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Construction of a Mathematical Model in the Technical Process of Dosing for Fabrics Whitening

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Abstract: The article considered the methods and functions of dispensing for fabric bleaching. The bleaching process was studied in order to increase the whiteness of the fabric on the bleaching line. Anautomatic control system has been created for accurate and adequate mathematical models and control processes. As a result of carrying out an automatically planned full factorial experiment in production conditions, an impregnation model was obtained, which makes it possible to assess the quality of the bleaching fabric.

Keywords: quality, concentration, system, sensor, automation, cloth spinning, working solution level, temperature, temperature of steam medium, steam consumption, washing.

For the quality control of bleaching processes in the textile industry, the automatic regulation of the flow rate of liquid, that is, free-flowing viscous media, is of paramount importance. The creation of automatic control systems in many cases is complicated by the lack of accurate and adequate mathematical models and control processes. The purpose of the bleaching process is to increase the whiteness of the fabric. The essence of the bleaching process is the destruction of natural dyes with the help of oxidants. In general, the production provides control and regulation of the temperature of the water in the baths, the level and concentration of working solutions in the baths, etc. However, the most vulnerable part of the process, which does not lend itself to automation, is maintaining the required concentration of solutions in the baths of alkaline, acid and especially peroxide machines [1].

Setting goals. One of the ways to increase the productivity of scientific work is the use of modern mathematical methods and technological means, such as experiment planning, operations research, mathematical modeling, and computer technology [2].Fabric bleaching is a multifaceted process. Let us consider the parameters of only one bath intended for treatment with a peroxide bleaching solution. The relationship between the parameters is shown graphically in Fig. 1.

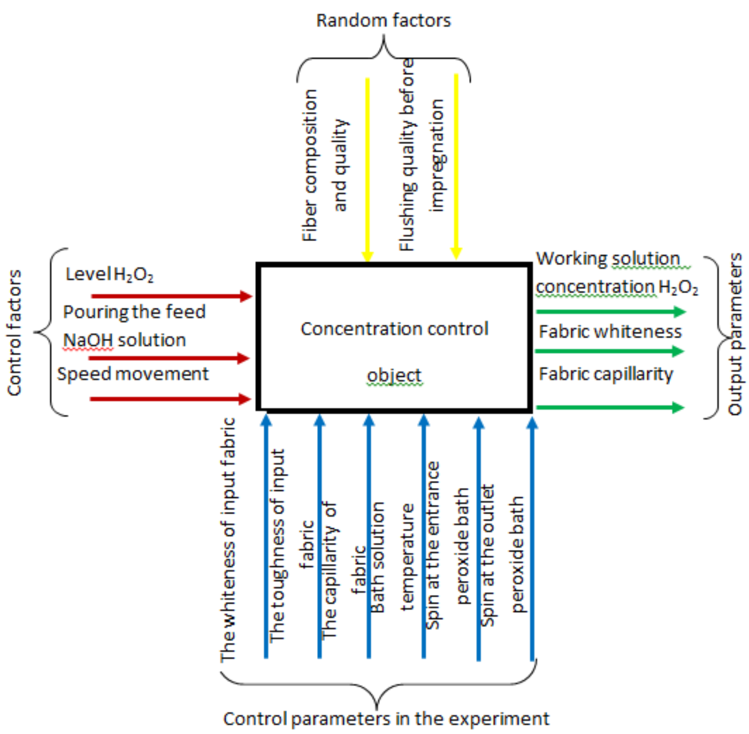

Fig. 1.Visualization of the relationship between the parameters.

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As a result of carrying out an automatically planned full factorial experiment in production conditions on the bleaching line, an impregnation model was obtained which makes it possible to assess the quality of the bleaching fabric [3,4].The peroxide bath has the following parameters: Wringing out the fabric at the inlet and outlet; concentration of chemicals; working solution level; working solution temperature; vapor temperature; steam consumption; and water consumption for flushing [5,6].The most important parameters that significantly affect the quality of the output product are: 1. Input parameters - chemical concentration, water level in the bath, fabric speed; 2. Output parameters - temperature, spinning. When choosing factors for the experiment, we also took into account the requirements for a set of factors- compatibility and independence [7,8].The compatibility of the factors means that all their combinations are feasible and do not lead to a loss in the quality of the output product during the experiment. Independence means the ability to establish a factor at any chosen level. In the course of the experiment, other parameters were also controlled, the stabilization of which was necessary for the required accuracy of the desired model [9].

Solving problems. The choice of the variation interval is a rather difficult task, since it is associated with the non-formalized stage of experiment planning. A full factorial experiment was carried out (type 2^k, where k is the number of factors).Before the experiment, 2 parallel experiments were carried out with this fabric to determine the error in the operation of the unit, i.e. errors of experiments. The results of the experiments are shown in Table 2. Factors will be called the most significant input - the values obtained as a result of screening experiments.

1. In the planning matrix (Table 1.), the upper level X_{iB} corresponds to "+1", and to the lower X_{iH}"-1" (to simplify the notation of "+" and "-").The input parameters are:

X_1- Hydrogen peroxide, norm (50 ÷ 40 g/l);

X_2-H_2O, norm (18 ÷ 22 l);

X_3- Fabric movement speed, norm (60 ÷ 100 m / min);

As output parameters:

Y_1- temperature (C);

Y_2- spinning (%).

Table 1. Planning matrix

Nº.	X_0	X_1	X_2	X_3	X_1X_2	X_1X_3	X_2X_3
1	+	+	+	+	+	+	+
2	+	-	+	+	+	+	-
3	+	+	-	+	+	-	+
4	+	+	+	-	-	+	+
5	+	-	-	+	-	-	+
6	+	-	+	-	-	+	-
7	+	+	-	-	+	-	-
eight	+	-	-	-	-	+	-

Table 2. Planning matrix

Nº.	X_1	X_2	X_3	X_1X_2	X_1X_3	X_2X_3	Y_1		Y_2		$\overline{Y_1}$	$\overline{Y_2}$
1	50	22	100	1100	5000	2200	60	65	113	120	62.5	116.5
2	40	22	100	720	5000	1080	50	60	110	105	55	107.5
3	50	eighteen	100	1100	2400	2200	37	45	120	130	41	125
4	50	22	60	720	5000	1080	65	70	115	125	67.5	120
5	40	eighteen	100	720	2400	2200	80	75	121	130	77.5	125.5
6	40	22	60	720	5000	1080	63	70	110	102	66.5	106
7	50	eighteen	60	1100	2400	1080	70	75	95	100	72.5	97.5
eight	40	eighteen	60	720	5000	1080	80	90	95	80	85	87.5

2. After the experiments, the reproducibility of the experiments is checked using the Cochran criterion:

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$$G\max = \frac{S^2 l \max}{\sum_{l=1}^{N} S^2 l}$$

where $S^2 l$ is the sample variance of the output value y in l- and the row of the planning matrix, obtained from m-parallel experiments;

$$S^2 l = \frac{1}{m-1}\sum_{g=1}^{m}(y_{\lg} - \bar{y}_1)^2$$

where y_{lg} is the value of the output quantity for l- and the row of the planning matrix $(l = \overline{1,N})$

From the g-th parallel experiment $\left(g = \overline{1,m}\right)$; $\bar{y}_1$ - the average value of the output variable obtained from parallel experiments on the l- and row of the planning matrix; N- number of experiments ($N = 2^n$)

$$S_1^2 = \frac{1}{2-1}(60-62.5)^2 + (65-62.5)^2 + (50-55)^2 + (60-55)^2 + (37-41)^2 + (45-41)^2 +$$
$$(65-67.5)^2 + (70-67.5)^2 + (80-77.5)^2 + (75-77.5)^2 + (63-66.5)^2 + (70-66.5)^2 +$$
$$(70-72.5)^2 + (75-72.5)^2 + (80-85)^2 + (90-85)^2 = 206.5$$

$$S_2^2 = \frac{1}{2-1}(113-116)^2 + (120-116.5)^2 + (110-107.5)^2 + (105-107.5)^2 + (120-125)^2 +$$
$$(102-106)^2 + (95-97.5)^2 + (100-97.5)^2 + (95-87.5)^2 + (80-87.5)^2 = 334.5$$

$$S^2 l_{\max} = S^2 2 = 334.5$$

$$G_{\max} = \frac{278.2}{206.4 - 278.2} = 0.61$$

With the number of degrees of freedom $f_1 = (m-1) = 2 - 1 = 1$, $f_2 = N = 8$, we find G_{crit} according to the table (G_{crit}= 0.67).In this case, $G_{max} < G_{crit}$ and the hypothesis of the homogeneity of the dispersion is accepted.

3. Estimates of the coefficients of the regression equation are calculated by the formulas:

$$\beta_0 = \frac{\sum_{l=1}^{N}\bar{y}_l}{N};\ \beta_j = \frac{\sum_{l=1}^{N}x_j\bar{y}_l}{N};\ \beta_{ij} = \frac{\sum_{l=1}^{N}x_{ij}x_{li}\bar{y}_l}{N}$$; where the index j takes the value 1,2,3 ...n(n is the number of linear effects);the index ij takes on a value corresponding to the evaluated interactions; X_{ij}- the value of factors in conditional variables ("+1" or "-1").

A_0= (62.5 + 55 + 41 + 67.5 + 77.5 + 66.5 + 72.5 +85) / 8 = 527/8 = 65.9

B_0= (116.5 + 107.5 + 120 + 125 + 125.5 + 106 + 97.5 + 87.5) / 8 = 885.5 / 8 = 110.6

A_1= (62.5 -55 + 41 + 67.5 - 77.5 - 66.5 + 72.5 - 85) / 8 = -5.062

B_1= (116.5 - 107.5 + 120 + 125 - 125.5 - 106 + 97.5 - 87.5) / 8 = 4.06

A_2= (62.5 + 55 - 41 + 67.5 - 77.5 + 66.5 - 72.5 - 85) / 8 = -3.062

B_2= (116.5 + 107.5 - 125 + 120 - 125.5 + 106 - 97.5 - 87.5) / 8 = 1.81

A_3= (62.5 + 55 + 41 - 67.5 + 77.5 - 66.5 - 72.5 - 85) / 8 = -6.93

B_3= (116.5 + 107.5 + 125 - 120 + 125.5 - 106 - 97.5 - 87.5) / 8 = 7.93

A_4= (62.5 + 55 + 41 - 67.5 - 77.5 - 66.5 + 72.5 - 85) / 8 = -8.18

B_4= (116.5 + 107.5 + 125 - 120 - 125.5 - 106 + 97.5 - 87.5) / 8 = 0.93

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A_5= (62.5 + 55 - 41-67.5-77.5 + 66.5-72.5 + 85) / 8 = -18.18

B_5= (116.5 + 107.5 - 125 + 120 - 125.5 + 106 - 97.5 + 87.5) / 8 = 23.6

A= (62.5 - 55 + 41 + 67.5 + 77.5 - 66.5 - 72.5 - 85) / 8 = -3.81

B= (116.5 - 107.5 + 125 + 120 + 125.5 - 106 - 97.5 -87.5) / 8 = 11.06

4. The hypothesis 0 of the static significance of the regression coefficients is tested using the Student's t criterion, which is formed as $t_j = \frac{|\beta_j|}{\sqrt{S^2_{\beta_{ш}}}}$, where $S^2_{\beta j}$ is the estimate of the variance of the coefficient determination error β_j; by static data;

$$t_{a1} = \frac{5.062}{2.054} = 2.46;\ t_{a2} = \frac{3.062}{2.054} = 1.48;\ t_{a3} = \frac{6.93}{2.054} = 3.37;\ t_{a4} = \frac{8.18}{2.054} = 3.98;\ t_{a5} = \frac{18.18}{2.054} = 8.84;$$

$$t_{a6} = \frac{3.81}{2.054} = 1.85;\ t_{b1} = \frac{4.06}{2.054} = 1.97;\ t_{b2} = \frac{1.81}{2.054} = 0.88$$

$$t_{b3} = \frac{7.93}{2.054} = 3.86;\ t_{b4} = \frac{0.93}{2.054} = 0.45;\ t_{b5} = \frac{23.6}{2.054} = 11.52;\ t_{b6} = \frac{11.06}{2.054} = 5.38;$$

With the number of degrees of freedom $f = N(m-1) = 8(2-1) = 8$. According to tabular data, t_{crit}= 2.3060. If t_{calc}>t_{crit}, then these regression coefficients are statistically significant.

$S^2\beta_j = \frac{S^2 y}{Nm} = \frac{\sum_{l=1}^{N} S^2 l}{N^2 m} = \frac{206.5 + 334.5}{64 \cdot 2} = \frac{541}{128} = 4.22$ and the estimate dispersion reproducibility

$$S^2 y = \frac{\sum_{l=1}^{N} S^2 l}{N} = \frac{206.5 + 334.5}{8} = 67.625.$$

If the found t - criterion for the corresponding assessment of the coefficient turns out to be greater than the critical t_{crit}, with the number of degrees of freedom $f=N(m-1)$and the significance level q%, then this regression coefficient is statistically significant. The regression coefficients for which t_{calc}>$t_{crit\ will\ be\ significant}$, and are excluded from the regression equation.

5. Testing the hypothesis about the adequacy of the mathematical description of the experimental results using F - Fisher's criterion in the form of a ratio:

$F_{calc-1} = \frac{S^2 a\partial}{S^2 y} = \frac{41.3}{67.625} = 0.61$ and $F_{calc-2} = \frac{S^2 a\partial}{S^2 y} = \frac{66.9}{67.625} = 0.98$ where is the $S^2 a\partial$ estimate of the variance of inadequacy.

$S^2 y$ - estimation of the variance of reproducibility.

Inadequacy variance estimation:

$$S^2_{a\partial 1} = \frac{1}{N-d}\sum_{l=1}^{N}\left(\overline{y_l} - y_l\right)^2 = \frac{1}{8-3} 206.5 = 41.3$$

$$S^2_{a\partial 2} = \frac{1}{N-d}\sum_{l=1}^{N}\left(\overline{y_l} - y_l\right)^2 = \frac{1}{8-3} 334.5 = 66.9$$

with degrees of freedom$f_1 = N\text{-}d = 8\text{-}5 = 3$ and $f_2 = N(m\text{-}1) = 8(2\text{-}1) = 8$.According to tabular data$F_{crit}=3.69$, where$d$ is thenumber of terms of the approximating polynomial.

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The calculated value of $F_{calc}$is compared with the critical value found by tabulated values for a given significance level*q, %* and the degrees of freedom$f_1=N-d$, $f_2=N(m-1)$.If $F_{calc}<F_{crit}$, then the hypothesis about the adequacy of the mathematical description to the results of the experiment is accepted.

6. After the calculated data, we obtain the regression equations in the following form:

$$\overline{y_1} = 65.9 - 6.63x_3 - 8.18x_1x_2 + 18.18x_1x_3$$

$$\overline{y_2} = 110.6 - 7.93x_3 - 23.6x_1x_3 + 11.06x_2x_3$$

Output. The compiled mathematical model shows the bleaching process to increase the whiteness of the fabric on the bleaching line.Amathematical model of the automatic control system and the control process has been created.It also increases the economic efficiency and reliability of the technical process.It should also be noted that this control method can be used for other objects of textile production, providing a comprehensive automation of production, which can be implemented for production of a continuous nature.As a result of carrying out an automatically planned full factorial experiment in production conditions, a treatment model was obtained, which makes it possible to assess the quality of the bleaching fabric.

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