E3S Web of Conferences **434**, 02016 (2023) https://doi.org/10.1051/e3sconf/202343402016
*ICECAE 2023*

# Study on issues of hydrodynamics of the roll squeezing process

*Firuza* Kurbanova[1*], *Kakhramon* Aliboev[1], *Samariddin* Mazhidov[1]

[1]Tashkent University of Architecture and Civil Engineering, 100011 Tashkent, Usbekistan

**Abstract.** The laws of distribution of hydrodynamic pressure and changes in extracted fluid in the pressing area are developed; they take into account the phenomena of contact interaction in the roll pair of the pressing machine. Hydraulic pressure in the compression zone increases from zero at the initial point of contact to a maximum value at a point lying on the line of centers. The distribution of hydraulic pressure in the recovery zone depends on the position of the water division point. It was revealed that the pattern of change of the removed fluid in the recovery zone depends on the position of the water division point. At the beginning of the recovery zone and up to the point of water division, the fluid flows from the coating into the material, and beyond this point, fluid is reabsorbed from the roll coating, and the amount of fluid removed from the material in the recovery zone is greater than the amount of absorbed fluid.

## 1. Introduction

For many industries, the task of increasing the efficiency of wet materials roll pressing is of great practical importance. For example, in the leather industry, the cost and quality of the output of finished products are related to the efficiency of squeezing the skin. Such solutions are impossible without considering the issues of hydrodynamics of the roll pressing processes, and the modeling of the laws of distribution of hydrodynamic pressure and changes in the removed fluid in the pressing area is of great importance.

Modeling the laws of distribution of hydrodynamic pressure and changes in the removed fluid in the squeezing area was studied in relation to the problems in various industries. In the pulp and paper industry, such studies are aimed at studying the dewatering of paper pulp, in the textile industry - at removing water from various fabrics, in the leather industry - at pressing the semi-finished leather product after tanning or dyeing, in construction - at molding various materials, etc.

An analysis of previous studies [1-30] showed that the mathematical models obtained for the laws of distribution of hydrodynamic pressure and changes in the removed fluid in the squeezing area do not correspond to real diagrams of the distribution of hydrodynamic forces and changes in the removed fluid, and they do not take into account the phenomena of contact interaction in roll pairs. Consequently, they do not allow revealing the physical phenomena of the roll pressing process.

The purpose of this study is to build mathematical models of the laws of distribution of hydrodynamic pressure and changes in the removed fluid in the pressing area, taking into account the phenomena of contact interaction in the roll pair of the squeezing machine.

## 2. Resultative Methods

Consider the generalized scheme of the squeezing machine [12], shown in Fig.1.

In the squeezing machine under consideration, the lower roll is taken as the first roll, and the upper one is the second roll. We consider that in each roll the contact curve consists of two zones separated by a centerline of rolls: the first is the compression zone, and the second is the recovery zone.

The pressed material, fed into the space between the rolls, is deformed under the action of an external load; a hydrodynamic pressure formed in its pores is called hydraulic pressure. It determines the flow of the filtered fluid in the direction opposite to the movement of the material.

*Corresponding author: ladykurbanova@mail.ru

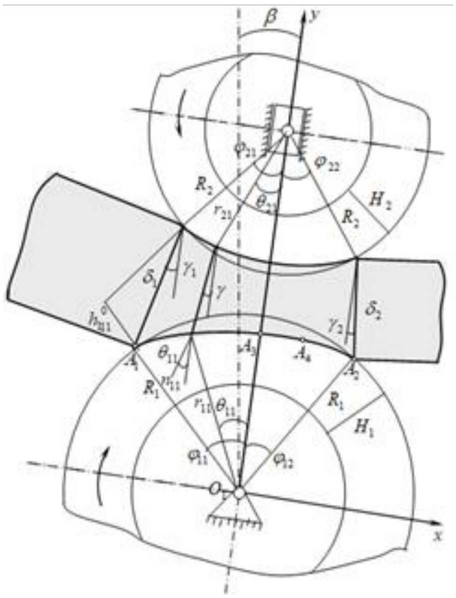


**Fig. 1.** Scheme of squeezing machine

There are various approaches to solving the problem of establishing the value of hydraulic pressure. So, in [5, 6], the law of distribution of hydraulic pressure is considered similar to the law of distribution of total pressure:

$$p_h = \alpha p_g , \tag{1}$$

where $\alpha -$ is a coefficient that determines the ratio of hydraulic pressure to total pressure.
In turn, it is believed [5, 6] that at each point of the roll contact curve, the total pressure is balanced by the compressive and hydraulic pressures:

$$p_g = p_c + p_h . \tag{2}$$

From equalities (1) and (2), it follows that

$$p_h = \frac{\alpha}{1-\alpha} p_c . \tag{3}$$

Due to the small size of the deformation zone, it can be assumed that the compressive load
is distributed according to the law of normal stresses $n(\theta)$ [5].
Then we have

$$p_h = \frac{\alpha}{1-\alpha} n . \tag{4}$$

Given that the squeezing machine under consideration has two rolls and each roll has two zones, for the compression zone of the lower roll we have

$$p_{11h} = \frac{\alpha_1}{1-\alpha_1} n_{11} . \tag{5}$$

It was determined in [26] that the normal stress along the roll contact curve is distributed according to the following law:

$$n_{11} = \frac{n_{1\max}}{2}\left(1+\cos\frac{\theta_{11}+\gamma}{\varphi_{11}+\gamma_1}\pi\right), \quad -(\varphi_{11}+\gamma_1) \le \theta_{11}+\gamma \le 0 , \tag{6}$$

where $n_{1\max} = B_{11}(\varphi_{11}+\gamma_1)^{2m_1^*}$, $B_{11} = A_1^*\left(\frac{R_1 \sin(\varphi_{11}+\varphi_{21})}{2(1+k_{11}\lambda_{11})\delta_1 \sin(\varphi_{21}-\gamma_1)}\right)^{m_1^*}$, $k_{11} = \frac{m_{11}H_1}{m_1^*\delta_1}$,

$m_{11}, m_1^* -$ are the coefficients of hardening of the points of elastic coating of the roll and the processed material; $\lambda_{11}$ - is the indicator that determines the ratio of the strain rate of the roll coating to the strain rate of the material being processed, $A_1^* -$ is the strain coefficient of the material being processed.
From equality (5), considering equality (6), we find

$$p_{11h} = \frac{\alpha_{11} n_{1\max}}{2(1-\alpha_{11})}\left(1+\cos\frac{\theta_{11}+\gamma}{\varphi_{11}+\gamma_1}\pi\right). \quad (7)$$

It is obvious that $\theta_{11}+\gamma=0$, $p_{11h}=p_{1\max h}$, $n_{11г}=n_{1\max}$.
Considering this condition, from equality (6) we obtain

$$\alpha_{11} = \frac{p_{1\max h}}{p_{1\max h}+n_{1\max}}.$$

Substituting $\alpha_{11}$ into equality (7), we obtain

$$p_{11h} = \frac{p_{1\max h}}{2}\left(1+\cos\frac{\theta_{11}+\gamma}{\varphi_{11}+\gamma_1}\pi\right). \quad (8)$$

To determine $p_{1\max h}$, we use the results given in [23]. There, models of the distribution of hydraulic pressure in the process of roller pressing were obtained.
According to [26], we have:

$$P_{11h} = c_{11}((\varphi_{11}+\gamma_1)^2-(\theta_{11}+\gamma)^2), \quad (9)$$

where $c_{11} = \dfrac{\upsilon v_m R_1^2 \cos(\varphi_{11}+\gamma_1)(\varphi_{11}+\gamma_1)^3}{12K_{11\min} h_{11}^0 (1+k_{11}\lambda_{11})(1+k_{11}\lambda_{11}\cos(\varphi_{11}+\gamma_1))}$.

here $v_m -$ is the feed rate of the material, $K_{11\min} -$ is the minimum coefficient of filtration in the direction along the warp threads of the material, $\upsilon -$ is the viscosity coefficient of the squeezed water.
From formula (9), considering condition (7), we obtain:

$$p_{1\max г} = 2c_{11}(\varphi_{11}+\gamma_1)^2. \quad (10)$$

Then from equality (9), we have

$$p_{11h} = b_{11}\left(1+\cos\frac{\theta_{11}+\gamma}{\varphi_{11}+\gamma_1}\pi\right), \quad -(\varphi_{11}+\gamma_1) \le \theta_{11}+\gamma \le 0, \quad (11)$$

where $b_{11} = \dfrac{\upsilon v_m R_1^2 \cos(\varphi_{11}+\gamma_1)(\varphi_{11}+\gamma_1)^5}{12K_{11\min} h_{11}^0 (1+k_{11}\lambda_{11})(1+k_{11}\lambda_{11}\cos(\varphi_{11}+\gamma_1))}$.

According to studies in [12], in the area of recovery of the contact curve of the lower roll, there is a water division point determined by the angle $\varphi_{14}+\gamma_4 = \varsigma_1(\varphi_{12}+\gamma_2)$, $0<\varsigma_1\le 1$; to the left of the water division point the fluid flows from the material to the roll coating, and to the right of it, on the contrary, from the coating to the material.
In view of the foregoing, by analogy with formula (11), we have

$$p_{12h} = b_{12}\left(1+\cos\frac{\theta_{12}+\gamma}{\varphi_{14}+\gamma_4}\pi\right), \quad 0 \le \theta_{12}+\gamma \le \varphi_{12}+\gamma_2; \quad \varphi_{14}+\gamma_4 = \varsigma_1(\varphi_{12}+\gamma_2), \quad (12)$$

where $b_{12} = \dfrac{\upsilon v_m R_1^2 \cos(\varphi_{12}+\gamma_2)(\varphi_{12}+\gamma_2)^5}{12K_{12\min} h_{12}^0 (1+k_{12}\lambda_{12})(1+k_{12}\lambda_{12}\cos(\varphi_{12}+\gamma_2))}$.

Similar to formula (12), we obtain

$$p_{21h} = b_{21}\left(1+\cos\frac{\theta_{21}-\gamma}{\varphi_{21}-\gamma_1}\pi\right), \quad -(\varphi_{11}-\gamma_1) \le \theta_{21}-\gamma \le 0, \quad (13)$$

where $b_{21} = \dfrac{\upsilon v_m R_2^2 \cos(\varphi_{21}-\gamma_1)(\varphi_{11}-\gamma_1)^5}{12K_{21\min} h_{21}^0 (1+k_{21}\lambda_{21})(1+k_{21}\lambda_{21}\cos(\varphi_{21}-\gamma_1))}$;

$$p_{22h} = b_{22}\left(1 + \cos\frac{\theta_{22} - \gamma}{\varphi_{24} - \gamma_4}\pi\right),\ \ 0 \le \theta_{22} - \gamma \le \varphi_{22} - \gamma_2;\ \ \varphi_{24} - \gamma_4 = \varsigma_2(\varphi_{22} - \gamma_2), \tag{14}$$

where $b_{22} = \dfrac{\upsilon v_m R_2^2 \cos(\varphi_{22} - \gamma_2)(\varphi_{22} - \gamma_2)^5}{12K_{22\min} h_{22}^0 (1 + k_{22}\lambda_{22})(1 + k_{22}\lambda_{22}\cos(\varphi_{22} - \gamma_2))}$.

An analysis of the calculated data and curves of hydraulic pressure distribution described by models (11) and (12) showed that they fully correspond to the theoretical conclusions and experimental diagrams of hydraulic pressure given in [5, 13, 23].

As is known [4, 5], the amount of removed fluid flowing along the roll contact curve can be determined by the following expression:

$$dF = -\frac{B\rho K_t}{\upsilon}\frac{\partial p_h}{\partial\theta}d\theta\,, \tag{15}$$

where $B-$ is the width of the material, $\rho-$ is the fluid density, $K_t-$ is the filtration coefficient.

Then for the compression zone of the lower roll, we obtain:

$$dF_{11} = \frac{B\rho}{\upsilon}\cdot\frac{K_{11\min}}{1 - \dfrac{K_{11\max} - K_{11\min}}{K_{11\max}}\vartheta_{11}^2}\frac{\partial p_{11h}}{\partial(\theta_{11} + \gamma_1)}d(\theta_{11} + \gamma_1)$$

or with expression (13)

$$dF_{11} = -\frac{B\rho\pi^2 K_{11\min} b_{11}}{\upsilon(\varphi_{11} + \gamma_1)}\cdot\frac{\theta_{11} + \gamma}{1 - \dfrac{K_{11\max} - K_{11\min}}{K_{11\max}}(\theta_{11} + \gamma)}d(\theta_{11} + \gamma).$$

After integration, we obtain:

$$F_{11} = \frac{B\rho\pi^2 K_{11\max} K_{11\min} b_{11}}{\upsilon(\varphi_{11} + \gamma_1)^2 (K_{11\max} - K_{11\min})}\ln\left(1 - \frac{K_{11\max} - K_{11\max}}{K_{11\max}}(\theta_{11} + \gamma)^2\right) + C_{11}.$$

Expanding the logarithmic function into a series, restricting with terms of second degree

with respect to $(\theta_{11} + \gamma)$ and considering condition $F_{11}(-(\theta_{11} + \gamma)) = 0$, we obtain:

$$F_{11} = \frac{B\rho\pi^2 K_{11\min} b_{11}}{\upsilon}\left(1 - \left(\frac{\theta_{11} + \gamma}{\varphi_{11} + \gamma_1}\right)^2\right). \tag{17}$$

By analogy with expression (17), we determine the patterns of change in the removed fluid that has flowed through the recovery zones of the lower roll and through the surfaces of the upper roll.

They have the following form:

$$F_{12} = \frac{B\rho\pi^2 K_{12\min} b_{12}}{\upsilon}\left(1 - \left(\frac{\theta_{12} + \gamma}{\varphi_{14} + \gamma_1}\right)^2\right); \tag{18}$$

$$F_{21} = \frac{B\rho\pi^2 K_{21\min} b_{11}}{\upsilon}\left(1 - \left(\frac{\theta_{21} - \gamma}{\varphi_{24} - \gamma_2}\right)^2\right); \tag{19}$$

$$F_{12} = \frac{B\rho\pi^2 K_{22\min} b_{22}}{\upsilon}\left(1 - \left(\frac{\theta_{22} - \gamma}{\varphi_{12} + \gamma_1}\right)^2\right). \tag{20}$$

## 3. Conclusions

Mathematical models were developed for the laws of distribution of hydrodynamic pressure and changes in the removed fluid in the squeezing area; these models take into account the phenomena of contact interaction in the roll pairs of squeezing machines.

1. The analysis of the graphs showed that the distribution curves of hydraulic pressure in the squeezing area, described by the developed mathematical models, fully correspond to the theoretical conclusions and experimental diagrams of hydraulic pressure given in the studies of other researchers.
2. Hydraulic pressure in the compression zone increases from zero at the initial point of contact to a maximum value at a point lying on the line of centers. The distribution of hydraulic pressure in the recovery zone depends on the position of the water division point.
3. The pattern of change in the removed water in the squeezing area depends on the position of the water division point. At the beginning of the recovery zone and up to the water division point, the fluid moves from the coating into the material, and beyond this point, water is reabsorbed from the roll coating, and the amount of fluid removed from the material in the recovery zone is greater than the amount of absorbed fluid.

## References

1. J.A. Dunford, P.M. Wild, Cyclic transverse compression of single wood pulp fibers, *Journal of pulp and paper science* **28**, 4 (2002)
2. D. Bežanović, C.J. Van Duijn, E.F. Kaasschieter, Analysis of Wet Pressing of Paper: The Three-Phase Model. Part II: Compressible Air Case, *Transp Porous Med* **67**, 171–187 (2007)
3. Sh.R. Khurramov, F.S. Khalturaev, Simulation of contact stresses in two-roll modules, *IOP Conf.Series: Earth and Environmental Science* **614**, 012097 (2020)
4. Sh.R. Khurramov, G.A. Bahadirov, E.S. Buriev, D.N. Abdukhalikova, Modeling of the roller pressing of fibrous materials, *E3S Web of Conference* **264**, 01019 (2021)
5. G.K. Kuznetsov, Research and methodology for designing roll squeezing devices for textile machines, Doc. Tech. Sci. Diss., Kostroma (1970)
6. N.E. Novikov, Pressing of paper web, Science, Moscow (1998)
7. V.S. Paramonov, The study of transport mechanisms in relation the creation of new skinning and similar roller machines for leather production, Cand. Tech. Sci. Diss., Moscow (1973)
8. S. Khurramov, F. Khalturaev, F. Kurbanova, *E3S Web of Conferences* **376**, 01053 (2023)
9. Yu.G. Fomin, Development of theoretical foundations and means to improve efficiency of processing of fabrics with roll modules of finishing machines, Dis. … Doc. Tech. Sci., Moscow (2001)
10. Sh.R. Khurramov, Filtration rates in roller pressing of fibrous materials, *AIP Conference Proceedings* **2402**, 030042 (2021)
11. Sh.R. Khurramov, F.S. Khalturaev, E.S. Buriev, Residual moisture content in semi-finished leather under roller pressing, *AIP Conference Proceedings* **2402**, 030038 (2021)
12. S.A. Polumiskov, Roll impregnator research and development of the method for calculating its design and technological parameters, Cand. Tech. Sci. Diss., Ivanovo (1997)
13. K. Turgunov, N. Annaev, A. Umarov, Optimizing the parameters of leather pressing machines, *Journal of Physics: Conference Series* **2373**, 072006 (2022)
14. Sh.R. Khurramov, A. Abdukarimov, F.S. Khalturayev, F.Z. Kurbanova, Modeling of friction forces in an asymmetric two-roll module, *IOP Conf. Series: Materials Science and Engineering* **916**, 012051 (2020)
15. O.P. Maksimenko, A.A. Nikulin, R.Ya. Romanyuk, Theoretical analysis of the gripping ability of rolls in steady state rolling, *News of universities. Ferrous metallurgy* **10**, 2008 (2008)
16. Sh.R. Khurramov, A. Abdukarimov, F.S. Khalturayev, F.Z. Kurbanova, Modeling of friction stress in two roll modules, *Journal of Physics: Conference Series* **1789**, 012008 (2021)
17. A. Kavalek, Forming of band curvature in asymmetrical rolling process, *Journal of Materials Processing Technolody* **155**, 2033-2038 (2004)
18. A. Kavalek et al., The analysis of the asymmetric plate rolling process, *Materials Science Forum* **706-709**,1438-1443 (2012)
19. A. Amanov, S.R. Khurramov, G.A. Bahadirov, A. Abdukarimov, T.Y. Amanov, Modeling of strain and filtration properties of a semi-finished leather product, *Journal of Leather Science and Engineering* **3(1)**, 14 (2021)
20. S. Khurramov, B. Abdurakhmonov, Contact Problems of the Theory of Roller Squeezing of Leather, *AIP Conference Proceedings* **2637**, 060003 (2022)
21. R.J. Clos, L.L. Edwars, I. Gunaman, A limiting consistency model for pulp dewatering and wet pressing, *Tappi Journal* **77**, 179-187 (1994)
22. M.V. Kolychev, N.N. Kokushin, Study of the deformation properties of press felt in paper making machines, *Cellulose Paper Cardboard* **6**, 68-72 (2015)

23. V.A. Nikolaev, A.A. Vasilyev, Analysis of Strip Asymmetrical Cold Rolling Parameters, *Metallurgical and Mining Industry* **2,** 405-412 (2010)
24. S. Khurramov, F. Khalturaev, F. Kurbanova, Deformation and Filtration Characteristics of a Leather Semi-Finished Product, In: A.G. Kravets, A.A. Bolshakov, M. Shcherbakov, (eds) Cyber-Physical Systems: Design and Application for Industry 4.0. Studies in Systems, Decision and Control, vol 342. Springer, Cham (2021)
25. D. McDonald, R.J. Kerekes, J. Zhao, Perspectives on deriving mathematical models in pulp and paper science, *BioResources* **15**, 7319-7329 (2020)
26. O. Iliev, G. Printsypar, S. Rief, On mathematical modeling and simulation of the pressing section of a paper machine including dynamic capillary effects: One dimensional model, *J Transport in Porous Media* **92**, 41-59 (2012)
27. S. Khurramov, F. Kurbanova, Hydraulic Problems of the Theory of Roller Pressing Hides, *AIP Conference Proceedings* **2637**, 060004 (2022)
28. E. Balan etal., Preventive maintenance features specific to offset printing machines, *MATEC Web of Conferences* **343**, 08012 (2021)
29. Sh.R. Khurramov, F.S. Khalturaev, F.Z. Kurbanova, Theoretical analysis of the conditions of capture in an asymmetric two-roll module, *Teknologiya Tekstil'noi Promyshlennosti* **4**, 2021 (2021)
30. G. Bahadirov, G. Tsoy, E. Nabiev, A. Umarov, Experiments on Moisture Squeezing from a Leather Semi-Finished Product, *Int. J. Recent Technology and Engineering* **8**, 3367-3371 (2020)