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Leather squeezing efficiency analysis

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Abstract. This paper presents the results of an efficiency analysis on the pressing of leather after dyeing, determined by the residual moisture content of the leather. The study establishes the law of changes in humidity during the leather pressing process. It was found that as the thickness and initial moisture content of the skin decreases, its final moisture content also decreases. An analytical dependence of the residual moisture content of the skin has been derived, which can be used to determine rational parameters for squeezing machines. The results show that reducing the skin thickness and increasing the roller radius lead to a decrease in the residual moisture content of the leather.

1 Introduction

In leather production, fluid removal processes play a special role; they aim to impart some hardness to the semi-finished product, necessary for the successful completion of subsequent operations. Fluid removal processes are conducted on roller squeezing machines. Each semi-finished product is processed twice on roller squeezing machines: for the first time - after tanning; and for the second time - after dyeing and fatliquoring operations.

The main functional purpose of squeezing machines is to provide the residual moisture content (of squeezed material) required by the technological process. To optimize the operation of existing and to create new efficient squeezing machines, it is appropriate to construct mathematical models of residual moisture to predict the degree of fluid removal caused by roller squeezing and to be easily used by engineers-practitioners.

Theoretical models of residual moisture were mainly obtained based on solving the problem of fluid filtration in a deformable porous medium, and the main studies were conducted to determine the moisture in paper after pressing on papermaking machines [1-18]. One of the significant drawbacks of these models is solving the filtration problem without considering the phenomenon of contact interaction in the squeezing zone.

In [19-24], the residual moisture content of wet material was determined considering the phenomenon of contact interaction in the squeezing zone, that is, by jointly solving the problem of contact interaction and moisture filtration. However, these models are too complex for practical use, and they also use empirical dependencies obtained experimentally. The analysis showed that at present there are no experimental and theoretical studies to investigate the process of squeezing leather after dyeing.

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2 Materials and methods

We consider leather and cloth to be two-phase media, consisting of a skeleton and fluid filling the pores between them. Due to the fact that the semi-finished product under the dyeing and fatliquoring processes is kept in liquid for a long time, there is no third phase - air, and the cloth, before coming into contact with the skin, is saturated with fluid from a water wedge formed as a result of squeezing moisture out of the pressing zone [23].

The skin, saturated with fluid, begins to shrink upon entering the contact zone of the rollers. Since compression of material saturated with fluid occurs as a result of the squeezing out [12], fluid is displaced from the leather into the cloth in the compression zone.

In this case, part of the applied pressure, and, as the spin is performed, the proportion of pressure perceived by the liquid decreases [21]. Moreover, under squeezing and compaction, the proportion of pressure perceived by fluid decreases, while that of the solid phase increases.

3 Results and discussion

From the compression zone we select an elementary volume of length dx.

In the free state of the skin, the volume of its element

$$dV_0 = B\delta_1 dx \tag{1}$$

has skeletal volume

$$dV_{s0} = m_0 B\delta_1 dx \tag{2}$$

and volume of fluid

$$dV_{mo0} = (1 - m_0)B\delta_1 dx, \tag{3}$$

where $m_0 -$ is the volume of the skeleton per unit volume of skin, $B -$ is the width of the skin, $\delta_1 -$ is the initial thickness of the skin (the thickness of the skin before squeezing).

$$dV = Bhdx, \tag{4}$$

the volume of the skeleton did not change and remained equal to:

$$dV_s = dV_{s0} = m_0 B\delta_1 dx. \tag{5}$$

Then the volume of fluid is

$$dV_{mo} = (h - m_0\delta_1)Bdx. \tag{6}$$

Moisture content (in %) of the skin of height h is [13]:

$$W = \frac{\rho_{mo} dV_{mo}}{\rho_{mo} dV_{mo} + \rho_s dV_s} 100, \tag{7}$$

where $\rho_{mo}, \rho_s -$ are the densities of fluid and skeleton, respectively.

From here we obtain

$$dV_{mo} = \frac{W}{100 - W} \frac{\rho_s}{\rho_{mo}} dV_s. \tag{8}$$

From equality (8) considering equalities (5) and (6), we determine:

$$\frac{m_0\delta_1}{h} = \frac{(100 - W)\rho_{mo}}{W\rho_s + (100 - W)\rho_{mo}}. \tag{9}$$

Considering that the skin in a free state has initial moisture content (moisture content before squeezing) W_{in} and initial thickness δ_1, we find

$$m_0 = \frac{(100 - W_{in})\rho_{mo}}{W_{in}\rho_s + (100 - W_{in})\rho_{mo}}, \tag{10}$$

where $W_{in}-$ is the initial moisture content of the skin (moisture content of the skin before squeezing).

By solving equality (9) with respect to W, we obtain:

$$W=\frac{\rho_{mo}h-m_0\rho_{mo}\delta_1}{\rho_{mo}h+(\rho_s-\rho_{mo})m_0\delta_1}100. \tag{11}$$

According to formulas (10) and (11), changes in the moisture content of the skin in the spin zone occur with a change in its thickness, which in turn depends on the geometric, kinematic and deformation parameters of the skin and the roller coating, as well as the forces acting on the roller supports [25-28]. A graph of changes in skin moisture from its thickness at different values of initial moisture is shown in Figure 1, the analysis of which shows that a decrease in the initial thickness and moisture of the skin leads to an increase in the efficiency of the process.

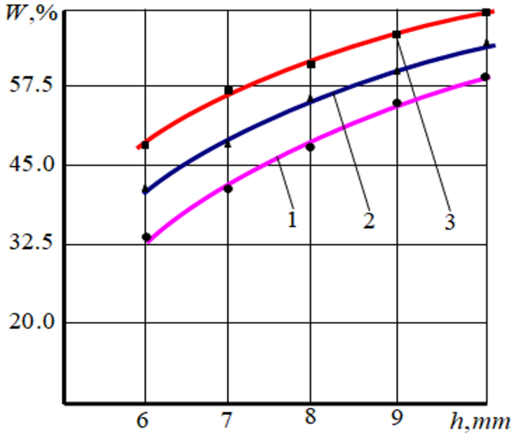

Fig. 1. Dependence of moisture content of the skin on its thickness: $1-W_{in}=60\%$, $2-W_{in}=65\%$, $3-W_{in}=70\%$.

Now we will determine the changes in the thickness of the skin in the roll module under the squeezing process.

The leather after dyeing has a uniform and thin thickness. Therefore, it is believed that the skin up to the line connecting the centers of rollers is compressed, but beyond this line, it is not deformed.

Consequently, the contact curves of each roll relative to the line of centers consist of two parts - curvilinear and rectilinear parts (Figure 2) and is described by the following system of equations [5]:

$$\begin{cases} r_1=\frac{R}{1+k}\left(1+k\frac{\cos\alpha_1}{\cos\theta_1}\right), & -\alpha_1\le\theta_1\le 0, \\ r_2=R\frac{\cos\alpha_2}{\cos\theta_2}, & 0\le\theta_2\le\alpha_2, \end{cases} \tag{12}$$

where $k=\frac{2H\lambda}{\delta_1}$, $\lambda-$ is the ratio of the deformation rates of cloth and leather during compression, α_1,α_2- are the contact angles.

According to Figure 2 under compression, the thickness of the skin changes according to the following law:

$$h_1 = \delta_1 + 2R\cos\alpha_1 - 2r_1\cos\theta_1 . \quad (13)$$

After substituting expression r_1 from the first equation of system (12) into equalities (13), we obtain:

$$h_1 = \delta_1 - \frac{2R}{1+k}(\cos\theta_1 - \cos\alpha_1)$$

or

$$h_1 = \delta_1 - \frac{R}{1+k}(\alpha_1^2 - \theta_1^2) . \quad (14)$$

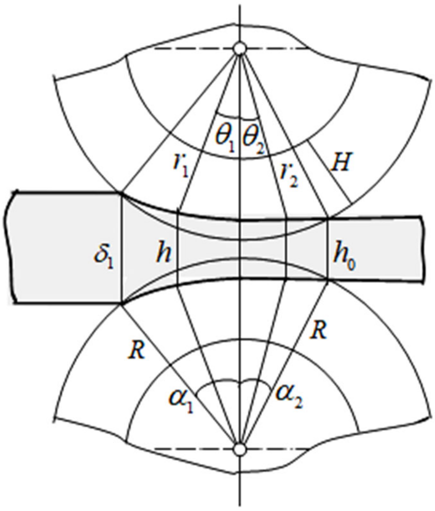

Fig. 2. Roller module diagram squeezing machine.

Under boundary condition $r_1 = r_2$, for $\theta_1 = \theta_2 = 0$, from system (12), it follows that

$$\frac{R}{1+k}(1 + k\cos\alpha_1) = R\cos\alpha_2 .$$

Hence

$$1 + k = \frac{1 - \cos\alpha_1}{\cos\alpha_2 - \cos\alpha_1}$$

or

$$1 + k = \frac{\alpha_1^2}{\alpha_1^2 - \alpha_2^2} .$$

Then from equality (14), we find

$$h_1 = \delta_1 - \frac{(\alpha_1^2 - \alpha_2^2)(\alpha_1^2 - \theta_1^2)}{\alpha_1^2} R . \quad (15)$$

From this dependence, it follows that the thickness of the skin on the line of centers is:

$$h_0 = \delta_1 - R(\alpha_1^2 - \alpha_2^2) . \quad (16)$$

The skin behind the line of centers is not deformed. Therefore, the thickness of the skin behind the line of centers is constant and has a value of h_0.

Considering expression (14) from equality (11), we obtain:

$$W = \frac{a\alpha_1^2 + \theta_1^2}{b\alpha_1^2 + \theta_1^2}100, \tag{17}$$

where

$$a = \frac{\delta_1(1-m_0) - R(\alpha_1^2 - \alpha_2^2)}{R(\alpha_1^2 - \alpha_2^1)}, \quad b = \frac{\rho_{mo}(\delta_1(1-m_0) - R(\alpha_1^2 - \alpha_2^2)) + \rho_s m_0 \delta_1}{\rho_{mo} R(\alpha_1^2 - \alpha_2^1)}. \tag{18}$$

From equality (17), we obtain:

$$W(0) = \frac{\rho_{mo}(\delta_1(1-m_0) - R(\alpha_1^2 - \alpha_2^2))}{\rho_{mo}(\delta_1(1-m_0) - R(\alpha_1^2 - \alpha_2^1)) + \rho_s m_0 \delta_1}100. \tag{19}$$

Formula (17) determines the patterns of changes in skin moisture content in the compression zone.

From Figure 3, it follows that at the beginning of the contact zone the skin moisture content is W_{in}, then as a result of skin compression it decreased, and at the end of the compression zone, it is $W(0)$.

The leather behind the centerline is not deformed, but the cloth restores the deformation. In this case, the cloth can reabsorb fluid from the skin. Reverse absorption is a surface effect that occurs along the straight part of the roll contact curve [13,15]. The content of moisture absorbed back depends on the properties of the cloth. Therefore, to increase the efficiency of the squeezing process, by selecting the type of cloth the absorbed moisture can be reduced to zero.

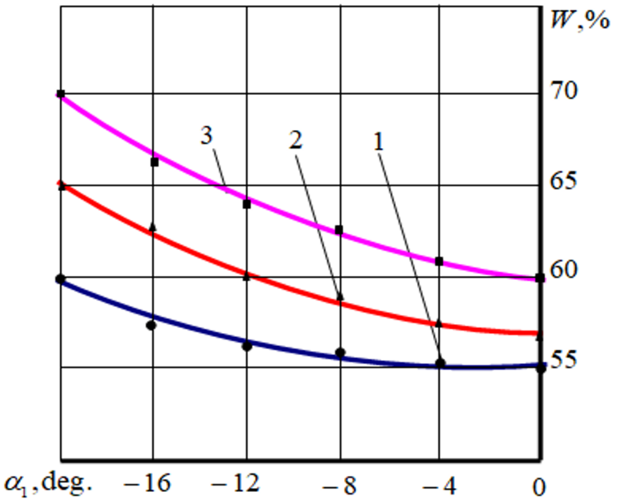

Fig. 3. The nature of changes in skin moisture in the compression zone: $1 - W_{in} = 60\%$, $2 - W_{in} = 65\%$, $3 - W_{in} = 70\%$.

Then we have

$$W_{res} = \frac{\rho_{mo}(\delta_1(1-m_0) - R(\alpha_1^2 - \alpha_2^2))}{\rho_{mo}(\delta_1(1-m_0) - R(\alpha_1^2 - \alpha_2^1)) + \rho_s m_0 \delta_1}100, \tag{20}$$

where W_{res} − is the residual moisture content of the skin.

4 Conclusion

The law of changes in humidity during the leather process after dyeing has been established.

It was found that as the thickness and initial moisture content of the skin decreases, its moisture content decreases.

It has been shown that reducing the thickness of the skin and increasing the radius of the rolls lead to a decrease in its residual moisture.

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