SYNTHESIS MAGNETIC FLUID BASED ON NANOPARTICLES CONTAINING IRON AND COBALT

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Abstract: In this work the magnetic fluids based on the $FeFe_2O_4$, $CoFe_2O_4$ nanoparticles have been synthesized by the chemical co-precipitation method. Morphological analysis of the $FeFe_2O_4$, $CoFe_2O_4$ nanoparticles were studied by transmission electron microscope (TEM). The comparative analysis of the experimentally measured diameter of nanoparticles $FeFe_2O_4$, $CoFe_2O_4$ in the magnetic fluid was carried out with semi-empirical calculations within the Langevin theory.

Key words: magnetic nanoparticle, EDX analysis, morphological analysis, Langevin theory.

1. Introduction.

Currently, there is great interest in studying the magnetic properties of magnetic fluids based on nanoparticles containing the metals Ni, Co and Fe. In recent years, experimental and theoretical studies have expanded the range of applications of such materials. In particular, magnetic fluids are currently used in technology throughout the world to dampen vibrations of damping systems, to seal vacuum systems as lubricants, in medicine to deliver drugs to the desired point in the human body, as well as in the treatment of malignant tumors using hyperthermia, as a contrast agent for tomographic and x-ray studies, for the separation of non-magnetic substances in the mining industry[1,2]. The study of the magnetizing properties of liquids containing ferromagnetic nanoparticles in an external magnetic field is of great importance in solving complex problems in the chemical industry and medical physics. Also, the microstructure of magnetic fluids based on nanoparticles containing simultaneously the metals Ni, Co, Fe, and the reasons for their different nature of magnetization have not been sufficiently studied. Therefore, this work aims to synthesize the magnetic fluid based on $FeFe_2O_4$, $CoFe_2O_4$ nanoparticles and study their morphology.

2. Materials and methods

Chemical reagents $FeCl_3\cdot 6H_2O$, $FeSO_4\cdot 6H_2O$, $Fe(NO_3)_3\cdot 9H_2O$, $Co(NO_3)_2\cdot 6H_2O$ with a purity of 99.8% were used in the preparation of magnetic fluids. KOH solution was used as a precipitant [3,4]. The reaction equation for the experimental process is shown below:

a) *Synthesis of $FeFe_2O_4$ nanoparticles*

$$Fe^{2+} + 2Fe^{3+} + 8OH^{-} \Rightarrow Fe(OH)_2 \cdot 2Fe(OH)_3$$

$$Fe(OH)_2 \cdot 2Fe(OH)_3 \xRightarrow[t = 30\text{мин}]{100^0 C} FeFe_2O_4 + 4H_2O$$

a) *Synthesis of $CoFe_2O_4$ nanoparticles*

$$Co^{2+} + 2Fe^{3+} + 8OH^{-} \Rightarrow Co(OH)_2 \cdot 2Fe(OH)_3$$

$$Co(OH)_2 \cdot 2Fe(OH)_3 \quad \underset{t = 30\,мин}{\overset{100^0 C}{\Rightarrow}} \quad CoFe_2O_4 + 4H_2O$$

In order to prevent agglomeration of particles in the preparation of magnetic fluid, sodium oleate was added to the filtered sediment and mixed by heating at a temperature of 80 ^{0}C. The resulting substance was dissolved in distilled water and a magnetic fluid was prepared.

3. Results and discussion

The size and shape of the cobalt ferrite particles in the magnetic fluid was checked by the TEM JEOL-2010 electron microscope (Fig.1). From the obtained results, it can be seen that the size of the particles is 10-40 nm and spherical in shape.

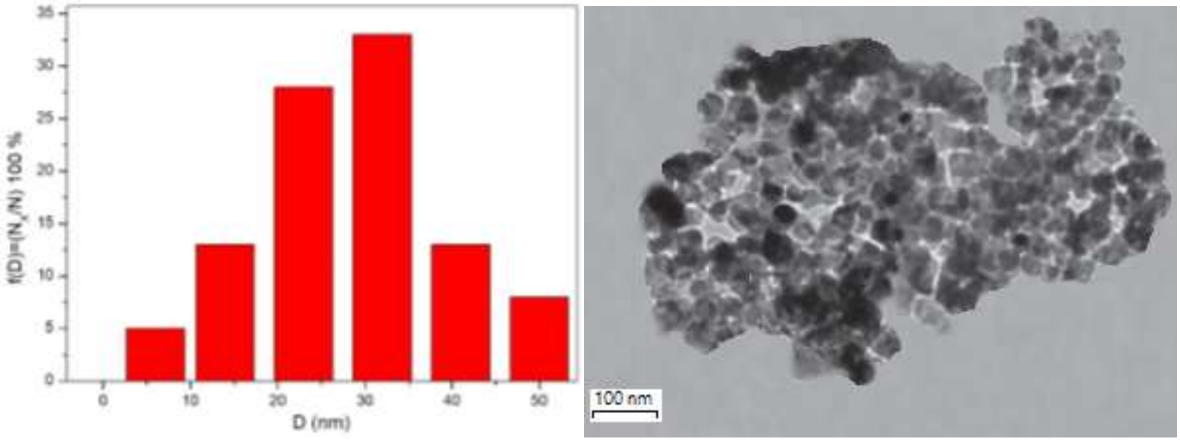

Fig.1. TEM image of the $CoFe_2O_4$ nanoparticles

The magnetic moments of colloidal particles in a magnetic fluid are always in Brownian motion. Therefore, to magnetization such a system, Langevin's theory of paramagnetism can be applied [5]. Based on this theory, the magnetization of the system can be written as follows:

$$I = I_{\infty} L(\xi) \qquad (1)$$

Here $L(\xi) = (cth\xi - \frac{1}{\xi})$ - is the Langevin function, I_∞ - is the saturation magnetization of the magnetic fluid.

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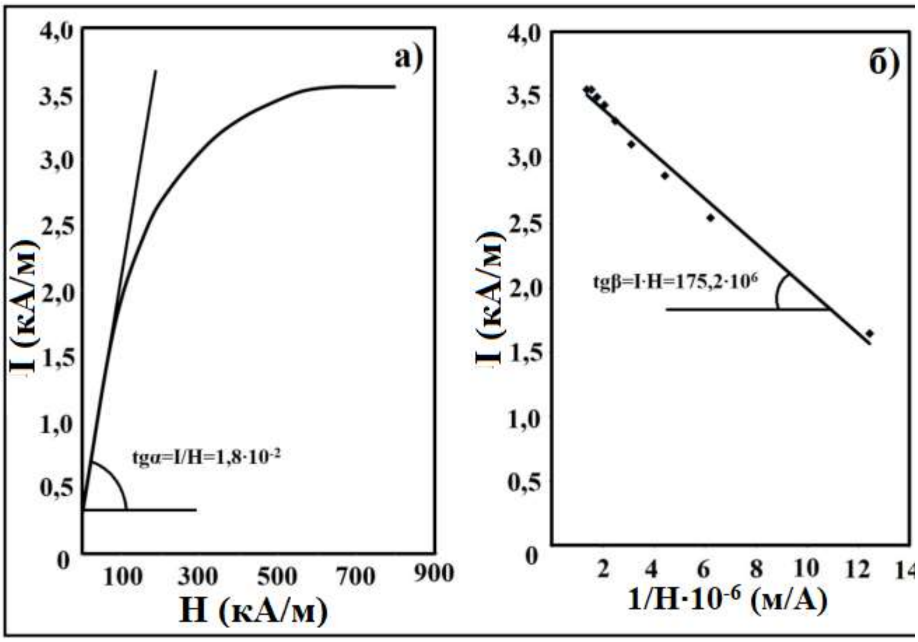

Fig.2. a) graph of the dependence I=I(H); b) graph of dependence I=I(1/H) of the magnetic fluid $FeFe_2O_4$.

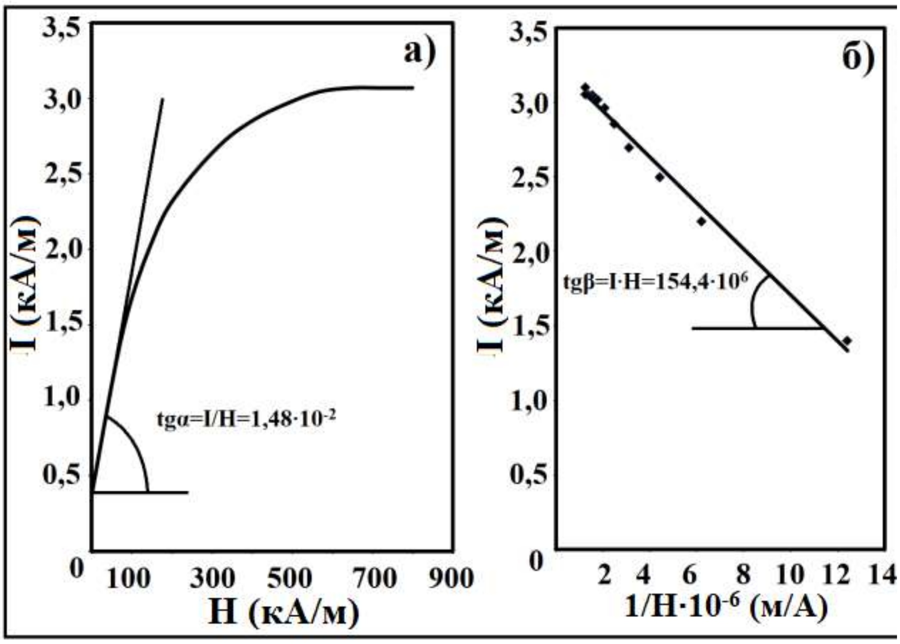

Fig.3. a) graph of the dependence I=I(H); b) graph of dependence I=I(1/H) of the magnetic fluid $CoFe_2O_4$.

Using Langevin's theory, from the graph of the dependence of magnetization on the external magnetic field *I=I(H)*, and magnetization on the inverse value of the external magnetic field *I=I(1/H)*, obtained experimentally for magnetic fluids, the diameter of the liquid particles was analyzed semi-empirically and compared with results obtained using an electron microscope. To do this, the diameter of particles in the liquid was determined using the following formula by determining the angle of inclination from the first part of the graph (Fig. 2.a):

$$d_0 = \sqrt[3]{\frac{18 \cdot tg\alpha \cdot kT \cdot \varphi}{\pi \mu_0 I_\infty^{\ 2}}} \qquad (2)$$

$$d_{\infty} = \sqrt[3]{\frac{6kT}{\pi\mu_0 \cdot tg\beta}} \qquad (3)$$

where d_0, d_∞ - are the particle diameters corresponding to the angles determined at the beginning and end of the liquid magnetization curve, I_∞ -saturation magnetization of magnetic fluid, φ- volume concentration of magnetic fluid particles, $tg\alpha$ and $tg\beta$ are angular tangents determined from the graphs $I=I(H)$ and $I=I(1/H)$ of the liquid.

Semi-empirical results obtained using TEM to measure magnetic fluid particles are presented in Fig. 2-3 and Table 1

Table 1. Diameters of $FeFe_2O_4$, $CoFe_2O_4$ nanoparticles, calculated semi-empirically using the hysteresis curve and obtained on TEM.

Sample	$tg\alpha$ (10^{-2})	$tg\beta$ (10^6 A^2/m^2)	$d_{s.e}$ *(nm)* (calculated semi-empirically)	d_e *(nm)* (experiment)
$FeFe_2O_4$	1,8	175,2	8,57 – 32,85	25 – 38
$CoFe_2O_4$	1,48	154,4	8,00 – 34,26	10 – 30

. It is clear from the results that semi-empirical calculations of the diameter of magnetic fluid particles and experimental results obtained using TEM are in good agreement with each other.

4. Conclusion

Magnetic fluids based on $CoFe_2O_4$ were synthesized by the chemical co-precipitation method. It is shown that the experimental dependences $M=M(H)$ of the studied magnetic fluids can be explained within the framework of Langevin's theory of para-magnetism. The sizes of magnetic particles, calculated from magnetization hysteresis, are in good agreement with the values obtained by electron microscopy.

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