A New Method to Wring Water-Saturated Fibrous Materials

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***Abstract*—The results of experimental studies are presented in the paper by determining the effect of the amount of water extracted from the leather semi-finished products under their simultaneous squeezing between rotating working rollers. A mathematical dependence of the amount of squeezed out water from wet leather semi-finished products under various pressures of the working rollers and the feed rate on the number of layers of leather semi-finished product with monshons was obtained. To increase the productivity of moisture extraction from wet leather semi-finished products of chrome tanning, the technological process was conducted by folding several layers of wet leather semi-finished products onto the base plate, between which moisture-extracting materials of the LASCH brand were pre-laid. According to the proposed method, the base plate with a folded package of wet leather semi-finished products and moisture-extracting materials is pulled in the vertical direction by means of traction chains between rotating squeezing rollers arranged horizontally. By increasing the number of simultaneous feeding of layers of semi-finished leather and increasing the pressing force of the squeezing rollers, the efficiency of the technological process is increased, which in general contributes to significant savings in energy consumption and labor costs. Based on the results of the experiment and their mathematical processing, a mathematical model was obtained to extract water from wet leather semi-finished products after chrome tanning, depending on the pressing force of the squeezing rollers and the feed rate. The proposed method to conduct the technological process of moisture extraction can be used by designers of new technological machines to remove moisture from various materials, for example, in the textile, pulp and paper industries.**

***Index Terms*—squeezing method, water-saturated material, experiment, roller stand, monshon, base plate, multilayer package (sandwich)**

I. Introduction

In Uzbekistan, leather and footwear production, in particular, the processing of leather raw materials and the manufacture of genuine leather, is predetermined by the presence of a rich base of leather raw materials. In the personal homesteads and farm households, the amount of cattle stock increases every year. More than 9 million hides are processed annually at the enterprises of the republic. The leather and footwear cluster is gradually being introduced; it includes the entire production cycle - from the slaughter of cattle and processing of raw hides to the production of high-quality footwear and leather goods. The main consumers of leather products are footwear manufacturers from India, China, Turkey, Pakistan, and other countries.

In modern industrial conditions, the manufacture of genuine leather consists of many technological processes, such as the preparatory processes (soaking, liming, pickling, softening, fermentation, degreasing), finishing processes - chemical (tanning), liquid, physicochemical (filling, dyeing, moisture extraction, drying, moistening) and mechanical (fleshing, shaping, setting, printing, tumbling, breaking staking, rolling, buffing), top dyeing and other processes.

In the leather industry, many technological machines are used, including a roller squeezing machine, which is used in many operations, for example, during pressing, degreasing and after drum dyeing of semi-finished leather products. The quality of the pressing operation determines the quality of subsequent technological operations, such as shaping and splitting of leather semi-finished products.

It is known that at present in Uzbekistan the production volumes for processing leather raw materials by business entities in the leather-footwear and fur industries are gradually increasing. According to the "Uzcharmsanoat" Association, the export of semi-finished products is reducing in order to enter foreign markets with the finished products. According to statistics, the export of finished products in 2018 amounted to 61%, in 2019 to 76%, and at present it is planned to increase this figure up to 87.1% [1].

Technological defects, often observed during leather semi-finished product squeezing and the ways to eliminate them were described in [2]. The importance of ensuring the constancy of required pressure between the

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squeezing rollers, the moisture content in the leather semi-finished product and the feed rate of the latter to the treatment zone were stated there.

The publications in [3–5] refer to the improvement of the technology of liquid processing of semi-finished leather products.

The study in [6] refers to the analysis of the structure and properties of collagens in semi-finished leather products after liquid processing.

So, we have examined the effect of such factors as the number of layers of a leather semi-finished product with water-removing materials (monshons) of LASCH brand on the technological process of water wringing from wet leather semi-finished products under their vertical feed to the support plate, implemented by the method developed by the authors [7–10].

[11–14] are devoted to improving the design of roller equipment, including the study of the interaction of the roller module with the processed material.

In [15] the development of the theory of calculation of working bodies, mechanisms, and technological processes in processing sheet materials is considered.

The aim of this paper is to study the factors affecting an increase in efficiency of technological process of wringing wet leather semi-finished products by improving the method of its implementation.

II. Methods

The authors have conducted an experimental study using the method of mathematical statistics, namely, the method of mathematical planning of the experiment.

The experiment was conducted on a special stand where the squeezing rollers were installed horizontally, and the base plate was made of a metal sheet of a thickness of 0.005 m, a width of 0.1 m, and a length of 0.3 m (see Fig. 1). One layer of the package consists of one leather semi-finished product and one moisture-extracting material (monshon) – the cloth of the LASCH brand.

The samples of the leather semi-finished product for the experiment were taken from the average weight bovine hide, after chrome tanning and splitting. According to the International Standard ISO 2588-85, the amount of hides was selected according to the formula n=0.2√x, where x is the number of leather semi-finished products for the experiment, taken from 2500 pieces batch, so, *n*=10 pcs. A total of 53 strips were cut out from each hide. A total of 530 pieces were prepared according to the method of asymmetric fringe [8, 16].

The experiment was conducted as follows. A strip of moisture-extracting cloth (monshons) of the LASCH brand of a thickness of 0.004 m was put on a metal base plate, followed by the hide layer and so on. Then the stand was turned on, the spring compression was set to the desired pressure by calibration, the rate was regulated by a rheostat, and the roller speed was controlled by a clock type tachometer TCH-10P.

Control samples of the leather semi-finished product were preliminarily fed and the spring compression was measured, that is, its deviation from the set one. If the deviation exceeded 3%, the springs were adjusted by tightening nuts. Then the basic samples of the leather semi-finished product were fed. The samples were weighed before and after squeezing on VLTE-500 laboratory scales, with 0.1 g resolution (ISO-9001).

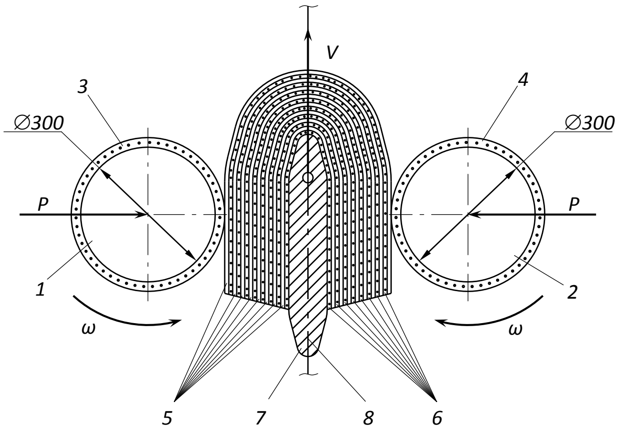


Figure 1. The scheme of the way to squeeze water from wet leather semi-finished products using moisture-extracting materials in between: 1, 2 – squeezing rollers, 3, 4 - moisture-extracting materials (BM), 5 - leather semi-finished products, 6 - moisture-extracting materials (LASCH), 7 - base plate, 8 – chain.

When processing the experiment results, the second-order D-optimal planning method was used with the Kano planning matrix since its application provides the greatest accuracy in estimating the regression coefficients [8, 16]. It was taken into account that the Kano planning matrix provides the variation of factors at three levels: lower (-), zero (0), and upper (+) ones, which is appropriate for this study. Based on a priori information, the process of water removal was studied taking into account three factors: x_1 – the pressure intensity P, kN/m; x_2 – the feed rate V, m/s; t - the number of layers of the leather semi-finished product with monshons of the LASCH brand, pcs.; the range of the down pressure was from 32 to 96 kN/m; the speed of squeezing rollers was from 0.17 to 0.34 m/s; the number of layers of the leather semi-finished product was from 2 to 8 pcs. based on the performance of various squeezing machines produced in various countries. In the experiment, the diameter of the squeezing rollers was 0.3 m, with 0.01 m coating made of cloth of the BM brand (monshon).

Before the experiment, the required number of measurements (the number of replicates), providing the required accuracy, was selected by the methods of mathematical statistics.

The working matrix was built using the Kano planning matrix for a three-factor experiment. The coding of factors was carried out according to the formula

$$x_i = \frac{c_i - c_{i0}}{t_0}$$

where: x_i is the coding of the factor value; 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 interval of the factor variation.

The levels and ranges of experimental factor variation are given in Table I.

TABLE I. THE LEVELS AND RANGES OF THE EXPERIMENTAL FACTOR VARIATION

Index	Coded value of factors	Natural values of factors		
		x_1, kN/m	x_2, m/s	x_3, pcs.
Upper level	+	96	0.340	8
Zero level	0	64	0.255	5
Lower level	-	32	0.170	2
Variation interval		32	0.085	3

Target functions were approximated by polynomial

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

where y is the amount of water removed in encoded form; b_0, b_i, b_{ij}, b_{ii} are the regression coefficients.

After the implementation of working matrix, the arithmetic mean values were obtained (Table II).

The homogeneity of the variance was ensured using the Cochren criterion with a confidence probability of α=0.95

$$G_{cal} = \frac{S^2_{\max}}{\sum_1^N S_i^2} \le G_T; \quad S^2_{er} = \frac{\sum_1^n (y_i - \bar{y}_i)^2}{n-1};$$

$$G_{cal} = \frac{4.545}{27.457} = 0.1655$$

G_{cal}=0.1655<G_T=0.188, N is the total number of variances, y_i is a series of parallel experiments, $\bar{y}_i$ - is the average value of each parallel experiment, n is the number of parallel experiments.

III. RESULTS AND DISCUSSIONS

Since G_{cal} is the calculated value of the Cochren criterion less than the tabulated G_T, the experiments are reproducible. We determined the regression coefficients b_0, b_i, b_{ij}, b_{ii} from the table given in [8, 16]: b_0=17.25896; b_{11}=-1.19788; b_{22}=0.85212; b_{33}=-1.0021; b_1=3.8108; b_2=-2.62312; b_3=-2.55076; b_{12}=0.01538; b_{13}=-0.03252; b_{23}=-0.1084.

The regression equation in encoded form is,

$$y = 17.2590 - 1.1979 \cdot x_1^2 + 0.8521 \cdot x_2^2 + 1.0021 \cdot x_3^2 +$$
$$+ 3.8108 \cdot x_1 - 2.6231 \cdot x_2 - 2.54272 \cdot x_3 +$$
$$+ 0.0545 \cdot x_1 \cdot x_2 - 0.03591 \cdot x_1 \cdot x_3 - 0.1871 \cdot x_2 \cdot x_3.$$

The hypothesis of the adequacy of obtained equations was checked using the Fisher test with a confidence probability of α = 0.95

$$F_{\text{cal}} = \frac{S^2_{ad}}{S^2\{y\}} < F_T$$

S^2_{ad} is the *residual* variance, or the variance of adequacy; $S^2\{y\}$ is the reproducibility variance.

S^2_{ad} and $S^2\{y\}$ were *defined* from Tables I and II in the form:

$$S^2_{ad} = \frac{\sum_1^N n \cdot (\bar{y}_i - \hat{y}_i)}{N - \frac{(k+2)(k+1)}{2}} = \frac{\sum_1^{21} 5 \cdot (\bar{y}_i - \hat{y}_i)^2}{21 - \frac{(3+2)(3+1)}{2}} =$$
$$= \frac{5 \cdot 5.6836}{11} = 2.58.$$

$$S^2\{y\} = \frac{\sum_1^N \sum_1^n (y_i - \bar{y}_i)^2}{N(n-1)} = \frac{109.828}{21(5-1)} = \frac{109.828}{84} = 1.3075 \cdot$$

Fisher test for model adequacy is

$$F_{\text{cal}} = \frac{S^2_{ad}}{S^2\{y\}} = \frac{2.58345}{1.3075} = 1.9759$$

TABLE II. EXPERIMENT PLANNING MATRIX

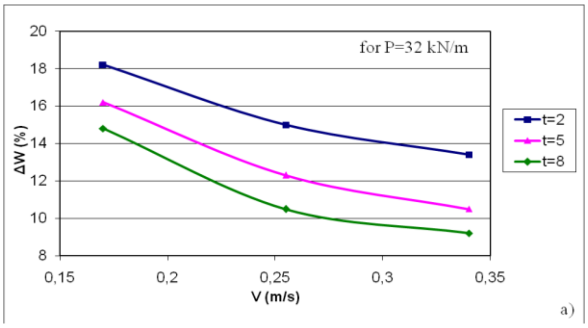
#	P, x_1	V, x_2	t, x_3	Measurements results, % y_1	y_2	y_3	y_4	y_5	$\bar{y}_m$	$\sum_1^n (y - \bar{y}_m)^2$	S^2_{er}	$\hat{y}$	$\bar{y}_m - \hat{y}$	$(\bar{y}_m - \hat{y})^2$
1	0	0	0	18.3	17.3	17.7	16.6	16.1	17.2	3.04	0.76	17.26	0.06	0.0036
2	+	+	+	16.6	16.4	16.2	15.8	15.5	16.1	0.70	0.175	16.39	0.29	0.0841
3	+	-	+	22.4	21.7	21.3	21.1	21.0	21.5	1.30	0.325	21.9	0.4	0.16
4	-	-	+	15.3	15.0	14.8	14.6	14.3	14.8	0.58	0.145	14.46	0.34	0.1156
5	-	+	+	9.6	9.4	9.2	9.0	8.6	9.2	0.60	0.15	8.4	0.80	0.64
6	+	+	-	25.0	24.2	20.5	22.0	20.3	22.4	18.18	4.545	21.92	0.48	0.2304
7	+	-	-	26.5	25.9	26.9	27.2	27.5	26.8	1.56	0.39	26.69	0.11	0.0121
8	-	-	-	16.5	19.3	19.8	17.6	17.8	18.2	7.16	1.79	19.1	0.9	0.81
9	-	+	-	12.2	14.0	14.1	12.8	13.9	13.4	3.98	0.995	13.79	0.39	0.1521
10	+	0	+	18.8	18.2	18.1	17.9	17.5	18.1	0.90	0.225	18.31	0.21	0.0441
11	0	-	+	19.4	19.0	19.9	18.6	18.6	18.5	4.04	1.01	19.38	0.88	0.7744
12	-	0	+	11.4	11.1	8.9	10.7	10.5	10.5	4.17	1.043	10.75	0.25	0.0625
13	+	-	0	24.6	25.3	23.0	21.5	22.7	23.4	9.31	2.328	23.29	0.11	0.0121
14	-	-	0	17.1	17.1	15.2	16.1	16.1	16.3	2.57	0.643	15.78	0.52	0.2704
15	-	+	0	10.7	10.9	10.8	10.1	10.0	10.5	0.70	0.175	10.42	0.08	0.0064
16	+	+	0	18.3	18.8	18.5	16.2	16.7	16.8	9.51	2.378	18.16	1.36	1.8496
17	0	+	+	14.4	14.0	12.9	12.0	13.5	13.4	3.58	0.895	19.76	0.36	0.1296
18	+	0	-	21.3	25.1	25.1	22.5	24.0	23.6	11.16	2.79	23.45	0.15	0.0225
19	0	-	-	26.2	24.1	22.5	23.6	25.6	24.4	9.02	2.255	24.09	0.31	0.0961
20	-	0	-	16.4	14.0	17.1	14.3	15.2	15.4	7.10	1.775	15.76	0.36	0.1296
21	0	+	-	18.9	20.3	21.4	17.1	19.8	19.5	10.66	2.665	19.22	0.28	0.0784
										Σ 109.828	Σ 27.457			Σ 5.6836

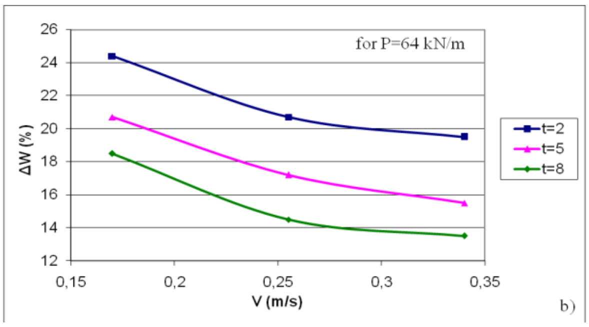
S_{ad}^2 is the variance of adequacy; $S^2\{y\}$ is the reproducibility variance; N is the total number of experiments; k is the number of factors; n is the number of repetitions in the experiment; y_i is the result of a separate observation; $\bar{y}_i$ is the arithmetic mean value of the experiment result; y_i is the calculated value of the criterion according to the regression equation for S_{ad}^2 =2.58; $S^2\{y\}$ =1.3075; $F_т$=2.40.

Since F_{cal}=1.9759<$F_т$=2.40, therefore, the adequacy of the model is accepted with a confidence probability of 0.95. The hypothesis of the adequacy (suitability) of the model using the Fisher criterion was considered above. If the value of the F-criterion, determined from the residual variance divided by the variance of reproducibility, is greater than the values of the Fisher criterion given in the table, then an additional experiment is required to refine the model.

TABLE III. CALCULATION OF THE REGRESSION COEFFICIENTS

#	P, x_1	V, x_2	t, x_3	Factors for the regression coefficients										$\bar{y}$
				b_0	b_{11}	b_{22}	b_{33}	b_1	b_2	b_3	b_{12}	b_{13}	b_{23}	
1	0	0	0	0.6554	-0.2479	-0.2479	-0.2479	0	0	0	0	0	0	17.2
2	+	+	+	-0.0861	0.0630	0.0630	0.0630	0.0804	0.0804	0.0804	0.0979	0.0979	0.0979	16.1
3	+	-	+	-0.0861	0.0630	0.0630	0.0630	0.0804	-0.0804	0.0804	-0.0979	0.0979	-0.0979	21.5
4	-	-	+	-0.0861	0.0630	0.0630	0.0630	-0.0804	-0.0804	0.0804	0.0979	-0.0979	-0.0979	14.8
5	-	+	+	-0.0861	0.0630	0.0630	0.0630	-0.0804	0.0804	0.0804	-0.0979	-0.0979	0.0979	9.2
6	+	+	-	-0.0861	0.0630-	0.0630	0.0630	0.0804	0.0804	-0.0804	0.0979	-0.0979	-0.0979	22.4
7	+	-	-	-0.0861	0.0630	0.0630	0.0630	0.0804	-0.0804	-0.0804	-0.0979	-0.0979	0.0979	26.8
8	-	-	-	-0.0861	0.0630	0.0630	0.0630	-0.0804	-0.0804	-0.0804	0.0979	0.0979	0.0979	18.2
9	-	+	-	-0.0861	0.0630	0.0630	0.0630	-0.0804	0.0804	-0.0804	-0.0979	0.0979	-0.0979	13.4
10	+	0	+	0.0861	0.0620	-0.1880	0.0620	0.0446	0	0.0446	0	0.0542	0	18.1
11	0	-	+	0.0861	-0.1880	0.0620	0.0620	0	-0.0446	0.0446	0	0	-0.0542	18.5
12	-	0	+	0.0861	0.0620	-0.1880	0.0620	-0.0446	0	0.0446	0	-0.0542	0	10.5
13	+	-	0	0.0861	0.0620	0.0620	-0.1880	0.0446	-0.0446	0	-0.0542	0	0	23.4
14	-	-	0	0.0861	0.0620	0.0620	-0.1880	-0.0446	-0.0446	0	0.0542	0	0	16.3
15	-	+	0	0.0861	0.0620	0.0620	-0.1880	-0.0446	0.0446	0	-0.0542	0	0	10.5
16	+	+	0	0.0861	0.0620	0.0620	-0.1880	0.0446	0.0446	0	0.0542	0	0	16.8
17	0	+	+	0.0861	-0.1880	0.0620	0.0620	0	0.0446	0.0446	0	0	0.0542	13.4
18	+	0	-	0.0861	0.0620	-0.1880	0.0620	0.0446	0	-0.0446	0	-0.0542	0	23.6
19	0	-	-	0.0861	-0.1880	0.0620	0.0620	0	-0.0446	-0.0446	0	0	0.0542	24.4
20	-	0	-	0.0861	0.0620	-0.1880	0.0620	-0.0446	0	-0.0446	0	0.0542	0	15.4
21	0	+	-	0.0861	-0.1880	0.0620	0.0620	0	0.0446	-0.0446	0	0	-0.0542	19.5





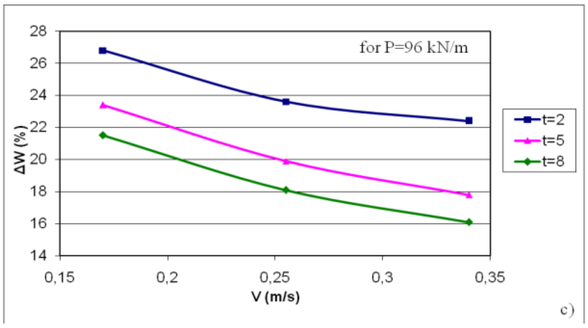


Figure 2. Dependence of the amount of removed water ΔW on the number of layers t of a leather semi-finished product between squeeze shafts at a pressure intensity: P=32 kN/m (a), P=64 kN/m (b), P=96 kN/m (c).

We transform the regression equations in coded form into a denominated form. The following is substituted instead of x_1, x_2, x_3 into the regression equation.

$$x_1 = \frac{P-64}{32};\quad x_2 = \frac{V-0.255}{0.085};\quad x_3 = \frac{t-5}{3}$$

Thus, the regression equation can be considered admissible with a 95 % confidence probability. The regression equation after decoding in a denominated form has the form

$$\Delta W = 26.6765 - 0.0011698P^2 + 117.9377V^2 + 0.1134t^2 + $$
$$+ 0.26557P - 93.3955V - 1.74455t - 0.02PV -$$
$$- 0.0003739Pt - 0.7337Vt.$$

According to Table III, we determined the coefficients of the regression equation b_0, b_i, b_{ij}, b_{ii}, by summing the products of the coefficient set to the number of the experiment by the value corresponding to the amount of extracted moisture.

Hence, a mathematical model was obtained for the dependence of the amount of moisture removed from the leather semi-finished product on such factors as the pressure, the speed of passage and the amount of simultaneous extraction of layers.

IV. Conclusions

In the hides processed for upper shoe leather, the maximum moisture content in the topography field reaches 73%, and in the butt section - up to 65%. The residual moisture content of the leather semi-finished product after pressing should be about 55-60% depending on the type and purpose of the semi-finished leather product. In our case, the residual moisture content of the leather semi-finished product should be no more than 60%. Therefore, we needed to squeeze out a maximum of 13% moisture more from each leather semi-finished product on a roller squeezing machine.

The analysis of experimental results (Fig. 2) shows that:

At down pressure of working rollers of 32 kN/m:

The maximum feed rate of a two-layer leather semi-finished product is 0.34 m/s.

The maximum feed rate of a five-layer leather semi-finished product is no more than 0.24 m/s.

The maximum feed rate of an eight-layer leather semi-finished product is no more than 0.21 m/s.

In the range from two to five layers of leather semi-finished products, the difference in extracted moisture was 2% at the feed rate of 0.17 m/s, and 1.3% at the feed rate of 0.34 m/s. And in the range from five to eight layers of leather semi-finished products, the difference in extracted moisture was 1.4% at the feed rate of 0.17 m/s, and 1.3% at the feed rate of 0.34 m/s.

At down pressure of working rollers of 64 kN/m:

The maximum feed rate of a two-layer leather semi-finished product is 0.34 m/s.

The maximum feed rate of a five-layer leather semi-finished product is slightly more than 0.34 m/s.

The maximum feed rate of an eight-layer leather semi-finished product is more than 0.34 m/s.

In the range from two to five layers of leather semi-finished products, the difference in extracted moisture was 2.2% at the feed rate of 0.17 m/s, and 2% at the feed rate of 0.34 m/s. And in the range from five to eight layers of leather semi-finished products, the difference in extracted moisture was 3.7% at the feed rate of 0.17 m/s.

At down pressure of working rollers of 96 kN/m:

The maximum feed rate of a two-layer leather semi-finished product is more than 0.34 m/s.

The maximum feed rate of a five-layer leather semi-finished product is more than 0.34 m/s.

The maximum feed rate of an eight-layer leather semi-finished product is more than 0.34 m/s.

In the range from two to five layers of leather semi-finished products, the difference in extracted moisture was 3.4% at the feed rate of 0.17 m/s, and 5.6% at the feed rate of 0.34 m/s. In the range from five to eight layers of leather semi-finished products, the difference in extracted moisture was 1.9% at the feed rate of 0.17 m/s, and 0.7% at the feed rate of 0.34 m/s.

The analysis of the experiment on extracting moisture from two-layer leather semi-finished products shows that when the down pressure of the squeezing rollers is 32, 64 and 96 kN/m, the maximum rate is more than 0.34 m/s.

An analysis of the experiment on extracting moisture from five-layer leather semi-finished products shows that when a down pressure of the squeezing rollers is 32 kN / m, the maximum feed rate is 0.20 m/s, and when a down pressure of the squeezing rollers is 64 kN/m, the maximum rate is slightly more than 0.34 m/s and when a down pressure of the squeezing rollers is 96 kN/m, the maximum feed rate is more than 0.34 m/s.

An analysis of the experiment on extracting moisture from five-layer leather semi-finished products shows that when a down pressure of the squeezing rollers is 32 kN/m the feed rate is 0.23 m/s, and, when a down pressure is 64 kN/m, the maximum rate is 0.34 m/s and when a down pressure is 96 kN/m, the maximum feed rate is more than 0.34 m/s.

The results of the experiment show that at a two-layer squeezing, the maximum productivity of squeezing rollers increases by 200 percent, and at squeezing five-layer semi-finished leather products, it increases by 500 percent. At an eight-layer squeezing of moisture from wet leather semi-finished products, the productivity increases by 800 percent.

At moisture squeezing from multilayer semi-finished leather products and at their bent down feeding on the base plate, the energy consumption required for the technological process of squeezing on a roller squeezing machine is reduced. Thus, the method of squeezing moisture considered in the article is currently more effective than the method of squeezing a single-layer product on roller squeezing machines used nowadays in production.

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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