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Synthesis, Technology and Analysis of Nanoparticles of Barium Hexaferrite for Creation of Magnetically Controlled Drug Delivery Systems

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Abstract

Introduction. The present research was focus to assess the possibilities of the chemical condensation as a method of synthesis of barium hexaferrite nanoparticles for their use in pharmaceutical drugs with magnetic properties.

Materials and Methods: For preparation of barium hexaferrite nanoparticles chemical condensation method. Based on the results of previous studies, the methodology of the synthesis and technology has been established. The reaction has been conducted by using solutions of the corresponding metal cations in an alkaline medium.

Results and Discussion: Transmission electron microscopy photo shows that the particles of the experimental sample had a plate-shaped hexagonal shape. Most of the particles of the system had a form approximate to the isometric, so for such particles the diameter parameter is twice as large as the thickness (d/h ~2). Synthesized particles do not exceed the upper limit of the single-domain in morphology of a diameter can be used as an object of investigation in a wide range of temperatures and MF parameters such as magnetic properties, interparticle magnetic interaction, and deviation from stoichiometry and physicochemical state of the surface.

Conclusion: By the method of chemical condensation the barium hexaferrite nanoparticles with an average particle size <d>= 450 nm and high magnetization σ_s = 64 Am^2/kg have been synthesized on the basis of which a magnetically controlled X-ray contrast mediums has been developed.

Key words: nanoparticles, barium hexaferrite, magnetic contrast medium.

Introduction

High dispersive particles of ferrite that with common technical use are now studied actively as objects for creating drugs with magnetic properties. Publications on this issue are so widespread [1-7] that the creation of a new direction in pharmacy such as magnetic nanopharmacy is noted. Among the basic requirements for nanoparticles of ferrite materials for medical and biological purposes, we can specify biological compatibility; sample dispersion; high values of magnetic parameters. The first requirement mainly depends on the chemical composition of the ferrite material, while other ones depend on the method, conditions and synthesis technology.

Particles of barium hexaferrite have a complete potential as a magnetic material for pharmaceutical drugs has. This ferrite belongs to the class of hard magnetic material. It has a rather large value of the coercive force and residual induction, after magnetization it can act as a permanent magnet. With the introduction of particles into the drug, it is possible to obtain a system that itself will be a source of magnetic field (MF). It can be used in the development of pharmaceuticals in the form of patches, suppositories, ointments.

Barium hexafferite with a rather large value of the coefficient of attenuation of X-rays is a promising material for creation of X-ray contrast mediums with magnetically controlled properties. Their use will make possible to control purposefully the movement of X-ray contrast medium and keep it in the target area. As a result, it will allow to improve early diagnostics and to specify the localization of tumors in the cavities and organs, the X-ray diagnostics of which is unsatisfactory while using the traditional aqueous suspension of barium sulfate.

In industry ferrites are obtained by conducting a solid phase ferritization reaction at high temperatures followed by grinding in ball mills, so by a mechanochemical synthesis method [8-10]. The study of the reaction mechanisms that are the basis of the formation of ferrites points to the complex nature of this process. For the mechanochemical method of synthesis, the passage of the ferritization process depends significantly on the diffusion constraints, therefore, the methods of "wet" or "soft" chemistry, which are associated with the use of solutions and amorphous co-precipitated and dehydrated hydroxides are increasingly used to produce oxide powders. It is a method of chemical condensation.

Purpose of work: to assess the possibilities of the chemical condensation as a method of synthesis of barium hexaferrite nanoparticles for their use in technological process pharmaceutical drugs with magnetic properties.

Materials And Methods

In the experimental work, particles of barium hexaferrite ($BaO \cdot 6Fe_2O_3$) have been synthesized by chemical condensation method. Based on the results of previous studies, the methodology of the synthesis and technology has been established. The reaction has been conducted by using solutions of the corresponding metal cations (99.99% purity, Aldrich) in an alkaline medium according to the following equation:

$$BaCl_2 \times 2H_2O + 12FeCl_3 \times 6H_2O + 19Na_2CO_3 \times 10H_2O \xrightarrow{t^\circ}$$

$$\xrightarrow{t^\circ} BaCO_3 \times 12FeO(OH)\downarrow + 18CO_2 + 38NaCl + 234H_2O$$

The use of an aqueous solution of sodium carbonate forms an alkaline medium (pH $\geq$ 12), co-precipitates Ba^{2+} and Fe^{3+} ions in the form of barium carbonate and iron (III) hydroxide. The resulting precipitate is heated for two hours at 800 °C. The chemistry of the ferritization process can be represented by the chemical equation:

$$BaCO_3 \times 12FeO(OH)\downarrow \xrightarrow{t^\circ} BaO \cdot 6Fe_2O_3 + CO_2\uparrow + 6H_2O$$

Scanning electron microscopy

The particle size has been determined by an electron microscope JSM-820 (JEOL) with the possibility of magnification of 150,000 times. This was used to ascertain the morphology of the particles, as well as to observe related microstructural features of the ferrite.

Vibrating sample magnetometer measurements

Vibrating Sample Magnetometer for magnetic measurement was used. The measurement of the magnetic properties of materials was performed as a function of magnetic field (MF), temperature, and time. The resulting hysteresis loop provides the relationship between magnetization and the applied field at temperature 300 K. The Parameters extracted from the hysteresis loop that are most often used are the saturation magnetization, the remanence, and the coercivity.

RESULTS AND DISCUSSION

The functional properties of the synthesized particles have been studied in order to obtain drugs with technology and magnetic properties on their basis. Sizes of the particles and their magnetic parameters of the synthesized system of barium hexaferrite particles have been studied.

Transmission electron microscopy photo (Figure (1)) shows that the particles of the experimental sample had a plate-shaped hexagonal shape. Most of the particles of the system had a form approximate to the isometric, so for such particles the diameter parameter is twice as large as the thickness (d/h ~2).

Barium hexafferite is a magnetic material with high anisotropy, has a flat hexagon structure, with crystallographic parameters ***a***=5.893 Å та ***c*** = 23,194 Å [10, 11]. From the established function of particle distribution in diameter, it can be seen that the synthesized barium hexaferrite particles belong to a high dispersive system of crystals with an average particle diameter of <d> = 450 nm.

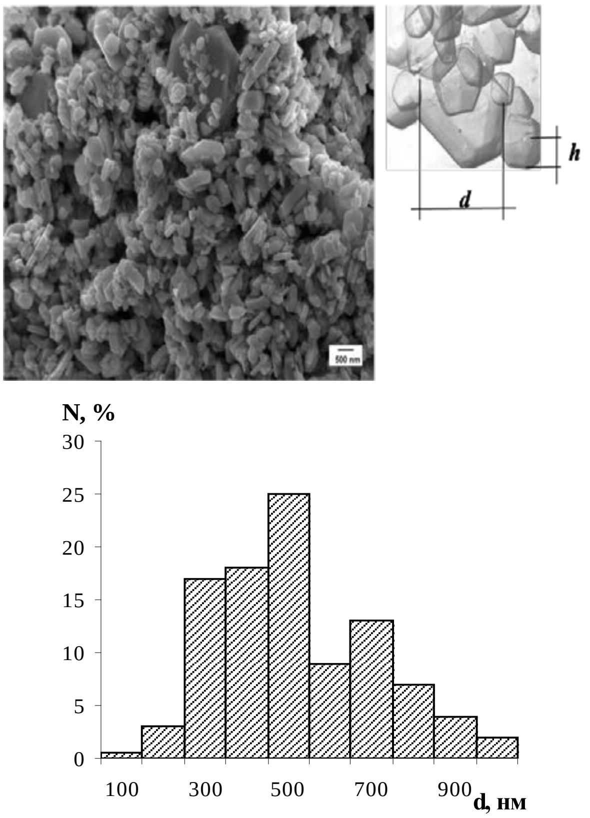


Figure (1) The electronic photograph and the normalized distribution function of particles of barium hexaferrite by size.

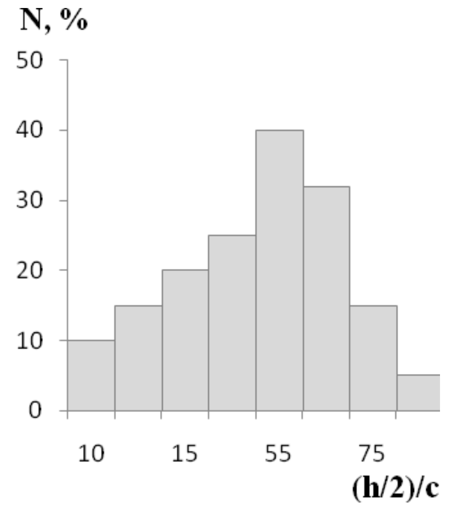
Based on the results (Figure (1)) of electron microscope studies (statistical sample ~ 500 particles), the values of the particle distribution in thickness (h) and in parameter ((h/2)/c) have been calculated (Figure (2)).

Synthesized particles do not exceed the upper limit of the single-domain (d 1.4 μm [12]) in morphology of a diameter can be used as an object of investigation in a wide range of temperatures and MF parameters such as magnetic properties, interparticle magnetic interaction, and deviation from stoichiometry and physicochemical state of the surface.

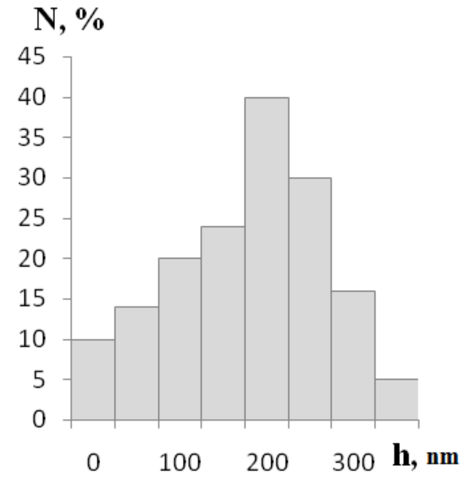
The crystallographic axis *c* is perpendicular to the basal plane of the crystal, so the thickness of the hexafferite crystals is compared with the value of this crystallographic parameter. As it can be seen from the diagram (Figure (3)), 10% of the particles have a thickness that corresponds to lattice parameters.

The normalization of the half-thickness of the particle (h/2) in the parameter of the crystal lattice is related to the fact that the open surface of the basal plane surrounding the platelet particle on both sides is the main source of excitation of its crystalline and, as a consequence, magnetic structure.

Taking into account the known fact [8, 10-13] that the thickness of the structurally defective near-surface layer with distorted magnetic structure for the particles of barium hexaferrite exceeds two parameters of the crystal lattice, the contribution of the near-surface layer in the particles of the experimental system is significant (40-10% of the volume of the particle) to obtain significant results. The determined value of the saturation magnetization of the synthesized sample of barium hexafferite is σs = 64 Am2/kg and differs from the macro-analogue by 11%.



a



b

Figure (2) Distribution of particles of synthesized samples of barium hexaferrite: parameter (h/2)/c (a); thickness (b)

DISCUSSION

The mentioned correlation $\sigma_S(d)$ (Figure (3)) clearly demonstrates the general tendency of magnetization reduction with a decrease in the average particle size. This dependence was established [14] for particles of barium hexaferrite synthesized by various methods and can be used for the attestation of particles of barium hexaferrite with a known one parameter (size or magnetization). The experimental sample completely corresponds in its parameters to the established correlation. In accordance with its size, the synthesized barium hexaferrite system has satisfactory technology and magnetic properties.

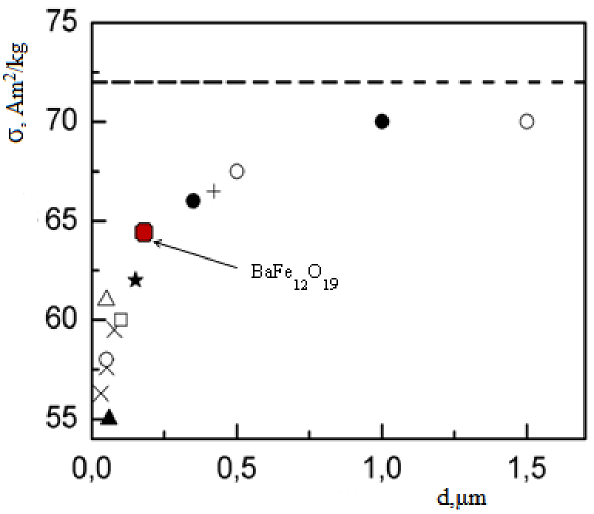


Figure (3) Magnetization of saturation of particles of barium hexaferrite of various dispersity relatively to the macro-analog (*T* = 300 K, *H* = 18 kOe)

The question of near-surface magnetism is important in the study of the basic properties of magnetic nanoparticles. Considering that the particles are three-dimensional objects, surface atoms, depending on the particle size, can occupy a sagnificantlly large fraction of the total volume of particles. Not only contribution of the exposed surface belongs to it, but also the adjacent structurally defective layers. The effect of the exposed surface is larger if proportion of the crystal is smaller. According to the postulates of the "shell model" [12-13], it is necessary to specify such technology parameters of particle size as the total diameter of the solid particle (d) and the thickness of the near-surface layer (δ) with a "canted" magnetic structure. The thickness of the near-surface layer depends on many parameters. The main role in this question belongs to the method and conditions for the synthesis of particles. For nanoparticles of barium hexaferrite (d = 14 nm) obtained by the mechanochemical method, δ = 2 nm. Therefore, the volume fraction of the structure-defective surface is almost 64% of the total volume of the particle. In this case, the saturation magnetization of the nanoparticles of hexaferrite is reduced compared to its single crystal analogue by 61.5%.

Conclusions

The chemical condensation method makes possible to obtain barium hexaferrite nanoparticles with a saturation magnetization value 5.6 times higher than for particles obtained by the mechanochemical method. The thickness of the near-surface layer of synthesized particles of barium hexaferrite is only δ~0.84 nm. The method of chemical condensation allows to accurately dosing the initial materials, which are used in the form of solutions. Under conditions of mixing and co-precipitation of the components in the liquid phase, a high dispersion and close contact is achieved, a uniform distribution of components of the ferrite is ensured.

Using the synthesized particles of barium hexaferrite, an X-ray contrast medium with magnetically controlled properties has been developed to diagnose diseases of the hollow organs of the digestive system (patent of Ukraine No. 90577). Its X-ray contrast properties are 1.55 times greater than in traditional nonmagnatic analogues (30% aqueous suspension of barium sulfate) [15]. Controlling the medium with an external magnetic field opens up new possibilities in technological process and diagnostics to improve its quality.

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