MATHEMATICAL MODEL OF THE INFLUENCE OF GEOMETRIC PARAMETERS OF THE SHAFT ON THE PRODUCTIVITY OF THE SCREW PRESS

Volodymyr Havran[1*] – Wojciech Sitek [2]

[1]Department of Computer-Aided Design, Institute of Computer Science and Information Technologies, Lviv Polytechnic National University, Lviv, Ukraine
[2]Faculty of Mechanical Engineering, Silesian University of Technology, Gliwice, Poland

ARTICLE INFO

***Article history*:**
Received: 11.12.2023.
Received in revised form: 31.01.2024.
Accepted: 07.02.2024.

Keywords:
Screw Presses
Screw Press Productivity
Oil Crop Pressing
Oil Extraction
Geometric Optimization
Food Production Efficiency

DOI: https://doi.org/10.30765/er.2415

Abstract:

The objective of the article is to describe influence of geometric parameters of the shaft on the screw press productivity. This study refines existing mathematical models, emphasizing the impact of geometric dimensions on press productivity. The research culminates in presenting a versatile screw press design tailored for diverse oil-containing raw materials. This design optimization aims to enhance oil extraction efficiency and offers crucial insights for the agro-industrial sector, supporting sustainable and high-quality food production.

1 Introduction

1.1 Importance of oil extraction

One of the most important strategic tasks of the European agro-industrial complex is to meet the physiological needs of the population with high-quality, biologically complete and safe food products [1]. To solve the problem, it is necessary to develop technologies and equipment to produce food products enriched with functional ingredients, including polyunsaturated fatty acids, dietary fibres, complete protein and other necessary nutrients [2]. Oil crops are of great economic importance. These include sunflower, linseed, mustard, rapeseed, castor oil, poppy, sesame, peanut, safflower, ginger, etc. The obtained oil is used in various industrial sectors, while the cake, as feed, is used in animal husbandry. Most oilseed crops have important agronomic significance [3]. For instance, sunflower, rapeseed, castor bean, and sesame are good precursors for cereals, as their crops help in the eradication of weeds. Vegetable oil is obtained through the pressing of oil crops, a process which is considered as follows: as the seeds progress along the screw shaft, they undergo pressing, causing the destruction of their outer shell and leading to the leakage of some oil [4]. With increasing pressure, simultaneously, the external surface decreases, and the number of voids between compressed particles reduces, resulting in the extraction of the remaining oil. Hydraulic or screw presses can be used for oil extraction through pressing [5]. Initially, the former had widespread use, but due to their low productivity and intermittent operation, they were replaced by screw presses.

The primary parameters ensuring the efficiency of the oil extraction process using such presses are the fullest oil extraction with minimal energy consumption [6]. Achieving these conditions is possible by refining existing designs of screw oil presses intended for using a specific type of oil-containing raw material and selecting optimal operating modes for them [7].

* Corresponding author.
E-mail address: volodymyr.b.havran@lpnu.ua

1.2 Overview of oil extraction process

The screw oil press is the main equipment in pressing lines, with the end products being high-quality oil and cake containing residual oil content of 8–22%. The choice of the press is made based on the oil production technology and the intended application area [8]. The research [9] exploited the versatile potential of cold-pressed mahaleb seed using single-head screw press. The extracted under 40 °C temperature oil, rich in linoleic and oleic fatty acids, γ - tocopherol and β - sitosterol, exhibited positive consumer acceptance, making it valuable for various applications. The paper [10] examines the use of Residence Time Distribution (RTD) to analyse flow in different screw presses for seed oil extraction. Two types of presses (Reinartz and Olexa) at different rotations were experimentally and theoretically investigated. The results showed the effect of geometry and rotation speed on seed flow in the press. The obtained data can serve to predict the efficiency of screw presses and develop improved equipment. The research [11] focused on the study of the effect of heating and freezing treatments on the extraction process of sunflower seed oil. It has been found that increasing the heating temperature increases the efficiency of oil extraction, while decreasing the freezing temperature has a negative effect on this process. With the help of linear equations, models of the dependence of oil pressing efficiency, energy per volume of oil and other indicators on temperature parameters were built. The obtained results indicate the possibility of using these data to optimize the process of oil expression using a mechanical screw press.

The literature analysis in the article [12] includes the study of various sources for determining the RCM method in the planning of preventive maintenance of the press brake. As a result, five priority breakdowns were determined, and maintenance schedules were proposed to directly prevent breakdowns depending on time or age of components. In work [13] authors describe perspective of using twin-screw press. Analysis confirms the wide use of screw oil presses for small volumes of seed processing, in particular of raw material. Modernization of the design allows to increase energy efficiency and improve the quality and productivity of the process [14]. Such presses are designed for small farms and households and can also be applied in production lines with various oil production needs. The screw press generates a maximum pressure of 30 MPa, with the compression ratio of the mash increasing between 2.8 to 4.4 times. The duration of the mash's stay in the screw channel under pressure depends on the type of press and ranges from 78 to 225 seconds. Depending on the working pressure and the oil content of the resulting cake, screw presses are divided into presses for preliminary (shallow) oil extraction, or pre-presses, and presses for final (deep) oil extraction. Pre-presses are widely used in technological schemes of extraction plants. They exhibit sufficiently high productivity (70-80 kg per day and higher in terms of raw material yield) with a relatively low oil output (oil content of the cake up to 15-17%). The rotational speed of the screw shaft of the pre-press is 18-36 rpm, the thickness of the initial cake is 8-12 mm, and the pressing duration averages 80 seconds.

The analysis of literature sources [15] within the framework of the study included consideration of mathematical models for studying the flow of sterilized oil palm fruits during isothermal operations. The focus is on considering analytical solutions for these models. Non-isothermal conditions were not taken into account due to the absence of significant temperature differences between the inlet and outlet of the press. To check the accuracy of the developed mathematical model, experimental and theoretically predicted values of volume flow were compared. The obtained results demonstrate the correspondence of the predicted values to the real operating conditions of the machine during isothermal operations. The aim of this study is to develop and apply mathematical models for the comprehensive analysis and optimization of the oil extraction process in screw presses. Through mathematical modelling, we seek to enhance understanding of the key parameters influencing the press performance, efficiency, and oil yield. The ultimate goal is to provide insights that contribute to the improvement and design optimization of oil screw presses for more efficient and sustainable oil extraction processes.

2 Theoretical and numerical investigation

The helical channel formed by the convolutions of the screw shaft along with the inner surface of the tapered cylinder significantly influences all the processes of oil extraction from oil-containing raw materials. This includes the degree of pressure increase, oil residue in the cake, productivity, and energy consumption. Therefore, when calculating and justifying the design parameters of screw presses, it is essential to consider these features and select optimal values. The diameter of the tapered cylinder and the inter-spiral space of the screw shaft determine the productivity and power consumption of the press drive.

Source [15] propose and justify a mathematical model for the material flow in the helical channel of the screw shaft, resulting in a productivity formula that considers material compression, changes in internal friction coefficients, wall slippage, oil extraction, screw shaft geometry, and operating parameters. However, this formula is incomplete as it lacks the analytical form of the slippage coefficients and requires refinement in the rheological parameters of the material. Let's consider an elementary volume of the helical channel of the working body (Figure 1), bounded by the surfaces of the screw, the seed cylinder, and two planes perpendicular to the surface of the screw shaft.

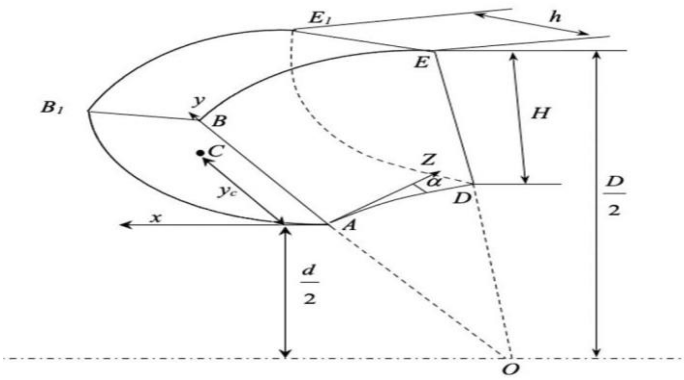

Figure 1. Scheme of the cut-out elementary volume of the helical channel of the screw shaft.

Let us compute geometric properties of the generated volume. The determination of the contact area A_1 between the seed material and the front wall of the channel in the quadrilateral *ABED* can be done in the following manner:

$$A_1^* = \left(\frac{D^2}{4} - \frac{d^2}{4}\right)\frac{1}{\cos\alpha} \tag{1}$$

where the screw shaft's outer and inner diameters are denoted as *D* and *d*, respectively both measured in meters. To calculate the area A_2 of the quadrilateral BB_1EE_1, which represents the region where the working body comes into contact with the seed cylinder, the following calculations will be used:

$$A_1 = h\cos\alpha\frac{D}{2}\frac{d\phi}{\cos\alpha} = h\frac{D}{2}d\phi, \quad m^2; \quad d\phi = \frac{2\pi dx}{h} \tag{2}$$

The pitch of the screw shaft, expressed in meters, is denoted by the variable *h*, the angle of inclination of the helical line and the cross-section of the screw is represented by the angle α, measured in degrees. The determination of the cross-sectional area A_t of the screw shaft channel, which represents the area of the curvilinear triangle AB_1B, will be carried out in the following manner:

$$A_t = Hh\cos\alpha - \int_0^{h\cos\alpha} y(x)dx \tag{3}$$

where $H = \frac{D-d}{2}$ denotes the depth of the screw shaft channel, measured in meters, *y(x)* is the analytical expression of the curve connecting points AB_1.

Let us consider that

$$y(x) = H\left(\frac{x}{h\cos\alpha}\right)^k \tag{4}$$

where $k > 0$ is an arbitrary real number (for $k = 2$ the equation describes a square parabola, for $k = 3$ a cubic parabola, etc.)

Substituting expression (4) into formula (3), we get:

$$A_t = Hh\cos\alpha - H\int_0^{h\cos\alpha}\left(\frac{x}{h\cos\alpha}\right)^k dx, m^2 \tag{5}$$

To enhance convenience, let us substitute the variable:

$$x = h\cos\alpha \cdot u;\ \mathrm{d}x = h\cos\alpha \quad du \tag{6}$$

In such an event:

$$A_t = Hh\cos\alpha\left(1 - \int_0^1 u^k du\right) = \frac{k}{k+1}Hh\cos\alpha \tag{7}$$

To determine the location of the centroid of this region, we need to compute its static moment S_x:

$$S_x = \frac{1}{2}H^2 h\cos\alpha - \frac{1}{2}\int_0^{h\cos\alpha} y^2(x)dx \tag{8}$$

Substituting expression (4) into formula (8), we get:

$$S_x = \frac{1}{2}H^2 h\cos\alpha\left(1 - \int_0^1 u^{2k} du\right) = \frac{k}{2k+1}H^2 h\cos\alpha \tag{9}$$

Then

$$y_c = \frac{S_x}{A_t} = \frac{k+1}{2k+1}H \tag{10}$$

The elementary volume of the selected element (Figure 1) will be equal to:

$$\Delta V = A_t\left(\frac{d}{2} + y_c\right)\frac{d\phi}{\cos\alpha} = \frac{kHh}{k+1}\left(\frac{d}{2} + \frac{k+1}{2k+1}H\right)d\phi \tag{11}$$

Any screw oil press (Figure 2) consists of a body 1, a screw shaft 2, a feeding hopper 3, a tapered cylinder 4, a blocking cone 5, cake discharge holes 6, and oil discharge holes 7. Seeds enter the first coil of the screw shaft through the feeding hopper. Frictional forces between the outer surface of the screw shaft 2 and the inner surface of the seed cylinder 4 create the necessary opposing force for compacting and crushing the seeds. The crushed seeds then move to the pressing zone *A*, where pressure increases due to resistance from the blocking cone 5, resulting in oil extraction.

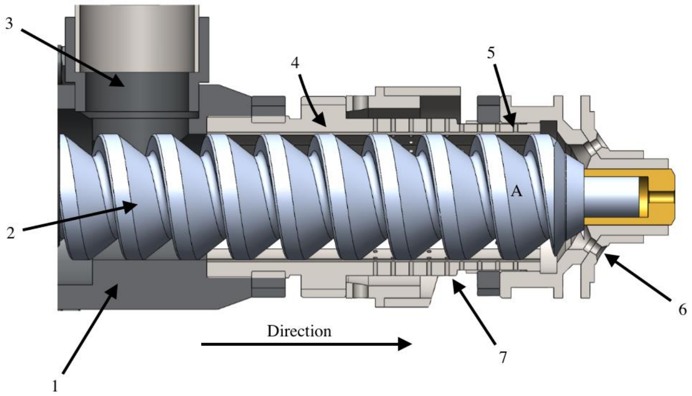

Figure 2. Screw oil press model.

The productivity of the screw press can be determined by examining various indicators in the process of pressing oilseeds. To calculate the productivity, a specific formula can be utilized:

$$Q = \rho_{rm} \cdot V_0 \cdot \omega, kg/s \tag{12}$$

where ρ_{rm} is the bulk mass of rapeseed, kg/m^3; ω – angular speed of rotation of the screw shaft, rad/s; the volume of the initial rotation is represented by V_0, m^3.

Having calculated formula (11), the volume V_0 will be:

$$V_0 = \frac{kHh}{k+1}\left(\frac{d}{2} + \frac{k+1}{2k+1}H\right) / \cos\alpha \tag{13}$$

The press productivity's dependence on the screw shaft's rotational frequency and the pitch of the turns were acquired by utilizing equations (12) and (13), as shown in Figure 3.

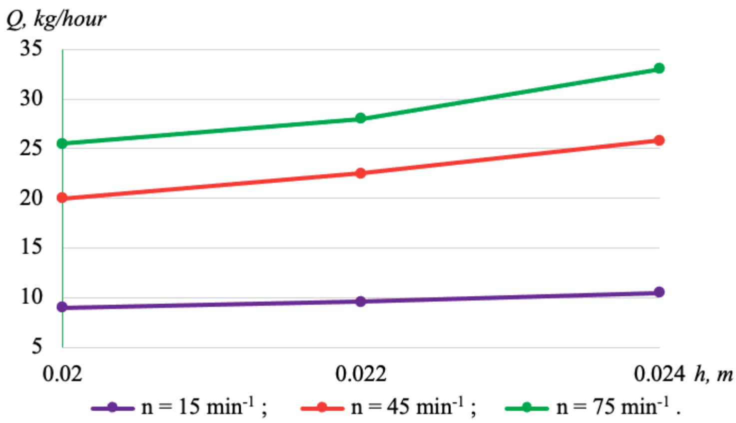

Figure 3. The dependence of the press productivity on the frequency of rotation of the screw shaft and the pitch of its turns.

Analysis of Figure 3 showed that the pitch of the turns is not the factor that can significantly impact the performance. For n = 15 min^{-1} and the pitch of turns of the screw shaft h = 0.02 m, the productivity is calculated as Q = 8.72 kg/hour, and for the same rotation frequency and h = 0.024 m, productivity will be a bit higher, Q = 10.5 kg/hour. The productivity Q of the screw press is more prominently influenced by the frequency of rotation of the screw shaft. For the pitch of turns h = 0.024 m frequency n = 15 min^{-1}, the productivity equals Q = 10.5 kg/hour, and for n = 75 min^{-1} productivity is significantly higher, Q = 33 kg/hour.

To determine the volumes V_1 and V_2, representing the amount of cake and oil respectively, we can establish a system of equations:

$$\begin{cases} \rho_c V_1 + \rho_{oil} V_2 = \rho_{rm} V_0 \\ V_1 + V_2 = \xi V_0, \end{cases} \tag{14}$$

where ρ_c is the bulk mass of the cake, kg/m^3; ρ_{oil}– oil density, kg/m^3; $\xi \leq 1$ – volume filling factor of V_0 with rapeseed.

After resolving the system of equations (14), we arrive at the solution:

$$V_1 = \frac{\xi\rho_{oil} - \rho_{rm}}{\rho_{oil} - \rho_c} V_0 \quad ; \quad V_2 = \frac{\rho_{rm} - \xi\rho_c}{\rho_{oil} - \rho_c} V_0. \tag{15}$$

We will elucidate the correlation that defines the conservation of mass at the discharge of the cake from the compression chamber, taking into account the acquired data (15):

$$\omega(V_1 + \xi_1 V_2) = \nu A_{dh} \eta_1 \tag{16}$$

where ν is the speed of cake exit through the discharge holes; η_1– representing the irregular utilization of the exit hole area coefficient; A_{dh}– total area of discharge holes, m^2; $\xi_1$is a coefficient that characterizes the remaining oil in the pulp.

Let us describe the velocity of the cake as it passes through the discharge holes using formula (16):

$$\nu = \frac{\omega(V_1 + \xi_1 V_2)}{A_{dh}\eta_1} \tag{17}$$

In order to determine the cake's output through the holes, we will apply the theorem regarding the alteration in the mechanical system's movement amount:

$$\omega(\rho_c V_1 + \xi_1 \rho_{oil} V_2)\left(-\frac{\omega(V_1 + \xi_1 V_2)}{A_c} + \nu\eta_1\right) = P_c A_{dh}\eta_1 - P_c A_{dh}\eta_1 f - P_0 A_{dh}\eta_1 \tag{18}$$

where the pressure within the end chamber, denoted as P_c is expressed in units of megapascals (MPa); the end chamber's cross-sectional area, denoted asA_c, is measured in square meters (m^2), and the coefficient influenced by the rotational speed of the screw shaft and the friction coefficient of the blend of partially crushed seeds and extracted oil is denoted as f.

$$f = 1 - (1 - f_0)\left(\frac{\omega}{\omega_{max}}\right)^3 \tag{19}$$

where f_0 is the friction coefficient while separating oil.

Moving forward:

$$P_c = P_0 + \frac{\omega^2}{A_{dh}(1 - f)\eta_1}(\rho_c V_1 + \xi_1 \rho_{oil} V_2)(V_1 + \xi_1 V_2)\left(\frac{1}{A_{dh}\eta_1} - \frac{1}{A_c}\right) \tag{20}$$

When the oil is fully extracted, then the equation becomes $\xi_1 = 0$. It is important to mention that $P_1 = 0$and could be disregarded. Consequently, we will obtain:

$$P_{max} = \frac{\rho_c V_1^2 \omega^2}{A_{dh}(1-f)\eta_1}\left(\frac{1}{A_{dh}\eta_1} - \frac{1}{A_c}\right) \tag{21}$$

Analysis of formula (21) indicates that the maximum pressure value is influenced by the screw shaft rotation speed, the area of the cake discharge holes, and the volume of the shaft turns. Having calculated the formula (21) now we can obtain the dependency (Figure 4) between the rotation speed of the shaft and the maximum pressure on the turns pitch.

Dependency illustrated in Figure 4 led to the conclusion that within the investigated range of screw shaft rotation speeds and turns pitches, the maximum pressure, $P_{max} = 19$MPa, is achieved at $n = 15$ min^{-1} and a pitch of coils $h = 0.024$ m with a hole area of $s = 4.7 \times 10^{-4}$ m^2.

Assuming P_{max} is predetermined value, then the total area of the cake discharge holes, A_{dh}, can be found from:

$$A_{dh} = \frac{2A_k}{\sqrt{4\frac{\rho_{max}}{\rho_c V_1^2 \omega^2}\frac{A_c^2}{} + 1} + 1} \approx 2\sqrt{\frac{\rho_c V_1^2 \omega^2}{\eta P_{max}}} \tag{22}$$

Having calculated (22), it has been defined that for a pressure of $P_{max} = 13.1$ MPa, a pitch of turns $h = 0.02$ m, and a shaft rotation speed of $n = 15$ min^{-1}, the cake discharge holes area would be 0.0000769 m^2. For a comprehensive study of the screw press operation, it is necessary to determine the length of the screw shaft.

The elementary volume shown in Figure 1 is subjected to the distributed load shown in Figure 4.

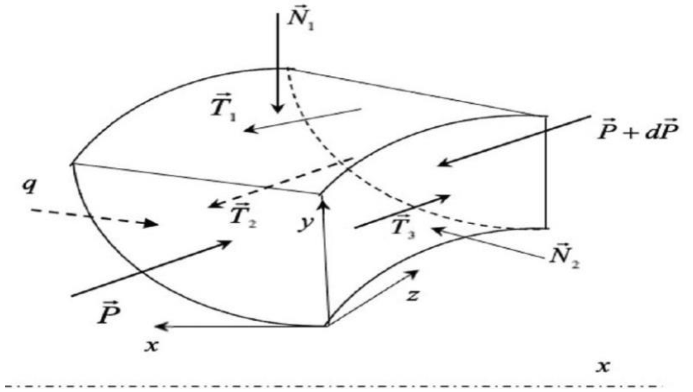

Figure 4. Scheme of force action on elementary volume.

$\vec{P}$– pressure that changes along the axis of the screw shaft; q – action on the volume from the side of the screw shaft, which causes the movement of the working body; $N_1 = \eta_1 P$, $N_2 = \eta_2 P$– normal reactions; η_1–pressure transfer coefficient; $T_1 = f_1\eta_1 P$– force of friction due to pressure P; $T_2 = f_2 q$– force of friction from q; $T_3 = f_3\eta_3 P$ – the force of friction against the turns of the screw shaft due to the pressure P; f_1, f_2 – sliding friction coefficients. We consider that changes along the axis of the screw shaft in proportion to the pressure, i.e. $q = k_3 P$.

The isolated volume moves along the screw shaft at a constant speed, which is equal to the speed of the centre of mass of this volume:

$$V_c = \omega\left(\frac{d}{2} + y_c\right) tg\alpha \tag{23}$$

and $\sum_{k=1}^{n} F_{kx} = 0$, let us derive the statics equation for the volume moving along the screw shaft axis:

$$(P + dP)A_t \sin\alpha - PA_t + T_1A_2 \sin\alpha - qA_1 \cos\alpha - N_2A_1 \cos\alpha + T_3A_1 \sin\alpha + T_2A_3 \sin\alpha = 0. \tag{24}$$

Taking into account that $d\phi = \frac{2\pi dx}{h}$ upon simplification of (24), we arrive at the differential equation:

$$\frac{dP}{dx} + k_1P = k_2k_3P => \frac{dP}{dx} - (k_2k_3 - k_1)P = 0 \tag{25}$$

Where $k_1 = \frac{2\pi(f_1\eta_1A_1 + \eta_2A_1 \cos\alpha + f_2A_1\eta_2 \sin\alpha)}{hA_t \cdot d\phi}$, $k_2 = \frac{2\pi(A_1 \cos\alpha - f_2A_3 \sin\alpha)}{hA_t \sin\alpha \cdot d\phi}$

The outcome of solving this equation is:

$$P(x) = ce^{(k_2k_3 - k_1)x} \tag{26}$$

The unidentified parameter *c*, derived from the boundary conditions and the pressure value *P*, needs to adhere to the specified boundary conditions:

$$P_{x=x_0} = P_0 \quad , \quad P_{x=L-a_0} = P_{max} \tag{27}$$

where L-a_0 is the abscissa of the point along the axis of the screw shaft, where the pressure *P* reaches its maximum value; *L* is the length of the screw shaft excluding the first turn.

From the boundary conditions we find: $c = P_0$

$$(L - a)(k_2k_3 - k_1) = ln\left(\frac{P_{max}}{P_0}\right) \tag{28}$$

Hence, the coefficient k_3 will be:

$$k_3 = \frac{k_1}{k_2} + \frac{1}{k_2(L - a)} ln\left(\frac{P_{max}}{P_0}\right) \tag{29}$$

Substituting (28) and (29) into (26), we obtain the dependence of the pressure distribution along the axis of the screw shaft:

$$P(x) = P_0\left(\frac{P_{max}}{P_0}\right)^{\frac{x}{L-a_0}} \tag{30}$$

In the area $L - a \le x \le L$, the pressure decreases to the value P_3 according to the law:

$$P(x) = P_{max} \left(\frac{P_3}{P_{max}}\right)^{\frac{x-(L-a_0)}{a_0}} \tag{31}$$

Calculation (31) made it possible to obtain the dependence of the pressure distribution along the axis of the screw shaft (Figure 5)

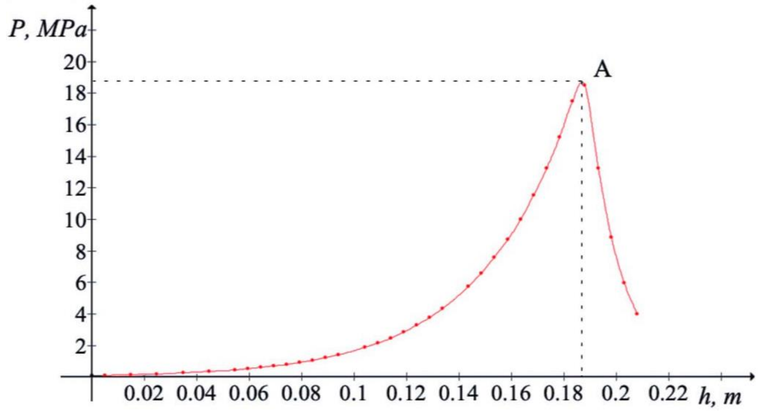

Figure 5. Pressure distribution along the axis of the screw shaft.

From the analysis of formulas (21) and (31) and Figure 5, it can be stated that the pressure gradually increases due to the compression of rapeseed and the resistance of the press's blocking cone. Its maximum value is reached at point *A*, corresponding to a screw shaft length of 0.187 meters.

3 Results and discussion

Based on theoretical and numerical studies, the design parameters and their impact on press productivity have been substantiated. It was investigated that productivity Q of the screw press is more influenced by the frequency of rotation of the screw shaft (n) and less influenced by the pitch of its turns (h). For n = 75 min^{-1} and h = 0.024 m, the productivity Q = 33 kg/hour was achieved. The research has also shown that the maximum pressure value (P_{max}) is influenced by the shaft rotation frequency, the area of the cake discharges holes (s), and the shaft turns. It increases with a decrease in the rotation speed and an increase in the pitch of the turns. The maximum pressure value was defined as P_{max} = 19 MPa, and achieved at n = 15 min^{-1}, pitch of the turns h = 0.024 m, and a hole area of $s = 4.7 \times 10^{-4}$ m^2. Based on the study of force action on elementary volume, the dependence of the pressure distribution along the axis of the screw shaft was established. It reached its maximum value at a length of 0.187 m.

The presented findings allowed for a design of a screw press with an increased productivity. This press can be used for oil production in small batches from various raw materials. The design is depicted in Figure 6. The shaft is manufactured of the alloyed steel to increase strength, maintain resistance and hardness. Its application expands the technological possibilities of pressing seeds and allows to increase the yield of oil by 7%, compared to a serial press, signifying a substantial improvement.

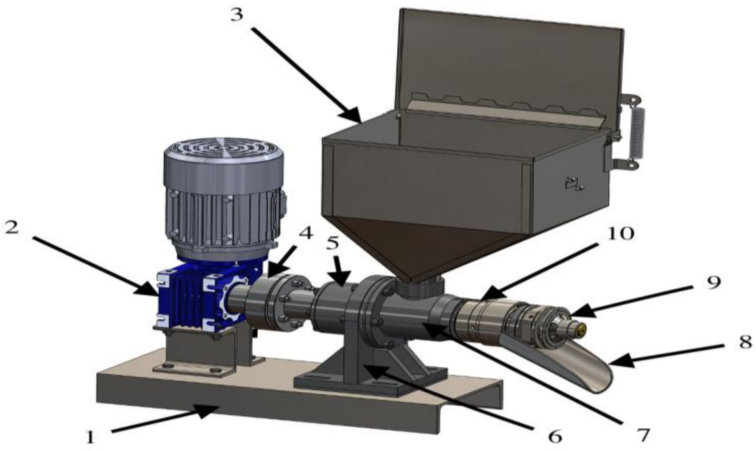

Figure 6. Screw oil press.

1 – stationary base; 2 – geared motor; 3 – hopper feeder; 4 – coupling; 5,7 – sleeves; 6 – housing; 8 – chute; 9 – flanges; 10 – spacers.

4 Conclusion

In conclusion, the study delves into the analysis of impact of geometric parameters of the shaft on the screw press productivity in the context of oilseed pressing via screw presses. Calculations regarding various geometric characteristics of the press provide crucial insights into the intricate mechanics of the pressing process. The discussion encompasses an in-depth evaluation of formulae governing geometric areas, volumes, and forces acting within the screw oil press system. The dependency of press productivity on the rotation frequency of the screw shaft, pitch of its turns, area of the cake discharge holes, pressure value is thoroughly examined, emphasizing the substantial impact of these parameters on the extraction process. This paper offers valuable insights into optimizing screw press performance, aiding in understanding the dynamics of oilseed extraction processes and potentially informing enhancements for efficiency and productivity in agro-industrial settings. The productivity of the press is significantly affected by the rotational speed, while the pitch of the screw shaft's turns has a lesser impact. It was concluded that productivity can be greatly increased by increasing the pitch of turns of the shaft and its rotation frequency. As a result, the productivity was elevated to $Q = 33$ *kg/hour*. Based on the theoretical studies and mathematical model calculations, the screw press for oil production in small batches from various oil-containing raw materials has been suggested. The improved design not only broadens the technological implementation of seed pressing but also significantly boosts oil yield by 7% compared to a standard press. In addition, a comprehensive analysis will be conducted to examine the influence of these parameters on the quantitative and qualitative characteristics of the extracted oil during further investigations on the subject.

References

[1] Kemper, T. Oil Extraction. In Bailey's Industrial Oil and Fat Products. pp. 1–38, 2020 https://doi.org/10.1002/047167849x.bio013.pub2

[2] Versino, F., López, O., García, M. Sunflower Oil Industry By-product as Natural Filler of Biocomposite Foams for Packaging Applications. Journal of Polymers and the Environment. 29(6), pp. 1869–1879, 2021. https://doi.org/10.1007/s10924-020-01981-8.

[3] Tekin-Cakmak, Z., Karasu, S., Kayacan-Cakmakoglu, S., Akman, P. K. Investigation of potential use of by-products from cold-press industry as natural fat replacers and functional ingredients in a low-fat salad dressing. Journal of Food Processing and Preservation. 45(8), 2021.https://doi.org/10.1111/jfpp.15388

[4] Romanić, R. Cold pressed sunflower (Helianthus annuus L.) oil. In Cold Pressed Oils: Green Technology, Bioactive Compounds, Functionality, and Applications. pp. 197–218, 2020. https://doi.org/10.1016/B978-0-12-818188-1.00017-7

[5] Petraru, A., Ursachi, F., Amariei, S. Nutritional characteristics assessment of sunflower seeds, oil and cake. Perspective of using sunflower oilcakes as a functional ingredient. Plants, 10(11), 2021. https://doi.org/10.3390/plants10112487.

[6] Ovsyannikov, V., Berestovoy, A., Lobacheva, N., Toroptsev, V., Trunov, S. Research of the process of vegetable oil extracting under the influence of a high frequency wave field. In IOP Conference Series: Materials Science and Engineering (Vol. 941), 2020. https://doi.org/10.1088/1757-899X/941/1/012052

[7] Yang, L., Chen, H., Yin, C., Song, S., Zhang, Y., Liu, X., Hu, Z. Research on mechanical-structure properties during sunflower seed extrusion-oil extraction. Journal of Food Processing and Preservation, 46(1), 2022. https://doi.org/10.1111/jfpp.16158

[8] Akhihiero, E., Eshiemogie, S., Oginenwa, D., Gbandi, E., Akhihiero, D. Design of a Manual Hydraulic Press for Oil Extraction from Oil-Bearing Seeds. Advances in Engineering Design Technology, 3, pp. 30–38, 2021. https://doi.org/10.37933/nipes.a/3.2.2021.4.

[9] Yilmaz, E., Karatas, B. Evaluation of the sensory properties, volatile aroma compounds and functional food potentials of cold-press produced mahaleb (Prunus mahaleb L.) seed oil. OCL - Oilseeds and Fats, Crops and Lipids, 30, 2023. https://doi.org/10.1051/ocl/2023018

[10] Bogaert, L., Mhemdi, H., Vorobiev, E. Residence time distribution and flow pattern modeling of oilseeds in a pilot screw press. OCL - Oilseeds and Fats, Crops and Lipids, 27, 2020. https://doi.org/10.1051/ocl/2020060.

[11] Gürdil, G., Kabutey, A., Selvi, K., Hrabě, P., Herák, D., Fraňková, A. Investigation of heating and freezing pretreatments on mechanical, chemical and spectral properties of bulk sunflower seeds and oil. Processes, 8(4), 2020. https://doi.org/10.3390/PR8040411.

[12] Pohan, F., Saputra, I., Tua, R. Scheduling Preventive Maintenance to Determine Maintenance Actions on Screw Press Machine. Jurnal Riset Ilmu Teknik, 1(1), pp. 1–12, 2023. https://doi.org/10.59976/jurit.v1i1.4.

[13] Romero-Guzmán, M., Jung, L., Kyriakopoulou, K., Boom, R., Nikiforidis, C. Efficient single-step rapeseed oleosome extraction using twin-screw press. Journal of Food Engineering, 276, 2020. https://doi.org/10.1016/j.jfoodeng.2019.109890

[14] Shevchuk, R., Sukach, O. Test of the modernized screw oil press. Bulletin of Lviv National Agrarian University. Agroengineering Research, 24(1), pp. 69–76, 2020. https://doi.org/10.31734/agroengineering 2020.24.069.

[15] Badmus, G., Owolarafe, O., Osunleke, A., Ajadi, S., Ajayi, O. Mathematical modelling of digester-screw press process for expression of oil from oil palm fruit. Ife Journal of Science, 21(3), 193, 2020. https://doi.org/10.4314/ijs.v21i3.16.