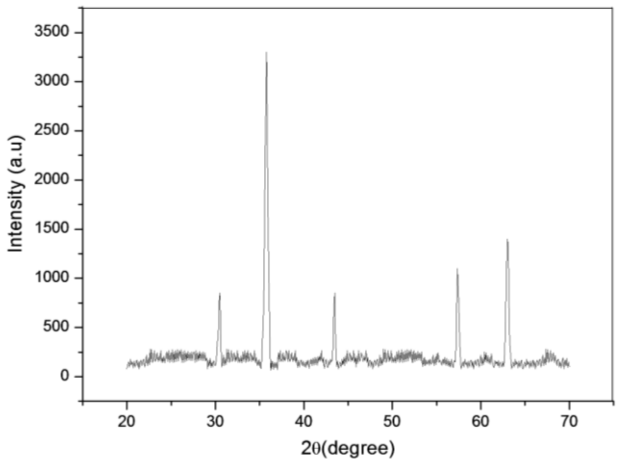

Fig. 2. XRD pattern of Fe_3O_4 powder

Because samples are liquid their electrical conductivity was measured using by the cuvette which size is 1,5x1x1,5 sm^3. Fig.3. The magnetic fluid was putted in the cuvette and source started up. The copper plate (4) on both sides of the cuvette has been used as an electrode. From fig.3 It can be seen that the amperemeter and voltmeter indicate the current and voltage in the fluid. Electrical conductivity of the samples was determined using Ohm's law:

$$\sigma = \frac{I}{U} \cdot \frac{l}{S} \tag{3}$$

Here – *I*, *U* are the current and voltage of the fluid, *l* – is the distance between electrodes (1,5 sm), *S* – is surface of electrodes (1,5 sm^2).

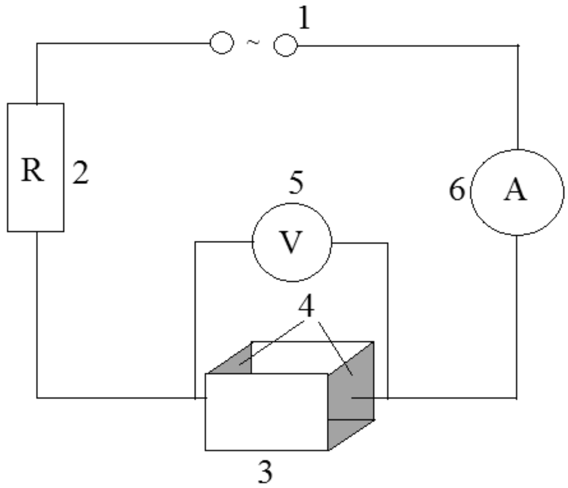

Fig. 3. Schematic image of the measure device for electrical conductivity of the magnetic fluid. 1 – variable current source, 2 – resistor (R=10 kOm), 3 – cuvette, 4 – copper electrodes, 5 – voltmeter, 6 – amperemeter

The dependence of magnetic fluid electrical conductivity on volume concentration of magnetite was measured. The obtained results are showed in Figure 4. What stands out from Fig.4 is that the electrical conductivity of the liquid increases nonlinear, with the increasing of the volume concentration of magnetite.

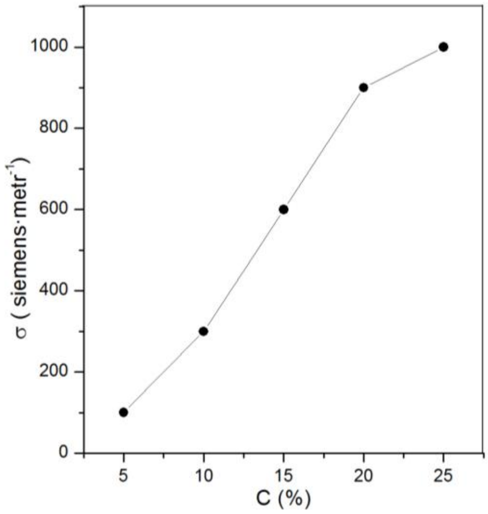

Fig. 4. Concentration dependences of electrical conductivity of magnetic fluid based on the olive oil

The electrical conductivity of the magnetic fluid is directly related to the nature of the particles, the surfactant layer and the carrier liquid. As the volume concentration of the disperse phase rises, the concentration of charge ions grows, so the electrical conductivity of the liquid monotone increases.

The variation of electrical conductivity of the fluid with the increase in temperature is shown in Fig.5. Our experiments have shown that the electrical conductivity of the samples increases nearly linear in the temperature range 20-80. The increase in electrical conductivity with temperature is due to the rise mobility of ions in the fluid.

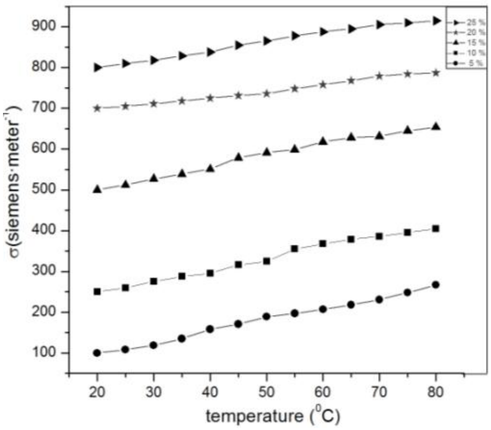

Fig. 5. The dependence of magnetic fluid specific electrical conductivity on temperature

Experiments show that the electrical conductivity of the magnetic fluid at little values concentration of dispersed phase (0 < φ <0.32 %) does not depend on the magnetic field [9], however, in the case of high concentrations this law is violated. The variation of specific electrical resistance of in different concentrations fluids with the increase in magnetic field is shown in Fig.6.

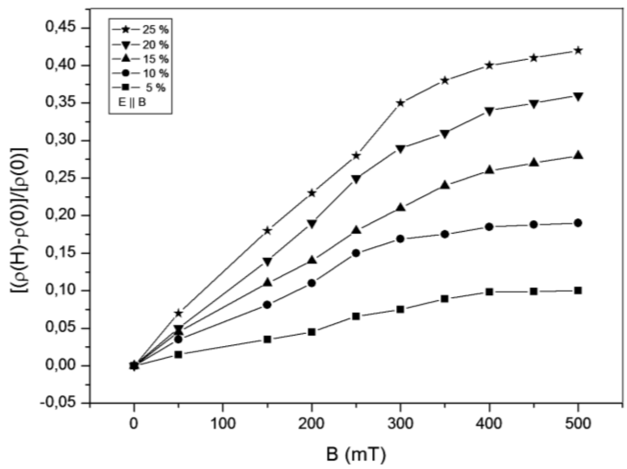

Fig. 6. Magnetic field dependence of relative changes specific electrical resistance of magnetic fluid

As can be seen in Fig.6 the relative changes of specific electrical resistance of samples slightly increases in the high alteration range of magnetic field and also we can see that saturate in the high values of magnetic field.

Magnetic susceptibility of the obtained samples was measured by the help of Quince's method [10]. The Quince method is applied only to liquids. The magnetic fluid is poured into a U – shaped capillary tube and it is placed between the poles of the electromagnet. Depending on the properties of liquids the meniscus rises or falls. By changing the height of the liquid column, determined the magnetic susceptibility of the sample with the help of following formula:

$$\chi = \frac{2g\Delta h}{\mu_0 H^2} \tag{4}$$

Here – g = 9,81 m/s^2 is the acceleration of gravity, Δh – is the meniscus height, μ_0 – is vacuum permeability, H – is the magnetic field strength.

The measured results are shown in Fig.7. As can be seen in Fig.7 the magnetic susceptibility of the liquid increases with the rising of the volume concentration of magnetite. That's the reason magnetic susceptibility depend magneto – dipole interaction of the particles in the high concentrations of the hard phase of the liquid.

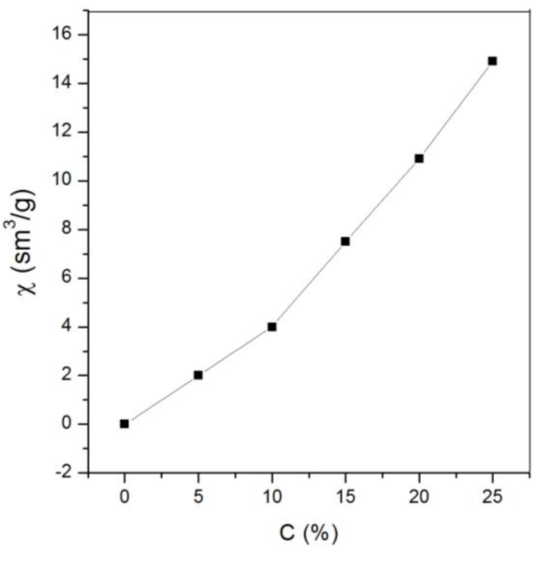

Fig. 7. The dependence of magnetic fluid magnetic susceptibility on volume concentration of magnetite

Conclusion: Study of crystal structure and morphology showed that the sizes of the colloidal particles of magnetic fluid are distributed log-normal law. The measured results show that the electrical conductivity of the samples depends on the magnetic field at high concentrations.

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