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# ADDING ANTIBACTERIAL/ANTIVIRAL PROPERTIES TO MEDICAL PURPOSE MATERIALS BY MODIFICATION WITH SILVER AND COPPER NANOPARTICLES

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*In modern times, especially during epidemics and pandemics, respiratory protection becomes especially important. One of the most effective means of protection against airborne infections such as influenza, SARS, and COVID-19 is 3-layer medical mask. The aim of this research is to modify medical purpose materials with Ag NPs and a mixture of Ag and Cu NPs to give their surface antibacterial/antiviral properties.*

*The study of the adsorption properties of medical purpose fabrics (using BET method for determining the specific surface area and distribution of pores by size depending on their radius in the tested fabric sample) has shown that their surface is characterized by the presence of micro-, meso-, and macropores, which is why, in addition to its high adsorption capacity for various substances, it can be used for modification with NPs using the method of adsorption from solutions. The nanoparticles are encapsulated by the porous structure of the tissue and retained in mesopores of 2–50 nm in size due to the action of capillary forces. To give the surface of medical purpose materials antibacterial/antiviral properties, a water-glycerol nanosuspension of Ag and a bicomponent water-glycerol nanosuspension of Ag and Cu were applied to their surface by the method of adsorption from solution. To modify the fabric, we used nanoparticles implanted physically (using ion-plasma technology in an environmentally friendly technological cycle, the ELIPS technology) into food glycerol and stabilized in it without the slightest additional chemical reagents. The initial suspension with Ag and Cu NPs and the structural transformations of immobilized nanoparticles on the tissue surface were studied by electron microscopy and micro-X-ray spectral analysis.*

*The results of a comprehensive study of the antiviral, antimicrobial, and antimycotic activity of Ag NPs and a mixture of Ag NPs and Cu has shown that bactericidal, fungicidal, and virucidal effects were observed at Ag NP concentration of 10 ppm. The composites of Ag and Cu NPs stabilized by silicon dioxide NPs were more active in inhibiting the growth of both Gram-negative and Gram-positive bacteria than those without the addition of silicon dioxide NPs.*

*Thus, NP-modified fabrics can be recommended for the manufacture of the middle layer of 3-layer medical masks, medical dressings, various underwear pads, baby nappies and diapers, bedding, medical uniforms, and other types of medical purpose products.*

***Keywords**: silver and copper nanoparticles (NPs), surface modification of medical purpose materials, adsorption from solutions, antibacterial and antiviral properties*

## INTRODUCTION

Medical purpose materials represent a category of goods used for medical care, initial examinations, diagnostics, treatment, and preventive procedures [1]. Most of these products are required be sterile in order to protect healthcare workers and their patients from infection. Choosing the right fabric for bed linen, medical uniforms, clothing, and accessories (medical masks and gloves), sanitary pads and tampons, baby nappies and diapers, and fabrics for medical dressings is crucial for both healthcare professionals and patients who require comfortable, functional, and safe wear during their work hours.

In modern times, especially during epidemics and pandemics, respiratory protection becomes especially important. One of the most effective means of protection against airborne infections such as influenza, SARS, and COVID-19 is 3-layer medical mask [2–6]. It consists of three layers, each of which plays a different role in air filtration. The outer layer protects against large droplets and splashes, the middle layer traps the smallest particles, and the inner layer protects the skin of the face and respiratory tract. Such masks are designed for long wear with comfort in mind. They provide good ventilation, which reduces discomfort and sweating. Soft ear loops and flexible band on the nose bridge allow the mask to fit tightly to the face, minimizing air leakage from the sides of the mask. This makes the medical mask comfortable and easy to use for extended hours.

Thus, a medical 3-layer mask serves as an effective and comfortable means of protecting the respiratory tract under conditions of increased viral activity. It combines high filtration efficiency, comfortable wearing, hygiene, compliance with medical standards and universal use. The ideal material for the middle layer of a 3-ply medical mask is thin knitted fleece. Fleece is a synthetic material with a fluffy pile. It is lightweight, quite durable, hypoallergenic, and its modification with silver nanoparticles (NPs) adds antibacterial and/or antiviral properties to the surface of the fabric.

It is common knowledge that silver has antimicrobial effects and does not produce adverse effects on the human body; thus, it was approved by the Federal Food and Drug Administration for use in the United States back in 1920 [5]. Recent studies have proven that nanosilver is a natural antibiotic that can fight all harmful microorganisms, that is why NPs of silver find increasing use in medicine [7–12]. They have become an integral part of diagnostic procedures. More and more drugs containing silver NPs are being introduced into clinical practice. The use of such drugs in medicine is especially important for the prevention of infectious diseases and further introduction of new highly effective broad-spectrum antiviral drugs into medical practice.

The exact mechanism of the antiviral activity of Ag NPs has not been established, and there are several views on this issue [13–17]. For example, Ag NPs can interact with the protein membrane of the virus surface, as well as with the components of the cell membrane, preventing the virus from contacting the cell and penetrating inside. Also, Ag NPs can react with the viral genome inside the cell or with viral and cellular factors necessary for the virus repair process.

In Ukraine, nanosuspensions of various metals in food glycerol are produced using ion-plasma technology in an environmentally friendly technological cycle under the International Patent PCT/UA2007/000007 and Ukrainian patent No. 80513 [18]. Detailed studies of nano-suspensions obtained using this technology are presented in [19].

The undoubted advantage of high-purity nanosilver (the product's commercial name is “AgNanofluid”$^{TM}$), physically implanted in food glycerol and stabilized in it without the use of any additional chemicals (ELIPS technology), is its extremely low toxicity to humans and animals along with high bactericidal and effective antiviral properties against a wide range of viruses and bacteria, which allows it to be effectively used to modify surfaces of various physical and chemical nature [18]. The preparation is transparent, containing Ag NPs in a water-glycerol solution. The absence of stabilizers in its composition promotes the sorption of NPs by receptors of pathogenic microorganisms, therefore, it neutralizes the biological activity of the pathogen much faster [20]. Adding Cu NPs to the nanosuspension significantly increases its effectiveness against pathogens [18–19, 21–22].

A comprehensive study of the antimicrobial, antifungal and antiviral activity of “AgNanofluid”$^{TM}$ was performed at the D.K. Zabolotny Institute of Microbiology and Virology of the National Academy of Sciences of Ukraine [18].

The fungicidal activity of the preparation was studied in the Laboratory of bacteriological control of the State Research Institute of Veterinary Preparations and Feed Additives (Lviv). The fungicidal concentration of the mixture of Ag and Cu NPs against the pathogens *Candida utilis* Lia-01B, *Candida albicans* UCM V-2681 (ATSS 10231), *Zygosaccharomyces rouxii* NCYC 381, *Saccharomyces cerevisiae* ATSS 9763, *Candida pseudotropicalis*, *Aspergillus* *niger* was significantly higher than of the nanosuspension that did not contain Cu NPs – 25 and 50 ppm, respectively [18].

A stable bactericidal effect of "AgNanofluid"™ against test cultures of *Pseudomonas aeruginosa* B-907 UCM (ATSS 27853), *Escherichia coli* B-906 UCM (GISC 240533), *Staphylococcus aureus* B-904 UCM (ATSS 25923) and fungistatic effect of this preparation against yeast *Candida albicans* Y-2681 UCM (ATSS 10231) was established. The zone of inhibition of the growth of those bacteria when applied to the inoculated test cultures remains unchanged for up to 8 days, which indicates a stable and long-term bactericidal effect of the drug [23].

It has also been demonstrated that the treatment of textile materials with "AgNanofluid"™ is promising for giving biocidal protection properties to those materials. On the surface of the "Oxford" polyester fabric treated with the product, cells of test cultures of *Pseudomonas aeruginosa*, *Escherichia coli*, *Staphylococcus aureus* and yeast *Candida albicans* undergo significant morphological changes (deformations, damage to the surface and cell integrity). Under those conditions, the cells of the test cultures of microorganisms selectively accumulate certain chemical elements (silicon), which leads to their destruction [23].

In April 2014, a group of scientists from research centers in the United States, the Netherlands, and China published a joint paper on the activity of nanosilver against the TGEV coronavirus (a type of coronavirus that causes diarrhea and is an experimental model of HCoV-19) [20]. The authors found that the use of non-toxic (harmless to humans) concentrations of Ag NPs, which are not coated with surfactants, in contrast to those coated with surfactants, significantly reduces cell infection, and lowers the number of apoptotic cells (genetically programmed to die) induced by the virus. Thus, Ag NPs are effective in the prevention of TGEV-mediated cellular infection as a virucidal (antiviral) agent or an inhibitor (retarder) of virus entry into the cell, and those results suggest a new perspective on antiviral therapy of coronaviruses.

The aim of the present research work is to modify medical materials with Ag NPs and a mixture of Ag and Cu NPs to give their surface antibacterial and/or antiviral properties.

## MATERIALS AND METHODS

The object of study was a synthetic knitted thin fleece fabric with a density of 100–200 g/m$^2$ produced in China.

To modify the fabric, we used Ag NPs and mixtures of Ag and Cu NPs produced with the ELIPS technology [18].

To stabilize the NPs in a water-glycerol solution, a gel sorbent (6 % suspension of highly dispersed silica in water) produced by Zhytomyrbioproduct LLC was used in a 1:1 dilution in deionized water.

Tissue modification with AgNPs and a mixture of Ag and Cu NPs was performed by adsorption from the solution in an ultrasonic bath during 15 min. After immobilization of the NPs, the tissue samples were dried at 20 °C.

The distribution of the NPs in the solution before triple application to the tissue with different concentrations of NPs was studied by laser photon correlation spectroscopy using Zetasizer Nano ZS (Malvern, UK) at 25 °C. The kinematic viscosity of the suspensions, which was required to calculate the size distribution of the NPs, was measured using a Malvern SV-10 vibrating viscometer (Japan).

The nitrogen adsorption/desorption isotherms of the fabric samples were measured at -196 °C using a Quantachrome NovaWin unit (Quantachrome, USA). The specific surface area ($S$) of the samples was determined by the BET method, the total pore volume ($V_S$) was calculated from the nitrogen adsorption at $p/p_s = 0.99$, and the pore distribution was determined by the DFT (density functional theory) method [24].

The state of the NPs in the suspension and on the surface of the fabric was studied by electron microscopy and micro-X-ray spectral analysis using a Mira 3 LMU, Tescan. The preparation of the sample for the study included the application of 1 ml of the preparation, which was diluted 10 times with deionized water, to a smooth conductive silicon wafer. The solution was dried at up to 90 °C, and after evaporation of the solution, metal particles remained on the surface of the substrate. In that form, the substrate with the NPs was placed in the chamber of a scanning electron microscope.

The study of the bactericidal activity of different concentrations of the composite of Ag and Cu NPs stabilized with silicon dioxide NPs against bacteria, viruses and fungi of the genus

*Candida* was carried out in the Laboratory of microbiology, virology and mycology of State Institution "Academician O.F. Vozianov Institute of Urology" of the National Academy of Medical Sciences of Ukraine using the agar diffusion method [25]. This method enabled us to determine the ability of the tested preparation to inhibit the growth of microorganisms by analyzing the size of the growth inhibition zones of different bacterial strains. If the growth inhibition zone was up to 10 mm in diameter, the strain was considered insensitive. Growth inhibition zones with a diameter of more than 10 mm indicated the sensitivity of the strain to a given concentration of the antimicrobial agent.

The antiviral activity of the silver nanosuspension was studied in the laboratory of experimental chemotherapy of viral infections of the State Institution "L.V. Gromashevsky Institute of Epidemiology and Infectious Diseases" of the National Academy of Medical Sciences of Ukraine on the model of porcine transmissible gastroenteritis coronavirus**.** Studies of the activity of "AgNanolfluid"$^{TM}$ against the TGEV family coronavirus have shown that a concentration of 5 ppm of Ag or a mixture of 2 ppm of Ag NPs + 2.2 ppm of Cu NPs effectively inhibits the reproduction of coronavirus with a selectivity index of 40.0 (the threshold value of the selectivity index is 16.0), which is twice as effective as when using other disinfectants [25].

## RESULTS AND DISCUSSION

***Study of the state of NPs in suspension and water-glycerol medium.*** Fig. 1 shows a SEM image of a mixture of Ag and Cu NPs (in characteristic electrons) on the surface of a silicon substrate with an indication of the size of individual particles. Detailed studies of Ag and Cu NPs in solutions by electron and atomic force microscopy are described in [19].

Measurements of the size of the NPs in a water-glycerol medium with an initial silver concentration of 20 ppm were carried out in time from the moment of dilution of the nanosuspension with deionized water for 20 days. The size distribution of Ag particles is displayed in volume percent on Fig. 2. As shown by preliminary calculations, the initial solutions of Ag NPs in glycerol with 100 ppm silver concentration, and further diluted in water to a concentration of 10 ppm should remain kinetically and aggregative stable forming almost no agglomerates for a considerable time. This conclusion was made after comparing the ratio of particle sedimentation rates and their chaotic movement due to Brownian motion, which for water-glycerol solutions is also associated with the existence of a highly structured adsorption solubilizing layer that makes it impossible for particles to approach the distance of effective interaction [18, 26–27]. The adsorbed layer of glycerol molecules (a biphilic molecule, i.e., a surfactant) remains on the hydrophobic surface of Ag NPs, imparts hydrophilic properties to the NPs, thereby stabilizing the solution. To clarify the established fact and assess the stability of silver and copper agglomerates, the state and parameters of NPs' aggregation in a water-glycerol medium were studied.

The measurements showed that the average size of Ag NPs in glycerol was 34 nm (Fig. 2 *a*). When diluted in water after 30 min, the average size of the NPs increased to 196 nm (Fig. 2 *b*), but after 5 days it decreased again to 142 nm (Fig. 2 *c*), and after 20 days - to 60 nm (Fig. 2 *d*). Thus, over time, there is a tendency to reduction of the size of the NPs almost to their initial parameters. Similar results were obtained when studying the state and parameters of aggregation of a mixture of Ag and Cu NPs in the initial solution (pure glycerol with 40 ppm silver + 10 ppm copper concentration). Therefore, to prevent the agglomeration process of NPs, the application of the water-glycerol solution was carried out during sonication. We have discovered that such treatment effectively destroys Ag NPs aggregates [18]. In this work, we also used a method to prevent the agglomeration of NPs by adding silicon dioxide to the NP suspension.

The data on the dependence of the zeta potential of the Ag NPs on the pH of the medium are shown in Fig. 3. In contrast to NPs obtained by a chemical method, having a positive charge, the NPs obtained by a physical method, according to zeta potential measurements, are characterized by a negatively charged surface. The water dilution of the suspension containing Ag NPs practically does not form agglomerates for a considerable time in alkaline media, but partially loses stability in acidic solutions (at pH less than 4). This makes it possible to use the obtained suspensions with no further stabilization in alkaline environments and add them to all liquid detergents and cosmetics. And fleece fabric inserts saturated with Ag and Cu will not be affected even when washed.

***Study of the structural transformations of silver and copper NPs immobilized by adsorption from solutions on the surface of a fabric.*** For the studied fabric samples, the value of the specific surface area was determined to be 95.2 m$^2$/g. Fig. 4 shows the adsorption isotherm and the distribution of pores by size depending on their radius in the fabric sample under study. As follows from the data, the fabric was characterized by the presence of micro-, meso-, and macropores, which is why the adsorption isotherm of this fabric sample showed hysteresis characteristic of mesoporous systems. It is known that capillary condensation occurs in mesoporous systems, so, in addition to their high adsorption capacity for various substances, they can be used for long-term storage of substances without affecting their biological properties [28–30]. Thus, the adsorption properties of the studied fabric sample confirm its ability to filter and encapsulate effectively the majority of NPs by adsorption from solutions.

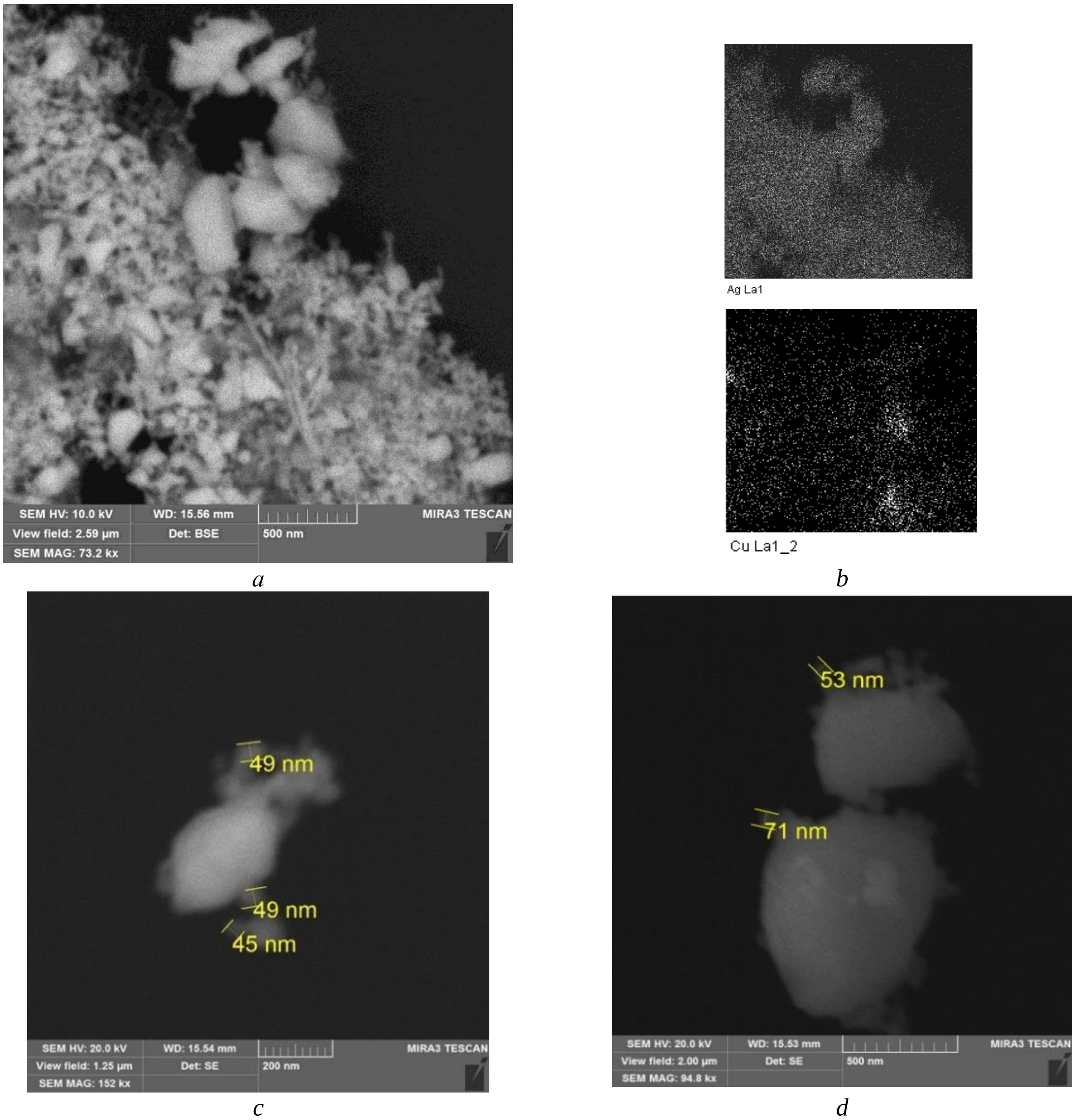


**Fig. 1.** SEM image of a mixture of Ag and Cu NPs: *a* – general view of the nanosuspension; *b* – in characteristic electrons*; c*, *d* – individual aggregates of NPs found in the nanosuspension

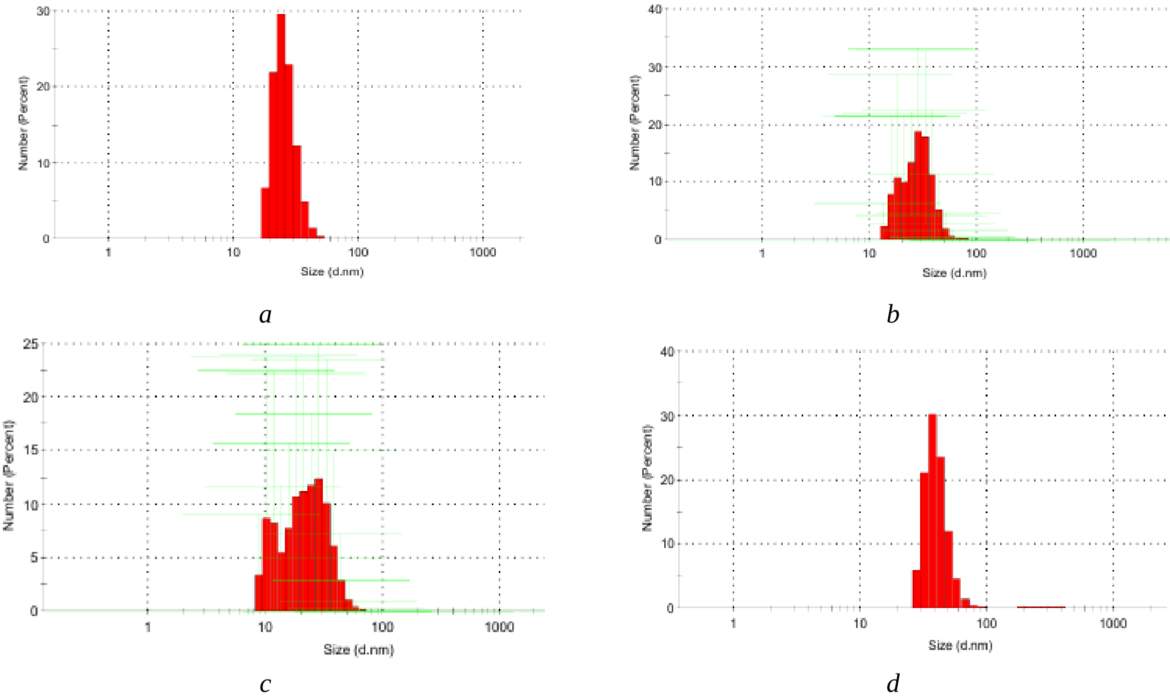


**Fig. 2.** Size distribution of Ag NPs in glycerol (*a*), and in water-glycerol solution after 20 min (*b*), and 7 (*c*) and 20 (*d*) days, respectively

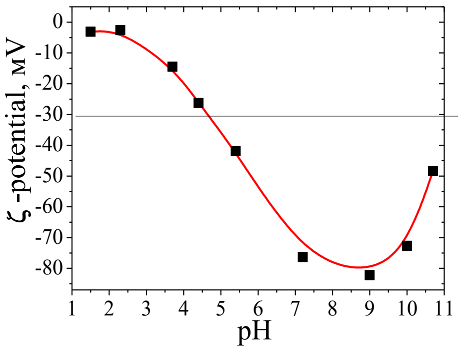


**Fig. 3.** Dependence of the zeta potential of the Ag NPs on the pH of the medium and zone of aggregate stability of Ag NPs below –30 mV

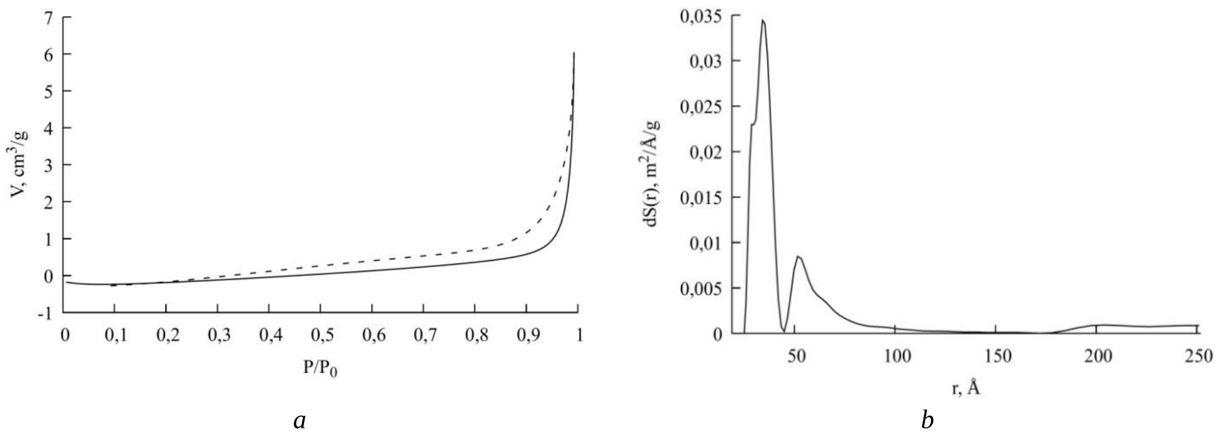


**Fig. 4.** Adsorption isotherm (*a*), and distribution of pores by size versus their radius (*b*) in the studied fabric sample

Fig. 5 shows a SEM image of the characteristic appearance of the fabric surface at different magnifications before and after Ag and Cu NP treatment, with individual aggregates on the surface indicating the locations of XRD analysis. It can be seen that aggregates of NPs with sizes of 40–80 nm are evenly distributed on the fabric surface. It is probable that those are the particles (of larger size) that failed to implant into the porous structure of the material. Smaller particles are encapsulated by the porous structure of the material and retained in the mesopores due to capillary forces.

***Study of biological activity of composite silver and copper nanosuspension against bacteria, viruses, and fungi.*** The original nanosuspensions obtained by the physical method using the ELIPS technology do not contain stabilizers and surfactants, so when diluted with water, NPs aggregate (see Fig. 2), which creates the need for additional stabilization. To prevent the agglomeration of NPs, silica NPs were added to the suspension. The study of biological activity was performed using a composite of a mixture of Ag and Cu NPs stabilized with NPs of silica. The experiment was conducted with test cultures of bacteria, viruses, and fungi of the genus *Candida*. To 0.9 ml of the suspension of test cultures with a concentration of bacteria and fungi $10^5$–$5\times10^5$ CFU/ml (colony forming units per ml), 0.1 ml of composite with an initial concentration of 23.5 ppm of Ag + 25 ppm of Cu stabilized by silica NPs was added, and thus the final concentration was 1.17 ppm for Ag and 1.25 ppm for Cu. The result of biological action is shown in Table 1.

As evidenced by the results obtained (Table 1), when using the minimum final concentrations of Ag NPs of 1.17 ppm and Cu NPs of 1.25 ppm, the biological effect of inhibiting the growth of test cultures of bacteria and fungi was minimal. Therefore, we increased the final concentration of Ag NPs to 2.35 ppm and Cu NPs to 2.5 ppm. The effect was significant (sample No. 2). Thus, the concentration of *K. pneumoniae* decreased to $10^3$ CFU/ml after 24 hours, and after 48 hours and up to 8 days (observation period), there was no growth of the culture.

In terms of determining the sensitivity of fungi of the genus *Candida* to the above composites (samples No. 1 and No. 2), no significant changes were observed (Table 1). The effect on gram-positive *S. aureus* was the most significant. When using the composite (sample No. 1), after 24 hours of cultivation, the concentration of *S. aureus* decreased from $5\times10^5$ CFU/ml to $10^3$ CFU/ml. After 48–72 hours, a complete absence of *S. aureus* growth was observed. When using the composite (sample No. 2), *S. aureus* growth was absent after 24 hours.

The results of comparative study of the antiviral, antimicrobial, and antimycotic activity of Ag and Cu NPs are presented in Table 2. The results show that at a concentration of 10 ppm of NPs in the suspension, bactericidal, fungicidal, and virucidal effects are observed. Analyzing the results obtained, it should be emphasized that composites based on a mixture of Ag and Cu NPs with the addition of silica NPs at the given concentrations were more active in inhibiting the growth of bacteria, both gram-negative and gram-positive, than those without the addition of silica NPs.

**Table 1.** The effect of a mixture of Ag and Cu NPs stabilized with silica NPs on bacteria and fungi of the genus *Candida*

| **Composites** | **Observation time (hours)** | **Culture control CFU/ml** | **Test strains, CFU/ml** | | |
|---|---|---|---|---|---|
| | | | ***K. pneumoniae*** | ***S. aureus*** | ***C. albicans*** |
| No. 1 Ag NPs 1.17 ppm, +Cu NPs 1.25 ppm + 6 % $SiO_2$ NPs | Ex tempore | $5\times10^6$ | $5\times10^6$ | $5\times10^5$ | $5\times10^5$ |
| | 3 hours | $5\times10^6$ | $5\times10^6$ | $10^3$ | $5\times10^5$ |
| | 24 hours | $10^6$ | $5\times10^5$ | 0 | $10^5$ |
| | 48 hours | $10^6$ | $10^5$ | 0 | $5\times10^4$ |
| | 72 hours | $10^6$ | $10^3$ | 0 | $10^4$ |
| | 8 days | $10^6$ | $10^3$ | 0 | $10^4$ |
| No. 2 Ag NPs 2.35 ppm, + Cu NPs 2.5 ppm +6 % $SiO_2$ NPs | Ex tempore | $5\times10^6$ | $5\times10^6$ | $5\times10^5$ | $5\times10^5$ |
| | 3 hours | $5\times10^6$ | $10^5$ | $10^5$ | $5\times10^5$ |
| | 24 hours | $10^6$ | $10^3$ | 0 | $10^4$ |
| | 48 hours | $10^6$ | 0 | 0 | $10^4$ |
| | 72 hours | $10^6$ | 0 | 0 | $10^4$ |
| | 8 days | $10^6$ | 0 | 0 | $10^4$ |

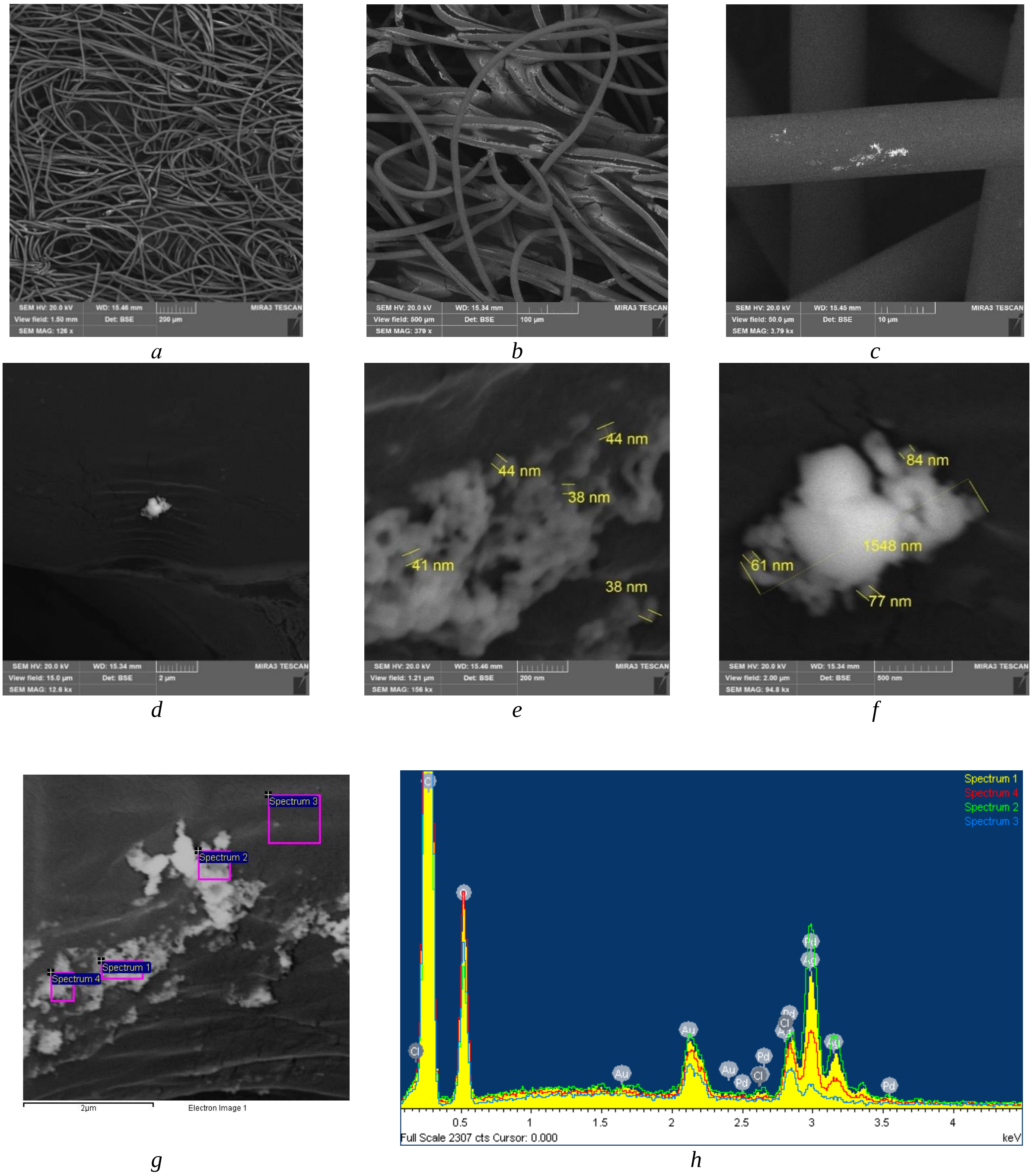


**Fig. 5.** SEM image of the fabric surface before treatment with NPs at different magnifications (*a*, *b*), after treatment with NPs (*c*, *d*, *e*, *f*), with individual NP aggregates on the surface and indicating the locations of X-ray spectral analysis (*g*, *h*)

Thus, it was proven that modification of medical tissues that are characterized by a mesoporous structure (pores of 2–50 nm in size) with Ag NPs or a mixture of Ag and Cu NPs obtained by the physical method using ELIPS technology allows reaching the desired antibacterial/antiviral properties. Fleece in the form of a knitted fabric with a density of 100–200 g/m$^2$ was studied as a material for the middle layer of 3-layer medical masks. Based on these studies, the fabric modified by NPs was used by the LTD “Medical Stream” to produce 3-layer medical and personal protective masks to combat the Covid-19 pandemic. Product examples are shown in Fig. 6.

**Table 2.** Effect of Ag and Cu NPs on microbial cells (comparative data)

| **Ag NPs 1.5 ppm** [18] | **Ag NPs 1.17ppm + Cu NPs 1.25ppm** [this study] | **Ag NPs 2.35ppm + Cu NPs 2.5ppm** [this study] | **Ag NPs 5ppm or mix of Ag NPs 2ppm + Cu Nps 2.2ppm** [25] | **Ag NPs 6ppm** [18] | **Ag NPs 9.87ppm** [18] | **Ag NPs 7.5-10ppm** [18] |
|---|---|---|---|---|---|---|
| in 3 minutes 80 % of bacteria and fungi stop growing | *S.aureus* dies in 24 hours | *K.pneumoniae* dies in 48 hours | effectively inhibits coronavirus reproduction with a selectivity index of 40.0 | in 3 minutes 99 % of *Escherichia coli* bacteria dies | *Candida albicans* fungi die in 3 minutes | prevention and protection against herpes, vesicular stomatitis and AFM1/47 H1N1 influenza viruses |


**Fig. 6.** 3-layer medical mask "Medical Stream nano"TM produced by LTD "Medical Stream"

CONCLUSIONS

The study of the adsorption properties of medical purpose fabrics has shown that their surface is characterized by the presence of micro-, meso-, and macropores, which is why, in addition to its high adsorption capacity for various substances, it can be used for modification with NPs using the method of adsorption from solutions. The nanoparticles are encapsulated by the porous structure of the tissue and retained in mesopores of 2–50 nm in size due to the action of capillary forces.

The results of a comprehensive study of the antiviral, antimicrobial and antimycotic activity of Ag NPs and a mixture of Ag and Cu NPs obtained by the physical method using the ELIPS technology has shown that at a concentration of 10 ppm ("AgNanofluid"TM product) corresponding biocidal effects were observed.

Composite mixtures of Ag and Cu NPs stabilized by silicon dioxide NPs has shown greater activity in inhibiting the growth of both Gram-negative and Gram-positive bacteria than those without addition of silica NPs. At the same time, the solutions used in the concentrations of 2.35 ppm Ag NPs + 2.5 ppm Cu NPs did not significantly affect the fungi of the genus *Candida*.

Such medical materials modified with Ag NPs or mixtures of Ag and Cu NPs can be recommended for the manufacture of the middle layer of 3-layer medical masks, fabrics for production of medical dressings, various underwear pads, baby nappies and diapers, bedding, medical uniforms, *etc*.

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## Надання антибактеріальних/антивірусних властивостей матеріалам медичного призначення шляхом модифікування наночастинками срібла й міді

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*В умовах сучасності, особливо під час епідемій і пандемій, захист дихальних шляхів стає особливо важливим. Одним із найефективніших засобів захисту від повітряно-крапельних інфекцій, як-от грип, ГРВІ та COVID-19 є 3-шарова медична маска. Метою даної роботи було модифікування наночастинками (НЧ) Ag та суміші НЧ Ag й Cu матеріалів медичного призначення для надання їхній поверхні антибактеріальних/антивірусних властивостей.*

*Дослідження адсорбційних властивостей тканини медичного призначення (методом БЕТ визначали питому поверхню та розподіл пор по розмірах від їхнього радіуса у дослідженому зразку полотна) показало, що її поверхня характеризується наявністю мікро- мезо- та макропор, саме тому, крім високої адсорбційної ємності по відношенню до різних речовин, вона може бути використана для модифікування НЧ методом адсорбції з розчинів. Наночастинки інкапсулюються пористою структурою тканини та утримуються в мезопорах розміром 2–50 нм, ймовірно, за рахунок дії капілярних сил. Для модифікування полотна застосували НЧ, імплантовані фізичним способом (з використанням іонно-плазмової технології в екологічно чистому технологічному циклі, технологія ELIPS) у харчовий гліцерин і стабілізовані в ньому без додаткових хімічних реагентів. Дослідження вихідної суспензії з НЧ Ag й Cu та структурні перетворення іммобілізованих НЧ на поверхні тканини виконували методом електронної мікроскопії та мікрорентгеноспектрального аналізу.*

*Результати комплексного дослідження антивірусної, антимікробної, та антимікотичної активності НЧ Ag та суміші НЧ Ag й Cu показали, що за концентрації НЧ 10 ppm спостерігається бактерицидний, фунгіцидний і вірулецидний ефекти. Композити суміші НЧ Ag й Cu, стабілізовані НЧ діоксиду кремнію, були активнішими щодо пригнічення росту бактерій як грамнегативних, так і грампозитивних, ніж без додавання НЧ діоксиду кремнію.*

*Модифіковані НЧ тканини можна рекомендувати для виготовлення середнього шару 3-шарових медичних масок, медичних перев'язувальних матеріалів, різноманітних прокладок для нижньої білизни, дитячих пелюшок і підгузків, постільної білизни, медичної форми та інших видів товарів медичного призначення.*

***Ключові слова**: НЧ срібла та міді, модифікування поверхні матеріалів медичного призначення, адсорбція з розчинів, антибактеріальні та антивірусні властивості*

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