MATHEMATICAL MODELING AND THEORETICAL INVESTIGATION OF AN IMPROVED HARROW-TYPE WOOL WASHING MACHINE

Nosirov Muhammadali Ismoilovich
Doctoral student of Fergana Polytecnic Institute
Phone: +99 (891) 325 50 55Email: : m.i.nosirov@ferpi.uz
Kayumov Juramirza Abdiramatovich
DSc., Professor of Samarkand State University of Archhitecture and Construction named after Mirzo Ulugbek
Phone:+998990510855,Email: juramirza@gmail.com
Maxmudov Abdulrasul Abdimajitovich
Senior lecturer at Fergana State Technical University
Phone: +99 (893)640 80 34
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Abstract. In this article, the efficiency of the improved harrow wool washing machine was theoretically studied based on the mathematical modeling method. In the study, the main input parameters affecting the operation of the machine - the frequency of the crank rotation, the speed of wool supply and the number of rows of harrow piles - were evaluated using the central non-compositional experimental design method, the washing efficiency, the degree of wool entanglement and the effect on work productivity. Based on the experimental results, regression equations were constructed, their adequacy was checked using the Fisher criterion and the significance of the coefficients was checked using the Student criterion. As a result of the study, the optimal operating modes of the machine were determined, and the technological efficiency of the proposed design was substantiated.

Keywords: wool washing machine, harrow mechanism, mathematical model, central noncompositional experiment, regression equation, optimization, productivity, washing efficiency, wool tangling, Fisher criterion, Student criterion.

Аннотация. В статье приведены результаты теоретического исследования эффективности, усовершенствованной боронной машины для мойки шерсти на основе математического моделирования. Исследовано влияние частоты вращения кривошипа, скорости подачи шерсти и количества рядов зубьев бороны на производительность, степень спутывания шерсти и эффективность мойки с использованием метода центрального некомпозиционного планирования эксперимента. По результатам экспериментов построены регрессионные модели, проверена их адекватность по критерию Фишера и значимость коэффициентов по критерию Стьюдента. Определены оптимальные режимы работы машины и обоснована эффективность предложенной конструкции.

Ключевые слова: машина для мойки шерсти, боронный механизм, математическая модель, центральный некомпозиционный эксперимент, регрессионная модель, оптимизация, производительность, эффективность мойки, спутывание шерсти, критерий Фишера, критерий Стьюдента.

Introduction

In the process of processing wool fiber, after the cleaning stage, the remaining fat-sweat substances and mineral impurities in the fiber are removed by water washing [1]. The quality and efficiency of the washing process largely depend on the transport mechanism that moves the wool along the water bath. In existing harrow machines, the harrow piles move in a circle or ellipse, entangling the fibers together. In the proposed improved machine, the harrow piles move in a straight line (advance), as a result of which the entangling of the fibers decreases, the washing quality and efficiency increase [2]. Since the wool washing process consists of a complex of physical and mechanical phenomena, it can only be successfully studied using modern scientific methods. Therefore, it is advisable to study the operating modes of the machine based on multifactor mathematical modeling. The following indicators were taken as influencing (input) factors in the study: x_1 - the frequency of rotation of the harrow (harrow driving mechanism) (rpm), x_2 - the speed of wool supply (rpm), and x_3 - the number of rows of harrow piles (pcs). The levels and ranges of change of the factors under study are presented in Table 3.1.

Levels and ranges of change of the factors under study

Table 3.1

Name and designation of factors	−1	0	+1	Change interval
x_1 – Frequency of rotation of the crankcase, rpm	3	5	7	2
x_2 – Wool supply speed, rpm	4	6	8	2
x_3 – Number of pile rows, pcs.	16	21	26	5

Student's test was used to determine the significance of the regression coefficients, and Fisher's test was used to check the adequacy or inadequacy of the mathematical model. The output factors were selected as Y_1 - wool tangle rate (%, minimized), Y_2 - washing efficiency (%, maximized), and Y_3 - work productivity (kg/h, maximized) [3].

One of the important characteristics of the production equipment (Y_1) is the wool tangle rate, which represents the percentage of fibers entangled with each other during the washing process (%), and it is required to reduce it as much as possible. The second output indicator (Y_2) is the washing efficiency, which is evaluated by the percentage of fat-sweat and dirt substances removed from the fiber composition (%). The third indicator (Y_3) is the work productivity, which represents the amount of wool washed per unit of time (kg/h).

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One of the important characteristics of the production equipment (Y_1) is the degree of wool entanglement, which represents the percentage of fibers entangled with each other during the washing process (%), and it is required to reduce it as much as possible. The second output indicator (Y_2) is the washing efficiency, which is evaluated by the percentage of fat-sweat and dirt substances removed from the fiber content (%). The third indicator (Y_3) is the productivity, which represents the amount of wool washed per unit of time (kg/h) [4,5].

The experiments were conducted by testing 3 input factors in 15 different cases based on the central non-compositional experiment (CNE) matrix. The experimental matrix and the results obtained are presented in Table 3.2.

Table 3.2

Central non-compositional experiment matrix and results

№	x_1	x_2	x_3	x_1x_2	x_1x_3	x_2x_3	x_1^2	x_2^2	x_3^2	Y_1	Y_2	Y_3	$S_u^2(Y_1)$	$S_u^2(Y_2)$	$S_u^2(Y_3)$
1	+	+	0	+	0	0	+	+	0	20,2	85,6	578	0,22	0,18	3,7
2	+	−	0	−	0	0	+	+	0	11,6	91,5	446	0,15	0,12	2,1
3	−	+	0	−	0	0	+	+	0	14,0	80,4	513	0,28	0,22	4,2
4	−	−	0	+	0	0	+	+	0	7,7	83,8	412	0,19	0,16	2,6
5	+	0	+	0	+	0	+	0	+	17,9	91,5	521	0,17	0,20	3,6
6	+	0	−	0	−	0	+	0	+	13,3	84,4	504	0,24	0,15	2,6
7	−	0	+	0	−	0	+	0	+	11,6	83,3	476	0,20	0,19	4,8
8	−	0	−	0	+	0	+	0	+	9,2	79,9	449	0,26	0,14	2,6
9	0	+	+	0	0	+	0	+	+	18,4	84,8	567	0,21	0,17	4,5
10	0	+	−	0	0	−	0	+	+	13,3	81,1	525	0,18	0,13	3,5
11	0	−	+	0	0	−	0	+	+	10,3	90,5	441	0,23	0,21	2,5
12	0	−	−	0	0	+	0	+	+	8,9	84,3	424	0,16	0,15	1,5
13	0	0	0	0	0	0	0	0	0	11,2	87,9	498	0,13	0,16	4,6
14	0	0	0	0	0	0	0	0	0	11,4	88,0	495	0,13	0,14	3,2
15	0	0	0	0	0	0	0	0	0	10,7	88,4	499	0,10	0,14	2,3

The encoded values of the factors in the matrix are: “+” → (+1), “−” → (−1), “0” → central level. S_u^2 is the variance of repeated measures in each experiment.

Based on the experimental results, we search for a second-order regression multifactor mathematical model. In general, the model is written as follows:

$$Y_R = b_0 + \Sigma b_i x_i + \Sigma b_{ij} x_i x_j + \Sigma b_{ii} x_i^2$$

Since three factors are involved in our experiment, this expression takes the following form:

$Y_R = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_{12}x_1x_2 + b_{13}x_1x_3 + b_{23}x_2x_3 + b_{11}x_1^2 + b_{22}x_2^2 + b_{33}x_3^2$

Here, b_0, b_1, ... are regression coefficients; x_1, x_2, x_3 are coded values of factors. For MNKT (N=15), the coefficients are calculated with the following multipliers (g): g_1=0.2 (b_0 variance), g_3=0.125 (b_i), g_4=0.25 (b_{ij}), g_7=0.3125 (b_{ii} variance).

Y_1 – regression coefficients for optimizing the level of wool tangling (%)

$b_0 = (1/N_s)\cdot\Sigma\bar{Y}_u = (1/3)\cdot(11{,}2 + 11{,}4 + 10{,}7) = \mathbf{11{,}10}$

$b_1 = 0{,}125\cdot(20{,}2 + 11{,}6 - 14{,}0 - 7{,}7 + 17{,}9 + 13{,}3 - 11{,}6 - 9{,}2) = \mathbf{2{,}562}$

$b_2 = 0{,}125\cdot(20{,}2 - 11{,}6 + 14{,}0 - 7{,}7 + 18{,}4 + 13{,}3 - 10{,}3 - 8{,}9) = \mathbf{3{,}425}$

$b_3 = 0{,}125\cdot(17{,}9 - 13{,}3 + 11{,}6 - 9{,}2 + 18{,}4 - 13{,}3 + 10{,}3 - 8{,}9) = \mathbf{1{,}687}$

$b_{12} = 0{,}25\cdot(20{,}2 - 11{,}6 - 14{,}0 + 7{,}7) = \mathbf{0{,}575}$

$b_{13} = 0{,}25\cdot(17{,}9 - 13{,}3 - 11{,}6 + 9{,}2) = \mathbf{0{,}550}$

$b_{23} = 0{,}25\cdot(18{,}4 - 13{,}3 - 10{,}3 + 8{,}9) = \mathbf{0{,}925}$

$\Sigma x_1^2\bar{Y}_u = 20{,}2 + 11{,}6 + 14{,}0 + 7{,}7 + 17{,}9 + 13{,}3 + 11{,}6 + 9{,}2 = 105{,}5$; $\Sigma x_2^2\bar{Y}_u = 104{,}4$; $\Sigma x_3^2\bar{Y}_u = 102{,}9$

$\Sigma\Sigma x_i^2\bar{Y}_u = 312{,}8$; $\Sigma\bar{Y}_u = 189{,}7$

$b_{11} = 0{,}25\cdot105{,}5 + 0{,}0208\cdot312{,}8 - 0{,}1667\cdot189{,}7 = \mathbf{1{,}275}$

$b_{22} = 0{,}25\cdot104{,}4 + 0{,}0208\cdot312{,}8 - 0{,}1667\cdot189{,}7 = \mathbf{1{,}000}$

$b_{33} = 0{,}25\cdot102{,}9 + 0{,}0208\cdot312{,}8 - 0{,}1667\cdot189{,}7 = \mathbf{0{,}625}$

The complete equation with the determined coefficients is:

$Y_{R1} = 11{,}10 + 2{,}562x_1 + 3{,}425x_2 + 1{,}687x_3 + 0{,}575x_1x_2 + 0{,}550x_1x_3 + 0{,}925x_2x_3 + 1{,}275x_1^2 + 1{,}000x_2^2 + 0{,}625x_3^2$

Y_2 – regression coefficients for optimizing washing efficiency (%)

$b_0 = (1/N_s)\cdot\Sigma\bar{Y}_u = (1/3)\cdot(87{,}9 + 88{,}0 + 88{,}4) = \mathbf{88{,}10}$

$b_1 = 0{,}125\cdot(85{,}6 + 91{,}5 - 80{,}4 - 83{,}8 + 91{,}5 + 84{,}4 - 83{,}3 - 79{,}9) = \mathbf{3{,}200}$

$b_2 = 0{,}125\cdot(85{,}6 - 91{,}5 + 80{,}4 - 83{,}8 + 84{,}8 + 81{,}1 - 90{,}5 - 84{,}3) = \mathbf{-2{,}275}$

$b_3 = 0{,}125\cdot(91{,}5 - 84{,}4 + 83{,}3 - 79{,}9 + 84{,}8 - 81{,}1 + 90{,}5 - 84{,}3) = \mathbf{2{,}550}$

$b_{12} = 0{,}25\cdot(85{,}6 - 91{,}5 - 80{,}4 + 83{,}8) = \mathbf{-0{,}625}$

$b_{13} = 0{,}25\cdot(91{,}5 - 84{,}4 - 83{,}3 + 79{,}9) = \mathbf{0{,}925}$

$b_{23} = 0{,}25\cdot(84{,}8 - 81{,}1 - 90{,}5 + 84{,}3) = \mathbf{-0{,}625}$

$\Sigma x_1^2\bar{Y}_u = 85{,}6 + 91{,}5 + 80{,}4 + 83{,}8 + 91{,}5 + 84{,}4 + 83{,}3 + 79{,}9 = 680{,}4$;

$\Sigma x_2^2\bar{Y}_u = 682{,}0$; $\Sigma x_3^2\bar{Y}_u = 679{,}8\Sigma\Sigma x_i^2\bar{Y}_u = 2042{,}2$; $\Sigma\bar{Y}_u = 1285{,}4$

$b_{11} = 0{,}25\cdot680{,}4 + 0{,}0208\cdot2042{,}2 - 0{,}1667\cdot1285{,}4 = \mathbf{-1{,}588}$

Y_3 – regression coefficients for optimizing productivity (kg/h)

$b_0 = (1/N_s)\cdot\Sigma\bar{Y}_u = (1/3)\cdot(498{,}0 + 495{,}0 + 499{,}0) = \mathbf{497{,}33}$

b_1 = 0,125·(578,0 + 446,0 − 513,0 − 412,0 + 521,0 + 504,0 − 476,0 − 449,0) = **24,875**

b_2 = 0,125·(578,0 − 446,0 + 513,0 − 412,0 + 567,0 + 525,0 − 441,0 − 424,0) = **57,500**

b_3 = 0,125·(521,0 − 504,0 + 476,0 − 449,0 + 567,0 − 525,0 + 441,0 − 424,0) = **12,875**

b_{12} = 0,25·(578,0 − 446,0 − 513,0 + 412,0) = **7,750**

b_{13} = 0,25·(521,0 − 504,0 − 476,0 + 449,0) = **-2,500**

b_{23} = 0,25·(567,0 − 525,0 − 441,0 + 424,0) = **6,250**

$\Sigma x_1^2\bar{Y}_u$ = 578,0 + 446,0 + 513,0 + 412,0 + 521,0 + 504,0 + 476,0 + 449,0 = 3899,0;

$\Sigma x_2^2\bar{Y}_u$ = 3906,0; $\Sigma x_3^2\bar{Y}_u$ = 3907,0

$\Sigma\Sigma x_i^2\bar{Y}_u$ = 11712,0; $\Sigma\bar{Y}_u$ = 7348,0

b_{11} = 0,25·3899,0 + 0,0208·11712,0 − 0,1667·7348,0 = **-5,917**

b_{22} = 0,25·3906,0 + 0,0208·11712,0 − 0,1667·7348,0 = **-4,167**

b_{33} = 0,25·3907,0 + 0,0208·11712,0 − 0,1667·7348,0 = **-3,917**

b_{22} = 0,25·682,0 + 0,0208·2042,2 − 0,1667·1285,4 = **-1,188**

b_{33} = 0,25·679,8 + 0,0208·2042,2 − 0,1667·1285,4 = **-1,738**

The complete equation with the determined coefficients is:

$Y_{R2} = 88,10 + 3,200x_1 - 2,275x_2 + 2,550x_3 - 0,625x_1x_2 + 0,925x_1x_3 - 0,625x_2x_3 - 1,588x_1^2 - 1,188x_2^2 - 1,738x_3^2$

The complete equation with the determined coefficients is:

$Y_{R3} = 497,33 + 24,875x_1 + 57,500x_2 + 12,875x_3 + 7,750x_1x_2 - 2,500x_1x_3 + 6,250x_2x_3 - 5,917x_1^2 - 4,167x_2^2 - 3,917x_3^2$

Assessing the significance of regression coefficients using Student's t-test

To determine the significance of the coefficients, first the variance of the output parameter is calculated, and then the variances in determining the coefficients are calculated. The variance of the variance is determined by 3 replicates at the center point:

To determine the significance of the coefficients, first the variance of the output parameter is calculated, and then the variances in determining the coefficients are calculated. The variance of the variance is determined by 3 replicates at the center point:

$S^2\{\bar{Y}\} = (1/(N_s-1))\cdot\Sigma S_u^2\{Y\}$

For Y_1:

$S^2\{\bar{Y}\}$ = (1/2)·(0,13 + 0,13 + 0,10) = **0,180**

$S\{b_0\} = \sqrt{(0,2 \cdot 0,180)} = 0,245$;
$S\{b_i\} = \sqrt{(0,125 \cdot 0,180)} = 0,150$;
$S\{b_{ij}\} = 0,212$;
$S\{b_{ii}\} = 0,221$
Table-3.3

Estimation of Y_1 coefficients by Student's test

Koeff.	b qiymati	t_R	t_j	Conclusion
b0	11,100	45,32	2,77	significant
b1	2,562	17,08	2,77	significant
b2	3,425	22,83	2,77	significant
b3	1,687	11,25	2,77	significant
b12	0,575	2,71	2,77	insignificant
b13	0,550	2,59	2,77	insignificant
b23	0,925	4,36	2,77	significant
b11	1,275	5,77	2,77	significant
b22	1,000	4,53	2,77	significant
b33	0,625	2,83	2,77	significant

The table value of the Student's t-test is t_j [P=0.95; f=2] = 2.77. The coefficient(s) b12, b13, whose calculated value is less than the table value, are removed from the equation as insignificant. The equation with significant coefficients is rewritten:

$Y_{R1} = 11,10 + 2,562x_1 + 3,425x_2 + 1,687x_3 + 0,925x_2x_3 + 1,275x_1^2 + 1,000x_2^2 + 0,625x_3^2$

Y_2 uchun:

$S^2\{\bar{Y}\} = (1/2) \cdot (0,16 + 0,14 + 0,14) = \mathbf{0,220}$
$S\{b_0\} = \sqrt{(0,2 \cdot 0,220)} = 0,271$;
$S\{b_i\} = \sqrt{(0,125 \cdot 0,220)} = 0,166$;
$S\{b_{ij}\} = 0,235$;
$S\{b_{ii}\} = 0,244$

Estimation of Y_2 coefficients by Student's test

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Koeff.	b qiymati	t_R	t_j	Xulosa
b0	88,100	325,33	2,77	significant
b1	3,200	19,30	2,77	significant
b2	-2,275	13,72	2,77	significant
b3	2,550	15,38	2,77	significant

b12	-0,625	2,67	2,77	insignificant
b13	0,925	3,94	2,77	significant
b23	-0,625	2,67	2,77	insignificant
b11	-1,588	6,50	2,77	significant
b22	-1,188	4,86	2,77	significant
b33	-1,738	7,12	2,77	significant

The table value of the Student's t-test is t_j[P=0.95; f=2] = 2.77. The coefficient(s) b12, b23, whose calculated value is less than the table value, are removed from the equation as insignificant. The equation with the significant coefficients is rewritten:

$Y_{R2} = 88{,}10 + 3{,}200x_1 - 2{,}275x_2 + 2{,}550x_3 + 0{,}925x_1x_3 - 1{,}588x_1^2 - 1{,}188x_2^2 - 1{,}738x_3^2$

For Y_3:

$S^2\{\bar{Y}\} = (1/2)\cdot(4{,}60 + 3{,}20 + 2{,}30) = \mathbf{5{,}050}$

$S\{b_0\} = \sqrt{(0{,}2\cdot 5{,}050)} = 1{,}297$; $S\{b_i\} = \sqrt{(0{,}125\cdot 5{,}050)} = 0{,}795$; $S\{b_{ij}\} = 1{,}124$; $S\{b_{ii}\} = 1{,}169$

Table 3.5

Estimation of Y_3 coefficients by Student's t-test

Koeff.	b qiymati	t_R	t_j	Xulosa
b0	497,333	383,32	2,77	significant
b1	24,875	31,31	2,77	significant
b2	57,500	72,37	2,77	significant
b3	12,875	16,20	2,77	significant
b12	7,750	6,90	2,77	significant
b13	-2,500	2,22	2,77	insignificant
b23	6,250	5,56	2,77	significant
b11	-5,917	5,06	2,77	significant
b22	-4,167	3,56	2,77	significant
b33	-3,917	3,35	2,77	significant

The table value of the Student's t-test is t_j[P=0.95; f=2] = 2.77. The coefficient(s) b13 whose calculated value is less than the table value are removed from the equation as insignificant. The equation with the significant coefficients is rewritten as:

$Y_{R3} = 497{,}33 + 24{,}875x_1 + 57{,}500x_2 + 12{,}875x_3 + 7{,}750x_1x_2 + 6{,}250x_2x_3 - 5{,}917x_1^2 - 4{,}167x_2^2 - 3{,}917x_3^2$

Checking the adequacy of mathematical models using the Fisher criterion

To check the adequacy of the model, the calculated values (Y_R) are found for each experimental point according to the equation with significant coefficients and their deviations from the experimental values are determined. The adequacy variance and Fisher's criterion are calculated as follows:

$S^2\{ad\} = \Sigma(Y_{R,u}-\bar{Y}_u)^2/(N'-L)$; $F_R = S^2\{ad\} / S^2\{\bar{Y}\}$

Here $N' = 12$ is the number of edge (off-center) points of the matrix, L is the number of significant coefficients. The calculated deviations are presented in Table 3.6.

Table 3.6

Computational results for the adequacy variance (edge points)

№	Y_1	Y_{R1}	$(Y_1-Y_{R1})^2$	Y_2	Y_{R2}	$(Y_2-Y_{R2})^2$	Y_3	Y_{R3}	$(Y_3-Y_{R3})^2$
1	20,2	19,4	0,64	85,6	86,2	0,36	578	577	0,36
2	11,6	12,5	0,81	91,5	90,8	0,49	446	447	0,81
3	14,0	14,2	0,04	80,4	79,8	0,36	513	512	0,81
4	7,7	7,4	0,09	83,8	84,4	0,36	412	413	0,36
5	17,9	17,3	0,36	91,5	91,4	0,01	521	525	17,64
6	13,3	13,9	0,36	84,4	84,5	0,01	504	500	20,25
7	11,6	12,1	0,25	83,3	83,2	0,01	476	476	0,25
8	9,2	8,8	0,16	79,9	79,9	0,00	449	450	0,64
9	18,4	18,8	0,16	84,8	85,4	0,36	567	566	1,21
10	13,3	13,5	0,04	81,1	80,3	0,64	525	528	6,76
11	10,3	10,1	0,04	90,5	90,0	0,25	441	438	6,76
12	8,9	8,5	0,16	84,3	84,9	0,36	424	425	1,21
Σ			3,11			3,21			57,1

$S^2\{ad\}(Y_1) = 3{,}11 / 4 = 0{,}824$; $F_R = 0{,}824 / 0{,}180 = \mathbf{4{,}58}$

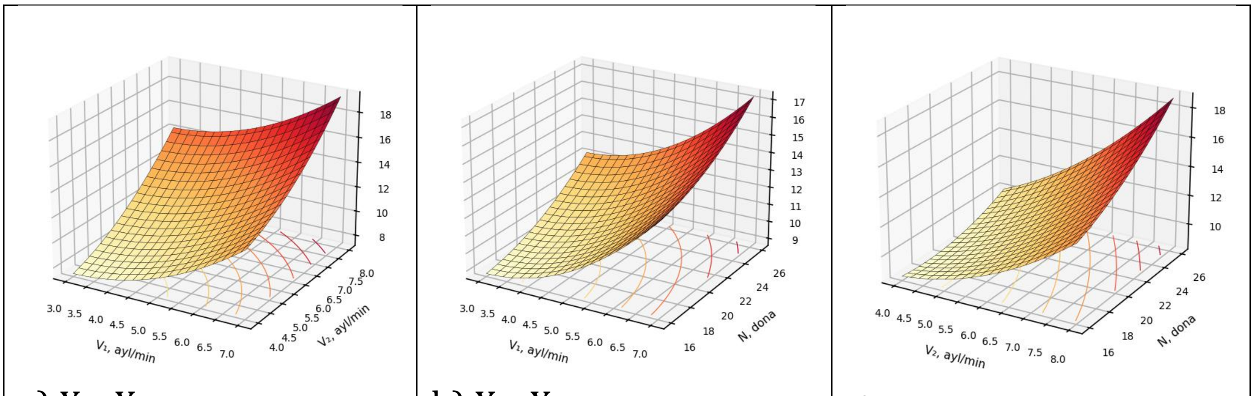
$S^2\{ad\}(Y_2) = 3{,}21 / 4 = 0{,}799$; $F_R = 0{,}799 / 0{,}220 = \mathbf{3{,}63}$

$S^2\{ad\}(Y_3) = 57{,}06 / 3 = 19{,}250$; $F_R = 19{,}250 / 5{,}050 = \mathbf{3{,}81}$

Table values of Fisher's exact test (P=0.95): $F_j(4; 2) = 19.25$ for Y_1 and Y_2; $F_j(3; 2) = 19.16$ for Y_3. Since $F_R < F_j$ in all three cases, the obtained regression mathematical models represent the studied process with sufficient accuracy (adequate).

Response surfaces and optimization

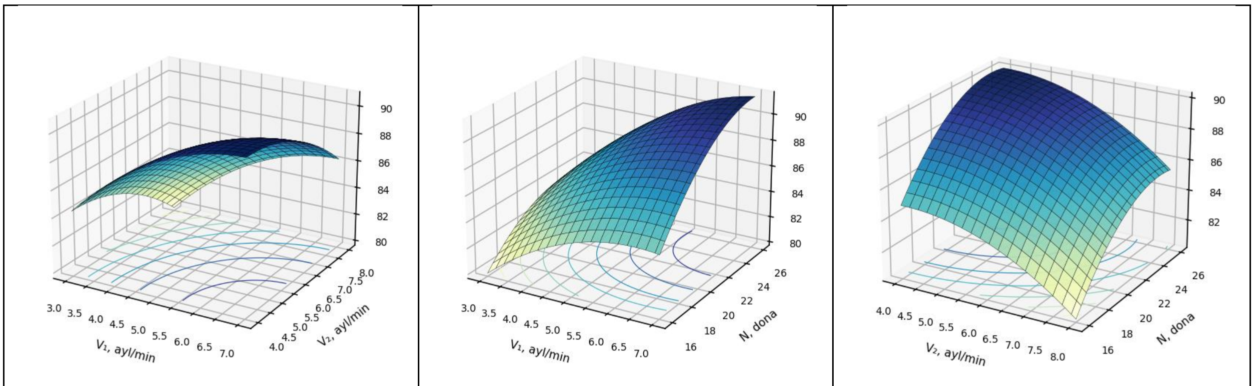
Since the equation for each output indicator is three-dimensional, one of the factors is taken in the central position (x_i=0), and isolinear response surfaces are constructed for the remaining two factors (Figures 3.1–3.3).



a) X_1–X_2 b) X_1–X_3 c) X_2–X_3

Figure 3.1. Response surfaces of the model for Y_1 – the degree of wool tangle

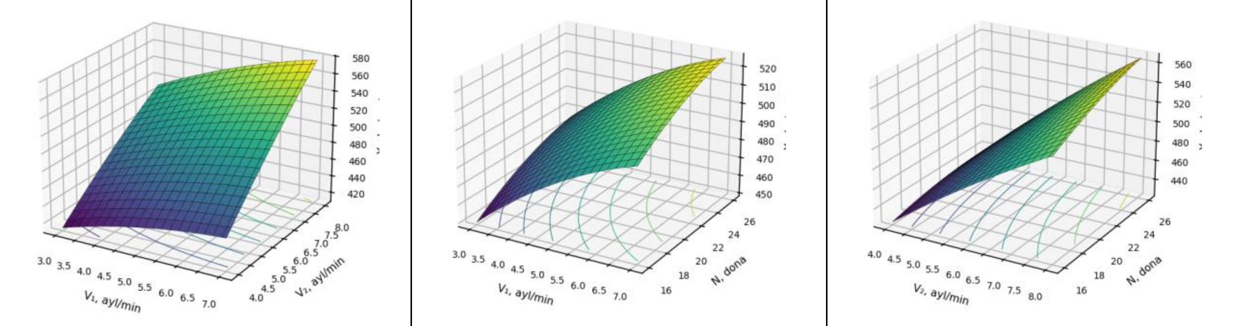
Figure 3.1 shows the dependence of the wool entanglement level (Y_1) on the input factors in the form of isolinear response surfaces. a) The figure (at x_3=0) depicts the combined effect of the spinner rotation frequency (x_1) and the wool supply speed (x_2): with an increase in both factors, the entanglement level increases, while the effect of the supply speed (x_2) is stronger - the fiber accumulates and becomes entangled when it is quickly transferred to the bath. b) In the figure (at x_2=0), entanglement increases with an increase in the frequency (x_1) and the number of pile rows (x_3), in which x_1, which determines the intensity of the mechanical effect, plays a leading role. c) In the figure (at x_1=0), an increase in the supply speed and the number of piles also increases entanglement. As can be seen from the figures, the minimum entanglement level (Y_1≈7.2%) is achieved when x_1=3 rpm, x_2=4 rpm, and x_3≈16–18 pieces.



a) X_1–X_2 b) X_1–X_3 c) X_2–X_3

3.2-rasm. Y_2 – yuvish samaradorligi bo'yicha modelning javob sirtlari

Figure 3.2 shows the dependence of the washing efficiency (Y_2) on the input factors in the form of response surfaces. a) In the figure (at x_3=0), an increase in the frequency (x_1) increases the washing efficiency (mechanical processing increases), while an excessive increase in the supply speed (x_2) reduces the efficiency by reducing the time the fiber is in the bath. b) In the figure (at x_2=0), the efficiency increases with an increase in the frequency and the number of pile rows, an internal (dome-shaped) maximum is observed on the surface. c) In the figure (at x_1=0), the efficiency is highest at a low supply speed and a high number of piles. As can be seen from the figures, the maximum washing efficiency (Y_2≈92.5 %) is achieved when x_1=7 rpm, x_2≈4 rpm and x_3=26 pieces.



a) X_1–X_2 b) X_1–X_3 c) X_2–X_3

3.3-rasm. Y_3 – ish unumdorligi bo‘yicha modelning javob sirtlari

Figure 3.3 shows the dependence of productivity (Y_3) on input factors in the form of response surfaces. a) In the figure (at x_3=0), the wool supply speed (x_2) has the strongest effect on productivity, an increase in frequency (x_1) also increases productivity, and there is a positive interaction between them. b) In the figure (at x_2=0), productivity increases with an increase in frequency and the number of pile rows, with x_1 being relatively stronger. c) In the figure (at x_1=0), the supply speed (x_2) remains the leading factor, the effect of the number of piles is weaker. As can be seen from the figures, the maximum productivity (Y_3≈592 kg/h) is achieved when x_1=7 rpm, x_2=8 rpm and x_3=26 units.

Table 3.7

Optimal operating modes for each criterion

Purpose	**x_1 (V_1), rpm**	**x_2 (V_2), rpm**	**x_3 (N), piece**	**Result**
Y_1 → min	3,0	4,0	18	Y_1 ≈ 7,2 %
Y_2 → max	7,0	4,1	26	Y_2 ≈ 92,5 %
Y_3 → max	7,0	8,0	26	Y_3 ≈ 592 kg/hour
Agreed mode	5,6	5,8	21–24	Y_1≈12,6%; Y_2≈89,9%; Y_3≈502 kg/hour

The obtained models show that increasing the wool supply speed (x_2) and the frequency of the skein (x_1) significantly increases the productivity (Y_3), but at the same time increases the degree of wool entanglement (Y_1). The washing efficiency (Y_2) increases with an increase in x_1 and x_3, and decreases with an excessive increase in x_2. Therefore, a coordinated mode ($x_1 \approx 5.6$ rpm; $x_2 \approx 5.8$ rpm; $N \approx 23$–24 pieces) is recommended as a technologically optimal mode, which keeps entanglement low and provides a balance between washing efficiency and productivity.

General conclusions on the output factors

1. Wool tangling level (Y_1). All linear coefficients of the model are positive ($\beta_1=2.56$; $\beta_2=3.43$; $\beta_3=1.69$), that is, an increase in each of the three factors increases tangling. The strongest effect is shown by the wool supply speed (x_2), followed by the shearing frequency (x_1). The positivity of the quadratic terms indicates an upward slope of the surface, that is, a faster increase in tangling at higher levels. To reduce tangling to a minimum value (≈7.2%), it is necessary to set all factors to low levels ($x_1=3$ rpm, $x_2=4$ rpm, $x_3 \approx 16$–18 pieces).

2. Washing efficiency (Y_2). Frequency ($\beta_1=3.20$) and number of pile rows ($\beta_3=2.55$) increase the efficiency, as mechanical treatment and fiber opening are increased; supply speed ($\beta_2=-2.28$) decreases it, as the fiber retention time in the washing liquid is reduced. The negativity of the quadratic terms indicates the presence of an internal (dome-shaped) maximum. Maximum efficiency (≈92.5%) is achieved at high frequency, low supply and high pile number ($x_1=7$, $x_2 \approx 4$, $x_3=26$).

3. Productivity (Y_3). This indicator is mainly determined by the speed of wool supply ($\beta_2=57.5$ - the largest coefficient), followed by the frequency of shearing ($\beta_1=24.9$) and the number of pile rows ($\beta_3=12.9$). The positive interaction of x_1x_2 and x_2x_3 indicates an additional increase in productivity when the factors are increased together. The maximum productivity (≈592 kg/h) is recorded at the highest level of all factors ($x_1=7$, $x_2=8$, $x_3=26$).

4. General contradiction and agreed solution. If productivity (Y_3) and part of the washing efficiency require increasing factors, then entanglement (Y_1) increases in this case - that is, the goals are contradictory. Taking into account the three criteria together (minimizing entanglement, maximizing efficiency and productivity), the agreed optimal mode is $x_1 \approx 5.6$ rpm, $x_2 \approx 5.8$ rpm and $N \approx 23$–24 pieces, where $Y_1 \approx 12.6\%$, $Y_2 \approx 89.9\%$ and $Y_3 \approx 502$ kg/h. This mode provides sufficient washing quality and productivity while maintaining low fiber

entanglement, which confirms the advantage of the proposed linear harrow mechanism.

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