Представлені результати розробки композиційного складу поверхнево-активних речовин для підготовки бавовняного трикотажного полотна на основі методу математичного планування експерименту – симплекс-решітчастого плану Шеффе другого порядку. Оптимізація математичних моделей «склад-властивості» проведена за змочуючою і миючою здатністю розробленої композиції. Отримана композиція поверхнево-активних речовин забезпечує отримання капілярності трикотажного матеріалу 180 мм за 60 хв. і збільшення ступеня фіксації активного барвника на 7,5 % при подальшому його фарбуванні

Ключові слова: трикотажне полотно, поверхнево-активні речовини, підготовка трикотажу, композиція поверхнево-активних речовин, план Шеффе

Представлены результаты разработки композиционного состава поверхностно-активных веществ для подготовки хлопчатобумажного трикотажного полотна на основе метода математического планирования эксперимента – симплекс-решетчатого плана Шеффе второго порядка. Оптимизация математических моделей «состав-свойства» проведена по смачивающей и моющей способности разработанной композиции. Полученная композиция поверхностно-активных веществ обеспечивает получение капиллярности трикотажного материала 180 мм за 60 мин. и увеличение степени фиксации активного красителя на 7,5 % при последующем его крашении

Ключевые слова: трикотажное полотно, поверхностно-активные вещества, подготовка трикотажа, композиция поверхностно-активных веществ, план Шеффе

UDC 543.395:677.075
DOI: 10.15587/1729-4061.2016.75027

DESIGNING A COMPOSITION FORMULATION OF SURFACE ACTIVE SUBSTANCES FOR THE PRETREATMENT OF KNITTED FABRIC

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1. Introduction

Knitwear industry is the largest sector of world production because knitted goods possess unique consumer properties.

Important components of chemical-engineering process of the pretreatment of knitted fabric are textile auxiliaries (TA), whose application promotes the removal of oils, fats, waxlike substances and solid contaminants. Therefore, during the pretreatment of textile materials, there are a number of significant problems: selection of efficient and biodegradable surface-active surfactants (SAS); reduction in the destructive impact of the bleaching agents and TA; reduction in the volumes of water consumption and other forms of material resources; search for new, more efficient methods of pretreatment (biotechnology, treatment in the medium of low-temperature plasma and others) [1].

However, TA used in the Ukrainian knitted industry do not always ensure the required quality of the pretreatment of textile material, which subsequently affects negatively the quality of dyeing. At present, international quality standards place high demands to the textile products, which is predetermined by the need for creating and applying new ecologically safe TA for the provision of contemporary level of conducting technological processes, in particular, during the pretreatment of knitted fabric [2].

Improvement in the quality of the produced goods in the process of preliminary pretreatment of knitted fabrics is connected to designing highly efficient technologies with the use of new composition TA on the base of different classes of SAS [3, 4]. The need to create such preparations is predetermined by complex physical-chemical character of the treated material and by multistage nature of the processes of its treatment. The formulation of such compositions include the components that are compatible with each other, which either act additively or synergistically at one stage of the process or they are activated at its different stages.

The most widely used in the operations of pretreatment are the SAS, which possess a set of properties (washing, dispersing, emulsifying, wetting, anti-breakable).

Unbleached linen is poorly wetted in the solutions as a result of the presence of hydrophobic natural impurities and greasing substances in the fibers, which leads to the reduction in capillarity of knitted fabric. The lowered capillarity of textile materials hampers bleaching, dyeing, printing and treatment of these materials in aqueous solutions, as well as causes defects when conducting these processes (spots, unevenness of dyeing and others).

The quality of the pretreatment of textile material also influences to a considerable degree the result of its dyeing, which must have increased wettability, capillarity, a capability for swelling and perception of the molecules of dye.

Those preparations, which are used at the knitted enterprises of Ukraine for washing knitted fabrics, are characterized by significant cost and are frequently non-ecological. The relevance of the work is defined by the need to seek and design new efficient and economically sound composition preparations of SAS for the pretreatment of knitted fabrics [5–7].

2. Scientific literature analysis and the problem statement

In the production of knitted fabrics, with the purpose of increasing operational stability of knitting machines, the threads are treated with the greasing substances. The removal of greasing substances, as well as natural substances associated with cotton (nitrogen containing, pectic, waxlike substances, sugars, ash and coloring substances), from the knitted fabrics in the process of pretreatment presents great difficulties.

If technological and natural contaminants of cotton knitted fabric are not removed completely or their resorption occurs during washing, then this will lead to the reduction in its capillary properties and, during subsequent dyeing, to the incomplete dyeing in the places of contaminants deposition.

The studies [8] examined in detail the properties of SAS, produced in Ukraine, and demonstrated the peculiarities of the development of composition SAS for the treatment of textile materials [9]. In the papers [10–12], the composition for the pretreatment of cellulose-containing fabrics was designed, based on efficient emulsifiers and moisteners, which facilitate the removal of wax substances and remains of cuticular film from the surface of cotton fiber.

In the work [13], the authors assessed a washing action of a three-component mixture of SAS, based on determining the parameters of washing action, and proposed a washing formulation for cleaning woolen goods.

It was shown in the paper [14] that the binary mixtures and complex multicomponent systems based on SAS possess a higher wetting and washing capacity as compared to individual SAS that are contained in the mixtures.

The authors of [15] selected optimum parameters for the pretreatment of knitted fabric with the application of ferments: pH, temperature, concentration of a ferment.

The researchers in the [16] experimentally studied synergism of different affinity of both the individual SAS and those contained in the mixture. It was established that the wetting properties of the mixture of SAS are higher than the individual solutions of SAS.

The mixture of nonionogenic SAS with anionic SAS were investigated in the paper [17]. The measurement of surface tension was used for determining the values of CCMF and other parameters of adsorption. It was established that the formation of chain increases in the mixture of SAS.

The authors of [18] carried out studies of determining a washing capacity depending on the structure of nonionogenic and anion-active SAS on textile materials in non-aqueous medium (perchlorethylene). It was established that the best washing capacity is possessed by anion-active substances (alkylsulfates), which increase considerably a washing capacity of the pure solvent; introduction of nonionogenic hydrophilic groups to hydrocarbon radicals is accompanied by the decrease in washing capacity.

Analysis of scientific and technical information testifies to the lack of the purposeful and systematic studies in Ukraine with regard to the development of preparations for washing knitted fabrics. The Ukrainian knitted factories (PAO “Trikotazhnaya fabrika “Roza”, Kiev, OOO “T-Style”, Rovno) use washing imported preparations in the process of pretreatment, which is not always economically efficient.

Taking into account a continuous growth in the production of knitted fabrics and the goods made of them, it is promising at present to search for and design new compositions of SAS and the technologies of pretreatment, which will take into account peculiarities of the structure of knitted fabric and of conducting the processes of its pretreatment and which will make it possible to ensure improvement in the quality of the obtained raw material with the efficiency of technologies.

3. The purpose and objectives of the study

The purpose of this work was to develop composition formulation of SAS for the pretreatment of knitted fabric by the method of mathematical planning of the experiment and to study efficiency of applying the designed composition in the process of washing and its influence on the subsequent dyeing of knitted fabric.

To achieve the set goal, the following tasks were to be solved:

– to conduct optimization of single mathematical models “composition- property” according to a series of selected initial parameters of optimization of the composition;

– to determine optimal composition of the SAS formulation for pretreatment of knitted fabric by the Scheffe’s simplex lattice method of the second order;

– to determine capillarity and dyeability of the knitted fabric, prepared with the application of the designed composition of SAS.

4. Materials and methods of the study

We used SAS of different functional designation and chemical composition (Table 1), as well as cotton knitted fabric, article 1.170.(102)K.40.180 (95,2 % – cotton, 4,8 % – lycra) (OOO “T-Style”, Rovno, Ukraine).

Determining of wetting capacity of SAS was carried out by the Draves immersion method, which involves alternating immersion of the samples of knitted fabrics into prepared aqueous solutions of SAS with subsequent recording of time before their complete immersion [18].

For determining washing capacity of the examined SAS, the samples of knitted fabric were weighed accurate to four significant figures. Then the samples underwent boiling in the aqueous solutions of the examined SAS (0,2–5 g/l) at M=50, T=80 °C for 30 minutes with subsequent washing by warm water and repeated determining of the mass.

Table 1

Characteristic of the examined SAS

Designation	SAS class	Chemical composition
SAS 1	Nonionogenic	Composition of nonionogenic SAS
SAS 2	Anionogenic/ Nonionogenic	Liquid preparation on the base of polyether copolymer
SAS 3	Anion-active	Composition of derivatives of fatty alcohols with alkanol and modified methylpolysiloxanes
SAS 4	Nonionogenic	Alkyldimethyl-amineoxide

Washing capacity of SAS was determined by the formula:

$$X=\frac{(m_1-m_2)}{m_1}\cdot 100, \tag{1}$$

where m_1 is the mass of the sample before boiling, g; m_2 is the mass of the sample after boiling, g [19].

For determining foaming capacity of the composition of SAS and stability of the foam, 20 ml of the solution with concentration 5 g/l at the temperature of 20 °C was put to a graduated cylinder with capacity of 100 ml with a ground stopper. The cylinder with the solution was then shaken vigorously for 10 s. The volume of the formed foam was measured immediately after the shaking, as well as in 5, 10, 30 and 60 min [20].

The foaming capacity (F) and the stability of foam over specific time (Y) were calculated by the formulas:

$$F=\frac{V_1\cdot 100}{V_0}; \tag{2}$$

$$Y=\frac{V_2\cdot 100}{V_1}, \tag{3}$$

where V_1 is the volume of foam after shaking, ml; V_0 is the initial volume of the solution, ml; V_2 is the volume of foam after specific time after shaking, ml [20].

Surface tension of the solutions was determined by the du Noüy ring method, which is based on determining the force, necessary for detachment of the liquid, which wets the ring of the radius R, from the surface of the liquid. The force, necessary for lifting the ring, was determined with the aid of the du Noüy scale by the formula:

$$\sigma_X=\frac{\sigma_{H_2O}\cdot\phi_X}{\phi_{H_2O}}, \tag{4}$$

where ϕ_x, ϕ_{H_2O} is the force of lifting the ring from distilled water and from the examined solution; σ_{H_2O} is the surface tension of distilled water [21–23].

Determining of capillarity of plain and prepared knitted fabrics was carried out according to GOST 3816-81 "Textile fabrics. Methods of determining hygroscopic and water-repellent properties".

Dyeing of the prepared fabric was performed by a periodic way at temperature 60 °C, for 170 min with the use of bifunctional active dye Auxicolor Red ARD 2B («Auxicolor», Spain).

Determining of the degree of fixation of the dye was carried out based on the spectrophotometric analysis of the initial dyeing solution, residual after dyeing of the solution and wash baths. The degree of fixation DF, %, was calculated by the formula [24]:

$$DF=100-\frac{D_{den}+\sum D_{res}}{D_{init}}\cdot 100, \tag{5}$$

where D_{den} is the optical density of the solution, residual after dyeing; D_{res} is the optical density of washing solution; D_{init} is the optical density of initial dyeing solution.

The optimum formulation of the SAS composition was determined with the help of the Scheffe's simplex lattice method of the second order [25, 26].

5. Designing a SAS composition for the pretreatment of knitted fabric by the method of mathematical planning

In the previously cited work [27], the washing and wetting capacities of different classes of SAS were determined and preparations that ensure optimum capillary properties in the pretreatment of knitted fabric were selected based on this. It was established that nonionogenic, anion-active SAS have the best washing capacity while nonionogenic ones possess the best wetting capacity.

For creating efficient washing formulation, it is necessary to define their optimum ratio. Usually the formulation of compositions is selected by empirical way based on the results of trial washings or removal of the contamination, for the washing of which this substance was created.

The most promising for designing multicomponent compositions is considered to be the use of methods of mathematical planning of experiment, which make it possible to considerably reduce the volume of experiment, exclude the need for a spatial representation of complex surfaces because the properties of compositions may be presented in the form of equations.

At present, for optimization of calculation of the formulations of compositions based on the mathematical model "composition-property", the simplex lattice plans proposed by Scheffe are the ones most widely applied [28].

In the study of properties of the mixture, which depend only on the ratios of components, factor space is a correct (q–1) – measured simplex. The following ration is fulfilled for such systems:

$$\sum_{i=1}^{q} x_i=1, \tag{6}$$

where $x_i \geq 0$ is the concentration of component; q is the quantity of components.

The Scheffe's plans ensure the uniform spread of experimental points on (q–1) – measured simplex. Experimental points present {q, n} – lattice on the simplex, where n is the degree of polynomial.

Since the designed composition will consist of four components (q=4), then a correct simplex will be presented as a tetrahedron, each apex of which corresponds to clean components. Each edge of the tetrahedron is a two-component system and the face – three-component. Each point inside the tetrahedron corresponds to a four-component system (Fig. 1).

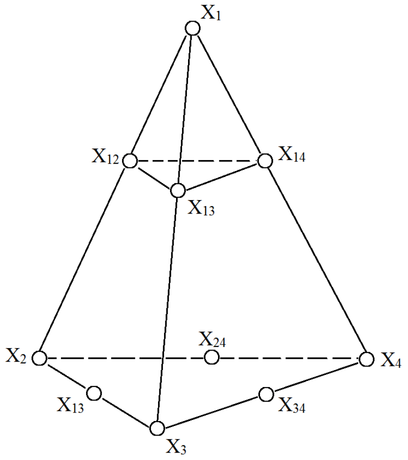

Fig. 1. Correct simplex – tetrahedron of a four-component system

Thus, component x_1 is absent from the edge x_2, x_3 and x_4, and along the sections of the tetrahedron, approaching the apex x_1, the content of the component x_1 increases.

Graphically this system is presented in the form of the sections of a tetrahedron by the planes, perpendicular to one of the axes. The formulation of a four-component mixture, which lies at the plane of the section, is determined in this case by a two-dimensional plane that it makes it possible to present a change in the properties of the system in the form of contour curves.

The rate of change in the properties of a multicomponent formulation is characterized by the inclination of the magnitude of the expected response for the i-th component at the point x_1:

$$\frac{\partial v}{\partial \chi} = b_0 + b_1 x_1, \tag{7}$$

where

$$b_0 = \frac{1}{q-1}\left[q\beta_i - \sum_{i=1}^{q}\beta_i + \sum_{i=1}^{i-1}\beta_{li} + \sum_{j=i+1}^{q}\beta_{ij} - 2\sum_{j\langle k,k\neq 1}^{q}\frac{\beta_{jk}}{q-1}\right], \tag{8}$$

$$b_1 = \frac{2}{q-1}\left[\sum_{j\langle k,k\neq i}^{q}\frac{\beta_{jk}}{q-1} - \sum_{i=1}^{q}\beta_{li} - \sum_{j=i+1}^{q}\beta_{ij}\right]. \tag{9}$$

For a q-component formulation, the expression (6) corresponds to gradient of the (q–1)-th surface along the axis of the i-th component [25].

The research was conducted in the local area of factor space, which was limited above and below by the boundaries of concentrations:

$0{,}02 \leq x_1(\text{SAS1}) \leq 0{,}5;$

$0{,}02 \leq x_2(\text{SAS2}) \leq 0{,}5;$

$0{,}02 \leq x_3(\text{SAS3}) \leq 0{,}1;$

$$0{,}02 \leq x_4(\text{SAS4}) \leq 0{,}35. \tag{10}$$

I. e., the field of research represented a polygon with eight apexes and sides, which was reduced to a simplex with the number of apexes m·n=q. Since a simplex-study is small in comparison with the entire area of research, it is necessary to make transition from the components x_i to the pseudo-components z_i.

The Scheffe's simplex lattice plan of the second order for a four-component formulation is presented in Table 2.

Table 2

The Scheffe's simplex lattice plan of the second order for a four-component formulation

№ of experiment	z_1	z_2	z_3	z_4	x_1	x_2	x_3	x_4
1	1,00	0,00	0,00	0,00	0,500	0,130	0,020	0,350
2	0,00	1,00	0,00	0,00	0,050	0,500	0,100	0,350
3	0,00	0,00	1,00	0,00	0,500	0,460	0,020	0,020
4	0,00	0,00	0,00	1,00	0,500	0,050	0,100	0,350
5	0,50	0,50	0,00	0,00	0,275	0,315	0,060	0,350
6	0,50	0,00	0,50	0,00	0,500	0,275	0,020	0,185
7	0,50	0,00	0,00	0,50	0,500	0,090	0,060	0,350
8	0,00	0,50	0,50	0,00	0,275	0,480	0,060	0,185
9	0,00	0,50	0,00	0,50	0,275	0,275	0,100	0,350
10	0,00	0,00	0,50	0,50	0,500	0,255	0,060	0,185
11	0,25	0,25	0,25	0,25	0,388	0,285	0,060	0,268

The properties of the composition formulation were evaluated according to a number of initial parameters Y_i:

– the time of SAS wetting of knitted fabric, sec;
– washing capacity SAS of knitted fabric, %;
– surface tension of SAS, mN/m;
– foaming capacity of SAS, %;
– foam stability of SAS, %.

Each experiment was repeated twice. Results of the study in the form of mean values of the initial parameters are presented in Table 3.

Table 3

Value of the initial parameters according to the Scheffe's simplex lattice plan of the second order for a four-component formulation

№ of experiment	$T_{wet.}$, sec	$T_{wash.}$, %	σ, mN/m	F, %	Y, %
1	242,0	0,73	45,1	120	83,3
2	874,0	0,85	47,6	180	61,1
3	143,5	0,95	50,9	230	73,9
4	102,5	0,52	47,9	150	66,7
5	179,5	0,15	49,9	100	100,0
6	917,0	0,34	52,2	100	100,0
7	598,0	0,67	47,9	100	100,0
8	407	0,37	47,8	100	100,0
9	202,5	0,57	47,3	100	100,0
10	328,5	0,64	51,7	150	66,7
11	132,5	0,47	49,1	180	61,1

Model of dependency of the time of wetting of knitted fabric on the composition formulation:

$$T_{wet.}=242,0z_1+874,0z_2+143,5z_3+102,5z_4-$$
$$-1514,0z_1z_2+2897,0z_1z_3+1703,0z_1z_4-$$
$$-407,0z_2z_3-1143,0z_2z_4+822,0z_3z_4. \qquad (11)$$

Model of dependency of washing capacity on the composition formulation:

$$T_{wash.}=0,73z_1+0,85z_2+0,95z_3+0,52z_4-$$
$$-2,56z_1z_2+2,00z_1z_3+0,18z_1z_4-2,12z_2z_3-$$
$$-0,46z_2z_4-0,38z_3z_4. \qquad (12)$$

Model of dependency of surface tension on the composition formulation:

$$\sigma=45,1z_1+47,6z_2+50,9z_3+47,9z_4+$$
$$+14,4z_1z_2+16,8z_1z_3+5,7z_1z_4-5,9z_2z_3-$$
$$-1,7z_2z_4+9,5z_3z_4. \qquad (13)$$

Model of dependency of foaming capacity on the composition formulation:

$$F=120,0z_1+180,0z_2+230,0z_3+150,0z_4-$$
$$-200,0z_1z_2-300,0z_1z_3-140,0z_1z_4-$$
$$-420,0z_2z_3-260,0z_2z_4-160,0z_3z_4. \qquad (14)$$

Model of dependency of foam stability on the composition formulation:

$$Y=83,3z_1+61,1z_2+73,9z_3+66,7z_4+$$
$$+111,1z_1z_2+85,5z_1z_3+100,0z_1z_4+$$
$$+130,0z_2z_3+144,5z_2z_4-14,4z_3z_4. \qquad (15)$$

The availability of mathematical models makes it possible to thoroughly examine the object or process of study, namely: to conduct interpolation or extrapolation of data, i. e., to forecast results, to carry out the ranking of factors according to the degree of their influence, to accomplish optimization – to find the best variants from the point of view of the set goals. In most cases, mathematical models are used for optimization.

The studied process of treating knitted fabric is characterized by the fact that for the full characteristic of the formulation of SAS, it is necessary to have a number of mathematical models, which characterize composition by several output parameters (optimization criteria) in complex.

Determining the optimum formulation of a composition comes down to optimization of the system of mathematical models, each of which describes the selected properties of the compositions. In this case, the optimization problem may be formulated as follows: to find in the area of the allowed values of factors Ω those values, for which the output parameters take minimum or maximum values. The output parameters are evaluated by the scalar optimization criteria, which form the vector of efficiency: $\overline{Y}=\overline{T_{wet.},T_{wash.},\sigma,F,Y}$ and they are connected by the dependency $Y=F(z_1, z_2, z_3, z_4)$ through the factors with a generalized optimization criterion. This expression is the system of mathematical equations, which must be optimized with the limitations by the factors $0 \le z_1 \le 1$.

The system of equations can be represented as follows:

$$Y=\begin{cases} T_{wet.} \to \min, \\ T_{wash.} \to \max, \\ \sigma \to \min, \\ F \to \text{const}, \\ Y \to \text{const}. \end{cases} \qquad (16)$$

As the calculations show, the joint solution to the system for the obtained model "composition-properties" is lacking (16). Consequently, for finding the optimum results, the system (16) must be slightly changed.

For obtaining reliable data on optimization of the SAS composition formulation, it is necessary to conduct the optimization of single models "composition-properties".

From the point of view of the treatment of textile material in the aqueous solutions of SAS, foaming and foam stability influence the efficiency of the process by not more than 10 % [28].

For efficient conducting of the process of treatment of textile materials in the aqueous solutions of SAS, their surface tension must be lower than the surface tension of water by 20 units and amount to about 52 mN/m.

Results represented in Table 3 show that the values of the surface tension of the compositions vary in the range from 45 to 52 mN/m. Therefore, these models can be excluded from the optimization.

That is why, with the purpose of determining optimum formulation of the composition, it is expedient to conduct optimization of the models "composition-properties" by wetting and washing capacities.

For the wetting capacity, it is necessary to determine the optimum formulation of the composition at the minimum values of the time of wetting:

$$T_{wet.} \to \min,\ 0 \le z_i \le 1. \qquad (17)$$

For the washing capacity, it is necessary to determine the optimum formulation of the composition at the maximum value of the degree of removal of contamination:

$$T_{wash.} \to \max,\ 0 \le z_i \le 1. \qquad (18)$$

Results of optimization are presented in Table 4.

Table 4

Optimization of mathematical models "composition-property" that characterize wetting and washing capacity of the composition

	z_1	z_2	z_3	z_4	Y_{opt}
Proposed composition	Mathematical model of wetting capacity				
	0,0128	0,3474	0,1541	0,3586	130
	Mathematical model of washing capacity				
	0,0117	0,3561	0,1413	0,3517	0,98

In Table 4, the values z_i are presented in the form of pseudo-components, whose values are expanded to the entire diagram "composition-properties", not in the local section, i. e., they vary in the range from zero to one. For finding natural values of the shares of components x_i in the local section, it is possible to use formulas of connection between the natural variables and the pseudo-components in the compositions.

The formulas for the transfer of one affine system to another one:

$$z_1 = z_1^{(1)} + x_2\left(z_1^{(2)} - z_1^{(1)}\right) + x_3\left(z_1^{(3)} - z_1^{(1)}\right) + \ldots + x_q\left(z_1^{(q)} - z_1^{(1)}\right), \quad (19)$$

$$z_2 = z_2^{(1)} + x_2\left(z_2^{(2)} - z_2^{(1)}\right) + x_3\left(z_2^{(3)} - z_2^{(1)}\right) + \ldots + x_q\left(z_2^{(q)} - z_2^{(1)}\right), \quad (20)$$

……………………………………………………………………

$$z_{q-1} = z_{q-1}^{(1)} + x_2\left(z_{q-1}^{(2)} - z_{q-1}^{(1)}\right) + x_3\left(z_{q-1}^{(3)} - z_{q-1}^{(1)}\right) + \ldots + x_q\left(z_{q-1}^{(q)} - z_{q-1}^{(1)}\right), \quad (21)$$

where the values $z_i^{(j)}$ are found at solving (q–1) system of equations with the use of shares of components from the system (10).

For the composition:

$$0{,}50Z_1^{(1)}+0{,}13Z_1^{(2)}+0{,}02Z_1^{(3)}+0{,}46Z_1^{(4)}=1;$$

$$0{,}05Z_1^{(1)}+0{,}50Z_1^{(2)}+0{,}10Z_1^{(3)}+0{,}35Z_1^{(4)}=0;$$

$$0{,}50Z_1^{(1)}+0{,}46Z_1^{(2)}+0{,}02Z_1^{(3)}+0{,}02Z_1^{(4)}=0;$$

$$0{,}50Z_1^{(1)}+0{,}05Z_1^{(2)}+0{,}10Z_1^{(3)}+0{,}35Z_1^{(4)}=0; \quad (22)$$

$$0{,}50Z_2^{(1)}+0{,}13Z_2^{(2)}+0{,}02Z_2^{(3)}+0{,}46Z_2^{(4)}=0;$$

$$0{,}05Z_2^{(1)}+0{,}50Z_2^{(2)}+0{,}10Z_2^{(3)}+0{,}35Z_2^{(4)}=1;$$

$$0{,}50Z_2^{(1)}+0{,}46Z_2^{(2)}+0{,}02Z_2^{(3)}+0{,}02Z_2^{(4)}=0;$$

$$0{,}50Z_2^{(1)}+0{,}05Z_2^{(2)}+0{,}10Z_2^{(3)}+0{,}35Z_2^{(4)}=0; \quad (23)$$

$$0{,}50Z_3^{(1)}+0{,}13Z_3^{(2)}+0{,}02Z_3^{(3)}+0{,}46Z_3^{(4)}=0;$$

$$0{,}05Z_3^{(1)}+0{,}50Z_3^{(2)}+0{,}10Z_3^{(3)}+0{,}35Z_3^{(4)}=0;$$

$$0{,}50Z_3^{(1)}+0{,}46Z_3^{(2)}+0{,}02Z_3^{(3)}+0{,}02Z_3^{(4)}=1;$$

$$0{,}50Z_3^{(1)}+0{,}05Z_3^{(2)}+0{,}10Z_3^{(3)}+0{,}35Z_3^{(4)}=0. \quad (24)$$

Numerical values $z_{(i)}^{(j)}$ for the composition are presented in Table 5.

Table 5

Values $z_i^{(j)}$ at solving the system (22)–(24)

$z_1^{(1)}$	–0,019	$z_2^{(1)}$	–1,092	$z_3^{(1)}$	1,078
$z_1^{(2)}$	–0,019	$z_2^{(2)}$	1,129	$z_3^{(2)}$	1,078
$z_1^{(3)}$	1,221	$z_2^{(3)}$	–0,110	$z_3^{(3)}$	–0,105
$z_1^{(4)}$	–0,319	$z_2^{(4)}$	1,431	$z_3^{(4)}$	–1,665

Further, for the mathematical model (Table 5), it is possible to write down the equations of relation between the natural values of the shares of components and their pseudo-components and to calculate the optimum values of natural shares in the compositions, for example, for the model of wetting:

$$-1{,}019+x_2(-0{,}019+0{,}019)+$$
$$+x_3(1{,}221+0{,}019)+x_4(-0{,}319+0{,}019)=0{,}0128;$$

$$-1{,}092+x_2(1{,}129+1{,}092)+$$
$$+x_3(-0{,}110+1{,}092)+x_4(1{,}431+1{,}092)=0{,}3472;$$

$$-1{,}078+x_2(1{,}078-1{,}078)+$$
$$+x_3(-0{,}105+1{,}078)+x_4(-1{,}665+1{,}078)=0{,}1541. \quad (25)$$

The solution of the system (25) gives:
$x_2=0{,}270$; $x_3=0{,}097$; $x_4=0{,}295$.

We determine the x_1 value from the condition:
$x_1=1-x_2-x_3-x_4$, $x_1=0{,}342$.

As a result of calculations, we obtained the optimum values of natural components during optimization of the model of wetting for the SAS composition:
$x_1=0{,}342$; $x_2=0{,}270$; $x_3=0{,}097$; $x_4=0{,}295$.

The optimum values of natural components for the models of wetting and washing capacities are presented in Table 6.

Table 6

Values of natural components in the composition at optimization of the model "composition-properties"

	x_1	x_2	x_3	x_4	Y_{opt}
Proposed composition	Mathematical model of wetting capacity				
	0,342	0,270	0,097	0,295	130
	Mathematical model of washing capacity				
	0,338	0,280	0,092	0,290	0,98

It is possible to highlight optimum formulation for the proposed composition in mass fractions from Table 6:

x_1 – from 0,338 to 0,342;
x_2 – from 0,270 to 0,280;
x_3 – from 0,092 to 0,097;
x_4 – from 0,290 to 0,295.

In making up the composition, it is necessary to adhere to conditions of the formula (6): the sum of the shares of components must equal one.

Based on the compositions given above, it is possible to project various formulations. For example, it is possible to propose the following composition (in mass fractions):

x_1 – 0,340;
x_2 – 0,275;
x_3 – 0,095;
x_4 – 0,290.

After transfer to the mentioned values, we obtain optimum formulation of the SAS composition (g/l):
SAS1=3,40; SAS2=2,75; SAS3=0,95; SAS4=2,90.

The application of this formulation ensures maximum indicators of wetting (130 s) and washing capacity (0,98 %).

6. Study of the influence of the developed composition of SAS on the capillarity of knitted fabric and its dyeability

For exploring the influence of the designed composition on the quality of the pretreatment of knitted fabric, we carried out a study of capillarity of the knitted fabric, pretreated by applying the developed formulation (proposed mode) of concentration from 0,5 to 2 g/l and under the conditions of an enterprise (basic mode) (Fig. 2).

Results presented in Fig. 2 demonstrate that the application of the developed composition of SAS provides reaching high indicators of capillarity of knitted fabric. Thus, maximum capillarity of the knitted fabric, pretreated in the basic mode, is 60 mm. The textile material, washed with the application of the designed composition of SAS, capillarity of 60 mm is reached in 3 min while maximum one is 180 mm (at the concentration of the developed SAS composition from 1,2 to 2,0 g/l).

The influence of the mode of pretreatment of knitted fabric on its dyeability by an active dye was further determined. Fig. 3 presents the results of determining the degree of fixation of the active dye Auxicolor Red ARD 2B of the knitted fabric, prepared in the basic and designed modes.

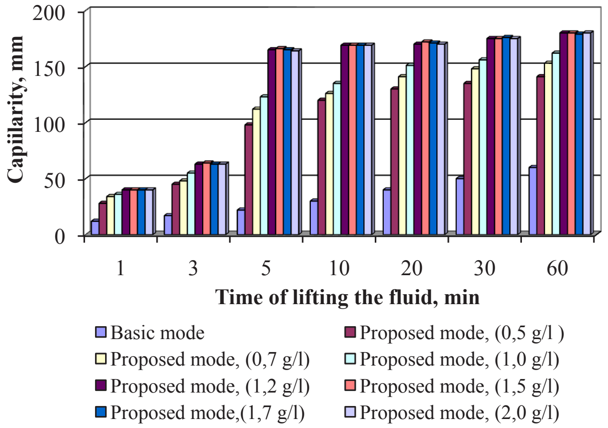

Fig. 2. Study of capillary properties of knitted fabric, pretreated by the basic and proposed mode

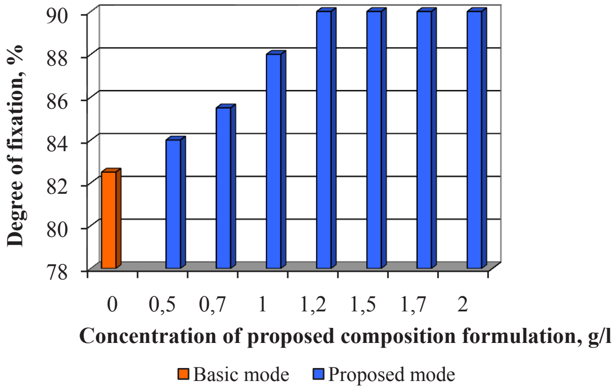

Fig. 3. Determining the degree of fixation of dye at the periodic method

Obtained results (Fig. 3) make it possible to conclude that the SAS composition, developed for the pretreatment of knitted fabric, provides obtaining high-quality coloration in the subsequent process of dyeing the knitted material. This is explained by the fact that the recommended SAS possess maximal wetting and washing capacity, which makes it possible to efficiently remove hydrophobic impurities and contaminations and they are characterized by minimal capacity to form foam, which facilitates conducting and increases the rate of technological processes of pretreatment and subsequent dyeing.

Based on determining the influence of the developed SAS composition on the capillarity of knitted fabric and its dyeability, it is possible to draw a conclusion that the proposed composition of SAS is most efficient at the concentration of 1,2 g/l, an increase in the concentration of SAS composition to 2 g/l insignificantly influences the indicators of indicated parameters and it is not rational from the economic point of view.

7. Conclusions

1. It was found that for the pretreatment of cotton knitted fabric in the aqueous solutions of SAS, foam formation, foam stability, surface tension have little influence on the efficiency of the process. The wetting and washing capacity of SAS are the main indicators for optimization of composition formulation. With the purpose of determining the optimum formulation of composition, we carried out optimization of mathematical models "composition-property" by the wetting and washing SAS capacities.

2. The optimum formulation of SAS composition for the pretreatment of cotton knitted fabric for dyeing (g/l) was defined by the Scheffe's simplex lattice plan of the second order:

SAS1=3,40;
SAS2=2,75;
SAS3=0,95;
SAS4=2,90.

3. Composition formulation of SAS, designed for the pretreatment of knitted fabric, possesses maximal wetting and washing capacity, as well as ensures obtaining high quality coloring in the subsequent process of dyeing the knitted material, which is confirmed by an increase in the capillarity (by 3 times) and the degree of fixation of active dye (by 7,5 %).

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