Effect of Multilayer Processing of Semi-finished Leather Products

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Abstract—An experimental study was carried out to substantiate the simultaneous removal of excess moisture from two layers of wet leather semi-finished products. For the experiment, a multilayer package was compiled, consisting of two layers of wet leather semi-finished products and two layers of permeable cloth, laid between them. The selection of samples of semi-finished leather products for the experiment were selected from chrome plated bovine hide of medium weight, double. The excess moisture content from the wet leather semi-finished products was squeezed out by means of a vertical chain transmission on the base plate under pressure between the rotating shafts. The working shafts are covered with a permeable cloth. The experiment used the second-order D-optimal planning method. On the basis of the obtained experimental results, mathematical equations were obtained expressing the amount of moisture removed from the first and second layers of leather semi-finished products, depending on different feed rates and clamping forces of the working shafts. The main parameters of the technological process of two-layer processing of wet leather semi-finished products with their vertical feeding on the base plate between the shafts are experimentally substantiated. The parameters of the feed rate, the pressing force of the working shafts and the values of the residual moisture of the processed wet leather semi-finished products have been determined. In the future, the results obtained will serve to determine the maximum (permissible) number of layers of wet capillary-porous materials during their simultaneous processing, taking into account the provision of the necessary residual moisture in each of them.

Index Terms—moisture extraction, semi-finished leather product, roller machine, residual moisture

I. Introduction

The improvement of existing designs and the introduction of new technological equipment is one of the ways of innovative development of enterprises (manufacturing finished products), which adapt to the modern requirements of consumers, ensure the competitiveness of leather products and the profitability of enterprises in the market. In solving these issues, it is necessary to strive to improve the quality of treatment of leather raw materials in its mechanical processing. That is the aim of this experimental study.

The widespread use of roller squeezing machines, as well as modern requirements for them, contribute to the development of research to improve the roller technological machines, as well as the processing technology and properties of leather and fur products.

In particular, on the basis of the international ISO standard, the physical and chemical properties of ten different samples of leather for the shoe upper were investigated, such as tensile strength, percentage of elongation, crack resistance, permeability to water vapor, bending endurance, abrasion resistance, sweat resistance, color abrasion resistance, adhesion strength, and moisture [1]. It was revealed that to maintain all these properties, it is required to provide a sufficient amount of chromium oxide and the content of fatty substances during leather processing.

The study by Uddin et al. [2] is devoted to the physical properties of leather after aldehyde and chrome tanning. It was observed that the properties of the experimental leather are quite comparable to those of chrome-tanned leather and can meet the requirements for leather for the shoe upper. It was revealed that the use of aldehyde tanning could minimize the chromium content during tanning in the production of leather for the shoe upper, and reduce the release of toxic waste and their impact on the environment.

The influence of internal stresses on the properties of the dermis during drying of a semi-finished leather product was investigated by Radnaeva [3]. Changes in the limit indices on the operations of flattening and staking of leather and fur semi-finished product were investigated. It was established that under flattening, the strength of the leather tissue decreases and under staking it increases; this must be taken into account when setting the parameters for performing these technological operations.

The study by Ostrovskaya et al. [4] was devoted to the properties and methods of processing raw hides and finished leather. The defects obtained after pressing the leather semi-finished product were investigated by

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Abdullin et al. [5], and methods for the prevention of technological defects were described. The importance of ensuring the required pressure of the squeezing rollers and the feed rate of the leather product during its squeezing was noted. It has been previously reported that the quality of materials processing was improved by taking into account their properties, developed models of roller machines for leather and fur treatment, which allow determining the forces between the working and auxiliary rollers [6].

The vibro-dynamic characteristics of hair cleaning and fleshing machines were investigated [7] and a mathematical model was developed for the scientifically grounded improvement of roller machines to increase the quality of processing of semi-finished leather products. Ivanov and Rashkin analyzed the state of the leather industry and studied the prospects for the development of the leather processing industry [8]. The methods of the most reliable assessment of the quality indices of the processed leather semi-finished product by reducing the vibration load of the working bodies of roller machines are described.

The operational properties of technological machines for leather goods have been investigated in a previous study [9]. In addition, various physical, chemical and mechanical properties of leather depending on the area of their application were investigated by Maina et al [10]. The actual change in the temperature of the helical cutting roller was investigated taking into account the effect of friction during leather processing [11]. Natural and artificial leather were investigated, and nine different types of materials; their textures and technical characteristics were compared, possible areas of their application were determined [12].

Physical and mechanical properties and characteristics of fibrous materials were investigated by many scientists [13–15]. The issues of improving the technological processes, equipment and technological machines for pressing out leather have been discussed in previous studies [16, 17].

It is well known that in leather production there are many ways to squeeze out excess moisture from wet capillary-porous materials after their liquid tanning process: by the squeezing rollers, pressing, vacuum drying; the method of squeezing moisture between rotating rollers is the most widely used one, due to the lowest electricity consumption in implementing this technological process. There is a way to press the moisture out of wet capillary-porous materials by feeding them one-by-one to a horizontal conveyor and sequential gripping by supporting plates of vertically moving conveyor between two squeezing rollers located one above the other. Considering modern production requirements to save the maximum energy potential, this method of squeezing is less productive.

Thus, as a result of the analysis of studies from literary sources, the main directions of improving the processes of mechanical processing of semi-finished leather, and the development of the main devices and mechanisms of roller technological machines were determined. It has been previously reported in our study that a method consisting in the simultaneous processing of several semi-finished leather products between a pair of shafts was developed to improve the efficiency of moisture removal from wet semi-finished leather products [18].

Wet leather semi-finished products intended for processing are folded one layer at a time on the transporting base plate. One or more layers of permeable cloth are placed between each layer of semi-finished leather. By means of a chain drive, the transporting base plate with a package of semi-finished leather products is pulled in the vertical direction between a pair of rotating working shafts. The working shafts are located horizontally, next to each other on the bed of the experimental stand.

II. Methods

The squeezing of semi-finished leather products is carried out as follows. A semi-finished leather product and a moisture-permeable material that make up a multiple sandwich (a package) are laid one-by-one on the horizontal conveyor and the supporting strips. The motion of the horizontal conveyor feeds this package into the gripping area of the base plate. The base plate, strutting the support strips from below, transfers a package of leather semi-finished products with moisture-permeable materials vertically upward between two pairs of squeezing rollers, located one above the other. Chains, by a tension force, feed a package of leather semi-finished products and moisture-permeable materials with a base plate, providing the stretching of leather products.

The proposed method allows for increasing the efficiency and productivity of moisture extraction due to the simultaneous processing of several leather semi-finished products. Fig. 1 shows a diagram of the implementation of the method of moisture extraction from wet leather semi-finished products.

The technological machine works as follows.

Wet semi-finished leather products with moisture-permeable materials are placed on special support strips, then, the input unit is fed into the area of the base plate. Further, the base plate, moving vertically, moves apart the strips, grips a package of leather semi-finished products and transfers it to the squeezing rollers. To ensure the extraction of moisture from a package of leather semi-finished products, a device for ensuring constant chain tension was installed.

The effectiveness of the proposed method lies in the simultaneous processing of several semi-finished leather products with moisture-permeable materials, by hanging them by turns on the support strips of the input unit; then they are moved to the squeezing zone, where the package of leather semi-finished products is gripped by the base plate, moved apart by the support strips, transfers them vertically to two pairs of squeezing rollers. The downward pressure of the second upper pair of squeezing rollers is greater than that of the first lower pair of rolls. This provides additional moisture extraction. The feed of a package of leather semi-finished products with moisture-permeable materials, with a tension force to the squeezing rollers, ensures moisture extraction with stretching, which increases the useful area of the leather.

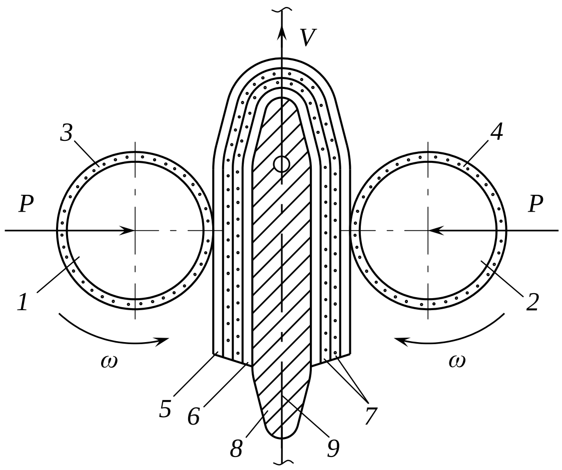

Figure 1. Scheme of feeding wet semi-finished leather products to the squeezing zone: 1, 2 - squeezing rollers, 3, 4 - moisture-removing materials (BM), 5 - the first layer of semi-finished leather product, 6 - the second layer of semi-finished leather product, 7 - moisture permeable materials (LASCH), 8 - base plate, 9 - chain

So, in contrast to the existing analogs, in the method proposed by the authors, several wet leather semi-finished products can be simultaneously processed, resulting in multiple increases in productivity of the technological machine, and in the yield of the leather usable area due to its additional stretching between two roller pairs.

To substantiate the effectiveness of the proposed method for extracting moisture from wet leather semi-finished products, we made a test bench, on which experimental studies were conducted to study the method performance.

Squeezing rollers of diameter 0.3 m were used in tests to determine rational parameters of moisture squeezing process from a two-layer package of wet fibrous materials.

The experiment was carried out on a special test bench, with horizontally installed squeezing rollers, and the base plate of 0.005 m thick, 0.1 m wide and 0.3 m long (Fig. 2).

The material of the semi-finished leather products for the experiment was the hide of bovine of medium weight, after chrome tanning, bifurcated. According to the International Standard ISO 2588-85, the required amount of semi-finished leather was selected according to the formula $n = 0{,}2\sqrt{x}$, where x is the number of hides taken for the experiment from a batch of 2500 pieces, so, n = 10 pcs. From these 10 hides, the strips 0.05×0.25 m were cut out with a cutter across the spine line; the strips were numbered and assembled into groups of 5 pcs [19]. Then the bench was switched on and samples of leather semi-finished product passed between the squeezing rollers. Samples were weighed on a VLTE-500 laboratory balance, with a resolution of 0.01 g, before and after squeezing, and the amount of extracted moisture was measured (in %).

In the experiment, the squeezing rollers 1, 2 with a coating of cloth 3, 4 of the BM brand (0.01 m thick each) were used, and between the leather semi-finished products 5 and 6, two layers of cloth 7 of the LASCH brand (0.008 m thick each) were placed (Fig. 1).

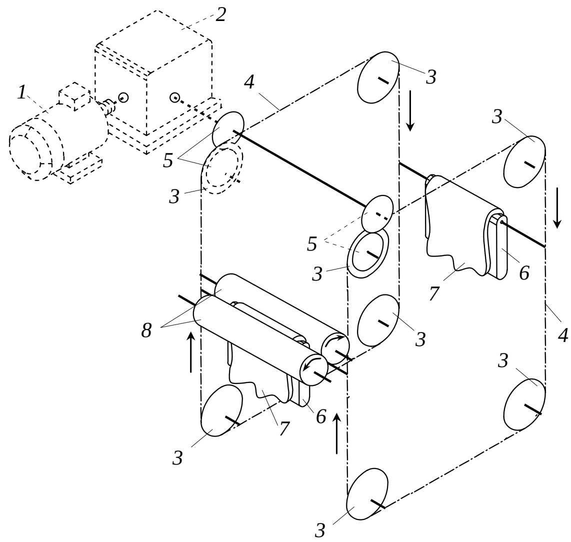

Figure 2. Diagram of the improved design of a roller stand for pressing semi-finished leather products. 1 - electric motor, 2 - gearbox, 3 - sprockets, 4 - conveyor chain, 5 - gear wheels, 6 - base plate, 7 - leather semi-finished product, 8 - squeezing rollers

The method of D-optimal planning of the second order using the Kano design matrix was applied in processing experimental results; its application provided the greatest accuracy in the regression coefficients estimates [20, 21].

Based on a priori information, the process of moisture extraction was studied considering two factors: x_1 – the intensity of down pressing P in the range from 32 to 96 kN/m; x_2 – the speed of passage V in the range from 0.17 to 0.34 m/s. In the study, the diameter of the squeezing rollers was 0.3 m and the coating thickness – 0.01 m made of felt cloth of the BM brand, the coating of the base plate – 2 layers of cloth of the LASCH brand (0.008 m thick each). The levels and intervals of variation of the experimental factor are given in Table I.

TABLE I. THE LEVELS AND RANGES OF EXPERIMENTAL FACTOR VARIATION

Index	Coded value of factors	Natural values of factors	
		x_1, kN/m	x_2, m/s
Upper level	+	96	0.340
Zero level	0	64	0.255
Lower level	–	32	0.170
Variation interval		32	0.085

Before carrying out the experiment, the required number of measurements (the number of replicates), which provided the required accuracy, was selected by the methods of mathematical statistics. The working matrix was drawn up according to the Kano design matrix for a two-factor experiment. Factors were encoded according to the formula (1):

TABLE II. EXPERIMENTAL DATA ON THE MOISTURE EXTRACTION FROM A WET LEATHER SEMI-FINISHED PRODUCT

№	x_1	x_2	y_1, gr		y_2, gr		y_3, gr		y_4, gr		y_5, gr	
			y_{in1}	y_{fin1}	y_{in2}	y_{fin2}	y_{in3}	y_{fin3}	y_{in4}	y_{fin4}	y_{in5}	y_{fin5}
1	0	0	70.5	56.3	77.0	62.0	94.0	74.6	84.2	66.2	86.6	65.7
			74.3	59.2	85.3	66.1	96.8	77.3	95.2	74.0	86.7	69.2
2	+	+	86.7	65.3	80.0	62.4	75.1	58.5	95.8	73.9	71.7	57.1
			98.3	72.9	62.5	47.3	83.3	66.1	86.7	76.1	79.4	62.9
3	–	+	68.3	59.4	81.6	68.0	84.5	72.0	79.3	69.6	73.3	63.5
			83.1	72.7	63.9	55.5	81.2	70.2	90.7	68.0	75.8	66.1
4	–	–	94.1	76.2	98.5	80.3	78.1	61.8	72.4	60.8	89.5	73.3
			91.6	72.8	66.9	53.1	85.1	71.4	86.9	72.7	92.0	77.3
5	+	–	88.7	59.9	93.1	67.7	76.2	55.7	88.4	68.6	68.4	49.7
			89.6	63.2	85.5	61.3	69.9	52.8	82.5	63.2	73.4	55.9
6	+	0	76.0	56.0	72.5	56.4	62.5	44.8	73.1	57.2	94.9	74.3
			75.5	56.1	66.1	51.9	94.9	71.6	68.1	52.2	92.5	70.4
7	0	+	92.6	70.5	97.5	79.8	81.2	66.9	80.2	64.6	92.6	72.8
			73.5	55.9	96.7	76.1	75.1	60.2	87.7	71.9	70.0	57.4
8	0	+	65.5	54.7	89.7	74.6	73.4	60.0	81.0	66.5	89.4	71.7
			73.5	62.0	79.7	76.3	73.0	58.3	84.8	71.4	76.1	64.8
9	+	0	66.0	48.2	62.5	48.1	91.9	67.2	70.7	53.3	84.3	65.2
			89.8	64.6	69.6	55.3	79.8	59.0	84.7	67.1	70.7	52.7

y_{in} is the initial weight of wet leather semi-finished product sample;
y_{fin} is the weight of the leather semi-finished product sample after extraction.

TABLE III. EXPERIMENT PLANNING MATRIX

№	P, x_1	V, x_2	Semi-finished leather product	Measurements results in %						$\sum_1^n (y-\bar{y})^2$	S^2_{er}	y_{cal}	$\bar{y}-y_{cal}$	$(\bar{y}-y_{cal})^2$
				y_1	y_2	y_3	y_4	y_5	$\bar{y}$					
1	0	0	1	20.2	19.5	20.6	21.4	24.1	21.8	15.7	3.93	22.5	0.7	0.49
			2	20.3	22.5	20.1	22.3	20.2	21.1	4.85	1.21	21.7	0.6	0.36
2	+	+	1	24.7	22.0	22.1	22.9	20.3	22.8	5.0	1.25	22.0	0.8	0.64
			2	25.7	24.3	20.6	21.1	20.8	22.5	21.94	2.14	21.0	1.5	2.25
3	-	+	1	13.0	16.6	14.8	12.2	13.4	14.0	12.42	0.32	13.7	0.3	0.09
			2	12.5	13.2	13.5	14.0	12.8	13.2	23.46	0.32	12.9	0.3	0.09
4	–	–	1	19.0	18.5	20.9	16.0	18.1	18.5	12.42	3.1	18.3	0.2	0.04
			2	20.5	20.6	16.1	16.3	16.0	17.9	23.46	0.86	17.6	0.3	0.09
5	+	–	1	32.5	27.3	26.9	22.4	27.4	27.5	29.22	9.05	26.8	0.7	0.49
			2	29.5	28.3	24.5	23.4	23.9	26.9	9.56	6.30	26.2	0.7	0.49
6	+	0	1	26.3	22.2	29.0	21.7	21.7	24.2	43.95	10.98	24.8	0.6	0.36
			2	25.7	21.5	24.5	23.4	23.9	23.8	9.56	2.39	23.6	0.2	0.04
7	0	+	1	23.9	18.2	17.6	19.4	21.4	20.5	27.28	6.82	19.7	0.8	0.64
			2	24.0	21.3	19.8	18.0	18.0	20.1	21.21	0.54	19.8	0.3	0.09
8	–	0	1	16.5	16.6	18.2	17.9	19.8	17.8	7.3	1.82	16.4	1.3	1.69
			2	15.6	16.8	20.1	15.8	14.8	16.6	19.42	4.85	14.9	1.7	2.89
9	0	–	1	26.9	23.0	26.9	24.6	22.6	25.6	20.14	5.04	24.4	1.1	1.21
			2	28.1	20.6	26.1	20.8	25.4	24.8	59.18	4.14	24.4	0.4	0.16
										Σ 173.43	Σ 43.36			Σ 5.65
										Σ 192.64	Σ 48.16			Σ 6.46

$\bar{y}$ is the arithmetic mean values of the result of the experiment

TABLE IV. DETERMINATION OF THE REGRESSION EQUATION COEFFICIENTS

№	P, x_1	V, x_2	Coefficients factors						№ of layers of capillary-porous materials	$\bar{y}$
			b_0	b_{11}	b_{22}	b_1	b_2	b_{12}		
1	0	0	0.5772	–0.3234	–0.3234	0	0	0	1	21.8
									2	21.1
2	+	+	–0.1067	0.1691	0.1691	0.1961	0.1961	0.25	1	22.8
									2	22.5
3	–	+	–0.1067	0.1691	0.1691	–0.1961	0.1961	–0.25	1	14.0
									2	13.2
4	–	–	–0.1067	0.1691	0.1691	–0.1961	0.1961	0.25	1	18.5
									2	17.9
5	+	–	–0.1067	0.1691	0.1691	0.1961	–0.1961	–0.25	1	27.5
									2	26.9
6	+	0	0.2114	–0.3883	–0.3383	0.1078	0	0	1	24.2
									2	23.8

7	0	+	0.2114	–0.3383	0.1617	0	0.1078	0	1	20.5
									2	20.1
8	0	+	0.2114	0.1617	–0.3383	–0.1078	0	0	1	17.8
									2	16.6
9	–	0	0.2114	–0.3383	0.1617	0	–0.1078	0	1	25.6
									2	24.8

$$x_i = \frac{c_i - c_{i0}}{t_0}, \quad (1)$$

where x_i – is the coding of the factor values; c_i, c_{i0} are the natural values of the factor at the current and zero levels; t_0 – is the natural value of the factor variation interval.

Target functions are approximated by a polynomial

$$y = b_0 + \sum_{i=1}^{k} b_i x_i + \sum_{i,j=1}^{k} b_{ij} x_i x_j + \sum_{i=1}^{k} b_{ii} x_i^2 \quad (2)$$

where y – is the amount of extracted moisture in coded form; b_0, b_i, b_{ij}, b_{ii} – are the regression coefficients.

After the working matrix implementation, the arithmetic mean values were obtained (Tables II, III and IV). The homogeneity of the variance was carried out using the Cochran test [20, 21] at a confidence level of α=0.95. Knowing the total number of variances estimates N and the number of degrees of freedom f=k–1, we calculate from [20, 21] and find G_t = 0.358, for N=9; f=k–1=5–1=4; k is the number of parallel experiments.

$$S_{er}^2 = \frac{\sum_{1}^{n} (y - \bar{y})^2}{n-1} \quad (3)$$

$$\sum_{1}^{N} S_i^2 = \frac{\sum_{1}^{N}\sum_{1}^{n} (y - \bar{y})^2}{N(n-1)} \quad (4)$$

$$G_{cal1} = \frac{S_{max}^2}{\sum_{1}^{N} S_i^2} = \frac{10{,}98}{43{,}36} = 0.253$$

$$G_{cal2} = \frac{S_{max}^2}{\sum_{1}^{N} S_i^2} = \frac{6{,}3}{48{,}16} = 0.131$$

G_{cal1}=0.253<G_T=0.358; G_{cal2}=0.131<G_T=0.358.

Next, we determine the regression coefficient in coded form for each layer of the leather semi-finished product in the appropriate order.

Consequently, the study results are reproducible. Determine the regression coefficients b_0, b_i, b_{ij}, b_{ii} from [20, 21] (Table IV). For the first layer of a semi-finished leather products in coded form they are: b_0 = 22.4553; b_{11} = –1.8533; b_1 = 4.1805; b_{22} = –0.4026; b_2 = –2.3539; b_{12} = –0.05.

For the second layer of a semi-finished leather product in coded form they are: b_0 = 21.7024; b_{11} = –2.4638; b_1 = 4.3648; b_{22} = 0.3819; b_2 = –2.2951; b_{12} = 0.075.

The following regression equations in coded form were obtained:

For the first layer of semi-finished leather products;

$$y_1 = 22.4553 - 1.8533\tilde{x}_1^2 - 0.4026\tilde{x}_2^2 + 4.1805\tilde{x}_1 - 2.3539\tilde{x}_2 - 0.05\tilde{x}_1\tilde{x}_2 \quad (5)$$

For the second layer of semi-finished leather products;

$$y_2 = 21.7024 - 2.4638\tilde{x}_1^2 + 0.3819\tilde{x}_2^2 + 4.3648\tilde{x}_1 - 2.295\tilde{x}_2 + 0.075\tilde{x}_1\tilde{x}_2 \quad (6)$$

The hypothesis of adequacy of the obtained equations was tested using the Fisher criterion with a confidence level of α = 0.95 [20, 21].

$$F_{cal} = \frac{S_{ad}^2}{S^2\{\hat{y}\}} \le F_T \quad (7)$$

where S_{ad}^2 – is the residual variance, or the variance of adequacy; $S^2\{\hat{y}\}$ is the variance of reproducibility.

From [20, 21] S_{ad}^2 and $S^2\{\hat{y}\}$ are defined.

For the first leather semi-finished product:

$$S_{ad}^2 = \frac{\sum_{1}^{N} n(\bar{y} - y_{cal})^2}{N - \frac{(k+2)(k+1)}{2}} = \frac{5 \cdot 5.65}{3} = 9.42 \quad (8)$$

$$S^2\{\hat{y}\} = \frac{\sum_{1}^{N}\sum_{1}^{n} (y - \bar{y})^2}{N(n-1)} = \frac{173.43}{9(5-1)} = 4.82 \quad (9)$$

Fisher's criterion for the adequacy of the model is $F_{cal} = \frac{S_{ad}^2}{S^2\{\hat{y}\}} = \frac{9.42}{4.82} = 1.95$,

where N is the total number of experiments; k is the number of factors; n is the number of repetitions in the experiment; y_i is the result of a separate observation; $\bar{y}$ is the arithmetic mean values of the result of the experiment; y_{cal} is the calculated values of the criterion according to the regression equation.

$$F_{cal} = \frac{S_{ad}^2}{S^2\{\hat{y}\}} \le F_T; \qquad F_{cal} = 1.95 < F_T = 2.87.$$

For the second layer of a semi-finished leather product, similar to (8), we find $S_{ad}^2 = \frac{5 \cdot 6.46}{3} = 10.70$, and from (9) we find $S^2\{\hat{y}\} = \frac{192.64}{36} = 5.35$.

It was confirmed that the obtained experimental results are in good agreement with the reproducibility conditions.

III. Results and Discussions

Fig. 3 shows the dependence graphs of the amount of moisture extracted from a wet leather semi-finished products in percent on different speeds of passage and pressing forces.

Substituting into the regression equations (5) and (6) $x_1 \quad \frac{P \quad 64}{32}$ and $x_2 \quad \frac{V \quad 0.255}{0.085}$ where P is the pressing force of the squeezing rollers, V is the speed of passage of wet leather semi-finished products, we obtain the regression equations in the denominated form.

So, the regression equations (5) and (6) can be considered suitable with a 95% confidence probability; in the denominated form after decoding they have the form:

For the first layer of semi-finished leather products:

$$W_1 \quad 7.1231 \quad 0.0181\,P^2 \quad 55.7232\,V^2 \quad 0.4091\,P \quad 12.4891\,V \quad 0.1838\ P\,V \tag{10}$$

For the second layer of semi-finished leather products:

$$W_2 \quad 13.4524 \quad 0.0024\,P^2 \quad 52.8581\,V^2 \quad 0.4373\,P \quad 52.7233\,V \quad 0.2757\ P\,V \tag{11}$$

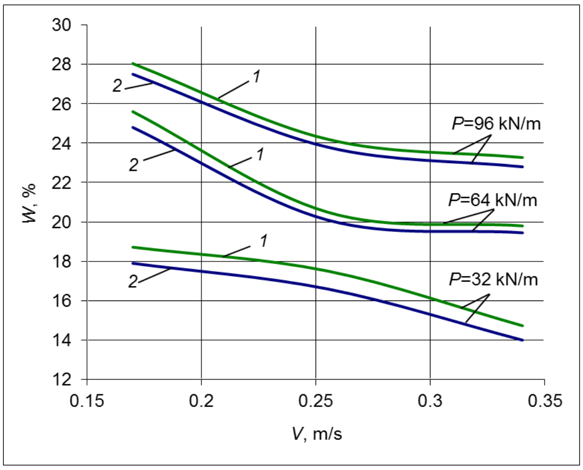

Figure 3. Dependence of the amount of extracted moisture W on the speed of passage V of the semi-finished leather products under the pressing force of the squeezing rollers P=32 kN/m; P=64 kN/m; P=96 kN/m.

So, as a result of the experiment, we obtained mathematical models in the form of regression equations (10) and (11) of the dependence of the amount of extracted moisture on the pressing force of the squeezing rollers and the speed of passage for the first and second layers of wet leather semi-finished products.

The amount of the minimum extracted moisture from the first layer of the leather semi-finished products is W_{min} = 14%, and the maximum amount is W_{min} = 27.5% of its initial weight.

The amount of the minimum extracted moisture from the second layer of the leather semi-finished products is W_{min} = 13.2%, and the maximum amount is W_{ma} = 26.9% of its initial weight.

At the same time, the difference in the removed moisture between the two layers of leather semi-finished products was from 0.6 to 0.8%. This shows the possibility of carrying out the process for the simultaneous extraction of moisture from two layers of leather semi-finished products.

IV. Conclusions

The results of the analysis of the calculation of the Fisher criterion according to the results of the experiment show that the calculated values for each of the two layers of leather semi-finished products according to the experiment are less than the tabular value. This shows that the regression Eq. (5) for the first layer of the leather semi-finished product and Eq. (6) for the second layer of the leather semi-finished product adequately describe the experimental data with a confidence level of 95%.

The amount of extracted moisture (W) was in the range from 13.2 to 27.5% under the pressing force of the squeezing rollers (P) 32 ÷ 96 kN/m at the passage speed (V) 0.17 ÷ 0.34 m/s. The maximum moisture content of semi-finished products made of the bovine hide of medium weight was 73 %, and its required residual moisture was 60%.

The analysis showed that in the range of spinning from 32 to 96 kN/m and the retraction speed from 0.17 to 0.34 m/s, the required excess amount of removed moisture from two layers of leather semi-finished products is provided. So, for the first layer of semi-finished leather, the removed moisture in excess of the required one was from 1 to 14.5%, and for the second layer from 0.2 to 13.9%. Consequently, this makes it possible to increase the speed of the process until the amount of removed moisture is equal to about 13% for two layers of leather semi-finished products. At the same time, it is possible to increase the speed of passing the first and second semi-finished leather products, which increases the productivity of the technological process of extracting moisture.

The experimental results showed that it is possible to simultaneously remove excess moisture from two semi-finished leather products (fed in layers), which makes it possible to double the productivity of the leather wringing machines, and significantly reduce the energy consumption during the technological process of extracting moisture from wet semi-finished leather products.

Analysis of the results of the experiment showed that the implementation of two-layer processing of wet leather semi-finished products in combination with two layers of permeable felts, laid between them, will increase the efficiency of the technological process of pressing by 250%. The obtained technological parameters of the process of two-layer pressing of semi-finished leather products may well be used by designers for the design of a prototype of a roll squeezing machine.

Conflict of Interest

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

AMN conducted the research; ATA analyzed the data; GAB and ATA supervised the paper; AMN, GNT and ATA wrote the paper; all authors had approved the final version.

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