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DEVELOPMENT AND INVESTIGATION OF ANTIMICROBIAL TEXTILE MATERIALS BASED ON PLANT EXTRACTS AND BIOPOLYMERS

Abstract. This study investigates the properties of textile materials modified with natural antimicrobial formulations. To impart biocidal characteristics, two types of compositions were utilized. In particular, Composition 1, containing wormwood extract, chitosan, and glycerol, and Composition 2, containing bay leaf extract, hyaluronic acid, and dexpanthenol, were employed for the research. Besides, the GOST 9.060-75 standard was used to evaluate the materials' resistance to microflora, whereas the GOST 9.048-89 standard was applied to determine their biocidal activity. It was established that while materials treated with the compositions retain their structural integrity, untreated samples experience molding and degradation. The highest biocidal resistance was observed in the material with the wormwood extract and chitosan-based formulation, which demonstrated complete inhibition of *Staphylococcus* bacteria growth. Scanning Electron Microscopy (SEM) morphological studies revealed a uniform distribution of biocidal particles on the fiber surfaces. FTIR spectroscopy data indicated changes in the chemical composition of the fibers, expressed in the appearance of bands corresponding to the functional groups of the components used. Furthermore, toxicological testing confirmed the safety of materials treated with natural biocidal components for human skin. The findings provide evidence for the possibility of producing antimicrobial materials that are suitable for medical, sanitary, and hygienic use on the basis of plant extracts and biopolymers.

Keywords: antibacterial materials, biocidal treatment, textiles, natural biocides, wormwood extract, chitosan, hyaluronic acid, dexpanthenol, microbiological testing, FTIR spectroscopy, electron microscopy, microflora resistance.



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Introduction. One of the major areas of advancement in modern textile manufacturing is the development of antibacterial qualities within textile materials. Particular attention is paid to environmental safety, biocompatibility, and the stability of functional coatings, which is associated with increasing demands on medical,

hygienic, and household products. Analysis of the available literature shows that three main approaches have gained significant momentum in recent years: the creation of composite materials based on cellulose and synthetic fibers; the modification of fiber surfaces with metal nanoparticles and biopolymers; and the use of natural plant extracts and dyes with intrinsic biological activity.

Research by Russian scientists demonstrates a fundamental approach to the formation of bioactive materials based on cellulose and synthetic fibers. Studies [1] examine the selection of active substances, their fixation methods, and their impact on fiber structure, which allows for the regulation of the physical, mechanical, and biological parameters of textile materials. The potential to create composite materials with antimicrobial qualities by blending natural and synthetic components to offer resistance to biodegradation and a wide range of antibacterial activity was confirmed in another publication by the same scientists [2]. The production of next-generation textile materials that combine the advantages of synthetic and cellulose fibers is made possible by these well-established patterns.

Metal nanoparticles' broad range of antibacterial action, resilience to pH changes, and capacity for long-lasting effects are their main advantages. As a result, researchers [3] proposed compositions that improve cotton textiles' bioprotective qualities, and [4] showed how well copper nanoparticles might be incorporated into cellulose fiber structures to produce a strong bactericidal effect.

Along with chemical modification, physical methods are actively evolving. Plasma activation of fibers, presented in [5], improves the adhesion of antibacterial substances and increases the penetrating power of natural dyes without degrading the strength characteristics of cotton. Thus, surface modification technologies can significantly expand the functional properties of textiles.

One of the most dynamic trends in recent years is the use of plant extracts containing flavonoids, phenolic compounds, tannins, and phytoncides. Research [6] demonstrates the pronounced antimicrobial activity of extracts of the medicinal plants *Andromeda polyfolia* and *Alchemilla subcrenata*.

International publications describe innovative methods for fixing plant extracts to textile fibers, ensuring long-term contact of the material with the skin and reducing the risk of irritation [7]. The use of *Rumex steudelii* extract for the finishing of cotton fabrics has shown a stable antibacterial effect and an environmentally friendly process [8].

Particular attention is paid to materials obtained through natural dyeing, in which the dyes themselves possess antimicrobial properties. The effectiveness of pitahaya extract in wool dyeing is confirmed by data on its persistent antimicrobial effect and high color uniformity [9]. In addition to offering vibrant color, natural dyes for cotton and silk have antibacterial properties, especially when paired with biopolymers like shellac or chitosan [10-12,16].

Biopolymer systems stand out as promising platforms for the fixation of natural agents. Chitosan, due to its positively charged structure, ensures excellent adhesion to cellulose fibers and enhances the biological activity of applied extracts, as confirmed by scientific studies [17], demonstrating the sustained preservation of antibacterial properties in chitosan coatings.

A number of analytical works have systematized current approaches to the creation of antimicrobial textile materials. Researchers argue that while natural agents are preferable in terms of biocompatibility, environmental friendliness, and safety for human skin, they are frequently less effective than synthetic ones in terms of duration of action [13,14].

The potential of natural dyes as substitutes for conventional chemical treatments has been explored in recent publications, particularly with regard to medical textiles [15,18,19]. The simultaneous achievement of bioprotection, environmentally responsible dyeing, and enhanced material functionality is made possible by the use of natural pigments and extracts.

Principally for cotton and silk fabrics, combined techniques like the utilization of plant extracts in a chitosan system show great prospect [20].

Current research findings indicate that the textile industry will remain focused on developing and utilizing biocompatible, eco-friendly, and natural ways to provide a functional product. In this way, the following new opportunities exist:

- the use of natural dyes and plant extracts as non-harmful antimicrobial agents;
- the application of biopolymers (chitosan, shellac) to enhance adhesion and biological activity of coatings;
- physicochemical modification of fiber surfaces, including plasma treatment;
- the development of biocidal compositions for cellulose and other fibers that provide adjustable functionality.

These methods serve as the scientific and technological basis for the development of next-generation materials with high bioprotective efficacy, safety, and environmental friendliness.

Materials and methods. The main research object in this study was sterile cotton gauze, known as a bandage.

To impart biocidal properties to the textile material, the following antimicrobial formulations were applied:

Composition 1: wormwood extract – 0.5%, chitosan – 1%, glycerin – 5%, water – up to 100%.

Processing method: The wormwood extract was mixed with a solution of chitosan and glycerin. The required amount of water was added to achieve the final solution volume. The textile material (gauze) was immersed in the resulting solution for impregnation and then dried at 80°C for 15 minutes.

Composition 2: bay leaf extract – 1%, hyaluronic acid – 1%, dexpanthenol – 3%, water – up to 100%.

Processing method: The bay leaf extract was mixed with a solution of hyaluronic acid and dexpanthenol. The required amount of water was added to achieve the final solution volume. The textile material (bandage) was immersed in the resulting solution for impregnation and then dried at 80 °C for 15 minutes.

Component properties:

Wormwood (Artemisia spp.) exhibits bactericidal, anti-inflammatory, and healing properties; however, at high concentrations, it contains the toxic compound thujone.

Chitosan is a natural polysaccharide polymer that is a derivative of chitin, such as that found in crustacean shells. It has properties that allow it to regenerate and be antifungal and bactericidal.

Glycerol acts as a humectant that keeps moisture on the surface of wounds, which is responsible for improving the body's ability to heal. Also, glycerol has biocidal properties and does not irritate the skin.

Bay leaf (Laurus nobilis) has engaging properties that make it suitable for use as a dressing, including its ability to have antimicrobial, anti-inflammatory, and antioxidant properties. However, its biocidal action should be strengthened with safe chemical agents, much like any component produced from plants.

Hyaluronic acid is a substance that is used to hydrate or restore skin. It advances the migration of cells, encourages the formation of new blood vessels (angiogenesis), and maintains the optimal level of moisture for the wounded tissue.

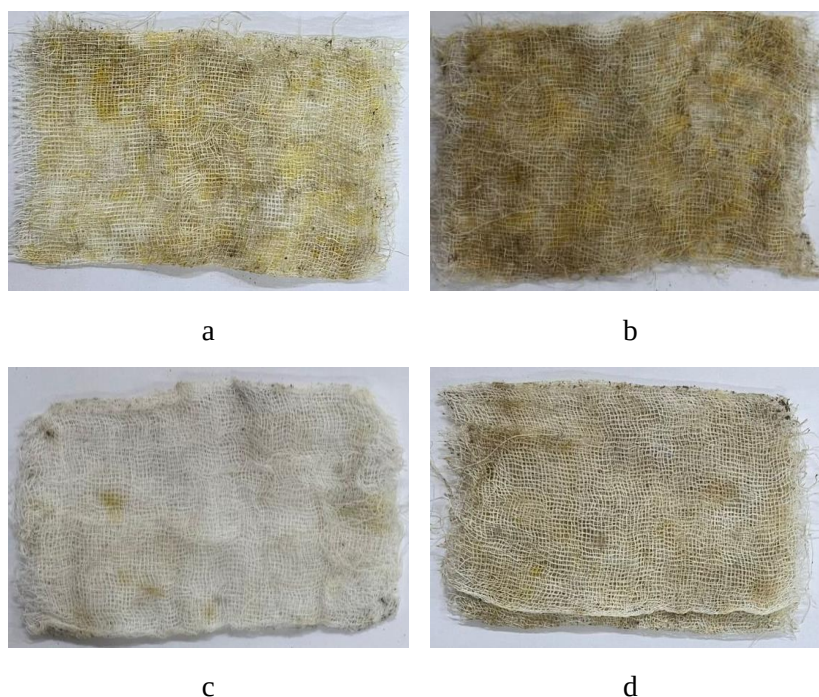
Dexpantenol (provitamin B5) is a moisturizing and soothing component that accelerates epithelialization and promotes faster tissue repair.

During this study, several complex research methods were used: the biocidal activity of the treated materials was determined according to GOST 9.060-75 and GOST 9.048-89 standards. Morphological and structural analyses were performed using a field-emission scanning electron microscope (JSM-6490LA, Japan) and a Fourier-transform infrared (FTIR) spectrometer (Spectrum-65 model).

Research results and discussion. The application of antibacterial textile materials containing natural components represents a promising area of medical science. Such materials not only effectively combat pathogenic microflora but also promote safe and rapid recovery of skin tissues.

In order to evaluate the antimicrobial resistance of the textile materials treated with the two different formulations, the samples were exposed to soil microflora in accordance with the GOST 9.060-75 standard.

The untreated material samples exposed to microflora began to mold and decompose. In contrast, the materials treated with the proposed compositions did not experience significant structural degradation (Fig. 1). The study showed that the material treated with the composition based on wormwood extract and chitosan exhibited the greatest biocidal resistance.



a, b – untreated material; c – material treated with Composition 1; d – material treated with Composition 2.

Fig. 1. Materials exposed to microbial flora

To further quantify the biocidal efficacy of the treated materials, a microbiological study was conducted according to the GOST 9.048-89 standard. The

textile material treated with Composition 1 demonstrated pronounced inhibitory activity against bacteria of the *Staphylococcus* genus: there was no microbial growth around the sample (Fig. 2).

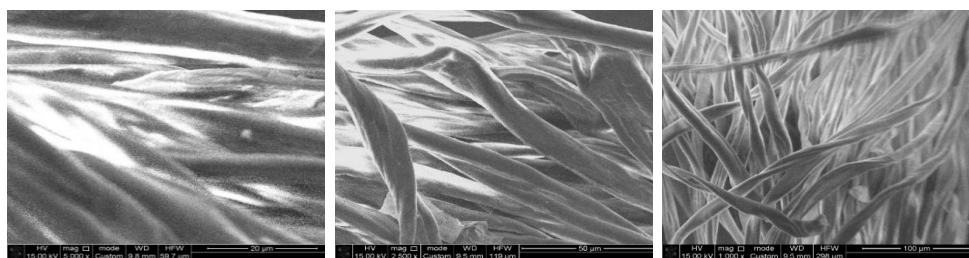


1 – untreated sample; 2 – sample treated with the wormwood extract–chitosan–glycerin formulation; 3 – sample treated with the bay leaf extract–hyaluronic acid–dexpanthenol formulation.

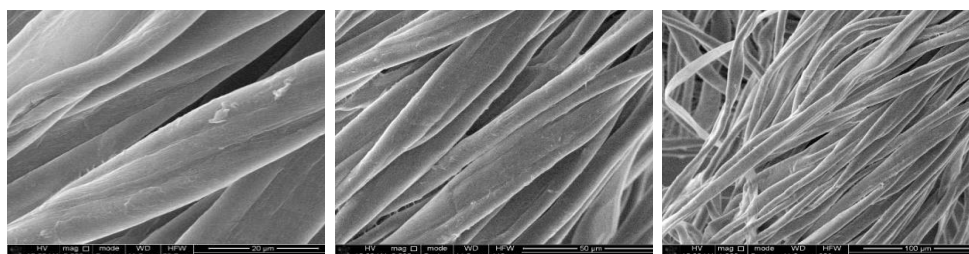
Fig. 2. Resistance of the textile material to *Staphylococcus* bacteria

Staphylococcus is an opportunistic pathogen commonly found on the skin; when the immune system is weakened or the bacteria enter a wound, it can cause infection and interfere with normal tissue healing.

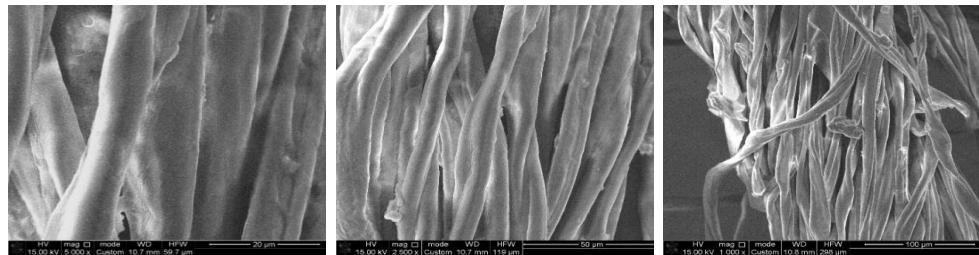
In addition, morphological changes in the treated fibers were examined using scanning electron microscopy (SEM). The structure of the cotton fibers is shown in Figure 3. A uniform distribution of biocidal particles on the fiber surfaces was observed.



Untreated sample



Sample treated with Composition 1



Sample treated with Composition 2

Fig. 3. Scanning electron microscopy images of the cotton material

Changes in the chemical composition of the cotton fiber surface after treatment with the natural-component-based antimicrobial formulations were also investigated using Fourier-transform infrared (FTIR) spectroscopy (FTIR spectrometer, model “Spectrum-65”).

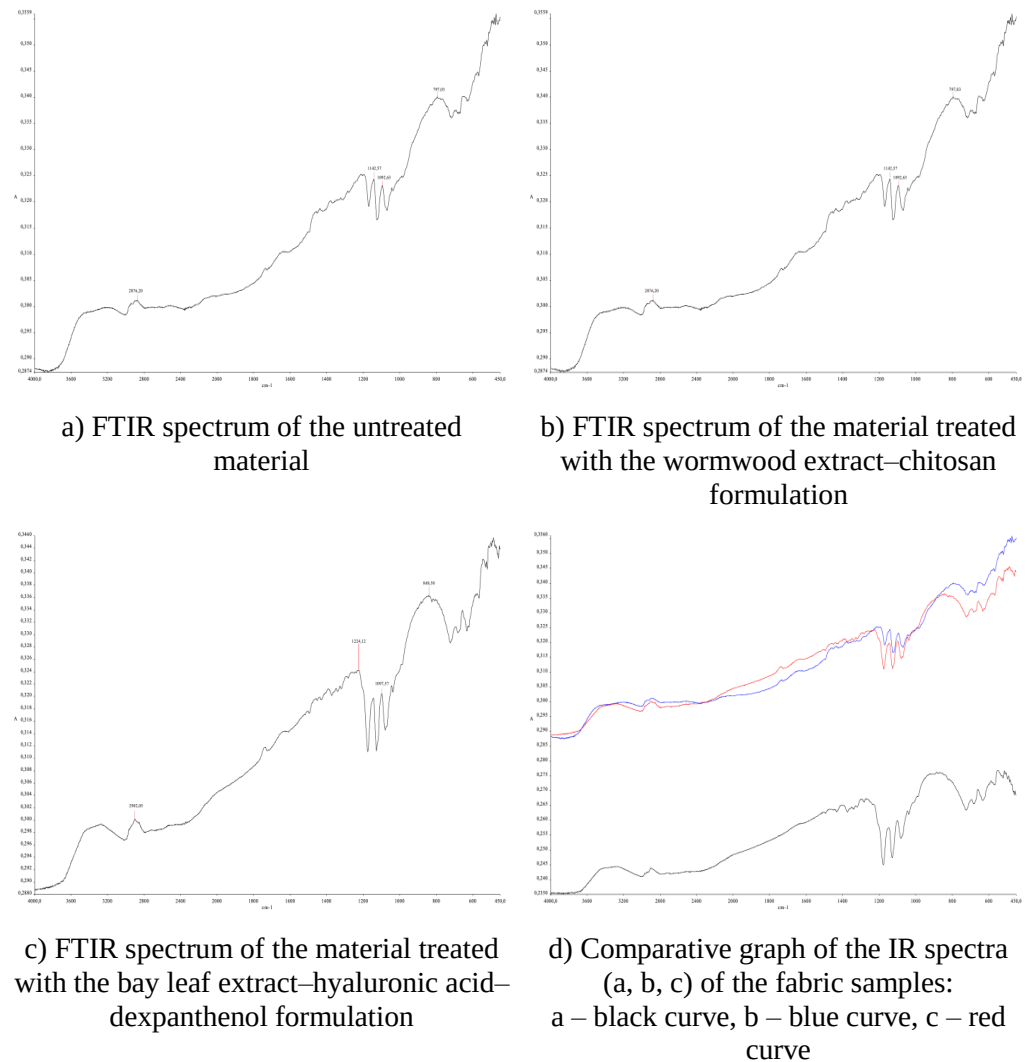


Fig. 4. IR spectra of the textile material before (a) and after treatment (b, c) with antimicrobial compositions

Treatment of cotton fabric with a chitosan-glycerol-wormwood extract composition leads to noticeable changes in the IR spectrum (Fig. 4b), confirming the fixation of bioactive components on the fabric surface. The appearance or intensification of bands in the region of 1650 cm^{-1} and 1560 cm^{-1} indicates the presence of amino groups and/or amide bonds (attributable to chitosan). An increase in intensity in the regions around 3300 cm^{-1} and $1040\text{--}1100\text{ cm}^{-1}$ suggests the presence of additional O–H and C–O groups (glycerol and possibly components of wormwood extract).

In the IR spectrum (Fig. 4c), a more pronounced and broadened O–H band is observed at $\sim 3300\text{ cm}^{-1}$, which may indicate an increased content of hydroxyl groups associated with hyaluronic acid and dexpanthenol. New peaks or enhanced intensity in the region of $\sim 1700\text{ cm}^{-1}$ are also detected, characteristic of C=O carbonyl groups present in hyaluronic acid and dexpanthenol. The intensification of the band near $\sim 1600\text{ cm}^{-1}$ may indicate the presence of amide bonds (N–H bending vibrations), typical of dexpanthenol and biopolymers. Changes in band intensities in the $1000\text{--}1200\text{ cm}^{-1}$ region suggest interactions with cellulose functional groups, possibly due to hydrogen or chemical bonding with components of the formulation.

The Technical Regulation of the Customs Union TR CU 017/2011 “On the Safety of Light Industry Products” and the regulatory document I.I.1.11-12-35-2004 were followed in conducting toxicological tests. The materials treated with plant-based biocidal agents do not irritate human skin, as the test results illustrated.

Conclusion This study examined a sterile cotton gauze modified with antimicrobial formulations based on natural components. It was shown that the proposed biocidal compositions, including Composition 1 with wormwood extract, chitosan, and glycerol and Composition 2 with bay leaf extract, hyaluronic acid, and dexpanthenol, provide the textile material with pronounced protective properties.

Testing for resistance to soil microflora (GOST 9.060-75) demonstrated that untreated control samples were susceptible to molding and degradation, while the treated materials retained their structural integrity. The highest biocidal resistance was exhibited by the material modified with the wormwood extract and chitosan formulation.

Microbiological tests (GOST 9.048-89) confirmed the pronounced antibacterial activity of the modified textile material, particularly the complete inhibition of *Staphylococcus spp.* growth around samples treated with Composition 1.

Morphological analysis of the fibers using scanning electron microscopy revealed a uniform distribution of biocidal particles on the surface of the cotton fibers.

According to IR spectroscopic analysis, changes in the chemical composition of the cotton fiber surface after treatment were established. For Composition 1, the appearance of bands at 1650 cm^{-1} and 1560 cm^{-1} indicates the presence of amino groups and amide bonds characteristic of chitosan, while increased intensity in the regions around $\sim 3300\text{ cm}^{-1}$ and $1040\text{--}1100\text{ cm}^{-1}$ confirms the presence of additional O–H and C–O groups associated with glycerol and components of wormwood extract. For Composition 2, the enhancement of the $\sim 3300\text{ cm}^{-1}$ band indicates an increased content of hydroxyl groups related to hyaluronic acid and dexpanthenol; the appearance or intensification of bands in the $\sim 1700\text{ cm}^{-1}$ region corresponds to carbonyl (C=O) groups of these components; and the strengthening of the band near $\sim 1600\text{ cm}^{-1}$ confirms the presence of amide bonds. Changes in band intensity within

the 1000–1200 cm⁻¹ region are consistent with an increased content of C–O and C–O–C groups characteristic of carbohydrate and polyol structures.

Toxicological testing conducted in accordance with the requirements of Technical Regulation of the Customs Union TR CU 017/2011 confirmed the safety of the developed formulations: the treated materials do not cause skin irritation in humans.

Thus, it has been established that the use of natural biocidal components effectively enhances the biostability of cotton textile materials while maintaining toxicological safety. The developed formulations can be recommended for the production of medical and sanitary-hygienic materials with prolonged antimicrobial properties.

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БИОПОЛИМЕРЛЕР ЖӘНЕ ТАБИҒИ ӨСІМДІК ТЕКТІ ЭКСТРАКТ НЕГІЗІНДЕГІ АНТИМИКРОБТЫҚ ТЕКСТИЛЬ МАТЕРИАЛДАРЫН ЖАСАУ ЖӘНЕ ЗЕРТТЕУ

Аңдатпа. Бұл жұмыста табиғи антимикробтық құраммен модификацияланған ттекстиль материалының қасиеттері зерттелді. Материалға биоцидтік қасиет беру үшін келесі композициялар қолданылды: 1-құрам – жусан сығындысы, хитозан және глицерин; 2-құрам – лавр жапырағының сығындысы, гиалурон қышқылы және декспантенол. Материалдардың микрофлора әсеріне төзімділігі ГОСТ 9.060–75 стандартына сәйкес бағаланды, ал биоцидтік белсенділік ГОСТ 9.048–89 стандарты бойынша анықталды. Зерттеу нәтижелері өңделмеген үлгілердің көгеріп, құрылымдық бұзылуға ұшырайтынын, ал композициялармен өңделген материалдардың өз құрылымын сақтайтынын көрсетті. Ең жоғары биоцидтік төзімділік жусан сығындысы мен хитозан негізіндегі құраммен өңделген материалда анықталды, бұл жағдайда Staphylococcus тектес бактериялардың өсуі толықтай тежелгені байқалды. Сканерлеуші электрондық микроскопия әдісімен жүргізілген морфологиялық зерттеулер биоцидтік бөлшектердің талшық бетінде біркелкі таралғанын көрсетті. ИҚ-спектроскопия деректері бойынша талшықтың химиялық

құрамының өзгеруі анықталып, қолданылған құрам компоненттеріне тән функционалдық топтарға сәйкес жолақтардың пайда болғаны байқалды. Токсикологиялық сынақтар табиғи биоцидтік компоненттермен өңделген материалдардың адам терісі үшін қауіпсіз екенін растады. Алынған нәтижелер өсімдік сығындылары мен биополимерлер негізінде медициналық және санитарлық-гигиеналық мақсатта қолдануға арналған антимикробтық материалдарды әзірлеудің перспективасы екенін көрсетеді.

Тірек сөздер: антибактериялық материалдар, биоцидтік өңдеу, тоқыма, табиғи биоцидтер, жусан сығындысы, хитозан, гиалурон қышқылы, декспантенол, микробиологиялық сынақтар, ИҚ-спектроскопия, электрондық микроскопия, микрофлораға төзімділік.

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РАЗРАБОТКА И ИССЛЕДОВАНИЕ АНТИМИКРОБНЫХ ТЕКСТИЛЬНЫХ МАТЕРИАЛОВ НА ОСНОВЕ РАСТИТЕЛЬНЫХ ЭКСТРАКТОВ И БИОПОЛИМЕРОВ

Аннотация. В работе исследованы свойства текстильного материала, модифицированного природными антимикробными составами. Для придания биоцидных характеристик использованы композиции: состав 1 – экстракт полыни, хитозан и глицерин; состав 2 – экстракт лаврового листа, гиалуроновая кислота и декспантенол. Оценка устойчивости материалов к воздействию микрофлоры проводилась в соответствии с ГОСТ 9.060–75, а биоцидная активность определялась по ГОСТ 9.048–89. Установлено, что необработанные образцы подвергаются плесневению и разрушению, тогда как обработанные композициями материалы сохраняют структуру. Наибольшая биоцидная устойчивость выявлена у материала, обработанного составом на основе экстракта полыни и хитозана, при этом отмечено полное подавление роста бактерий рода *Staphylococcus*. Исследования морфологии методом сканирующей электронной микроскопии показали равномерное распределение биоцидных частиц на поверхности волокон. По данным ИК-спектроскопии установлено изменение химического состава волокна, выражающееся в появлении полос, соответствующих функциональным группам компонентов используемых составов. Токсикологические испытания подтвердили безопасность материалов, обработанных природными биоцидными компонентами, для кожи человека. Полученные результаты показывают перспективность разработки антимикробных материалов на основе растительных экстрактов и биополимеров для медицинского и санитарно-гигиенического назначения.

Ключевые слова: антибактериальные материалы, биоцидная обработка, текстиль, природные биоциды, экстракт полыни, хитозан, гиалуроновая кислота, декспантенол, микробиологические испытания, ИК-спектроскопия, электронная микроскопия, устойчивость к микрофлоре.