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Research Article

Antibacterial effect of cotton fabric treated with silver nanoparticles of different sizes and shapes

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Abstract

Stable silver Nanoparticles in solutions of sodium-carboxymethylcellulose (Na-CMC) were synthesized, and their structure and physico-chemical properties were studied. The form and sizes of silver nanoparticles formed in solutions of CMC and cotton fabrics were studied using UV-VIS spectroscopy, atomic force microscopy and transmission electron microscopy methods. It was found that the silver nitrate concentration increase in sodium carboxymethylcellulose solutions, as well as photoirradiation of the hydrogel lead to the changes of the silver nanoparticles size and shape. Investigations have shown that spherical silver nanoparticles with sizes of 5-35nm and content of 0.0086 mass% in cotton fabrics possess high bactericidal activity. Stabilization of silver nanoparticles has preserved bactericidal and bacteriostatic activities during the washing of cotton fabrics and textiles on their base.

Introduction

Presently, there is great practical interest in the elaboration of cellulose fibers and textile biomaterials and products on their bases possessing a high bactericidal activity against pathogenic fungus and bacteria [1]. Bactericidal and bacteriostatic activity in the bases of cellulosic biomaterials and their products may take place by incorporating silver ions in their structure and following their reduction into nanoparticles, their interaction with the polymer matrix is carried out through the formation of coordinational bonds [2]. Silver (Ag) and Ag-based compounds have become the most widely represented and studied inorganic antimicrobial agents for use in textiles [3-8]. Silver is a leaching antimicrobial agent [9,10], whose efficiency depends directly on the concentration of silver cations (Ag^+) or Nanoparticles (NPs) released from the textile fibers in which they reside. After being released into the surrounding environment, these species act as a poison to a wide range of microorganisms, such as Gram negative and Gram-positive bacteria, fungi, molds, viruses, yeasts, and algae. In addition to its antimicrobial properties, Ag is assumed to offer the additional advantage of not constituting a major risk to human health, especially in low concentrations [11-13]. Currently, it is determined that silver and its compounds can inhibit the growth of and kill more than 650 types of bacteria, viruses, and fungi, consequently keeping up with the microelement, which is an essential part of the fabric of all living organisms [14].

Silver nanoparticles have an extremely large specific surface area, which increases when in contact with bacteria, viruses, and fungi. This significantly increases their bactericidal activity by decreasing the sizes of silver nanoparticles and by increasing their surface area to volume ratio [15].

According to the literature, the mechanisms of the antimicrobial activity of Ag^+ and Ag NPs are very similar to each other. Both Ag^+ and Ag NPs can participate in intermolecular interactions with the cell membrane of bacteria. Furthermore, Ag particles smaller than 10nm have been reported to penetrate into the interior of microorganism cells, where they bind to the thiol groups of enzymes and nucleic acids [16,17].

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Despite the findings that the use of Ag^+ and Ag NPs at low concentrations is relatively non-toxic to human cells and causes no serious risk for human health [18], dilemmas regarding the safety of Ag for humans and the environment are still present. It was demonstrated that humans can be exposed to Ag particles through different routes, including ingestion, inhalation and absorption through the skin [11]. The latter route is the most common in this context because sweat and other bodily excretions facilitate the release of Ag particles from textile fibers to the skin surface. It has been demonstrated that Ag NPs smaller than 30nm can be absorbed through the skin [19].

From the literature, it is evident that the Ag-modified medical textiles do not lead to cytotoxicity [20], irritation of the skin [21], and argyria [22]. In addition, they have no adverse effects on the ecological balance of healthy human skin microflora [23]. It was also found that the use of wound dressings with Ag even accelerates wound healing [24] and prevents postoperative infections [25].

The aim of this investigation is to elaborate on the presence of silver nanoparticles in bactericidal, antifungal fibers, and textile biomaterials and products, as well as to study their structure and physic-chemical, bactericidal properties.

Experimental

Material and methods

Cellulosic fibers, cotton fabrics (c/f), and on their base and purified sodium-carboxymethylcellulose (Na-CMC) with Degrees of Substitution (DS)=0.65-0.85 and Degrees of Polymerization (DP)=200–400 were used as polymer matrices. An aqueous solution of silver nitrate ($AgNO_3$) was used to form silver nanoparticles in solutions of Na-CMC. Strain pathogen microorganisms of human and animal diseases, *Staphylococcus epidermidis* and *Candida albicans*, were used. For the formation of stabilized silver nanoparticles, 0.1-0.4 wt.% aqueous solution of purified samples of Na-CMC with various DS and DP were used.

General procedure

Calculated quantities of 0.1-0.001mol/l aqueous solutions of $AgNO_3$ were added drop by drop to Na-CMC solution until a homogeneous solution of Ag^+CMC^- was obtained. Photochemical reduction of silver ions was performed in the structure of Ag^+CMC^- at 25°C through irradiation by a mercury lamp (DRSh-250) under high pressure until nanoparticles were obtained. To obtain dispersions of silver nanoparticles, the dispergator with the model number UZDN-1, Y-4.2 was used.

By means of work up treating cellulosic fibers, cotton fabrics and textile products with solutions contained the stabilized silver nanoparticles and after their subsequent heat treatment obtained cross-linked water-insoluble compositions of cellulosic fibers and cotton fabrics with antibacterial and antifungal properties.

Detection method

The size and shape of silver nanoparticles in the Na-CMC solution was controlled by spectrophotometer method in UV - spectroscopy, spectrophotometer model Specord M210 in the wavelength range from 200 to 900nm.

The size and shape of the silver nanoparticles in the cotton fabrics were determined through electron microscopy, using a transmission electron microscope (type TEM-100, Ukraine) and atomic-force microscope (AFM-5500, Austria). The variation coefficient was determined by treating the corresponding micrographs with the Math Cad program.

The content of silver nanoparticles in cotton fabric was determined through atomic absorption spectroscopy on a spectrophotometer model PERKIN-ELMER 3030 B (USA) with a flame analyzator (acetylene-air). Bactericidal activity of cotton fabrics containing silver ions and nanoparticles was investigated using the microbiological method [26], at the pathogenic bacterium *Staphylococcus epidermidis* and fungus *Candida albicans.*

Results and discussion

At the first stage of investigation, the formation of silver nanoparticles in the 0.2-0.4 wt.% concentrate solutions of Na-CMC with different DS=0.85 and DP=400 was carried out by photochemical reduction of silver ions [27]. It has been established that addition of silver ions in Na-CMC solutions causes an increase in the viscosity of the system due to the coordinational bonds between molecules with the formation of Ag^+CMC^- polycomplexes [28].

Formation of nanoparticles from silver ions in the structure of dilute solutions of Na-CMC with different DS = (0.65–0.85) and DP=(200-600) were carried out by photochemical reduction of silver ions [29,30].

It has been established that adding silver ions in Na-CMC solutions causes to increase the viscosity of system due to decreasing the solubility of Ag^+CMC^- and appearance of coordination bonds between molecules with formation of polycomplexes. Increasing the relative viscosity of Na-CMC contained silver cations dependence on decreasing the solubility due to formation of intermolecular coordination bonds between the silver ions and carboxylate anions in macromolecules of Na-CMC [31,32].

It is well known that colloidal silver particles are formed at the base of the photographic process, as explained through the Mott-Gurney theory [29,33]. During photochemical reduction, the optically generated electron migrates and catches with the electron catcher at the bedding interface and near the surface. The negative charge attracts one of interstitial Ag^+ ions presented in thermodynamic equilibrium which move to the trapped electron. This is the first step in the sequence of the electrons and interstitial atoms trapping and formation of silver clusters and nanoparticles as a basis of latent image.

Analyzing spectroscopic data nanocomposites based on silver and Na-CMC, were suggested that the negative ions of carboxymethyl group, is "catcher" for the positive charged of silver ions.

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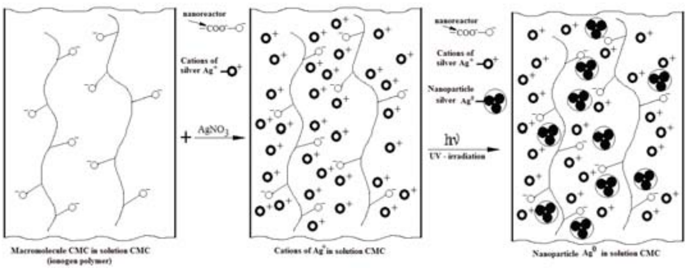
Then, the reaction sequence on the mechanism of the Mott-Gurney will be as follow:

$R\text{-}COO^{-} + (Ag^{+})_{n}$	$\xrightarrow{h\nu}$	$R\text{-}COO^{\cdot} : Ag^{0}$,	(1)
$R\text{-}COO^{\cdot} : Ag^{0} + e$	$\longrightarrow$	$R\text{-}COO^{-} : Ag^{0}$,	(2)
$R\text{-}COO^{-} : Ag^{0} + Ag^{+}$	$\xrightarrow{h\nu}$	$R\text{-}COO^{\cdot} : Ag_{2}^{0}$.	(3)
$R\text{-}COO^{-} : Ag_{2}^{0}$	$\xrightarrow{h\nu}$	$R\text{-}COO^{-} : (Ag^{0})_{n}$.	(n)

Thus, the photostimulated formation of silver nanoparticles in the $Ag^{+}CMC^{-}$ hydrogel can be considered as electron-stimulated nuclear process that may be based on Mott-Gurney theory [29], as the photography process.

Essentially, of this is that following the photochemical reduction, an electron and a proton are released in the process of regeneration of carboxylic anions of sodium-carboxymethylcellulose [34].

During the photochemical reduction the optically generated electron migrates and cached in electron catcher at the interfaces and near the surface (**Scheme** 1).



Scheme 1: Assumption scheme of formation nanoparticles of silver in structure Na-CMC.

Cations of silver attracts to carboxymethyl anion of CMC to form an ionic bonds. Reduction reaction begins with connected silver cations-at "nanoreactors" with formation clusters, which turn into nanoparticles, due to recovery of cations near nanoreactors. This is the first step in the sequence which the electrons and interstitial atoms catching, forming clusters and silver nanoparticles, which make on basis latent image.

Synthesized silver nanoparticles, by photochemical method, in Na-CMC solution provided high stability and didn't come to agglomeration during keeping at long times, to compare with nanoparticles reduced from silver ions in aqueous solutions by chemical agents.

After photolysis of Na-CMC solutions contained silver ions formed enough stable colloidal systems of nanosilver pale-yellow color, contained at the optical spectra maximum at λ_{max}=416nm, which characterizes nanoparticles of silver with sizes 5-25nm [35] (Figure 1, Curve 3). It can be seen in the spectra of initial solutions of Na-CMC and $Ag^{+}CMC^{-}$ at the 250-900nm optical region was no changes observed (Figure 1, curves 1,2).

With increasing the time of photolysis the color of solutions is changed from pale yellow to brown. According to literature such changes are probably dependent on with an increasing the number and size of formed silver nanoparticles.

For the confirm, this assumption absorption spectra's were taken at the different times of irradiation of systems $Ag^{+}CMC^{-}$ at concentration of Na-CMC -0.2% and $1{\cdot}10^{-2}$mol/l silver nitrate. Figure 2 shows the UV - spectrum solutions of Na-CMC contained silver nanoparticles which obtained at different times of photo irradiations.

One can see in Figure 2, after 5 minute photo irradiation in the spectrum observed the shoulder at region λ_{max}=270nm, which could be attributed to stable polyanions charged silver clusters, approximately Ag_{8}^{2+} [36,37], (Figure 2, curve 2).

After 15, 20 minutes photolysis at the spectrum observed increase the intensity of the absorption band at λ_{max} =270nm, which depends on with the formation of large stabilized clusters of silver with sizes 2-8nm [37] (Figure 2, curves 2,3).

Further irradiation brings to the appearance of new absorption peaks with maximums at regions λ_{max}=290nm and λ_{max}=420nm which belongs to larger clusters and nanoparticles of silver with sizes 5-35nm [37].

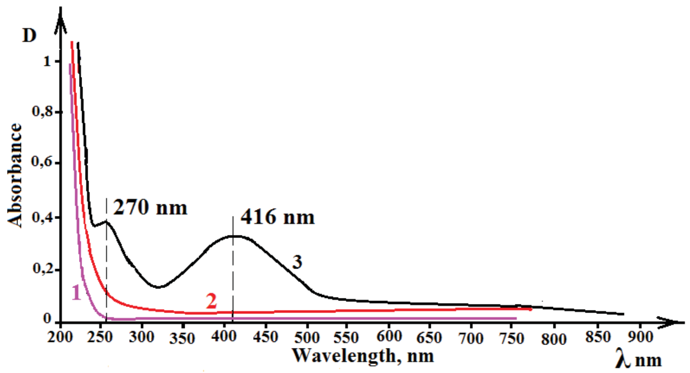


Figure 1: UV-VIS absorption spectra of the samples: 1) Na-CMC, 2) $Ag^{+}CMC^{-}$, 3) $Ag^{0}CMC$. Time of UV - irradiation for samples was 25min; [Na-CMC] = 0.008mol (2%); $[AgNO_{3}] = 3 \cdot 10^{-5}$mol (0.25 wt.%).

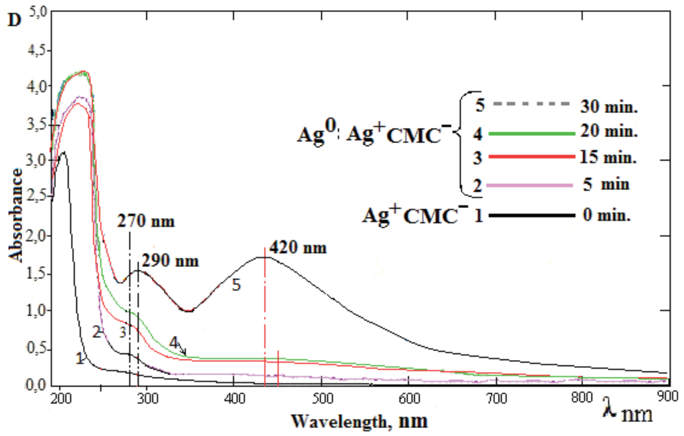


Figure 2: The absorption spectra of photochemical reduced silver ions samples $Ag^{+}CMC^{-}$. Concentration of [Na-CMC] = 0,2 %; and $[AgNO_{3}] = 1 \cdot 10^{-2}$mol/l. Time of UV-irradiation 0 (1) 5 (2) 15 (3) 20 (4) 30 (5).

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Homogeneity formed nanoparticles in different sizes can be obtained because of the macromolecules of Na-CMC covers the silver nanoparticles create charged shell around them to prevent nanoparticles' aggregation. Commonly, when polymer concentration is high, it tends to stabilize nanoparticles.

Increasing the local concentration of Na-CMC on the surfaces of silver nanoparticles created on the one hand, supports electrostatic and steric stabilization, and on the other hand - creates an conditions in which don't completely exclude interaction generated radicals by UV - photolysis of Na-CMC. To confirm the stability of formed silver nanoparticles in polymer matrix the UV - spectra of Na-CMC solutions containing stabilized silver nanoparticles has been taken which (Figure 3), keeping for the different periods of time.

One can see from Figure 3, form and content of silver nanoparticles in Na-CMC solutions, at during keeping times at home conditions absorption peak practically unchanged. Based on the experimental results it could be concluded that, with depending on the molecular weight, degree of substitution and the ratio components of Na-CMC and $AgNO_3$ able to control the size and shape of silver nanoparticles which will forms in solutions of Na-CMC by photochemical reduction.

With the aim of determining the form and sizes of silver nanoparticles in the structure of Na-CMC, samples have been investigated through the atom-force microscope. The data obtained are presented in Figure 4.

It can be seen from the AFM photographs that, at a low concentration of silver ions, spherical polydisperse nanoparticles of sizes 2-8nm were formed (Figure 4a). With an increase in the concentration of silver ions after photolysis, monodisperse nanoparticles of silver with sizes 5-35nm (Figure 4b) were obtained.

This can be explained by the fact that at the same time, silver cations in the compositions of CMC as they are connected with carboxylic anions (nanoreactor) of CMC were reduced by increasing the time of photolysis [34]. These processes occur with different speed, which probably bring to an increase in the polydispersity of formed nanoparticles.

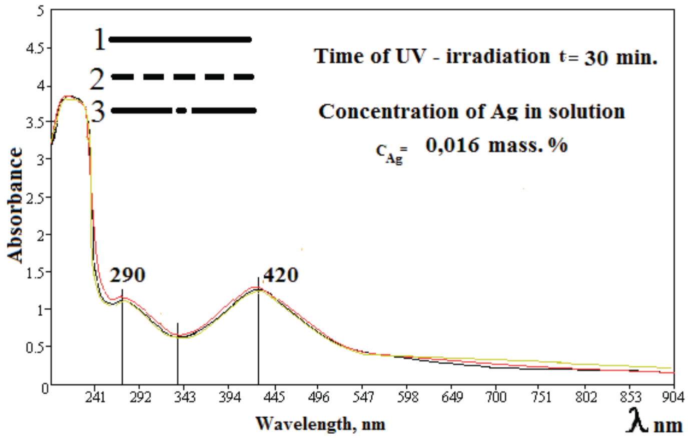
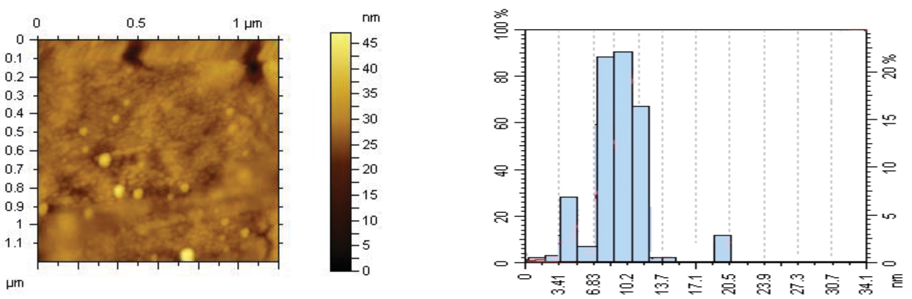
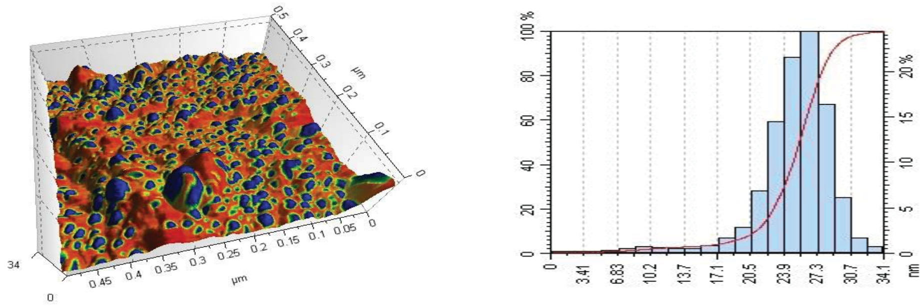


Figure 3: UV - absorption spectra of solutions of Na-CMC, contained silver nanoparticles for keeping during some times. 1) 1 - month. 2) 2 - months. 3) 6-months.



a. 2–8 nm (spherical)



b. 5–35 nm (spherical)

Figure 4: AFM microphotographs of Na-CMC solutions containing silver nanoparticles (a), and their distribution by size (b). Concentration of [Na-CMC] = 0,008mol (0,2 wt.%); $[AgNO_3]$ = $3 \cdot 10^{-6}$ (a) and $3 \cdot 10^{-5}$mol (b). Time of UV-irradiation=30min.

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Thus, the size and shape of silver nanoparticles formed by the photochemical reduction of silver cations, at systems Ag^+CMC^-, depend on DS and the concentration of solution of Na-CMC, and concentration of Ag^+ and times of photochemical irradiation.

Also was found that by keeping the concentration of carboxylate anions in the solution of Na-CMC with increasing content of silver cations in system by the same time occur increase the size of silver nanoparticles and their contents.

On the basis of the investigation results, further conditions for the formation of homogeneous spherical stable silver nanoparticles with sizes 5-35nm were determined: time of UV-irradiation = 30 min., content of Na-CMC in solution=0.2 wt.%, and content of $AgNO_3$ in solution=0.0086 mass%.

To obtain the bactericidal cotton fibers, biomaterials, and fabrics, they were treated with Ag^oCMC solutions. This low concentration of Na-CMC solution and the sizes of silver nanoparticles and ions promoted their penetration, i.e., inter-fiber and inter-molecular free spaces of the materials and fabrics obtained from cellulose [38]. The wet materials and cotton fabrics and products obtained were subjected to additional UV-irradiation, where restoration of unreacted silver ions in Na-CMC matrix structures was carried out [39]. The samples have been investigated through the transmission electron microscope. The obtained result data are presented in Figure 5.

From Figure 5b, it can be seen that the sizes of spherical silver nanoparticles are in the range of 2-30nm at their content in cotton fabrics of 0.0086 mass%.

Figure 6 shows the supposed scheme of the formation of silver nanoparticles in the structure of cotton fabrics, complex fibers, and elemental cellulose fibers.

When cotton fabrics, complex fibers, and elemental fibers of cellulose (Figure 6) graft with the mixture solutions of Ag^oCMC and CMC^-Ag^+, they squeeze in-between the free spaces of fibers (a) and those of the complexes of fibers, including in the structure of fabric (b). It was found that the macromolecule of Na-CMC contained nanoparticles and ions of silver that were able to squeeze in between free spaces of fibrils elemental of fiber cellulose (c), which indicates that the above-mentioned particles and ions of silver were "trapped".

After repeated photo-irradiation of wet fibers and the silver ions that were situated in–between the strings, fibers, and fibrils, the space in the structure of Na-CMC was reduced to nanoparticles, which, after drying, changed into an insoluble state through the formation of intermolecular hydrogen and covalent bonds between the carboxyl and hydroxyl groups of the macromolecules of Na-CMC and cellulose. This can be explained by the stability of the silver nanoparticles in the structure of fibers and fabrics after repeated washing.

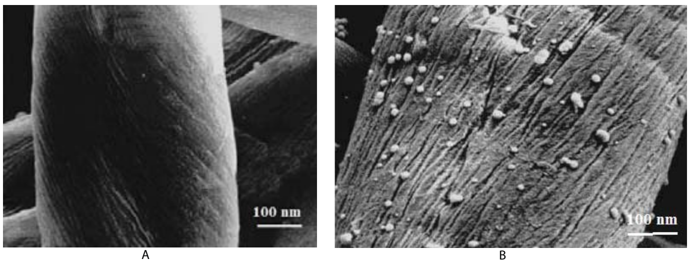

Figure 5: TEM photographs of initial cotton fiber (a) and silver nanoparticles on the surface of cotton fiber (b).

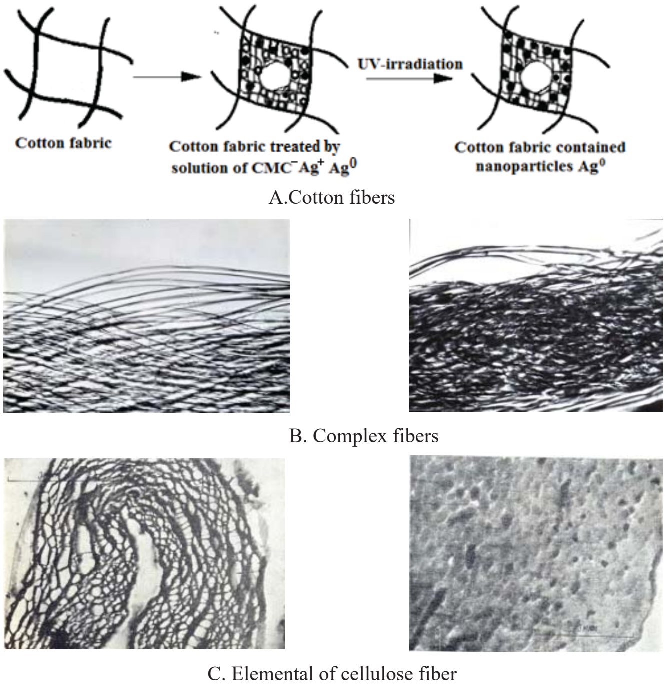

Figure 6: Supposed scheme of formation and fixing of silver nanoparticles in the structure of (a) cotton fibers, (b) complex fibers, and (c) elemental of cellulose fibers.

Bactericidal activity of the obtained samples of cotton fabrics grafted with the solution of CMC, containing nanoparticles of silver in test cultures of *Staphylococcus epidermidis* and *Candida albicans*, was studied in the laboratory of the Institute of Microbiology, Uzbek Academy of Sciences.

For the determine the antimicrobial activity of the samples, were added to test-tubes containing thioglycollic environments (for *Staphylococcus epidermidis*) and Saburo (for *Candida albicans*) at the following systems: 1. Control cotton fabrics physiological solution 2. Cotton fabric+Ag^+, C_{Ag^+}=0,0086mass.%; 3. Cotton fabric+Ag^o, C_{Ag^o}=0,0086mass.%; 4. Cotton fabric+Ag^o, C_{Ag^o}=0,086mass.%.

As a control in the same medium was added physiological solution of 10% NaCI with compared to the volume of the medium.

Within six hours test culture was added in the final concentration of 150CFU/ml in each test-tube. Samples were incubated at 34°C during 48hours (for *Staphylococcus epidermidis*) and 72h (for *Candida albicans*).

The result of microbiological investigations showed that all samples have a degree of antimicrobial activity against

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pathogenic microorganisms of human. Results of investigations samples of fabric are shown in Table 1.

You can see from the presented data in the Table 1, all the samples except the control and the sample number №2 (cotton fabric+ Ag^+, C_{Ag^+}=0,0086 mass.%); completely inhibit the growth of fungus *Candida albicans*.

Low activity of cotton fabric, contained silver ions connected with CMC, can be explained apparently so that the contact of silver ions bounded to the surface of these strains to make a coordination bond with functional groups where is on the surface of the strains. This brings to fast inactivation of the silver ions [40]. Samples № 2, № 3 and № 4 inhibited the growth of bacteria Staphylococcus epidermidis by 72%, 94.6% and 88%, respectively. Also you can see from the table the sample №3 has a high bactericidal activity against Staphylococcus epidermidis is 94,6%. It is probably depends on the smallest sizes of silver nanoparticles which [41], their content in the cotton fabric is 0.0086 mass.%.

Comparative bactericidal activity of silver nanoparticles with various sizes and shapes are presented in Table 2.

As you can see from the Table 2, in the control samples of cotton fabric is observed growing the strains of *Staphylococcus epidermidis*, and fungus *Candida albicans*, this demonstrated the absence of bactericidal activity of the polymeric matrix.

At investigations of cotton fabrics grafted with a solution of Na-CMC, contained silver nanoparticles with sizes 2.8nm, was found that they exhibit bactericidal activity against bacterium *Staphylococcus epidermidis* more than 80%, comparative to control, at fungus *Candida albicans* exhibit bactericidal activity to 98%.

Also you can see from the table, the most active against the strain of *Staphylococcus epidermis* and bacterium *Candida albicans* is cotton fabrics grafted with solution of Na-CMC, contained in the structure spherical nanoparticles of silver sizes 5-35nm, it could be explained by the content of silver nanoparticles and their surface area [42,43].

Cotton fabrics grafted with solution of Na-CMC, contained whiskers nanoparticles of silver with sizes in length 130-420nm and in width 15-40nm, less bactericidal active compared with cotton fabric grafted with solution containing silver nanoparticles of spherical structures with the size 5-35nm.

But, they are more active compared with cotton fabric grafted with solution contained silver nanoparticles with sizes 2-8nm, it could be explained by high content of silver nanoparticles in the cotton fabric.

The comparatively high bactericidal activity of silver nanoparticles (Table 2) with the silver ions (Table 1) probably due to the fact that:

- silver nanoparticles can`t make chemical bond with the functional groups [43], the strains of surface bacterium Staphylococcus epidermidis and fungus Candida albicans, and probably seems able to penetrate through wall of cell and into the nucleus of cells and inhibit their growth and activity;

- lowering the size of silver nanoparticles increased the total area of the surface and accelerating their ability to penetrate the cell nucleus of the above strains;

Comparatively, the bactericidal activity of cotton fabrics after repeated washing is presented in Table 3.

As Table 3 shows, five washes (cotton fabric+Ag^0) to wash

Table 1: Antimicrobial activity of cotton fabrics, contained silver ions and nanoparticles against strains of *Staphylococcus epidermidis* and *Candida albicans*.

No.	Samples	Content of silver nanoparticles in the cotton fabric, mass.%	Strains	
			Staphylococcus epidermidis	Candida albicans
1	Control	-	150 CFU*/ml	150 CFU/ ml
2	Cotton fabric+Ag^+	0,0086	24 CFU/ml	15 CFU/ml
3	Cotton fabric+Ag^0	0,0086	6 CFU/ml	Absent
4	Cotton fabric+Ag^0	0,086	9 CFU/ml	Absent

***Note.** Colony of forming unit CFU/ml - a unit of measurement is the number of colony forming units per milliliter of fluid.*

Table 2: Comparative results of the bactericidal activity of cotton fabrics grafted with solutions of Na-CMC contained silver nanoparticles with different shapes and sizes.

No.	Samples cotton fabric treated with a solution of Ag^0CMC at different concentrations of silver ions.	The size of the silver nanoparticles in the solutions Na-CMC, nm	Strains	
			Staphylococcus epidermidis	Candida albicans
1	Control	-	$5{\cdot}10^{12}$ CFU/ml	$1{\cdot}10^7$ CFU/ml
2	C_{Ag}=0,000003mol	2-8nm	$1{\cdot}10^{12}$CFU/ml	$1{\cdot}10^5$ CFU/ml
3	C_{Ag}=0,00003mol	5-35 nm (spherical)	Absent	Absent
4	CAg=0,0003mol	l1=130-420nm, l2=15-40nm (whiskers)	$1{\cdot}10^{10}$ CFU/ml	Absent

Table 3: Comparative results of the bactericidal activity of cotton fabric, after washing several times.

No. Samples	Number of washings	Content of silver nanoparticles in cotton fabric, mass.%	Strains	
			Staphylococcus epidermidis	*Candida albicans*
1. Control	-	-	$5{\cdot}10^{12}$ CFU/ml	$1{\cdot}10^7$ CFU/ml
2. Cotton fabric+Ag^0	Without washing	0.0086	Absent	Absent
3. Cotton fabric+Ag^0	1 time	0.0079	Absent	Absent
4. Cotton fabric+Ag^0	2 times	0.0068	$2{\cdot}10^8$ CFU/ml	$2{\cdot}10^8$ CFU/ml
5. Cotton fabric+Ag^0	3 times	0.0054	$2{\cdot}10^8$ CFU/ml	Absent
6. Cotton fabric+Ag^0	4 times	0.0033	$3{\cdot}10^6$ CFU/ml	Absent
7. Cotton fabric+Ag^0	5 times	0.0023	$5{\cdot}10^7$ CFU/ml	$1{\cdot}10^6$ CFU/ml

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away silver nanoparticles from the surface of the fibers of the polymeric matrix results in the decrease of their content from 0.0086 to 0.0023 mass%.

Bactericidal activity of the samples (cotton fabric+Ag^o) was preserved after two washes for strains, *Staphylococcus epidermidis*, and four washes for *Candida albicans*. Washing cotton fabrics containing silver nanoparticles more than five times exhibited bacteriostatic properties against these strains because of a decrease in the content of silver nanoparticles.

Conclusion

Optimal conditions of silver nanoparticles with different shapes and sizes formation in the structure of CMC solutions of different DS and DP were determined by the photoirradiation of solution.

It was established that the replaced silver ions in Na-CMC macromolecules mainly subject to restoration and play the role of «nanoreactors» in which the carboxylic groups of a negative ion, according to the theory of Mott-Gurney, are the «trap» for positively charged ions of silver and promote the photostimulated formation of silver nanoparticles. UV-spectroscopic method for control of the form and sizes of silver nanoparticles at process of their restoration is developed.

It was established that depending on concentration of polymeric substrate, silver ions and UV irradiation, spherical and rod-like stabilized silver nanoparticles of different sizes form in the structure of Na-CMC. The conditions of the formation of silver nanoparticles with different shape and size in dependence of components interaction reaction parameters and photochemical restoration were revealed.

Correlation dependence between the size and shape of silver nanoparticles in Na-CMC structure and their biological activity was established. It was shown that size of the silver nanoparticles decreasing promotes the increase of their antimicrobial activity at the same concentrations in polymeric matrix.

It was found that grafted cotton fabrics and products, which were stabilized through the contribution of silver nanoparticles, possessed bactericidal and bacteriostatic properties. Stabilization of silver nanoparticles in the structure of the polymeric matrix caused preservation of their bactericidal and bacteriostatic activities during washing. Based on the results of the investigation, the optimum conditions for obtaining bactericidal and bacteriostatic cotton fabrics and textiles were determined.

The obtained bactericidal biomaterials, based on the cellulose containing stabilized silver nanoparticles, possessed the antifungal effect, prevented offensive odor, decreased the level of pathogenic germs, and preserved the fungal disease.

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