Study of the magnetic property of supermagnetic fluid

O K Kuvandikov, Sh J Kuvandikov, M K Salakhitdinova and Kh A Kayumov
Faculty of Physics, Samarkand State University, Samarkand 140104, Uzbekistan
E-mail: kayumov0130@gmail.com

Abstract. In this work, the magnetic fluids based on Fe$_3$O$_4$ have been obtained by the chemical co-precipitation method. Analysis of the size and morphology of the synthesized iron oxide nanoparticles of the magnetic fluid using transmission electron microscopy revealed that nanoparticles are of 25-38 nm in size and spherical in shape. The elemental composition of magnetite nanoparticles of the fluid was examined in energy-dispersive X-ray analysis and determined to contain only Iron and Oxygen. The magnetic property of the magnetic fluid was measured using vibrating sample magnetometer. The results showed that the magnetic fluid has a superparamagnetic character which of specific saturation magnetization of 3.4 emu/g

1. Introduction
Since the 60s of last century, the physical properties of the magnetic fluids based on magnetite nanoparticles are being studied. According to their mechanical, thermal, electrical, magnetic, and other properties, these materials are widely used in various science fields. For example, such liquids have found numerous applications in biomedicine, electronics, industry mining, machinery, hyperthermia, and other fields [1,2]. Magnetic fluids are colloidal dispersed systems consisting of stabilized ferro or ferromagnetic nanoparticles suspended in liquid carriers [3]. The technological process to obtain magnetic fluids consists of two stages [4]. The first one is the synthesis of magnetic nanoparticles. The second is stabilizing of the synthesized nanoparticles in a carrier liquid by surfactants or polymers [5]. As of today, there is a variety of methods to synthesize magnetic nanoparticles, such as co-precipitation, hydrothermal, sol-gel, thermal decomposition, solvothermal, sonochemical, electrochemical, mechanical milling and other methods [6,7]. In the synthesis of the Fe$_3$O$_4$, the chemical co-precipitation method was acceptable because of its simplicity, convenience, low cost, and most importantly, the ability to control the size of the particles. The surfactant is used to prevent aggregation of the nanomagnetic particles of magnetic fluid. Generally, surfactant molecules have a polar “head” and a non-polar “tail” (or vice versa). One of the ends is adsorbed to the particle, and the other is attached to the liquid carrier molecules, forming a normal or reverse micelle around the particle, respectively [8]. We used sodium oleate as a surfactant in the preparation of the liquid.

If we consider the width of the field of application of magnetic fluids, the study of their magnetic properties at room temperature is actual. Therefore, this research aims to synthesize the magnetic fluid based on iron oxide nanoparticles and study their morphology, element composition, and magnetization.

2. Materials and methods
In the preparation of the magnetic fluids, Fe$_3$O$_4$ nanoparticles were initially synthesized by the chemical co-precipitation method. Each of the salts of FeCl$_3$·6H$_2$O, FeSO$_4$·7H$_2$O with the molar ratio
of Fe\(^{2+}\): Fe\(^{3+}\)=1:2 was dissolved separately in 100 ml of double distilled water, then was mixed together at 60 °C using a magnetic stirrer for 30 min. Afterward, 1M KOH as the precipitating agent was slowly added to the resulting salt solution drop by drop until the pH 7 and stirred at 100 °C 30 min. Then the precipitated nanoparticles were washed with double-distilled water several times to remove the impurities. The sediment was filtered, dried in the oven at 100 °C for 6 hours and pulverized to a powder. The reaction equation of the experiment is shown below:

\[
2\text{FeCl}_3 \cdot 6\text{H}_2\text{O} + \text{FeSO}_4 \cdot 7\text{H}_2\text{O} + 8\text{KOH} \rightarrow \text{Fe}_3\text{O}_4 \downarrow + 2\text{K}_2\text{SO}_4 + 6\text{KCl} + 23\text{H}_2\text{O}
\] (1)

Magnetic fluids were prepared under the condition that 1 g of sodium oleate dissolved in 50 ml of distilled water was added to the sediment as a surfactant to prevent particle agglomeration, then mixed well at 80 °C for 1 hr.

Morphology of the nanoparticles of the magnetic fluids and elemental composition of the Fe\(_3\)O\(_4\) powders have been examined using a transmission electron microscope (model: TEM LEO 912 AB) and an energy dispersive X-ray spectroscopy (EDX, model: X-ACT Silicon Drift Detector). The magnetizations of the fluid samples were measured with a vibrating sample magnetometer at the room temperature.

3. Results and discussion

3.1. TEM studies.

The shape, size, and morphology of the nanoparticles of the magnetic fluid were investigated by using transmission electron microscope (TEM). The obtained results are shown in figure 1. From TEM images it can be seen that almost all of the particles of the samples are spherical in shape. We can also see that the size of the particles are in the range from 25 to 38 nm. These results confirm that monodisperse and spherical magnetite nanoparticles were formed.

![Figure 1. TEM image of the Fe\(_3\)O\(_4\) nanoparticles](image)

3.2. Chemical composition studies.

The elemental compositions of the magnetite nanoparticles were analyzed by the energy dispersive X-ray (EDX) measurements. The measurement results are shown in figure 2. As can be seen from figure 2, the sample contains the elements Fe and O, and the value percentage of Fe is higher than O. It is known that magnetite is composed of Fe and O elements. The EDX spectrum indicates that the obtained sample is composed of only Fe and O. However, a small percentage of sulfur is present which might be due to the ferric salts used.
3.3. Magnetic properties.

The dependence of the magnetization of the magnetic fluid on the magnetic field was measured by Vibrating sample magnetometer at room temperature. The results of the measurements are shown in figure 3. From figure 3 it can be noted that the magnetization of the sample increases with increasing magnetic field and attains the saturation. From the magnetization hysteresis loops of the figure 3 we can determine the saturation magnetization, remnant magnetization and the coercivity values. The saturation magnetization value for the Fe$_3$O$_4$ magnetic fluid is 3.4 emu/g.

4. Conclusion

Magnetic fluid based on high purity iron oxide nanoparticles have been successfully synthesized using chemical co-precipitation method. Based on EDX analysis it was confirmed that the synthesized particles were Fe$_3$O$_4$. TEM measurements revealed that the sizes of the Fe$_3$O$_4$ nanoparticles of the magnetic fluid are about 25-38 nm. We have also revealed that the magnetite magnetic fluid shows superparamagnetic nature, and its saturation magnetization value was 3.4 emu/g.

References

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