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Mathematical Modeling of Screw Press Configuration for Processing Safflower Oil

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Abstract: This article is devoted to modeling the pressing process of an experimental screw press for safflower oil production in small enterprises of the grain processing industry. The theoretical analysis for developing the process of oil pressing in a screw press is considered. Using methods of mathematical modeling, the problem of squeezing the liquid phase from dispersed material is described and solved. The basic scheme and characteristics of the press equipment and the principle of its work are presented. The proposed method of the theoretical calculation of the pressing process helps to determine the optimal parameters and to press safflower oil using the proposed design of the screw press. During the process of pressing, the highest value of oil yield is reached at the diaphragm gap of δ = 0.1 mm and screw rotation speed of ω = 6.2 rad/s.

Keywords: equipment; press; screw; pressing cage; safflower; vegetable oil

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Citation: Mursalykova, M.; Kakimov, M.; Kassenov, A.; Iskakov, B.; Sergibayeva, Z.; Kaspakov, E.; Zhumadilova, G.; Shulenova, A.; Kokayeva, G.; Suychinov, A. Mathematical Modeling of Screw Press Configuration for Processing Safflower Oil. *Appl. Sci.* **2023**, *13*, 3057. https://doi.org/10.3390/app13053057

Academic Editor: Alberto Regattieri

Received: 7 November 2022
Revised: 10 February 2023
Accepted: 24 February 2023
Published: 27 February 2023

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1. Introduction

The oil and fat industry takes one of the leading positions in the food complex of Kazakhstan, which is associated with both the diversity and uniqueness of oil and fat raw materials and the important role of oils in human nutrition. Today, the oil and fat industry complex of the Republic of Kazakhstan is an integrated system of technologically and economically interconnected industries of the agro-industrial complex [1,2].

The technology of producing vegetable oils consists of various processes of oil raw material treatment. Mechanical processes are a significant part of this technology. Processes such as the cleaning of seeds from impurities, the destruction and separation of fruit and seed shells from the embryo and endosperm-kernel, and the grinding of the kernel and intermediate products of its processing are mainly mechanical processes, preparing the material for intensive physical and chemical transformations [3,4].

Recently, there is an increased interest in the use of new types of cultivated plants, which differ from traditional ones in the complex of features and useful properties. Safflower has an important role among the perspective of plant food resources, which in the future can compete with the traditionally known oil-bearing crops [5,6].

Safflower is a crop with a long history: for many centuries, this plant has been used to produce both dye from its petals and oil from its seeds. Safflower oil is a unique product of plant origin, the chemical composition of which allows it to be used for medical and cosmetic purposes, and for the production of food products. Taking into account its

biological values and rich composition of vitamins and phospholipids, the production of safflower oil is currently an urgent task [7–9].

One of the main methods in the production of vegetable oil is the pressing method. Most modern presses are constructed for pressing specific oils from individual crops. Therefore, it is very difficult to readjust this equipment for another crop, because the oil would then be pressed less efficiently. This is unacceptable for small-capacity facilities. A universal press for pressing oil from both low- and high-oil-bearing crops is needed [10,11]. The screw press is the most universal and low-cost process. However, screw presses are low-productivity machines compared to solvent extractors and consume more power and energy per ton of oil extracted than solvent extractors. The oil obtained by screw pressing is used either as a food product or as an industrial product [12–14]. Screw units are used in the oil industry and are one of the most efficient working elements of press machines. Screw units are used as versatile work tools for the simultaneous and continuous operation of multiple processes [15,16].

Modern methods of analysis of oil pressing processes are based on complex mathematical descriptions expressed by differential equations. This causes complexity in solving and obtaining information about the technical parameters of the described processes. Mathematical modeling can be an effective way to calculate the technological parameters of pressing [17,18].

The development of modern high-efficiency pressing equipment for pressing vegetable oils requires the use of more advanced calculation methods, as well as mathematical modeling of the influence of various design parameters, considering the change in the properties of the pressed material. The purpose of this work is to mathematically calculate the pressing process depending on the configuration of the screw and the pressing cage.

2. Materials and Methods

2.1. Samples

The seeds of safflower sort "Ahram" are used as a research object, and were preliminarily peeled. The weight of the loaded seeds is 5 kg, and the initial moisture content is 12%.

2.2. Description of the Press Equipment

The oil press RAWMID Dream Modern was used to press safflower, which comprises a frame, pressing screw, cone-shaped pressing cage, pressure-regulating mechanism in the pressing chamber, and a loading hopper (Figures 1 and 2).

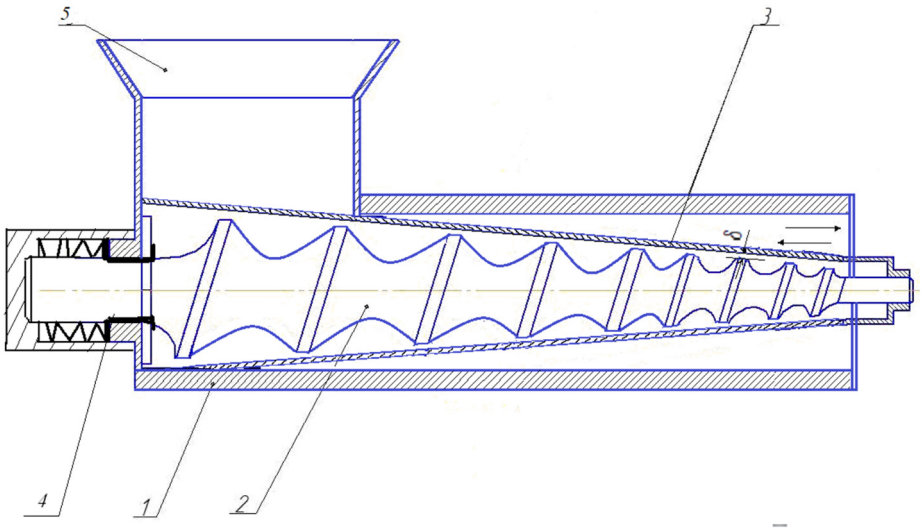


Figure 1. Structural scheme of the press for safflower oil production. 1—frame; 2—screw; 3—pressing cage; 4—pressure regulator mechanism; 5—loading hopper.

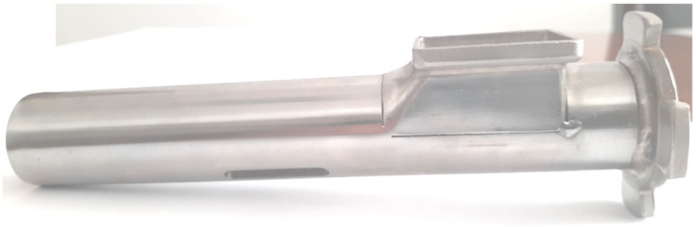


Figure 2. Pressing cage.

The screw is made of stainless steel with a total length of 0.20 m and a diameter of 0.16 m. The screw spiral has a constant spacing of 0.02 m, the coils have a constant thickness of 0.008 m, and the depth of the spacing is equal to a constant value (Figure 3).

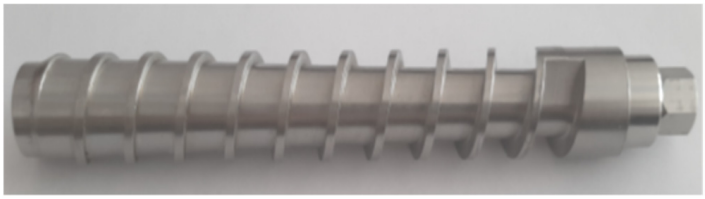


Figure 3. Pressing screw.

The design of the operating device is made with a regulating mechanism, which ensures optimum pressure delivery to each turn of the screw. In this mechanism, the screw press is designed as a back-and-forth motion. Based on the cone shape of the outer and inner diameters of the screw shaft, the reciprocating movement of the screw narrows parts of the gap between the pressing cage and the pressing screw. This design creates a condition for narrowing the section of each turn and at the same time provides a two-way side pressure on the raw material.

The pressure control mechanism consists of a spring, a locking nut, a check nut, two sliding lugs and washers, and a rubber sealing ring (Figure 4).

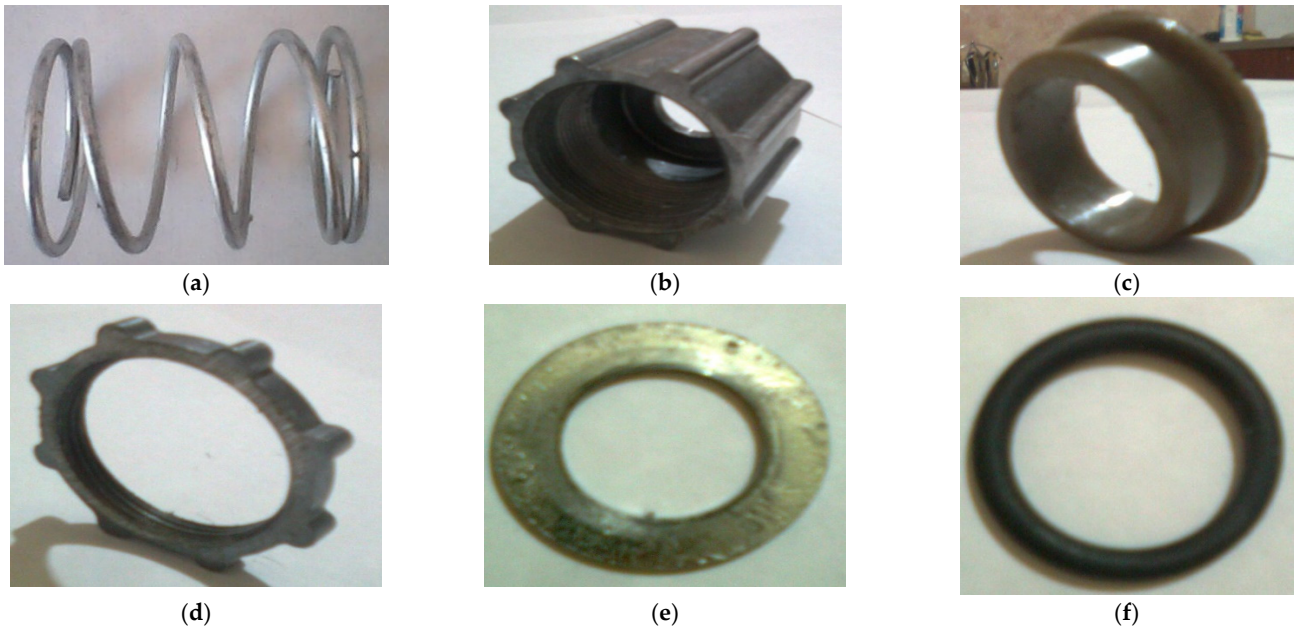


Figure 4. Pressure control mechanism: (**a**) pressure control spring; (**b**) lock nut; (**c**) sliding tip; (**d**) control nut; (**e**) washer; and (**f**) sealing ring.

The press works as follows: Peeled safflower seeds from the feed hopper enter the pressing chamber. The pressure rises as a result of the gradual reduction of the inner diameter of the pressing screw on the safflower. Oil is extracted through the cone-shaped openings of the pressing cage. The pressure required for oil separation is regulated on the basis of a specially designed pressure control mechanism.

The following dependencies were investigated during the improvement of the pressing process:

- Study of the effect of changing speeds (ω = 5.2 rad/s; ω = 6.2 rad/s; ω = 6.8 rad/s; and ω = 7.3 rad/s) on the duration of pressing;
- Study of the effect of changing the initial and final diaphragm gap between the screw and the pressing cage ($\delta = 1 \times 10^{-3}$ m; $\delta = 3 \times 10^{-3}$ m; $\delta = 5 \times 10^{-3}$ m; and $\delta = 7 \times 10^{-3}$ m) on the pressing pressure.

2.2.1. Determination of the Density of Safflower Cake

Three loads of 5 g of cake were placed in a mesh basket made of stainless steel with a thickness of 0.6 mm.

Before the test, the weight of the mesh basket with hangers was measured. Then, it was placed in a measuring cup, which is filled with ethyl ether, which is in a thermostatic vessel with a water temperature of 20 ± 0.5 °C. The ether in the beaker was stirred to remove air bubbles from the mesh basket with the cake. The readings of instrumental scales were set by means of weights, which were hinged on the arm of a beaker.

The volume of safflower cake in each sample V (m^3) was determined by the Equation (1):

$$V = \frac{m_\Gamma - m_\Pi}{\rho_ж} \quad (1)$$

where m_Γ and m_Π are the mass, respectively, of the load and the sample, kg; and $\rho_ж$ is the density of ether at 20 °C, kg/m^3.

The density of safflower cake in each sample ρ (kg/m^3) was found by the Equation (2):

$$\rho = \frac{m}{V} \quad (2)$$

where V is the volume of sample, m^3; and m_H is the weight of sample, kg.

The density of dry safflower cake ρ_c (kg/m^3) was found by the Equation (3):

$$\rho_c = \frac{\rho \times (100 - V)}{100 - W\rho} \quad (3)$$

where W is the moisture content of safflower cake, %.

2.2.2. Determination of Yield Stress

Determination of the yield stress was carried out on a cone penetrometer "Structurometer ST 2" ("Radius" firm, Moscow, Russia). A cone indenter with an apex angle of 45° was used to analyze the yield stress of the cake [19]. The yield stress θ (in Pa) was determined from the depth of cone immersion and calculated by Equation (4):

$$\theta = K \times \frac{F}{h^2} \quad (4)$$

where F is the load value, N; h is the total immersion depth of the cone, m; and K is the cone constant depending on the angle of the cone α at the apex.

2.2.3. Statistics

The data obtained from the study are the results of triplicate measurements. The results of measurements were analyzed using XlStat 2020 (Addinsoft Inc., Lille, France).

The differences between the samples were evaluated using a one-way ANOVA; $p < 0.05$ was considered statistically significant.

3. Results and Discussion

3.1. Construction Features of the Screw Press

The equipment for oil separation works as follows: peeled safflower seeds from the feed hopper enter the pressing chamber. The pressure is generated by the gradual reduction of the inner diameter of the pressing screw on the raw material in the direction of the product flow, and the oil is released through the cone-shaped openings of the pressing cage. The pressure required for oil separation is regulated on the basis of a specially designed pressure control mechanism.

During the experiment, it was observed that, under the initial conditions, the yield of safflower oil increased when the moisture content was reduced, the size of the oil outlet channel was reduced, and the rotational speed was decreased. However, this is not enough to obtain the optimal parameters of the process under consideration.

For making the final decision on the selection of the optimal modes of the studied process, it is necessary to conduct a series of experiments on the change of humidity, pressure, and temperature. In this case, the screw rotation frequency is taken to be equal to 65 rpm; at this value, there is an increase in oil yield. It is noted that when humidity decreases below 8%, there is a decrease in the yield of safflower oil due to the increased temperature of the oil press, since oil " burning" occurs. Increasing humidity above 10% also reduces oil yield, as excess moisture makes it difficult to compress the oilcake effectively. Figure 5 shows the safflower oil and cake after the pressing process.



(**a**) (**b**)

Figure 5. Safflower processing products: (**a**) safflower oil; (**b**) oilcake.

Installing the pressure regulator mechanism in the press design intensifies the pressing process, increases oil yield, reduces energy consumption, and improves oil quality.

3.2. Mathematical Modeling of the Separation and Output Dependence during the Pressing Process

For the calculation, it is necessary, first of all, to replace the existing press with its calculation (model) scheme. All features of the existing press that are not essential must be excluded from the model scheme, and only those that are principal to the calculation of the process and the unit must be retained, giving a comparatively simple model of the press machine.

Considering the motion of a viscous medium, the Navier–Stokes equation [20] is written as (Equation (5)):

$$\begin{aligned}
\frac{\partial v_x}{\partial \tau} + v_x\frac{\partial v_x}{\partial x} + v_y\frac{\partial v_x}{\partial y} + v_z\frac{\partial v_x}{\partial z} &= F_x - \frac{1}{\rho}\times\frac{\partial p}{\partial x} + \nu\left(\frac{\partial^2 v_x}{\partial x^2} + \frac{\partial^2 v_x}{\partial y^2} + \frac{\partial^2 v_x}{\partial z^2}\right),\\
\frac{\partial v_y}{\partial \tau} + v_x\frac{\partial v_y}{\partial x} + v_y\frac{\partial v_y}{\partial y} + v_z\frac{\partial v_y}{\partial z} &= F_y - \frac{1}{\rho}\times\frac{\partial p}{\partial y} + \nu\left(\frac{\partial^2 v_y}{\partial x^2} + \frac{\partial^2 v_y}{\partial y^2} + \frac{\partial^2 v_y}{\partial z^2}\right),\\
\frac{\partial v_z}{\partial \tau} + v_x\frac{\partial v_z}{\partial x} + v_y\frac{\partial v_z}{\partial y} + v_z\frac{\partial v_z}{\partial z} &= F_z - \frac{1}{\rho}\times\frac{\partial p}{\partial z} + \nu\left(\frac{\partial^2 v_z}{\partial x^2} + \frac{\partial^2 v_z}{\partial y^2} + \frac{\partial^2 v_z}{\partial z^2}\right),
\end{aligned} \tag{5}$$

where v is the kinematic viscosity, m^2/s; and F_x,F_y, and F_z are the mass force projections on the co-ordinate axes.

To solve the problem of continuum mechanics, the Poisson equation [21] can be written as follows (Equation (6)):

$$\frac{\partial^2 v_Z}{\partial x^2} + \frac{\partial^2 v_Z}{\partial y^2} = -\frac{\Delta p}{\eta_{эф} l}, \tag{6}$$

where $\eta_{эф}$ is the effective viscosity, Pa·s; Δp is the pressure difference, Pa; and l is the channel length, m.

To determine the volumetric capacity, let us calculate the double integral:

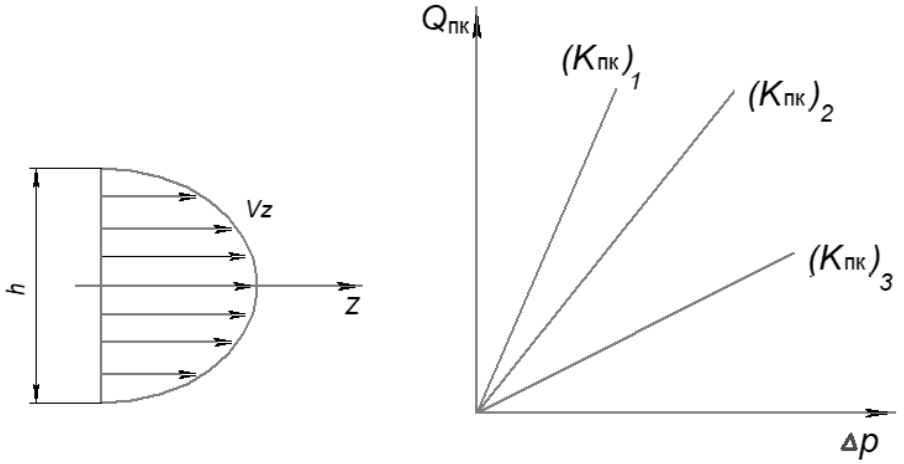
$$Q = \int_0^H \int_0^W \vartheta_z dx dy,$$

where Q is the press capacity, m^3/s; and v is the velocity along the channel axis, m/s.

Using Poisson's equation, let us determine the productivity of the screw channel at idle running without the impact of an extraneous mechanism, taking into account the geometric features of the screw channel (Figure 6, Equation (7)):

$$Q_{ПК} = \frac{K_{ПК}}{\eta_{эф}}\Delta p, \tag{7}$$

where $K_{ПК}$ is the pressing channel coefficient; $\Delta\rho$ is the pressure drop in the matrix forming device, Pa; and $\eta_{эф}$ is the effective viscosity, Pa·s.



(**a**) (**b**)

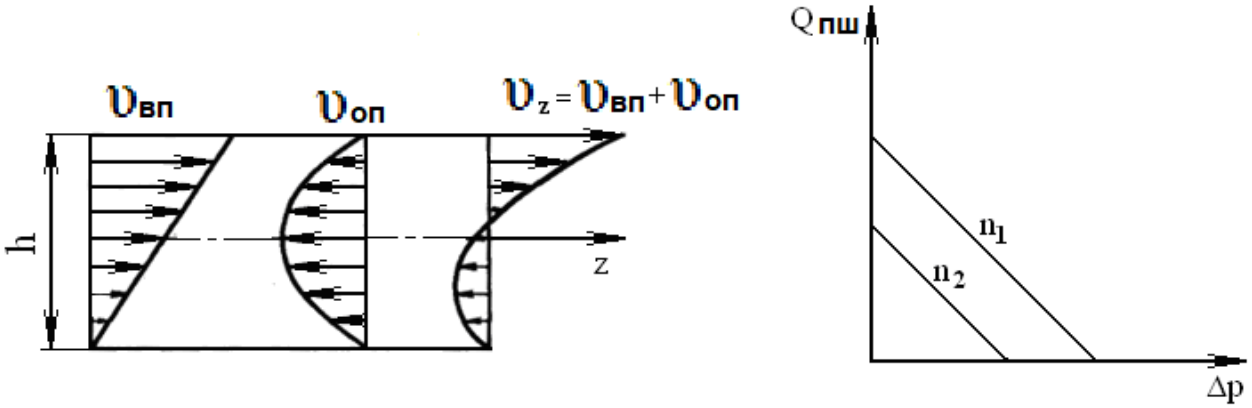
Figure 6. Dependence of pressing channel coefficient (**a**) on capacity and pressure at free running of the pressing screw (**b**).

This case in the presence of Δp has already been considered in the calculation of the pressing channel. Solving Equations (1) and (2) together, we obtain the following solution (Equation (8)):

$$\upsilon_Z = \frac{4\times\upsilon}{\pi}\sum_{m=1,3,5}^{\infty}\frac{1}{m}\times\frac{Sh\left(\frac{\pi m y}{w}\right)}{Sh\left(\frac{\pi m H}{w}\right)}\times\sin\left(\frac{\pi m x}{w}\right)-\frac{1}{\eta}\times\frac{dp}{dz}\times$$
$$\times\left\{\frac{y^2}{2}-\frac{yH}{2}+\frac{4\times H^2}{\pi^3}\times\sum_{m=1,3,5}^{\infty}\frac{1}{m^3}\times\frac{ch\left[\frac{\pi m(2x-w)}{2H}\right]}{ch\left(\frac{\pi m w}{x}\right)}\times\sin\left(\frac{\pi m y}{H}\right)\right\} \quad (8)$$

where F is the cross-sectional area of the selected layer, m^2; S_H is the perimeter of the layer along the inner cavity of the pressing cage, m; dz is the length of the elementary layer, m; and d is the screw shaft diameter, m.

In this equation, the first term characterizes the forced flow generated by the moving walls, and the second term characterizes the velocity distribution in the flow (Figure 7).



(**a**) (**b**)

Figure 7. Drawing of the total speed diagram over the height of the screw channel (**a**) and the performance of the press screw for two values of speeds (**b**). $\upsilon_{B\Pi}$—direct flow rate; $\upsilon_{O\Pi}$—back flow rate; υ_z—sum of speeds.

If we introduce the coefficients of the geometry of the pressing screw of forced flow $K_{B\Pi}$ and reverse flow $K_{O\Pi}$, then we determine the capacity of the pressing screw as follows (Equation (9)):

$$Q_\Pi = K_{B\Pi}n - \frac{K_{O\Pi}}{\eta_{эф.}}\Delta p, \quad (9)$$

where $Q_{\Pi\Pi\Pi}$ is the capacity of the pressing screw, kg/h; $K_{B\Pi}$ is the forced flow coefficient; $K_{O\Pi}$ is the reverse flow coefficient; Π is the screw rotation speed, rpm; $\eta_{эф}$ is the effective viscosity, Pa·s; and $\Delta\rho$ is the pressure drop in the matrix forming device, Pa.

Figure 8 shows the volumetric flow rate of total oil passing through the holes of the pressing cage at the smooth movement of the screw, m^3/s. This equation (Equation (10)) describes the geometric shape of the holes of the pressing cage.

$$Q = K\frac{\Delta p_{\max}}{\eta_M}, \quad (10)$$

where $Q_{ЗЦ}$ is the volumetric flow rate, m^3/s; and K is the geometric coefficient of the pressing cage.

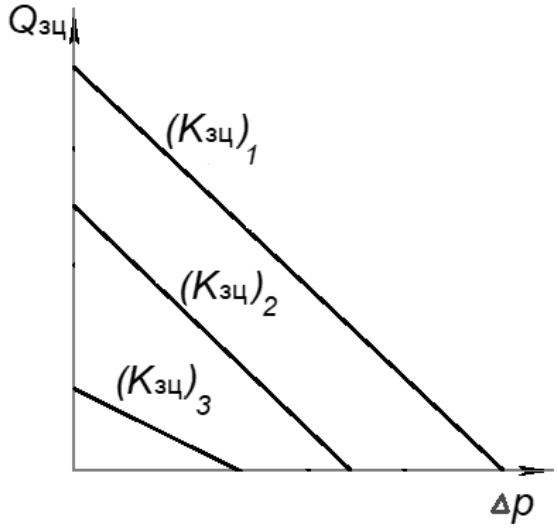


Figure 8. Dependence of pressing cage coefficient on capacity and pressure.

The pressure difference on the longitudinal axis of the screw for oil separation during pressing is determined by the expression (Equation (11)):

$$\Delta p_{\max} = q_\rho \frac{Q_\Pi}{K_3} \eta_{эф}, \tag{11}$$

where $\Delta p_{\max}$ is the pressure difference, Pa; and q_p is a qualitative indicator of the extraction of a certain amount of oil.

For the determination of the material flow rate of oil production, this equation describes the narrowing of the screw channels as a result of the geometric shape of the holes of the pressing cage and the mechanism of the pressure regulator (Equation (12)).

$$Q_M = \frac{K_{\Pi K} K}{K_{\Pi K} + K} n, \tag{12}$$

where Q_M is the oil capacity, kg/h; $K_{\Pi K}$ is the pressing channel coefficient; K is the pressing cage cylinder coefficient; and n is the screw rotation speed, rpm.

From here, we determine the material flow rate of the productivity of the cake (Equation (13)):

$$Q = \frac{K_{B\Pi} K_{\Pi K}}{K_{O\Pi} + K_{\Pi K}} n, \tag{13}$$

where Q is the cake yield, kg/h; $K_{\Pi K}$ is the pressing channel coefficient; K is the pressing cage cylinder coefficient; and n is the screw rotation speed, rpm.

Using the obtained equations and nomograms, according to the figure below, we draw a nomogram determining the productivity of the cake and separated oil, depending on the geometric features of the oil press equipment (Figure 9).

3.3. Study on the Dependence of the Oil Content of Safflower on Various Parameters in the Pressing Process

The main purpose of the work is to determine the optimal ways of safflower oil production to improve the oil press. Pressing the product by screw alone cannot provide the optimal pressure required for the process. Therefore, the press is additionally equipped with a regulating mechanism that creates pressure in the pressing chamber.

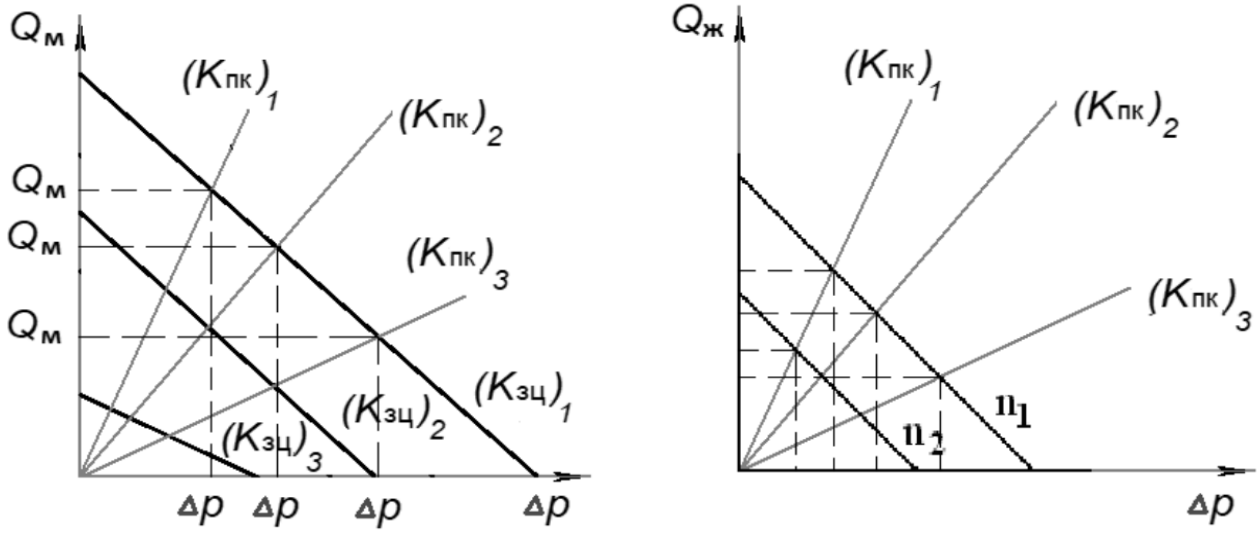


Figure 9. Graph of determining the capacity of a screw press for oil (**a**) and cake (**b**) depending on the press channel and pressing cage.

Figure 10a shows a schematic diagram of the pressure control mechanism for a traditional press. When this mechanism is adjusted, additional pressure is created in the press chamber by narrowing the size of the outlet slot. Due to the narrowing, the pressure is distributed to the product as it moves backward through the screw spiral channel. This pressure distribution cannot ensure a uniform pressure distribution in the screw turns [22,23].

Since the product is exposed to an additional mass-exchange process during pressing, the structural and mechanical properties of the product change at each section of the screw turn [24,25]. If, in the initial stage, the granular product becomes viscoplastic, then at the end of the pressing, it changes from viscoplastic to a semi-dry product. The change in the state of the product leads to an uneven pressure distribution, thereby causing a pressure jump. During the pressure jump, the pressure required to extract the oil from the product may be insufficient or exceeded [26,27]. In other words, this mechanism cannot provide the optimum pressure required for the pressing process.

Considering these disadvantages of the pressing screw in Figure 10b, an experimental screw with a regulating mechanism is proposed, which provides an optimal pressure supply to each turn of the screw [28]. In this mechanism, the screw press is designed as a reciprocating motion. Based on the conical shape of the outer and inner diameter of the screw shaft, the gap between the pressing cage and the pressing screw is narrowed by the reciprocating motion. This design creates the condition for narrowing the cross-section of each turn and at the same time ensures that the two-sided lateral pressure is applied to the raw material.

3.4. Determination of Safflower Cake Density

In the next stage, we determined the density of the cake depending on the change in the gap and screw speed. It should be noted that with an increase in the number of screw revolutions, there is a slight increase in the density of the cake. Therefore, if, at a revolution of 5.2 rad/s and a gap of 1 mm, the cake density was 1097 kg/m^3, increasing to 7.3 rad/s leads to an increase in density to 1120 kg/m^3 (Figure 11). The same tendency is observed with increasing the rotation of the screw. Increasing the speed of the screw leads to an increase in the press throughput. However, the residual oil content in the cake will be higher because less time is spent on squeezing oil from the safflower seeds [29,30].

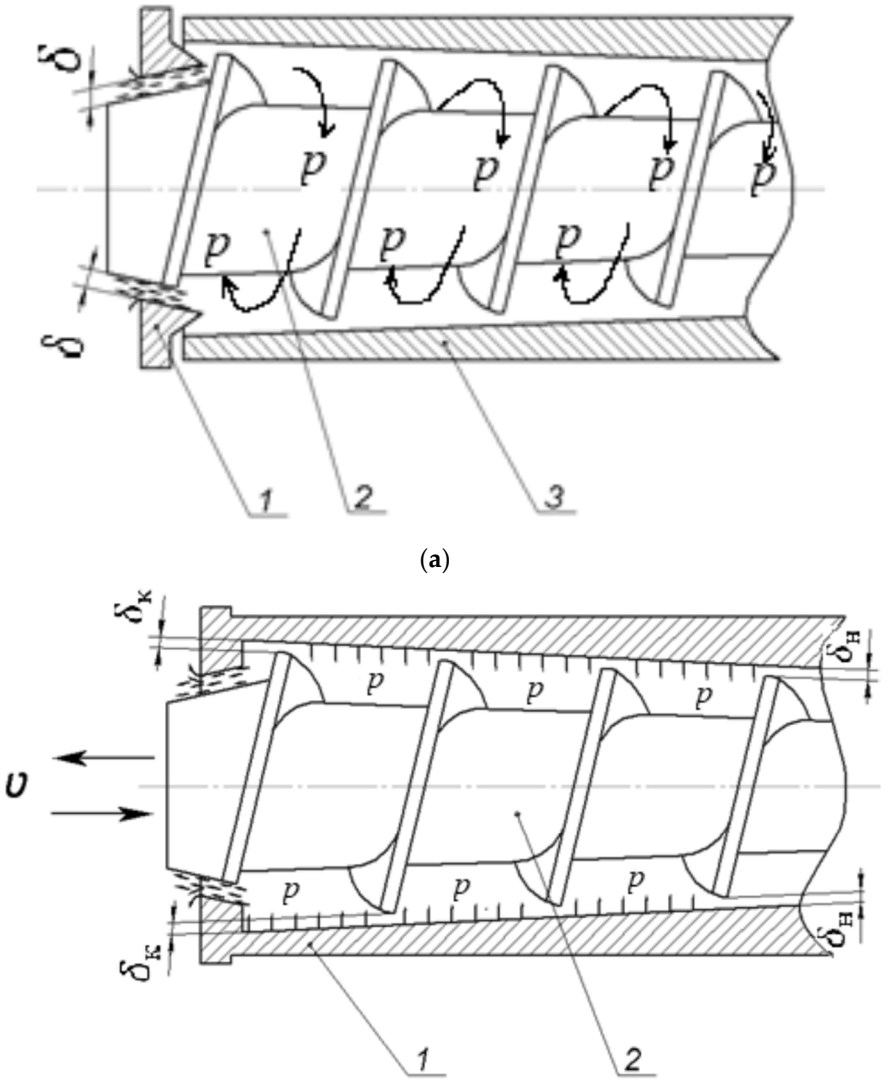


Figure 10. Design of the traditional press screw (**a**) δ—output slit; p—the longitudinal pressure generated by the output slit; 1—regulating mechanism; 2—pressing screw; 3—pressing cage and the experimental screw (**b**) P—lateral pressure resulting from the narrowing of the gap; ϑ—back-and-forth movement of the screw; δ_H, δ_K—initial and final gap between the screw and the pressing cage; 1—pressing cage; 2—pressing screw.

At a constant rotation of the screw, but changing the diaphragm gap from 1 mm to 7 mm, the density of the cake increases significantly. However, it should be noted that at a gap of 3 mm, the density of the cake decreases in comparison with a gap of 1 mm. Therefore, if we consider the option at which the screw rotation is constant (6.2 rad/s), then, at a gap of 1 mm, the cake density was 1105 kg/m^3, and, at 3 mm, it decreased to 1057 kg/m^3. However, at gaps of 5 mm and 7 mm, the density increased to 1162 kg/m^3 and 1218 kg/m^3, respectively. When the gap is reduced (the size of the nozzle), the pressure in the press chamber increases, which leads to an increase in oil yield. The increase in pressure is because more force is required to overcome the smaller gap [31,32].

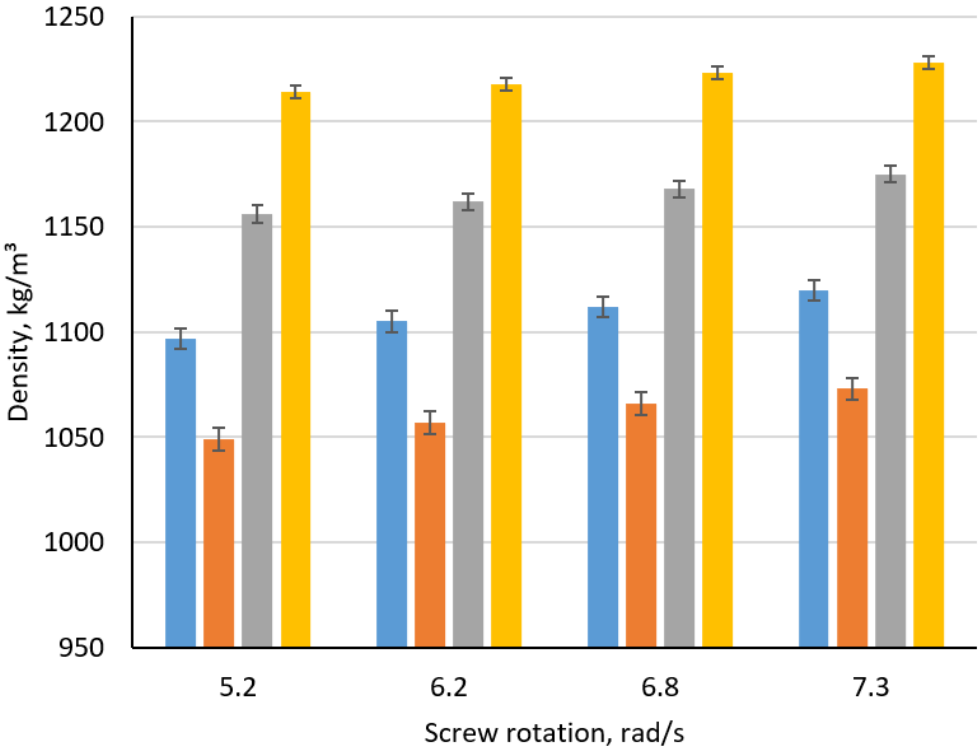


Figure 11. Influence of screw rotation speed and diaphragm gap on cake density.

Change of Rheological Properties Depending on Oil Content and Temperature of Safflower Cake

The rheological characteristics of the raw material, which depend on such factors as the fat content of the initial product and the temperature of pressing, are a determining parameter in the pressing process [33,34]. An analysis of the dependence of the rheological characteristics on the temperature and oil content of the safflower cake will allow us to consider the behavior of oil-bearing raw materials inside the screw press, and the impact of the temperature gradient on oil yield.

The rheological properties of the oilcake were studied within the temperature range of 20 to 80 °C. The temperature of 80 °C was taken as the upper investigated limit, which approximately corresponds to the beginning of the denaturation of proteins and the oil raw material from the viscoplastic state to the elastic state. The effect of the beginning of protein denaturation is expressed in the breaking of the solidity of the oil-bearing raw material [35,36].

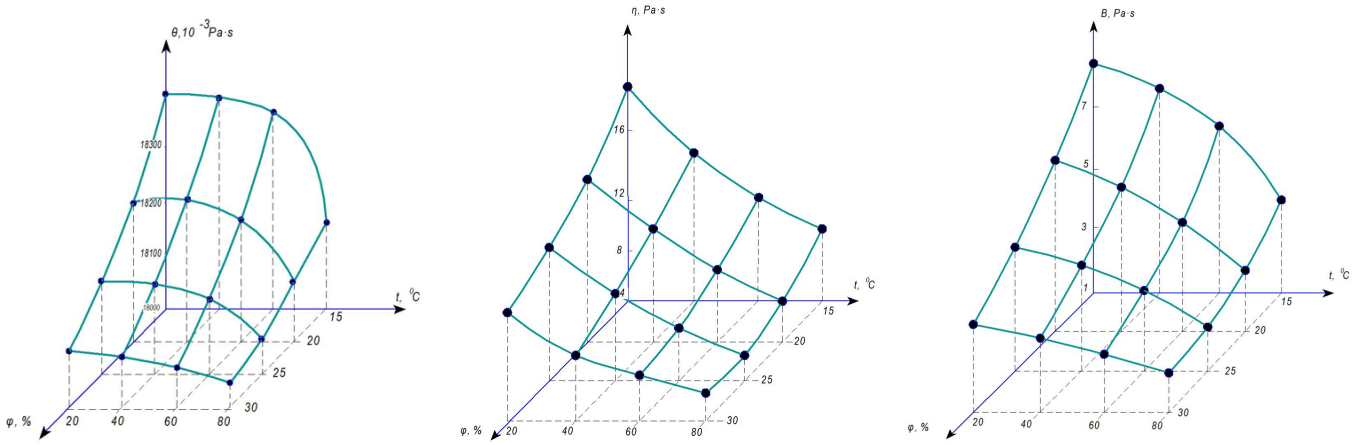
In the process of pressing, the yield stress was measured depending on the cake's temperature and oil content. It was found that the yield stress index decreases as the temperature of the raw material increases. Thus, if, at 20 °C, the yield stress of the cake was 18,200 Pa, when increasing the temperature to 80 °C, the yield stress decreased to 18,100 Pa, with a fat content of 30%. It should be noted that the lower the oil content of the product, the higher the yield stress. At 15% oil content, the yield stress was 18,430 Pa, while at 30% oil content, the yield stress decreased to 18,200 Pa (Figure 12).

The same trend is observed for plastic viscosity. The lower the raw material's temperature and oil content, the higher the plastic viscosity. At 20 °C and 15% oil content the viscosity was 18 Pa*s, while at 353 K and 30% oil content, the viscosity dropped significantly to 6 Pa*s.

The analysis of the graphs shows that increasing temperature causes a decrease in the values of all rheological properties, except for the rate of structure destruction. With increasing temperature, the bonds in the water–protein–salt interlayers weaken due to the molecules' more intensive thermal movement. This leads to the weakening of the strength

of the structure as a whole. In addition, diffusion–osmotic processes also seem to influence temperature changes in the structure strength [37].

The increase in the rate of structure destruction at 40–60 °C is due to the more rapid breakdown of the structure (its strength decreases). The reduction in the rate at 60–80 °C is due to the beginning of the denaturation processes that prevent the destruction of the structure.



(**a**) (**b**) (**c**)

Figure 12. Change of rheological characteristics depending on oil content (φ) and temperature (t) of safflower cake: (**a**) yield stress; (**b**) plastic viscosity; and (**c**) rate of structure destruction.

3.5. Dependence of Oil Content of Safflower on Screw Rotation Speed and Diaphragm Gap

Safflower seeds used for the experimental studies were preliminarily peeled. After finishing the separation of the husk from the kernel, the total protein and lipid fraction of the safflower seed was removed and subjected to pressing. Preliminary separation of the husks from the kernel helps to increase the oil content of the processed oil raw materials [38,39]. The raw material is cleared of low-oil-bearing components and the relative oil content in it increases.

At the same time, the productivity of the technological equipment increases, because the working volume of machines and devices are not loaded with ballast low-oil-bearing material—the husks. Oil quality increases, because when the husks are removed, husk lipids rich in waxes and wax-like substances do not enter the oil [40]. Their presence in oil deteriorates its commodity appearance; a suspension or "grid" of small wax crystals appears, which can be removed due to the chemical inertness of waxes as a result of the long oil treatment.

The removal of husks is necessary to simplify the process of pressing, as the mechanical strength of the husks compared to the kernel is quite high and their presence causes not only intense wear and tear of the working bodies of the machines but also reduces the efficiency of their operation [41,42]. However, determining the husk content in the main mass of the product is of great importance in the pressing process. To increase the oil yield, it is possible to use the husk when adding it to the main mass of the product. The presence of husks in the peeled safflower kernels reduces the plasticity of safflower, improves its structure, serves as a drainage factor in oil separation, and helps to reduce the amount of grease in safflower [43,44].

Oil flowability is related to its viscosity and its ability to crack under plastic deformation, that is, to its elasticity modulus [45,46]. The optimal content of the husk in the seed kernels reduces its plastic properties and improves its composition. Before adding the husks to the oil, it was milled. In the next stage, we analyzed the dependences of the oil content on the velocities and diaphragm gap during the pressing of safflower oil.

According to Figure 13, the highest value of the oil yield index is determined at a diaphragm gap equal to δ = 1.0 mm. As the velocity increases, the difference between the diaphragm gap and the change in oiliness can be noticed. This can be explained by the deterioration of the pressing process under the effect of the incomplete separation of oil because of high velocities (ω = 6.8 rad/s, ω = 7.3 rad/s) and the highest percentage of husk in the cleaned kernels of safflower seeds N_3 = 10%, N_4 = 15%. The presence of the highest amount of husks, due to their high porosity, in contact with oil can intensively absorb it, and then very strongly retain it (oiled) [47,48]. As a result, oil losses in production are increased, respectively; this parameter is not optimal.

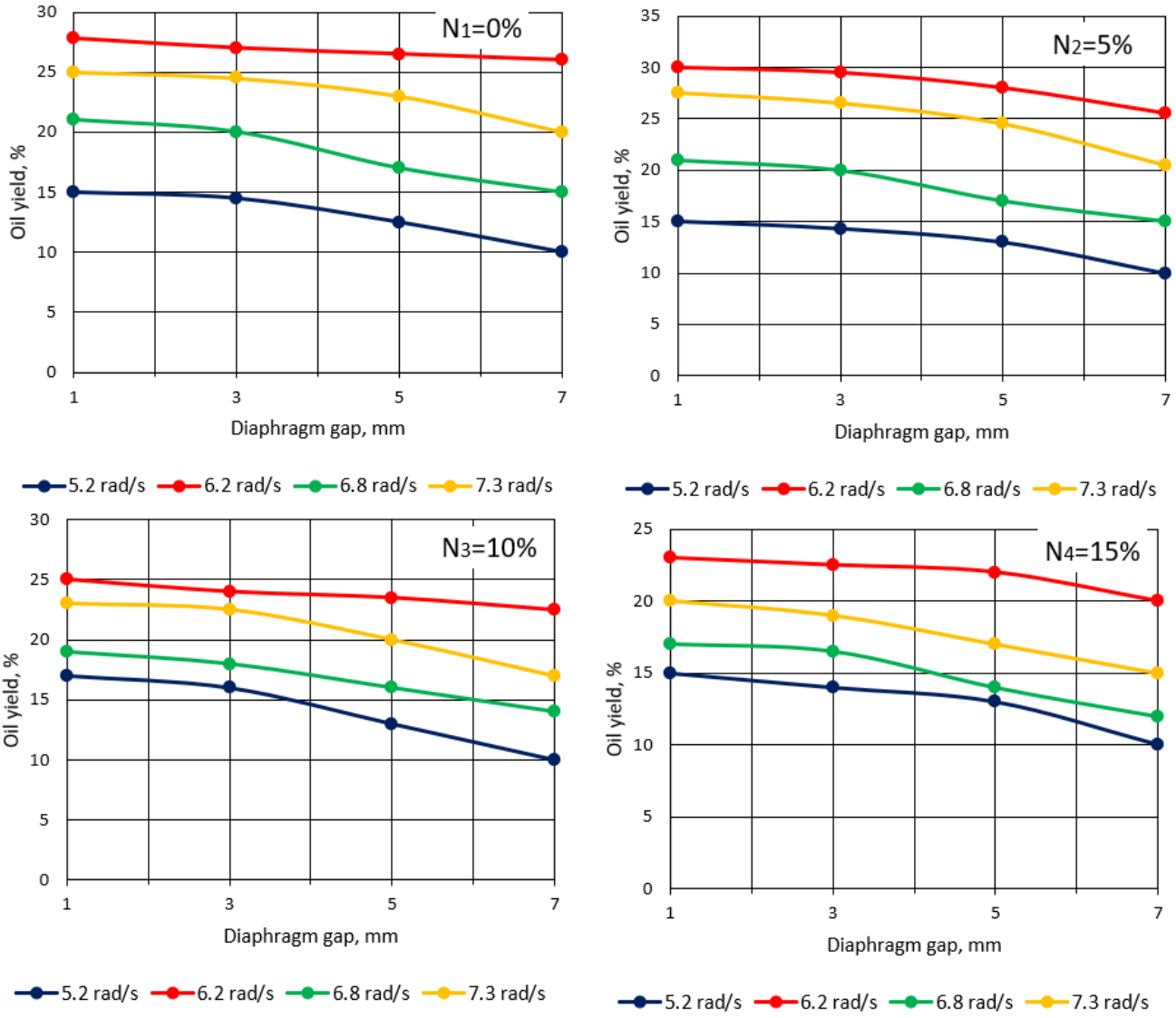


Figure 13. Dependence of safflower oil content on the diaphragm gap and screw rotation speed. N—husk content.

From the graph, it is visible that the highest value of oil yield is reached at the diaphragm gap equal to δ = 1.0 mm. Analysis of graphic dependences revealed that the optimum content of husk in the cleaned kernels of safflower seeds was N_2 = 5% at the speed ω = 6.2 rad/s, which provides the minimum residual oil content and, therefore, the maximum oil yield.

4. Conclusions

The design of the press is developed, which increases oil yield, reduces energy consumption, and improves oil quality. The pressing process dependence on the speed and diaphragm gap are investigated, and the optimal design parameters of the pressing process are determined. Thus, a mathematical model describing the process of pressing vegetable oilseeds in a screw oil press allows for calculating the basic design parameters of the oil press for oil extraction from safflower seeds. The Poisson Equation (5) proves that the pressing material is in continuous motion, based on continuum mechanics. The dependence of the pressing channel and the pressing cage, dependence of the pressing channel on productivity, and pressure at free work of the pressing screw are obtained. The obtained dependences (expressions) of the mathematical model make it possible to determine the optimal values with a preliminary consideration of the necessary parameters in the improvement of the pressing process. As a result of developing a screw press model, we obtained the possibility of designing presses for a small capacity with optimal parameters.

Author Contributions: Data curation, A.K. and G.Z.; formal analysis, M.K., G.Z. and A.S. (Anuarbek Suychinov); investigation, M.M. and A.S. (Assem Shulenova); methodology, A.K., E.K., B.I., G.K. and Z.S.; resources, B.I., A.S. (Assem Shulenova), G.K. and Z.S.; software, M.M., E.K. and B.I.; validation, M.K.; visualization, A.K. and A.S. (Anuarbek Suychinov); writing—original draft, M.M.; writing—review & editing, M.K. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: All data generated or analyzed during this study are included in this published article.

Conflicts of Interest: The authors declare no conflict of interest.

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