Дослідження спрямовано на розробку стабільної композиції на основі нанорозмірного силіцій діоксиду, яка може бути використана для кінцевої обробки бавовняних та поліефірних текстильних матеріалів. Сфери використання композиції – процеси виробництва та побутового прання текстильних виробів з метою покращення їх властивостей (гігроскопічності, вологовіддачі, вологопоглинання, вологості, паропроникності та забруднювальності). Виконано оптимізацію складів композицій та оцінку екологічного навантаження на навколишнє природнє середовище від їх використання в умовах промислового виробництва та при експлуатації текстильних виробів

Ключові слова: наночастинки, поверхнево-активна речовина, текстильні матеріали, суспензія, силіцій діоксид, нано-препарат

Исследование направлено на разработку стабильной композиции на основе наноразмерного диоксида силициума, которая может быть использована для конечной обработки хлопковых и полиэфирных текстильных материалов. Сферы использования композиции – процессы производства и бытовой стирки текстильных изделий с целью улучшения их свойств (гигроскопичности, влагоотдачи, влагопоглощения, влажности, паропроницаемости и загрезняемости). Выполнена оптимизация составов композиций и оценка экологической нагрузки на окружающую природную среду от их использования в условиях промышленного производства и при эксплуатации текстильных изделий

Ключевые слова: наночастицы, поверхностно-активное вещество, текстильные материалы, суспензия, силиций диоксид, нано-препарат

UDC 677.047
DOI: 10.15587/1729-4061.2016.79809

DEVELOPING COMPOSITIONS BASED ON NANOPARTICLES FOR FINAL TREATMENT OF TEXTILE MATERIALS

D. Matveitsova
Junior Researcher*
E-mail: matveitsovadariia@ukr.net
O. Paraska
PhD, Associate Professor
Department of Chemical Technology**
E-mail: olgaparaska@gmail.com
S. Karvan
Doctor of technical science, Professor*
E-mail: karvan@ukr.net
*Department of chemistry**
**Khmelnytsky National University
Instytutska str., 11, Khmelnitsky, Ukraine, 29000

1. Introduction

At present, many countries of the world, including Ukraine, face the problem of deterioration of socio-economic and environmental conditions, which affect the health of people. Therefore, modern society has certain requirements for the quality of textile materials and their products, the basis of which concerns safety, hygiene and functionality. Under such conditions, developing and expanding textile production in Ukraine is impossible without improving competitiveness in the domestic and foreign markets. Solving these problems mainly depends on the use of modern, progressive, economically and environmentally effective technologies of finishing, which include application of new high quality preparations, capable to provide textile materials and their products with a complex of high consumer properties.

One of the most promising directions of upgrading technological processes and improving the quality of textile materials is integration of nanotechnologies in textile industry.

Modern trends of applying nanotechnologies in textile industry can be divided into several categories:

– improvement of textile materials using nanomaterials and nanocoatings;

– using built-in electronic components and microelectromechanic systems in traditional materials;

– hybridization of textiles and biometric systems.

Given the trends of textile market and scientific interest, the promising direction of development is modification of the surface of fiber and fabrics with nanoparticles in the process of final treatment and in the use of ready-made clothes, as well as the need for the formulation of technology of finishing textile materials with the use of nanoparticles by improving classical technologies of textile production.

2. Literature review and problem statement

The latest research in the field of development of textile materials with new properties are basically aimed at generating nanocoatings on textile material in the process of its production [1] or finishing [2]. In the field of textile production, nanoparticles are used to obtain such properties as self-cleaning [3], antibacterial properties [4], and water repellence [5].

We will consider the most common method of applying nanopreparations on the surface of textile material with the aim of generating a nanocoating – the gel-sol method.

The gel-sol method of sedimentation is a universal, relatively easy and attractive technology for generation of coatings on different materials in order to ensure certain properties [1, 5–7]. Colloidal solutions, as a rule, are nanosols on the basis of nanoparticles of oxides in water or organic solvents. The gel-sol method, one of the most used techniques

in the textile industry, is implemented with wet methods of coating or immersion.

Nanoparticles have unique mechanical, thermal, tribological, electrochemical and other properties, they are promising components for making new compositions for treatment of textile materials. Nanodimensional silicon dioxide refers to the most common compounds in various areas of technology, as, thanks to the developed surface, silicon dioxide may be provided with specific properties by modifying structural composition and the surface of compound. A large area of active surface, formed by nanoparticles, defines a number of important properties of surface and structure of textile material, so the size of particles is a major factor. Since the nonuniformity of nanoparticles dimensions causes a change in the physical properties of composite materials, obtained with their use, development of the method of obtaining a composition based on nanoparticles of uniform composition, and its stabilization is one of the priority tasks in the process of obtaining new compositions for the treatment of textile materials.

Current research involving nanoparticles for the treatment of textile materials is aimed at achieving specified properties. Authors of work [8] considered the increase in the strength of textile materials using nanoparticles of Al_2O_3, SiO_2, ZnO, and carbon nanotubes. Based on the results of research [9, 10], the use of nanoparticles of soot, copper, polyperol, polyaniline and carbon tubes provide textile materials with the properties of electrical conductivity and antistatic. When modifying the fibers with TiO_2 nanoparticles, it is possible to give them the properties of self-cleaning [11], dirt- [12] and water repellence [11], water absorption [13], UV protection [12], and antibacterial properties [14].

SiO_2 matrix and montmorillonite can be used for the controlled release of active substances, pharmaceuticals or fragrances [15]. However, the niche of research into the use of nanoparticles for comprehensive provision of the properties of textile materials remains unfilled.

3. The aim and the tasks of the study

Conducted studies were aimed to develop tcompositions based on nanoparticles of silicon dioxide for finishing textile materials with the fiber composition of cotton-polyester in order to formulate and improve their consumer properties.

To achieve the aim, the following tasks were set:

– to select components of suspension from the range of textile auxiliary substances for its maximum stability and uniformity of distribution by dimensions and to determine technological parameters of the preparation of nanosuspension based on silicon dioxide;

– to explore the impact and to optimize composition formulations with a different composition for maximizing the change in the properties of textile materials and to assess the impact of its use on the environment.

4. Materials and methods of the study

4. 1. The studied materials and equipment used in the research

Silicon dioxide is highly dispersed, highly active, amorphous, and pyrogenic, obtained by flame hydrolysis of high-purity tetrachloride silicon of the Orisil 380 trade mark (TU U 24.1-31695418-002:2008);

Anionic SAS – sodium dodecylbenzensulphonate is a mixture of isomers of sodium salts of alkylbenzensulphoacid of the Sulfonol NP-3 trade mark (TU U 24.6-20257936-022:2006);

Cationic SAS – acetate of the product of interaction of β-oxiethyletylendiamin and higher lipid acids of coconut oil of the Barvamid 2K trade mark (TU U 24.1-32257423-118-2005);

Ampholyte SAS – cocamidopropylbetaine, derivative of cocamid (amid of lipid acids of coconut oil) and betaine glycin of the Betaine 40 trade mark (CAS:61789-40-0, ES:263-058-8);

Nonionic SAS – a mixture of complex esters of lauric acid, of the Twin-80 trade mark (TU U 24.5-25066661-004:2008);

Dispersion polyvinylacetate – TU U 24.1-33270581-020:2007;

Dispersion of carboximetylcellulose – TU U 24.6-251011682007-2002;

Polyvinyl alcohol – GOST 10779-78;

Starch modified by hydrolysis (DSTU 4380:2005).

To evaluate the colloid-chemical properties, we carried out the study of its sedimentation and aggregation stability using dispersion analysis, which was performed using the methods for determining average dimensions of colloidal particles by the characteristic of turbidity of the system by the method of separation of disperse system into separate fractions in the process of stilling. Turbidity was determined using the photocolorimeter KFK-2.

Analysis of the quantity of disperse phase that remains in the solution was carried out using the gravimetric method after treating textile material with the composition with a mass content of nanodimensional silicon dioxide in the range from 0,2 g to 6 g. Sedimentation of disperse phase was performed within 48 hours. After stilling, the sedimentary disperse phase was taken and dried to the constant mass at temperature of 115±2 °C. Assessment of the degree of redispersion of sedimented disperse phase under the influence of external mechanical forces was carried out by the following method: after sedimentation of the suspension with a mass content of NP 2 g/l, the suspension was stirred at a constant speed for eight hours using a laboratory mixer, taking samples every 5 minutes within an hour and then every 15 minutes, after the colloid-chemical properties of the suspension were determined. The quantity of surface active substances (SAS) in dispersive medium and in dispersive phase was determined using the extraction-colometric method of analysis.

4. 2. Methods for determining the properties of textile materials

The study of textile materials was performed according to the standard methods of research into the properties of textile materials existing in Ukraine.

Hydroscopic properties, water yielding capacity, and moisture absorption of textile materials were defined according to DSTU GOST 3816:2009 (ISO 811-81). Humidity and water vapor permeability were defined using the gravimetric method. Soiling of textile materials was assessed by measuring coefficients of reflection of textile materials samples defined by the photometric method after contamination with a complex artificial soiling agent based on oil and soot.

Before the study, textile materials were exposed to pretreatment, the essence of which is removing the production

finishing using the method of washing in a household washing machine in accordance with the procedure described in GOST ISO 6330-2011, followed by treatment with the use of the proposed compositions.

Method 1. Textile material is impregnated with the composition, spinned on the rolls to the 70–80 % humidity and dried at temperature 50 °C.

Method 2. Textile material is treated in a household washing machine in the process of rinsing with the addition of the composition at spinning parameters from 600 rpm to 800 rpm, followed by drying at room temperature.

5. Results of studying the influence of stabilizers on aggregation and sedimentation resistance of the system

According to preliminary studies, a suspension with nanoparticles of silicon dioxide may be considered monodispersed, and therefore, stable, after stilling for 17280 min, that is, 12 days under static conditions [16]. For the dispersed system, which is supposed to be used in the technological process of treating textile materials, the basic and necessary criteria when choosing potentially suitable stabilizers are the possibility to use them as textile auxiliary substances and the absence of negative impact on its properties. In order to effectively stabilize the suspension with primary dimensions of SiO_2, it is necessary to add a stabilizer.

The existence of negative centers (absorption centers) allows modifying the surface of the particles of silicon dioxide with surfactants (SAS). To study stabilization of suspensions, four SAS of different ionic character (cationic, anionic, nonionic and ampholyte) were selected as a stabilizing component. Polymers were chosen with regard to the most commonly used ones for treating textile materials with the selected fiber composition.

As the dimension of particles and colloids in the system is an important characteristic of stability of suspensions, we will give the characteristic of their equivalent radii in three-component SiO_2:H_2O:stabilizer systems, determined according to the procedure for determining the size of the particles, which are not subject to the Rayleigh equation. Dependencies of the weighted average of radii of colloidal particles with the addition of SAS as stabilizers are given in Fig. 1. For comparison, Fig. 1 displays the curve of dependency of the weighted average of radii of colloidal particles in bicomponent suspension SiO_2:H_2O.

According to the distribution of suspension with the stabilizer Barvamid 2K on the equivalent radii, displayed in graph (Fig. 1), the majority of fractions lie in a narrow dimension range from 80–90 nm. In the upper layer of the suspension, when the stabilizer Barvamid 2K was added, a much higher concentration of SiO_2 was observed, this may be explained by the foam formation of the stabilizing component of suspension. When adding the stabilizers Sulphonol NP-3, Twin 80 and Betaine, the specific sedimentation curves were observed.

To make the evaluation of the influence of stabilizers on the system properties more complete, the calculation data are presented in Table 1:

– the total number of particles that remain in solution (NΣ, p);

– distribution by the enlarged fractions depending on the equivalent dimensions of colloids in the intervals of less than 80 nm (<80); from 80 nm to 100 nm (80–100); more than 100 nm (>100);

– the number of nanoparticles in each fraction (N, p);

– percentage content of nanoparticles in fractions in relation to the initial content of nanoparticles (K, %);

– volumes of enlarged fractions (V, ml).

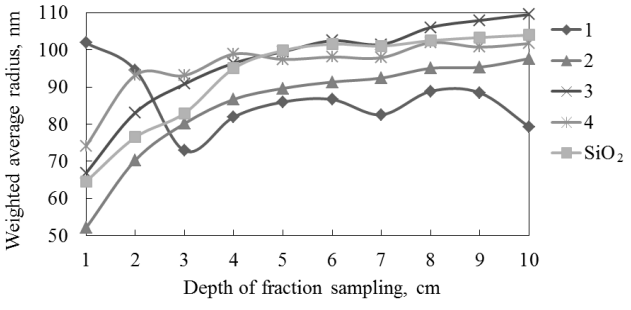

Fig. 1. Diagram of dependency of weighted average radii of colloidal particles with addition of SAS as stabilizers: 1 – Barvamid 2K; 2 – Sulphonol NP-3; 3 – Twin 80; 4 – Betaine; SiO_2 – without addition of stabilizer

Table 1

Number of particles that remain in solution and their distribution by enlarged fractions

Stabilizer		–	Barvamid 2K	Sulphonol NP-3	Twin 80	Betaine
N_Σ		$4.28 \cdot 10^{20}$	$1.06 \cdot 10^{20}$	$4.36 \cdot 10^{20}$	$5.50 \cdot 10^{20}$	$2.96 \cdot 10^{20}$
<80	N	$4.03 \cdot 10^{19}$	$1.86 \cdot 10^{19}$	$2.95 \cdot 10^{19}$	$9.97 \cdot 10^{18}$	$5.39 \cdot 10^{18}$
	K	1.61	0.82	1.18	0.40	0.21
	V	48	48	48	24	24
80–100	N	$1.17 \cdot 10^{20}$	$7.16 \cdot 10^{19}$	$4.17 \cdot 10^{20}$	$1.25 \cdot 10^{20}$	$1.72 \cdot 10^{20}$
	K	4.65	2.86	16.61	4.99	6.86
	V	72	168	192	92	144
>100	N	$2.71 \cdot 10^{20}$	$1.61 \cdot 10^{19}$	–	$4.25 \cdot 10^{20}$	$1.18 \cdot 10^{20}$
	K	10.82	0.64	–	16.93	4.70
	V	120	24	–	124	72

According to the data presented in Table 1, the number of particles remaining in bicomponent suspension SiO_2:H_2O is $4.28 \cdot 10^{20}$. According to the enlarged fractions, the percentage ratio in relation to the total content of nanoparticles in enlarged fractions is 9.4 % with dimensions less than 80 nm; 27.3 % – with dimensions from 80 nm to 100 nm; 63.3 % – with dimensions of more than 100 nm. A higher value of the number of particles in the suspension is observed in the case of using the stabilizers Sulphonol NP-3 and Twin 80. The largest number of particles remaining in the solution is observed with the use of the stabilizer Twin 80, however, 77,3 % with dimensions from 100 nm to 110 nm. In the percentage ratio, colloids with dimensions of less than 80 nm make 0,1 %; those with dimensions from 80 nm to 100 nm make 22,6 %; those with dimensions of more than 100 nm make 77.3 %. When Sulphonol NP-3 is used as a stabilizer, the number of particles in solution makes $5.22 \cdot 10^{20}$ and the percentage distribution by dimensions is as follows: dimensions of less than 80 nm make 6,77 %; those with dimensions from 80 nm to 100 nm make 95,64 %; whose with dimensions of more than 100 nm make 0 %. Therefore, the

introduction of Sulphonol NP-3 and Twin 80 as stabilizers into the suspension results in the system's demonstrating the features of stability, that is, monodispersity.

Authors made an assessment of stabilizing properties according to the dimensions of particles and colloids, which are formed in suspensions with adding polymers as stabilizing components: polyvinylacetate dispersion (PVA), carboximetylcellulose (CMC), polyvinyl alcohol (PVAl), modified starch (MS).

Fig. 2 displays the value of the equivalent radii of colloidal particles depending on the depth of fraction sampling.

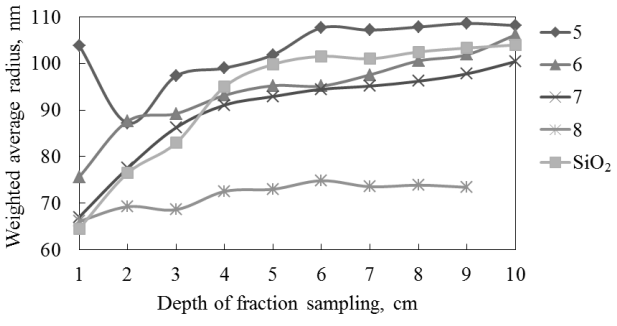

Fig. 2. Diagram of dependency of equivalent radii of colloidal particles on the depth of fraction sampling: 1 — PVA dispersion; 2 — CMC dispersion; 3 — PVAl; 4 — MS; SiO_2 — without adding stabilizer

According to the dependency, displayed in Fig. 2, with adding the PVA dispersion to the suspension, the largest equivalent radii of colloids are observed. In the suspension, two linear sections from the third to the fifth fraction and from the sixth to the tenth fraction are observed. The curves of dependencies of equivalent radii of colloidal particles on the depth of the fraction sampling for the CMC and PVAl dispersions reflect characteristic sedimentation of the suspension. With adding the MS as a stabilizer to the SiO_2:H_2O system, the distribution by the volume of particles in a narrow dimension range is observed, which testifies to stabilization of the suspension.

For a complete analysis, we calculated the number of particles that remain in the solution and their distribution by enlarged fractions according to the equivalent dimensions of colloids in the following intervals: <80; 80–100; >100, as well as the stability factor for each of the enlarged fractions. The calculation data are presented in Table 2.

Table 2

Number of particles that remain in solution and their distribution by enlarged fractions in the presence of polymers

Stabilizer		–	PVA dispersion	CMC dispersion	PVAl	MS
N, part.		$4.28 \cdot 10^{20}$	$5.08 \cdot 10^{20}$	$5.59 \cdot 10^{20}$	$3.36 \cdot 10^{20}$	$4.62 \cdot 10^{20}$
<80	N	$4.03 \cdot 10^{19}$	–	$1.76 \cdot 10^{19}$	$2.45 \cdot 10^{19}$	$2.77 \cdot 10^{20}$
	K	1.61	–	0.70	0.98	11.03
	V	48	–	24	48	216
80–100	N	$1.17 \cdot 10^{20}$	$1.19 \cdot 10^{20}$	$2.98 \cdot 10^{20}$	$2.59 \cdot 10^{20}$	–
	K	4.65	4.76	11.62	10.34	–
	V	72	72	144	168	–
>100	N	$2.71 \cdot 10^{20}$	$3.88 \cdot 10^{20}$	$2.43 \cdot 10^{20}$	$5.2 \cdot 10^{19}$	$1.86 \cdot 10^{20}$
	K	10.82	15.48	9.69	2.07	7.39
	V	120	168	72	24	24

According to the results (Table 2), the highest values of the number of particles remaining in suspension are observed with the use of the PVA dispersion, CMC dispersion and modified starch as stabilizers. The best result is observed with the use of CMC stabilizer, the majority of agglomerates lie in the dimension range from 80 nm to 100 nm. The percentage ratio is 3.2 % of colloids with dimensions less than 80 nm; 55,3 % – from 80 nm to 100 nm; 43,5 % – of more than 100 nm. With using the PVA as a stabilizer, the number of particles remaining in the solution is $5.08 \cdot 10^{20}$. The percentage distribution according to their dimensions in enlarged fractions is as follows: 23,5 % – from 80 nm to 100 nm; 76,5 % – more than 100 nm. In the process of introducing the MS stabilizer into the system, the number of particles in solution is $4.62 \cdot 10^{20}$ and their percentage distribution according to dimensions is 60.0 %; 0 %; 40.0 %.

Based on the above mentioned research results, it is not possible to choose a single stabilizer to provide the necessary stability and redispersing of the system, accordingly, the need for research of using the mixture SAS:polymer as a stabilizer was formed. It is assumed, that with using the mixture SAS:polymer as a stabilizer there is an increase in the stability of the suspension, i. e. it displays synergic properties.

6. Results of studying the influence of stabilized suspensions on the properties of textile materials with different fiber compositions

Further research of stabilization of nanosuspensions was performed in the direction of uniformity of treatment of textile materials. According to experimental studies, to assess the further impact on the textile material, the following compositions were chosen:

Composition No. 1 – silicon dioxide:cationic SAS:PVA dispersion:water;

Composition No. 2 – silicon dioxide:anionic SAS:MK: water;

Composition No. 3 – silicon dioxide:nonionic SAS:PVAl dispersion:water;

Composition No. 4 – silicon dioxide:ampholyte SAS: CMC dispersion:water.

With the aim of a comprehensive study of all compositions and taking into account the influence of components and relations between them, we carried out the planned experiment on the local section using simplex centroid plan for q=3, made relative to pseudo-components. Planning the experiment was conducted on the local section of the three-component mixture, which is a triangle with apices z_1 (40; 0; 60), z_2 (40; 60; 0), z_3 (0; 20; 80). The limits of composition formulations for final treatment (g/l): x_1=1, x_2=0,5, x_3=1.

The plan of the experiment for solving the set problem is presented in Table 3. From three to five parallel experiments depending on the procedure of studying the properties of textile material were performed for each point of the plan.

To determine the optimal composition of the mixture, which provides high values of properties of textile materials, the Harrington function of desirability was used. Building up

generalized function of desirability D implied the conversion of research values of responses y_n in nondimensional desirability scale d. Building up the desirability scale establishes relations between the value of response y and the correspondent value of private desirability function d. In this problem, there are unilateral constraints on the criteria of optimization of the view $y \le y_{max}$ and $y \ge y_{min}$, therefore, to convert the studied criteria y into the private of desirability d, the exponential dependency was used; coefficients b_0 and b_1 may be determined, if you set for two values of response the correspondent values of desirability d mainly in the range of $0.2<d<0.8$. To determine b_0 and b_1, the following method was used: the value of response, obtained in studying the original fabric sample, is given the value of desirability equal to 0.2, and the best value of response, obtained by the planning matrix, is given the value of desirability – 0.8.

Table 3

Matrix of experiment planning

No. of experiment	Composition of mixture					
	Pseudo-components			Initial components, %		
	z_1	z_2	z_3	x_1	x_2	x_3
1	1	0	0	40	0	60
2	0	1	0	40	60	0
3	0	0	1	0	20	80
4	0,5	0,5	0	40	30	30
5	0,5	0	0,5	20	10	70
6	0	0,5	0,5	20	40	40
7	0,333	0,333	0,333	26,68	26,54	46,78
8	0,15	0,595	0,298	29,80	40,80	29,40
9	0,3	0,49	0,21	31,60	33,60	34,80

To compute the ratio of components, with which are all indices tend to maximum values, we used MathCAD 15.0 software with satisfying the condition of maximizing D=max function. After processing the obtained equations of regressions in the initial coordinates, a ratio of components, presented in Table 4, was obtained.

Table 4

Recommended composition formulations

No. of composition	Composition formulations, mass %			
	Silicon dioxide	SAS	Polymer	Water
1	0.45–0.50	0.05–0.15	0.20–0.25	the rest
2	0.48–0.53	0.10–0.15	0.15–0.25	the rest
3	0.48–0.51	0.14–0.18	0.15–0.20	the rest
4	0.46–0.50	0.11–0.15	0.18–0.26	the rest

With such proportions of the components, a change in the properties of textile materials was experimentally defined. Results of the research are presented in Fig. 3.

Results of the studies, which are displayed in Fig. 3, indicate the possibility of using compositions with different components to improve the complex of properties of textile materials with different fiber compositions. For the cotton textile materials, the best characteristics were achieved by treating them with composition No. 1 (silicon dioxide: cationic SAS:PVA dispersion:water); for the polyester material – with composition No. 2 (silicon dioxide:anionic SAS:MS:water): for the mixed materials – with composition No. 3 (silicon dioxide:nonionic SAS:PVAl dispersion:water).

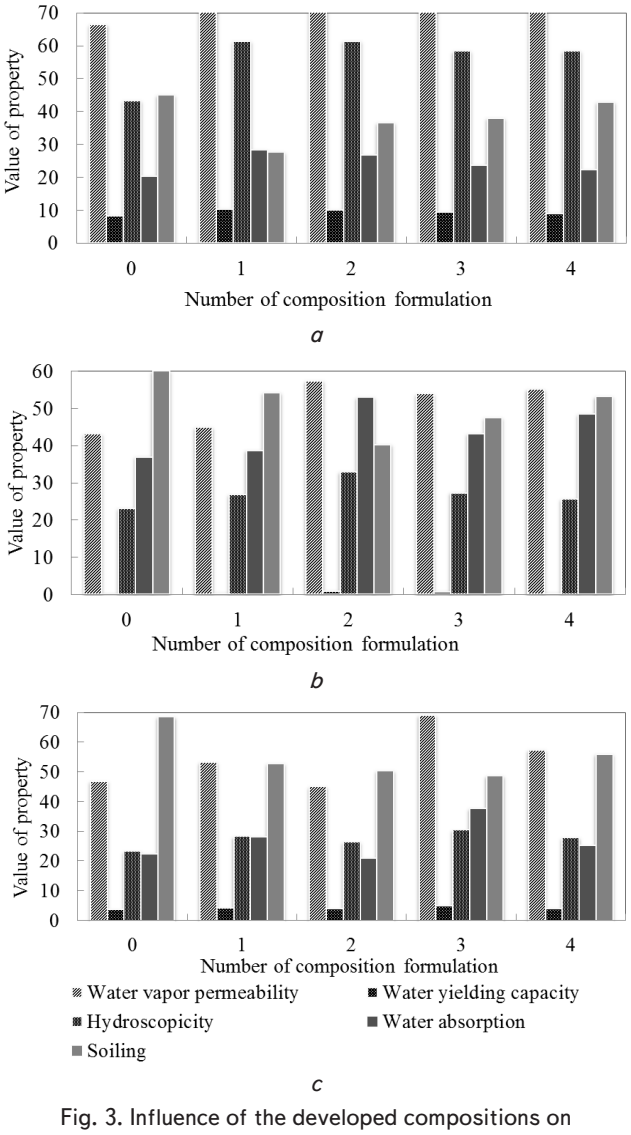

Fig. 3. Influence of the developed compositions on the change in properties: *a* — cotton textile material; *b* — polyester textile material; *c* — mixed textile material

In order to select an optimal composition formulation according to the characteristic of the system stability, it was appropriate to carry out stability assessment of the studied suspensions, the results of which are given in Table 5.

According to results given in Table 5, the best characteristics of stability are demonstrated by compositions No. 2 and No. 3. The number of particles remaining in composition No. 2 is $8.58 \cdot 10^{20}$ according to enlarged fractions. Percentage ratio of distribution of particles of silicon dioxide by enlarged fractions is 23.8 %; 74.7 %; 15.5 %. In composition No. 3, the number of particles in solution is $8.42 \cdot 10^{20}$ according to enlarged fractions and percentage ratio is 1.4 %; 91.2 %; 7.4 %. The main part of particles remaining in the compositions lies in the range of dimensions from 80 nm to 100 nm.

Researchers-environmentalists have come to the conclusion that the detection, extraction and analysis of nanomaterials in the samples from the environment require integrated use of various technologies. This is due to small dimensions,

unique structure, physical and chemical characteristics, surface modifications and interactions in the environment, including agglomeration and deaggregation of nanoparticles. To predict the probability of contamination of the environment and to assess the level of environmental safety of the use of nanosuspensions, the necessary parameter is determining their physical and chemical properties at the stage of recycling or regeneration.

Table 5

Number of particles that remain in solution and their distribution by enlarged fractions in the presence of composition formulations

Composition		1	2	3	4
N, part.		$7.16 \cdot 10^{20}$	$8.58 \cdot 10^{20}$	$8.42 \cdot 10^{20}$	$5.85 \cdot 10^{20}$
<80	N	$1.16 \cdot 10^{20}$	$2.04 \cdot 10^{20}$	$1.18 \cdot 10^{19}$	$4.22 \cdot 10^{19}$
	K	4.62	8.12	0.47	1.68
	V	48	48	24	48
80–100	N	$8.70 \cdot 10^{19}$	$6.41 \cdot 10^{20}$	$7.68 \cdot 10^{20}$	$3.75 \cdot 10^{20}$
	K	3.47	25.55	30.61	14.94
	V	144	168	192	144
>100	N	$5.13 \cdot 10^{20}$	$1.33 \cdot 10^{20}$	$6.20 \cdot 10^{19}$	$1.68 \cdot 10^{20}$
	K	20.44	0.53	2.47	6.70
	V	48	24	24	48

The evaluation of ecological safety of the compositions was performed by the following indices, which were determined after treating textile material:

– the amount of dispersed phase, remaining in the solution;

– the degree of redispersing of nanoparticles under the action of external mechanical forces;

– content of surfactants in the waste solution.

The amount of disperse phase that remains in solution after treating the textile materials using methods 1 and 2, is more than 50 % of the mass of the original one; it is observed in concentrations of silicon dioxide in solution of 1 g/l. It was a big problem at this stage of research, since it resulted in a decrease of the environmental safety of using compositions. According to results of the study, the optimal duration of mechanical action for redispersing of sediment in the suspension is 1 hour, which is consistent with the data of the compositions preparation. These results give reason to the possible reuse of compositions for treating textile material. The maximum permissible concentration of SAS in water bodies must not exceed 0,001 g/l. The research was carried out in the range of concentrations of recommended formulations listed in Table 4. To study the quantity of SAS in sedimentation residue, sediment washing, evaporation to 100 ml and determination of SAS were carried out The results of the research into the quantitative SAS content in the solution – C_1 and in the sediment – C_2 are given in Table 6.

Table 6

Amount of SAS in the solution and in the sediment

Composition	1	2	3	4
C_1, g/l	0.00076	0.00063	0.00072	0.00098
C_2, g/l	0.03870	0.03799	0.03566	0.03680
$\Sigma=C_1+C_2$	0.03846	0.03862	0.03658	0.03778

Based on the data from Table 6, it could be argued that after stilling for 48 hours the excess SAS is adsorbed on the fiber and on the surface of nanodimensional silicon dioxide. The amount of SAS that remains in the solution does not exceed the required values.

7. Discussion of results of research aimed at developing a stable composition based on nanodimensional silicon dioxide

The conducted research suggests the possibility of reusing sediment, thus minimizing ecological load on the environment. In the course of reusing, a basic parameter to be considered is the compensation of the mass content of the composition components.

As a result of the performed study, four compositions based on nano dimensional silicon dioxide were formed. The main advantages of the developed compositions are:

– significant increase in the indices of properties of textile materials with different fiber compositions after treatment;

– all the experiments were conducted at room temperature and low module treatment, which indicates energy efficiency in the process of using the developed compositions;

– the possibility of reusing solution of the composition allows minimizing ecological load on the environment and increasing economic efficiency.

However, a mechanism for fixing the composition on the surface and its distribution on the surface of textile material were not considered, the stability of treatment was not defined, the features of continuous contact of textile products with the skin of a human were not explored in the study.

Results of the study may be implemented in the production of textile materials. The composition may be used as a preparation for the final treatment of textile materials with the aim of improving their marketing prospects and consumer properties. It is possible to use the developed composition at enterprises of household services (laundries) and for individual home washing. In these cases, the use of the composition as a conditioner for rinsing is suggested.

It is worthwhile focusing further research on achieving monodispersed suspension with agglomerate dimensions in a narrow dimension range from 20 nm to 60 nm by adding auxiliary stabilizing components to the composition and by upgrading the redispersion technology. The aim of further studies is the development of a universal preparation for final treatment of textile materials and products, which differ in fiber composition, structure and coloration.

8. Conclusions

Stabilizing properties of surface active substances and polymers were revealed, the expediency of their joint use with the purpose of increasing the sedimentation and aggregation stability of the suspensions on the basis of silicon dioxide was substantiated.

The use of methods of mathematical planning using simplex centroid plan for q=3, compiled in relation to pseudo-components, allowed assessing the changes in properties in a limited area of components of the compositions: polymer from 0 g/l to 10 g/l, SAS from g/l to 5 g/l, nanodimensional silicon dioxide of less than 10 g/l. We managed to optimize the ratio between the components of the compositions using the Harrington desirability function for maximum enhancement of the properties of hydroscopicity, water yielding

capacity, moisture absorption, water vapor permeability, humidity and soiling of the studied textile materials.

Assessment of sedimentation and aggregation resistance of the developed composition formulations was carried out and the compositions were obtained, the percentage content of nanoparticles in fractions in relation to the initial content of nanoparticles increases. In the bicomponent suspension, 17.1 % of nanoparticles remain in the solution, and with adding a mixture of stabilizers their amount increases by 11.5 % for composition No. 1, by 17,1 % for composition No. 2, by 16.5 % for composition No. 3, and by 6,24 % for composition No. 4.

Characteristics of the compositions change by 1–3 % as a result of their redispersing after stilling for 30 days. The negative impact of using compositions on the environment was studied by analyzing the waste solution regarding the amount of surfactants. It was found that more than half silicon dioxide remains in the waste solution. The solution to the problem of avoiding the above mentioned negative phenomena by reusing sediment was formulated. However, no specific conclusions regarding the recommendation of one of the four studied compositions were made.

References

1. Brown, P. Nanofibers and Nanotechnology in Textiles [Text] / P. Brown, K. Stevens. – Woodhead Publishing, 2007. – 518 p.
2. Dongxue, L. Nanotechnology in Textiles Finishment [Text] / D. Liu, W. Dong // Modern Applied Science. – 2009. – Vol. 3, Issue 2. – P. 154–157. doi: 10.5539/mas.v3n2p154
3. Dastjerdi, R. A review on the application of inorganic nano-structured materials in the modification of textiles: Focus on antimicrobial properties [Text] / R. Dastjerdi, M. Montazer // Colloids and Surfaces B: Biointerfaces. – 2011. – Vol. 79, Issue 1. – P. 5–18. doi: 10.1016/j.colsurfb.2010.03.029
4. El-Molla, M. M. Nanotechnology to improve coloration and antimicrobial properties of silk fabrics [Text] / M. M. El-Molla, E. M. El-Khatib, M. S. El-Gammal // Indian J. Fibre Textile Res. – 2011. – Vol. 36. – P. 266–271.
5. Russell, E. Nanotechnologies and the shrinking world of textiles [Text] / E. Russell // Textile Horiz. – 2002. – Vol. 9, Issue 10. – P. 7–9.
6. Stevens, K. Sol-gel application for textiles: towards new ecological finishes [Text] / K. Stevens // 22-nd IFATCC, 2010.
7. Daoud, W. A. Low temperature sol-gel processed photocatalytictitania coating [Text] / W. A. Daoud, J. H. Xin // Journal of Sol-Gel Science and Technology. – 2004. – Vol. 29, Issue 1. – P. 25–29. doi: 10.1023/b:jsst.0000016134.19752.b4
8. Dong, W. G. Research on properties of nano polypropylene/TiO2 composite fiber [Text] / W. G. Dong, G. Huang // Journal of Textile Research. – 2002. – Vol. 23. – P. 22–23.
9. Sennett, M. Dispersion and Alignment of Carbon Nanotubes in Polycarbonate [Text] / M. Sennett, E. Welsh, J. B. Wright, W. Z. Li, J. G. Wen, Z. F. Ren // Applied Physics A: Materials Science & Processing. – 2003. – Vol. 76, Issue 1. – P. 111–113. doi: 10.1007/s00339-002-1449-x
10. Burniston, N. Nano Technology Meets Titanium Dioxide [Text] / N. Burniston, C. Bygott, J. Stratton // Surface Coatings International. – 2004. – Part A. – P. 179–814.
11. Wong, Y. W. H. Selected applications of nanotechnology in textiles [Text] / Y. W. H Wong, C. W. M. Yuen, M. Y. S. Leung, S. K. A. Ku, H. L. I. Lam // AUTEX Res. J. – 2006. – Vol. 6, Issue 1. – P. 1–8.
12. Song, X. Q. The effect of nano-particle concentration and heating time in the anti-crinkle treatment of silk [Text] / X. Q. Song, A. Liu, C. T. Ji, H. T. Li // Journal of Jilin Institute of Technology. – 2001. – Vol. 22. – P. 24–27.
13. Kathiervelu, S. S. Applications of nanotechnology in fibre finishing [Text] / S. S. Kathiervelu // Synthetic Fibres. – 2003. – Vol. 32. – P. 20–22.
14. Zhang, J. Hydrophobic cotton fabric coated by a thin nanoparticulate plasma film [Text] / J. Zhang, P. France, A. Radomyselskiy, S. Datta, J. Zhao, W. V. Ooij // Journal of Applied Polymer Science. – 2003. – Vol. 88, Issue 6. – P. 1473–1481. doi: 10.1002/app.11831
15. Harholdt, K. Carbon Fiber Past and Future [Text] / K. Harholdt // Ind. Fabric Prod. Rev. – 2003. – Vol. 88, Issue 4. – P. 14–28.
16. Karvan, S. Aggregative and sedimentation stabilization of aqueous nanodispersions. Innovations in Clothing Design, Materials. Technology and Measurement Methods [Text]: monograph / S. Karvan, D. Matveitsova, O. Paraska: I. Frydrych (Ed.). – Grazina Bartkowiak, & Maria Pavlowa, 2015. – P. 253–259.