Bacteriostatic properties of medical textiles treated with nanomaterials based on Fe$_2$O$_3$

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Abstract. The purpose of this work is to reveal the bacteriostatic properties of medical textiles treated with magnetite nanoparticles. Cotton materials with a surface density of 120 g/m$^2$ were used as textile materials. The mixture of magnetite nanoparticles is applied to the textile material. The characteristic of such a textile material is Q - Force per unit area of material from a magnet with an induction of 1 Tesla at a distance of 1 cm. A broth-based nutrient solution was prepared, which was impregnated with textile samples. The growth rate of such fungi is inversely proportional to the bacteriostatic properties of the material. Visual observation of the growth of molds in Petri dishes showed a significant difference in their growth efficiency depending on the saturation of the material with magnetite. Microscopic studies showed the lengths of molds grown on different samples of textile material. The content of magnetite in a textile material significantly affects its bacteriostatic properties. This makes it possible to recommend such materials as promising medicines for the treatment of purulent wounds.

1. Introduction
An obvious trend in modern technology is the improvement of medical textiles [1]. Antimicrobial and bacteriostatic functions are among the important properties of textiles that are used in the treatment of wounds [2]. A number of sources indicate that the inclusion of metal nanoparticles in textile materials can enhance antimicrobial properties [3]. In particular, it is indicated that magnetite nanoparticles possess both magnetic and antimicrobial and bacteriostatic properties. Real studies in this direction were carried out only for food products [8]. Considering the importance of providing bacteriostatic properties to textiles in the treatment of wounds, it is important to identify patterns of the influence of nanomaterials in the operation of medical textiles. The issues of the technology of applying nanomaterials to textile materials, as well as methods for revealing the patterns of distribution of nanoparticles in a textile material are considered in [9]. However, bacteriostatic properties have not been studied.

The purpose of this work is to reveal the bacteriostatic properties of medical textiles treated with magnetite nanoparticles.

2. Methods and experiments
Cotton materials with a surface density of 120 g/m$^2$ were used as textile materials. A mixture of ferrous and ferric nanoparticles is produced in a chemical reactor. Aqueous mixtures of ferrous sulfate and ferric chloride are mixed in the reactor. Ammonium alcohol through the dispenser is fed in drops into the reactor. The resulting mixture is applied to the textile material. The structure of the material obtained is examined under a microscope. Clusters of nanoparticles are revealed. The distribution of particles is
substantiated, which allows predicting their size in the nano-range without actual observation. The force of attraction of the obtained samples is measured by a magnet with a residual magnetic induction of 1.2-1.25 Tesla. The force of attraction is determined by weighing on an electronic balance under a magnet at a distance of 1 cm. The characteristic of such a textile material is $Q$ - Force per unit area of material from a magnet with an induction of 1 Tesla at a distance of 1 cm. We have determined the specific force for a number of samples $q = Q / Q_{\text{max}}$ ($Q_{\text{max}}$ is the maximum force of attraction for the sample with the maximum filling of magnetite).

A broth-based nutrient solution was prepared, which was impregnated with textile samples. Textile samples were aged in Petri dishes. In the course of exposure, mold cultures grew on the samples. The growth rate of such fungi is inversely proportional to the bacteriostatic properties of the material. As a result of microscopic studies, images of accumulations of nanoparticles in the fibers of a textile material were obtained (Figure 1).

![Figure 1. Accumulation of nanoparticles in textile fibers.](image)

The photographs demonstrate a fairly high adhesion of magnetite microparticles to tissue fibers. Since it is not possible to observe the effects characteristic of nanostructures using an optical microscope, a statistical model of the particle size distribution was substantiated, which, based on a quantitative analysis of the particle distribution in the visible range, makes it possible to determine the distribution of nanoparticles. This technique is described in [9-10].

Visual observation of the growth of molds in Petri dishes showed a significant difference in their growth. Textile materials with a significant magnetite content demonstrate a pronounced inhibitory effect on the development and growth of molds. This fact makes it possible to record the presence of bacteriostatic properties in the materials under consideration. Efficiency depending on the saturation of the material with magnetite (Figure 2).

To confirm the results obtained, microscopic studies of the substances that formed on textile materials were carried out. Microscopic studies investigated the lengths of molds grown on different samples of textile material.

Microscopic studies showed the lengths of molds grown on different samples of textile material (Figure 3).

For samples with a high content of magnetite, significantly less intensive growth of molds is observed.
Figure 2. Growth rate of molds in textile material with applied magnetite - the first figure is the maximum magnetite content, the last one is the minimum magnetite content.

Figure 3. Molds grown on textile material.
3. Results and discussion

The specific length of molds was determined as the ratio of the average length of molds for a given sample to the maximum for a sample with a minimum content of magnetite; it is characterized by the maximum length of molds) \( s = l / l \). The dependence of the size of molds on the content of magnetite is shown in Figure 4.

![Figure 4. Dependence of the size of molds on the content of magnetite in a textile material.](image)

During analyzing this dependence, the following conclusions can be drawn. In the zero coordinate, the value of the function is equal to one. A maximum is most likely observed at the same point. Mathematically, this should mean that the derivative is zero. The function most likely tends asymptotically to some value. There is an inflection in the graph in the range from 0 to 1.

The recommended function is

\[
s = e^{-aq^b}
\]

where \( a \) and \( b \) are coefficients characterizing the bacteriostatic properties of the test material with magnetite filling.

Determination of coefficients by the method of least squares makes it possible to determine the dependence in an explicit form. In this case, \( a=1,1 \), \( b=1,67 \).

The obtained dependence makes it possible to determine the bacteriostatic properties of a textile (in this case, cotton) material, depending on the content of magnetite, and also to reveal the necessary content of magnetite to ensure the specified bacteriostatic properties.

4. Conclusions

The content of magnetite in a textile material significantly affects its bacteriostatic properties. This makes it possible to recommend such materials as promising medicines for the treatment of purulent wounds. These materials can be used in food storage. The issues of safety of these materials for health, adhesion resistance of nanomaterials to textiles, bacteriostatic properties of various textile medical materials are subject to further study.
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