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Study of the Combined Deying Process and Finishing Process of Cotton Fabrics by the Method of Experimental Planning Test

M. Kh. Mirzakhmedova[1], I.G. Shin[2]

[1,2]Tashkent institute of textile and light industry

E-mail:mirzahmedova81@mail.ru

Annotation: The area of optimum considered functions of the casting was attended by the method of steep ascent, in the form of breaking load and elongation, the total opening angle and the concentration of the dye on the fiber with the combined technology of the dyeing process and the finishing process of cotton fabrics.

Key words: experiment planning, combined technology, Optimizations, breaking load and elongation, total opening angle, dye concentration.

The basic methods of development of modern finishing production are aimed at intensifying the main and auxiliary processes, by moving from periodic to continuous processes and combing operation, imparting sustainable consumer properties, ensuring their high quality due to the covalent chemical bonding of dyes and other finishing preparations with fiber.

Therefore, to the fore simultaneously with chemical modification of fibers the solution of environmental problems through the creation of environmentally technologies is being put forward.

This can be achieved by the transition to low-modulus water technology and replacing toxic home-based drugs with non-toxic ones [1, p-258], by increasing the degree of use dyes with the in application to physical, chemical and biological methods on intensification of finishing processes, a decrease in the number of flushes and the concentration of dyes and biomaterials in wastewater. The use of polycarboxylic acids provides along with the combination in two stages of dyeing and finishing process of fabrics, increasing the use of dyes, safety and environmental of the finished fabric, reduction of two technological operations (scrubbing and drying from dyeing technology), thereby reducing water consumption, energy and labor costs.

Relevant for the development of finishing process in industries of Uzbekistan are the use according to the possibility of natural chemicals and the development of environmentally, highly efficient, combined finishing processes, in particular dyeing processes and finishing - reducing the consumption of chemicals and dyes, imported from abroad.

To combine the technologies of these two processes into one, it is necessary to solve the following tasks:

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1) Compatibility in one bathtub of the power and the adaptive composition;

2) Possibilities for excluding the flushing process and drying from dyeing technology, by intensifying the processes of fabric impregnation with dyeing and dressing compounds;

3) Increasing the efficiency of covalent fixation of the sorbed dye by fibers to achieve color durability while eliminating the scouring process.

To solve the tasks investigated the influence of the main parameters on the quality of the finishing of the fabric and the stability of the preparation. The purpose of the drug K-4 has been determined, as a binder in the formulation, proceeding from such its properties, such as adhesive ability, film formation and the presence of functional groups, actively entering into chemical interaction with tissue at high temperatures and in the presence of a catalyst. To identify the influence of the main factors of the combined dyeing process and the final finishing on the quality indicators of the fabric, a full factorial experiment was carried out using statistical methods of experiment planning [2, 3], associated with the process of determining the number and conditions of conducting tests, necessary and sufficient for solving the supplied task with the required accuracy.

The solution to an extreme task consists in the search for the conditions of the process, which ensure the receipt of the optimal value of the selected parameter as an extraordinary function.

In general terms, the response function, which is also an optimization parameter η, can be represented by the expression

$$\eta=f\,(x_1, x_2, \dots , x_k), \qquad (1)$$

where x_1, x_2,…, xk are independent variable factors.

For the convenience of recording the conditions of experimentation and processing of the experimental data, the levels of factors are coded in accordance with the expression

$$x_i = \frac{\tilde{x}_i - \tilde{x}_i^o}{\varepsilon_i}\,, \qquad (2)$$

Where $\tilde{x}_i$ is natural value i - th factor;

$\tilde{x}_i^o$ is natural value of the main level i- th factor;

ε_i is variation interval i - th factor;

With full factorial experimentation, when all possible combinations of factor levels are realized, the number of experiences is determined by the expression

$$N=m^k, \qquad (3)$$

Annals of R.S.C.B., ISSN:1583-6258, Vol. 25, Issue 5, 2021, Pages. 3875 - 3886
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where m is the number of levels of each factor; k is the number of factors.

The production of a linear model for the first stage of planning an extreme experiment is intended to vary the factors at two levels (upper +1, lower -1). Therefore, the possible number of combinations of factor levels is 2k in this case. With a large number of factors (k> 3), the conduct of a full factorial experiment requires a large number of experiments, which is much more than the number of linear coefficients. The number of tests can be abruptly reduced by using a different factor experiment. This kind of experiment is possible with a linear approximation for the radiation (other replica) of the model, i.e. polynomial $y = b_0 + b_1x_1 + b_2x_2 +\ldots + b_kx_k$ describes an adequate model.

In this way, the other replica is part of a full factorial experiment and is denoted by the expression 2^{k-p}, where p is the number of linear effects, natural So, for example, if in the full factorial experiment 2^3 (Table 1) one of the interaction effects (x_1x_2, x_1x_3, x_2x_3, $x_1x_2x_3$) replace with a fourth factor x4, then we get a polurelika 2^{4-1} from a full factorial experiment $2^{4.}$.

Table 1

Full factorial experiment matrix of type 2^3

№ experience	x_0	x_1	x_2	x_3	x_1x_2	x_1x_3	x_2x_3	$x_1x_2x_3$	y
1	+	-	-	+	+	-	-	+	y_1
2	+	+	-	+	-	+	-	-	y_2
3	+	-	+	+	-	-	+	-	y_3
4	+	+	+	+	+	+	+	+	y_4
5	+	-	-	-	+	+	+	-	y_5
6	+	+	-	-	-	-	+	+	y_6
7	+	-	+	-	-	+	-	+	y_7
8	+	+	+	-	+	-	-	-	y_8

Since, in other replicas, some of the interactions are replaced by new factors, the found coefficients of the level of regression will be the joint effects of linear effect.

Other replicas will be set with the help of so-called generating proportions, which show which of the actions is taken as an unreasonable and replaceable new one.

Half replicas 2^{4-1} can be set by the generating ratio $x_4 = x_1x_2$; $x_4 = -x_1x_2$. The scheduling matrix for this polure is presented in the table. 2.

The levels and intervals of variation of the factors are given in table. 3, a matrix of planning tests - in table 4.

Table 2

Polureplika 2^{4-1} with a defining contrast $1 = x_1x_2x_4$

Annals of R.S.C.B., ISSN:1583-6258, Vol. 25, Issue 5, 2021, Pages. 3875 - 3886
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№ experience	x_0	x_1	x_2	x_3	x_4	y
1	+	-	-	+	+	y_1
2	+	+	-	+	-	y_2
3	+	-	+	+	-	y_3
4	+	+	+	+	+	y_4
5	+	-	-	-	+	y_5
6	+	+	-	-	-	y_6
7	+	-	+	-	-	y_7
8	+	+	+	-	+	y_8

Table 3

Levels and intervals of variation of factors

Factors	Code notation	Variation intervals	Factor levels		
			Upper (+1)	Basic (0)	lower (-1)
Bentonite, gram / liter	x_1	2	5	3	1
Drug K-4, gram / liter	x_2	20	50	30	10
Temperature, ^{0}C	x_3	25	85	60	35
Lemon acid, gram / liter	x_4	10	25	15	5

Table 4

Planning matrix and results of experiments

№	x_0	x_1	x_2	x_3	x_4	y_1		y_2		y_3		y_4
						warp	weft	warp	weft	warp	weft	
1	+	-	-	+	+	242,3	223,3	18,3	19,1	74	75,3	35,54
2	+	+	-	+	-	216,0	233	13,8	19,1	70	72	30,01
3	+	-	+	+	-	250,0	193,3	11,1	20,3	82	88	40,82
4	+	+	+	+	+	264,0	207,5	12,4	23	63	69	24,67
5	+	-	-	-	+	259,6	161,3	10,9	17	72	72,7	30,20
6	+	+	-	-	-	254,5	195,5	11,3	25,7	48,3	76,3	32,09
7	+	-	+	-	-	255,6	161,3	10,8	16,3	55,3	65	33,59
8	+	+	+	-	+	219,3	234,3	22,3	14	59	63,3	31,05

The generating ratio $x_4 = x_1x_2$ and $x_4 = -x_1x_2$ is set by multiplying by a new independent variable X4:$x_4^2 = x_1x_2x_4$, $x_4^2 = -x_1x_2x_4$

Where $x_4^2 = x_i^2 = 1$.

Thus, expressions are obtained, called defining contrasts:

$$1 = x_1x_2x_4; \qquad 1 = -x_1x_2x_4 \tag{6}$$

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Knowing the definition of the contour, one can find the ratios that give the joint estimates. For this, it is necessary to multiply the independent variables x_1, x_2, x_3 and x_4 by the defining contrast (6):

$x_1 = x_2x_4$,	$b_1 \to \beta_1 + \beta_{24}$
$x_2 = x_1x_4$,	$b_2 \to \beta_2 + \beta_{14}$
$x_3 = x_1x_2\,x_3x_4$,	$b_3 \to \beta_3 + \beta_{1234}$
$x_4 = x_1x_2$,	$b_4 \to \beta_4 + \beta_{12}$
$x_1x_3 = x_2\,x_3x_4$,	$b_{13} \to \beta_{13} + \beta_{234}$
$x_2x_3 = x_1\,x_3x_4$,	$b_{23} \to \beta_{23} + \beta_{134}$
$x_3x_4 = x_1x_2x_3$,	$b_{34} \to \beta_{34} + \beta_{123}$

As optimization parameters (values of the response function and) are taken:

y_1 – breaking load, Н;

y_2 – breaking elongation, %;

y_3 – total opening angle (СУР), º;

y_4 – dye concentration on fiber, г/кг.

С In order to obtain the regression equation for the optimization parameters, the experimental data are processed.

1. Optimization parameter y_1- breaking load Н.

The following values of the coefficients of the regression equation (by basis) were obtained:

$b_0 = \frac{\sum_{j=1}^{8} X_{0j}Y_j}{8} = 245{,}2$; $b_1 = \frac{\sum_{j=1}^{8} X_{1j}Y_j}{8} = 3{,}225$ и т.д.

For the rest of the coefficients, the following values were obtained:

$b_2 = 6{,}125$; $b_3 = 1{,}975$; $b_4 = 5{,}2$.

For weft, the given coefficients have the values: $b_0 = 201.188$; $b_1 = 18{,}375$; $b_2 = 4{,}625$; $b_3 = 19{,}8$; $b_4 = 12{,}125$.

The variance s_y^2 of the optimization parameter was calculated from the results of three tests in the center of the plan, i.e. at $x_1 = x_2 = x_3 = x_4 = 0$. The calculation of the dispersion is given in table 5.

Table 5

Auxiliary table for calculation S_y^2

№ experience at the center of the plan	y_u	$\bar{y}_u$	$y_u - \bar{y}_u$	$(y_u - \bar{y})^2$	s_y^2
1	263/165	$\frac{\sum_{u=1}^{4} y_u}{} =$	1,2/-1,8	1,44/3,24	$\frac{\sum_{u=1}^{n_0}(y_u-\bar{y})^2}{} =$

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2	263/170	= 261,8/166,8	1,2/3,2	1,44/10,24	$\frac{\sum_{u=1}^{4}(y_u-\bar{y})^2}{4-1}$ = 2,253/5,453
3	261/164		0,8/-1,2	0,64/1,44	
4	260/168		-1,8/1,2	3,24/1,44	
	$\sum_{u=1}^{4} y_u =$ 1047/667			$\sum_{u=1}^{4}(y_u-\bar{y})^2 = 6.76/16.36$	

Примечание. Значения разрывной нагрузки даны в числителе для основы, в знаменателе для утка. n_0 –число опытов в центре плана; y_u – значение параметра оптимизации в u – м опыте в центре плана.

Note. The values of the breaking load are given in the numerator for the base, in the denominator for duck. n_0 is the number of experiences in the center of the plan; y_u - the value of the optimization parameter in u - experience in the center of the plan.

Dispersion of the regression coefficients

$$S^2\{b_i\} = \frac{S_y^2}{N} = \frac{2.253}{8} = 0,282.$$

Confidence interval of coefficients

$$\Delta b_i = \pm ts\{b_i\} = \pm 3,18\sqrt{0,282} = \pm 1,688,$$

Where t – the tabular value of the Student's criterion, equal to 3,18 at 5% significance level and the number of degrees of freedom $t = n_0-1=4-1=3$.

Since the absolute values of the coefficients of the regression on a larger, confidence interval, they are all statistically means. Therefore, the equation of the regression with the coded variables for the optimization parameter y1 (based on the basis) has the form:

$$y_1 = 245,2+3,225x_1 + 6,125x_2 + 1,975x_3 + 5,2x_4, \quad (5)$$

Weft :

$$y_1 = 201,188 + 18,375x_1 + 4,625x_2 + 19,8x_3 + 12,125x_4. \quad (6)$$

In equation (8) all coefficients are in absolute terms of a larger confidential interval:

$s^2\{b_i\} = \frac{S_y^2}{N} = \frac{5,43}{8} = 0,679.$

$$\Delta b_i = \pm ts\{b_i\} = \pm 3,18\sqrt{0,679} = \pm 2,62.$$

To test the hypothesis of the adequacy on the model represented by Eqs. (5) and (6), we find the variance of the adequacy

$$s_{ад}^2 = \frac{\sum_{j-1}^{N}(y_j-\hat{y}_j)^2}{f}, \quad (7)$$

Where y_j - experimental value of the optimization parameter in j-м experience;

$\hat{y}_j$ – optimization parameter value in j-м experiment, calculated by the equation (5) and (6);

f- the number of degrees of freedom equal to $f = n-(k+1)=8-(4+1)=3$;

Annals of R.S.C.B., ISSN:1583-6258, Vol. 25, Issue 5, 2021, Pages. 3875 - 3886
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k- number of factors.

When calculating the values of $\hat{y}_j$ in equations (5) and (6), it is necessary to supply the coded values of the factors. The variance of the adequacy $s_{ад}^2$, calculated by the formula (7), was 18.8 and 35.2 for the base and the weft, respectively. The test of the hypothesis of the adequacy of the model is carried out according to the F - Fisher criterion. For this, we find the calculated value of the criterion

$$F_p = \frac{S_{ад}^2}{S_{\bar{y}}^2} = 8{,}36 \ \text{(warp)}; \qquad F_p = \frac{S_{ад}^2}{S_{\bar{y}}^2} = 6{,}46 \ \text{(weft)}$$

At a 5% level of significance and numbers of degrees of free for the numerator $f_i = 3$ and for the denominator $f_2 = 3$, the table value of the criterion $F_T = 9.3$. Since $F_P < F_T$, the model represented by equations (5) and (6) is adequate.

2. Parameter of optimization y_2 - elongation at break, %.

Processing of experimental data (table 4) according to the developed algorithm for the following equation of regression:

$$y_2 = 13{,}86 + 1{,}09x_1 + 0{,}29x_2 + 0{,}04x_3 + 2{,}11x_4 \quad \text{(warp)}, \tag{8}$$

$$y_2 = 19{,}3 + 1{,}14x_1 – 0{,}91x_2 + 1{,}06x_3 – 1{,}04x_4 \quad \text{(weft)}. \tag{9}$$

Confidence interval of coefficients:

$\Delta b_i = \pm$ ts $\{b_i\} = \pm 3{,}18\sqrt{0{,}004} = 0{,}2$ (warp),

$\Delta b_i = \pm$ ts $\{b_i\} = \pm 3{,}18\sqrt{0{,}068} = 0{,}83$ (weft).

Comparing the absolute values of the coefficients on the regression of the levels (8) and (9) with the reliable intervals, we will leave the coefficients that have statistical significance:

$$y_2 = 13{,}86 + 1{,}09x_1 + 0{,}29x_2 + 2{,}11x_4 \tag{10}$$

$$y_2 = 19{,}3 + 1{,}14x_1 – 0{,}91x_2 + 1{,}06x_3 – 1{,}04x_4 \tag{11}$$

The adequacy of the model described by the equation (10) and (11), is confirmed by a comparison of the calculated and tabular values of the F-criterion of Fisher (ratio $F_P = 4.32$ and F) = 4.32.

3.Optimization parameter y_3 - total disclosure angle (SDA), $^\circ$.

For this optimization parameter, the following regression equalizations with coded variables are obtained for the warp and weft :

$y_3 = 65{,}45 – 5{,}38x_1 - 0{,}625x_2 + 6{,}8x_3 + 1{,}55x_4$,

$y_3 = 72{,}7 – 2{,}55x_1 + 2{,}63x_2 + 3{,}38x_3 – 2{,}63x_4$.

Confidence interval of coefficients:

$\Delta b_i = \pm$ ts $\{b_i\} = \pm 3{,}18\sqrt{0{,}1671} = 1{,}29$ (warp),

$\Delta b_i = \pm$ ts $\{b_i\} = \pm 3{,}18\sqrt{0{,}4786} = 2{,}2$ (weft).

Annals of R.S.C.B., ISSN:1583-6258, Vol. 25, Issue 5, 2021, Pages. 3875 - 3886
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In this way, taking into account the statistical significance of the equalization coefficients on the regression for the total opening angle, it is suitable for the basis and the weft as follows:

$$y_3 = 65{,}45 – 5{,}38x_1 + 6{,}8x_3 + 1{,}55x_4, \quad (12)$$

$$y_3 = 72{,}7 – 2{,}55x_1 + 2{,}63x_2 + 3{,}38x_3 – 2{,}63x_4. \quad (13)$$

The adequacy of the model corresponding to equations (12) and (13) is confirmed by the fact that the calculated values F - Fisher's criterion is less than the table: F_P = 4,86 (warp) и F_P = 6,42 (weft), F_T = 9,3.

4. Optimization parameter y_4 - the concentration of the dye on the fiber (g / kg).

For this, the optimization parameter is derived from the following regression equation with coded variables:

$$y_4 = 32{,}25 – 2{,}79x_1 + 0{,}288x_2 + 0{,}514x_3 – 1{,}88x_4, \quad (14)$$

The confidence interval of the coefficients is

$$\Delta b_i = \pm \text{ ts } \{b_i\} = \pm 3{,}18\sqrt{\frac{0{,}4725}{8}} = \pm 0{,}188.$$

The absolute values of the coefficients of the equalization of the regression (14) are larger than the trustworthy interface and therefore they are statistically significant. The adequacy of the model (14) is confirmed by comparing the calculated and tabular values of the Fisher criterion.

The resulting equations (5), (6), (10), (11), (12), (13), and (14) allow us to analyze the degree of influence of input factors (concentration of bentonite, acidity, pressure of 4 to the output optimization parameter y.

Confirmation of the hypothesis the adequacy of the developed mathematical models in the residence equalized regression allows the implementation of the "steep ascent" method according to Box Wilson to achieve the definition of the optimal analysis of functions.

Steep ascent - this is the process of movement to the optimum along the steepest path (gradient) leading from a given point to the top of the slope under the condition that the factors are changed by their ratio.

In case of a steep ascent, it is important to choose the step of movement along the gradient, the minimum value of which should be greater than the error with which the factor is fixed.

It is necessary to take into account that, when moving to the optimum, a small step increases the number of additional experiences, and a large step can lead to an overshoot of the optimum range. The step of movement is chosen for one factor, and for the rest it is calculated according to the expression [2]:

$$\Delta_i = \Delta_l \frac{b_i \varepsilon_i}{b_l \varepsilon_l}, \quad (15)$$

Annals of R.S.C.B., ISSN:1583-6258, Vol. 25, Issue 5, 2021, Pages. 3875 - 3886
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Where Δ_l – selected movement step for factor l;

Δ_i – step of movement for i - th factor;

b_i, b_l – regression coefficients i – th and l – th factors;

$\varepsilon_i, \varepsilon_l$ – variation intervals i – th and l – th factors;

The movement along the gradient must start from zero point (the base level of each factor), since the coefficients of the regression are calculated for the response function in the series. Having determined the step of movement for each factor, we find the condition of the so-called "mental" experiences, some of which are realized in order to check the results of the cool-down. Steep ascents stop if the conditions for optimization are found or if the limits on the factors make further movement along the gradient unintelligible.

We will produce a steep ascent according to the surface of the response for the optimization parameter y_1 - bursting load, a mathematic model of the type 5 (description of level 6) It should be noted that a steep ascent is especially effective when all the factors at the factors are significant.

We start a steep ascent (table 5) from a zero point (basic levels): $x_1 = x_2 = x_3 = x_4 = 0$, which corresponds to the values of the factors (table 3) 3; 30; 60; 15. Let's take the step of movement for the factor x_3, equal to Δ_3 = 5 ºC. Using the formula (15), we calculate the step of motion for the factors x_1, x_2 and x_4:

$$\Delta_1 = \Delta_3 \frac{b_1 \varepsilon_1}{b_3 \varepsilon_3} = 5 \frac{3{,}225 \cdot 2}{1{,}975 \cdot 25} = 0{,}6532;$$

$$\Delta_2 = \Delta_3 \frac{b_2 \varepsilon_2}{b_3 \varepsilon_3} = 5 \frac{6{,}125 \cdot 20}{1{,}975 \cdot 25} = 12{,}405;$$

$$\Delta_4 = \Delta_3 \frac{b_4 \varepsilon_4}{b_3 \varepsilon_3} = 5 \frac{5{,}2 \cdot 10}{1{,}975 \cdot 25} = 5{,}2658.$$

Table 5

Calculation of steep ascent for the optimization parameter y1 - breaking load (on the warp)

denomination	x_1	x_2	x_3	x_4	y_1	y_4
Main level	3	30	60	15	-	-
Coefficient b_i	3,225	6,125	1,975	5,2	-	-
Variation interval ε_i	2	20	25	10	-	-
b_i x ε_i	6,45	122,5	49,38	52	-	-
Step Δ_i	0,6532	12,405	5	5,2658	-	-
Round step	0,65	12,4	5	5,27	-	-
Experience 9 realized	3,65	42,4	65	20,27	265	49,35
Experience 10 realized	4,3	54,8	70	25,5	273	46,16
Experience 11 realized	4,95	67,2	75	30,8	255	43,96
Experience 12 realized	5,6	79,6	80	36,1	-	-

Annals of R.S.C.B., ISSN:1583-6258, Vol. 25, Issue 5, 2021, Pages. 3875 - 3886
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Experiments 9, 10, 11 were implemented in laboratory conditions. The quantitative and qualitative characteristics of the colors are presented in the table. 6, a quality characteristics of dyed cotton fabric - in tab. 7.

Table 6
Color indicators of cotton fabrics in the implementation of optimized parameters, obtained by the method of "cool descent"

Experiment	Conditions for processing cotton fabrics	Fixation of the dye, g/kg	Dye utilization %	K/S	Color fastness in points	
					to the soap	to sweat
9	9	49,35	81	8,0	5/5/5	5/5/5
10	10	46,16	78	7,8	5/5/5	5/5/5
11	11	43,96	74	6,8	5/5/5	5/5/5

Note: Dressing agent based on K-4 preparation with optimized parameters.

Table 7
Quality characteristics of cotton fabrics, obtained by the combined technology of crushing and small-sized furniture with optimized parameters

Experiences	Shrinkage, %		SUR, º	Capillarity, mm/h	Air permeability, $cm^2/s*cm^3$	Breaking load N		Elongation,%	
	warp	weft				warp	weft	warp	weft
9	2,0	2,0	122	110	168,6	255,0	149,0	9,5	13,0
10	2,0	2,0	152	115	170,5	273,0	194,0	8,0	15,0
11	2,0	2,0	138	114	165,5	251,0	124,0	10,0	16,0

In 10 experience, the maximum bursting load of the investigated textile material was obtained after the combined process of crushing and switching off. In this way, the following optimal conditions of this combined process were obtained: bentonite - 4.3 g / l; preparation K-4 - 54.8 g / l; crushing temperature 70 ºC; citric acid -25.5 g / l.

Annals of R.S.C.B., ISSN:1583-6258, Vol. 25, Issue 5, 2021, Pages. 3875 - 3886
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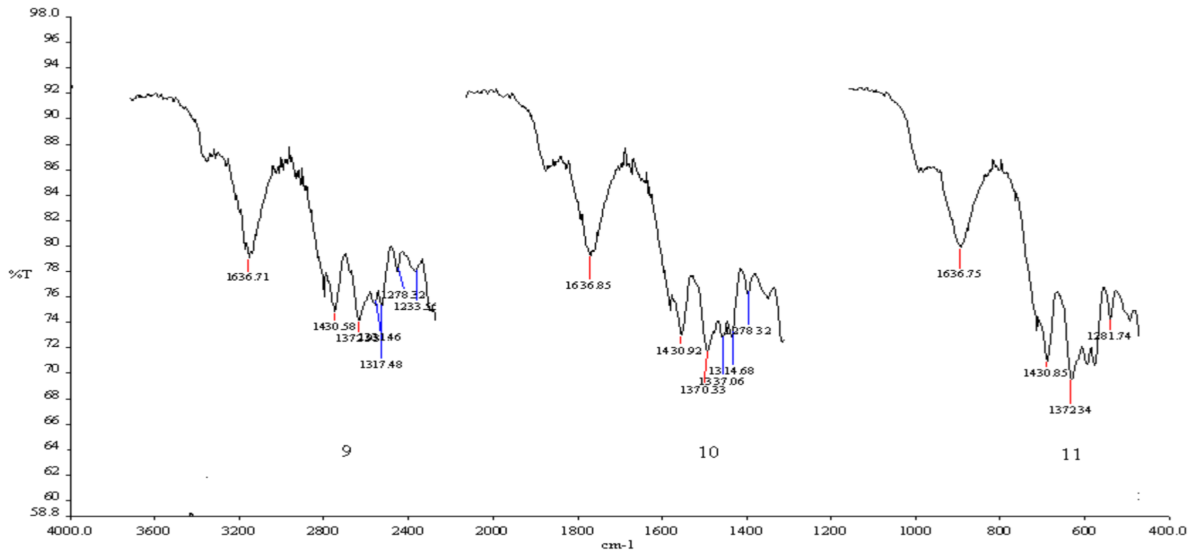

Fig. 1. IR spectrum of cotton fabrics 9, 10, 11th experiments
9- experiment: bentonite - 3.65 g / l, K-4 - 42.4 g / l, citric acid - 20.2 g / l, temperature impregnation 65 ºC
10- experiment: bentonite - 4.3 g / l, K-4 - 54.8 g / l, citric acid - 25.5 g / l, impregnation temperature 70 ºC
11- experiment: bentonite - 4.95 g / l, K-4 - 67.2 g / l, citric acid - 30.8 g / l, temperature impregnation 70 ºC

IFC - infrared spectroscopy analysis of cotton fabrics, processed in optimal conditions, obtained by the method of mathematical planning of the experiment, testifies to the presence of the 1636,85 sm^{-1}, in charge of >C=O, valence vibrations of the bands $-C\equiv N$ (1630-1680 sm^{-1}).

Apparently, the formation of an ester bond occurs with the participation of the drug K-4, which has except -SOON groups, and an unhydrolyzed nitrile group $-C\equiv N$, and also participation in the formation of an ester group between cellulose macromolecules of citric acid [4]. The sufficient absorption rate is evidence of the intensifying role of bentonite in the appetite in the amount of 4.3 g / l. Such an absorption band is present in all spectra of cotton fabrics, fitted with such a composition of the appli- cation, but with different conceptions of the composition (Fig. 1).

Conclusion

The obtained results of the experiments testify to the completion of the steep ascent to determine the parameter of optimization – breaking load. It is important to note, that under these optimal conditions of dyeing processes and finishing of textile materials a sufficiently high level of concentration of the dye on the fiber is provided, equal to 46.16 g / kg, and the degree of use of the dye is 78%, which determines the reliability of the proposed technological process.

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