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Influence of Grinding Degree and Screw Rotation Speed on Sunflower Oil Pressing Process

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Abstract: Sunflower is a major agricultural oilseed crop, and the Republic of Kazakhstan has been steadily strengthening its position as a producer of oilseeds. In this study, an oil pressing machine with two processes, including grinding sunflower seeds and pressing the obtained cake to separate the oil, is constructed. The experiment investigated the impact of different grinding degrees (hole diameters of plates of 5 mm, 4 mm, 3 mm, and 2 mm) and screw rotation speeds (ranging from 30 rpm to 250 rpm) on oil pressing efficiency. The study used sunflower seeds with an oil content of 45–47% and moisture of 7–9%. The results showed that increasing the grinding degree and screw rotation speed led to higher oil yield. The optimal condition was a grinding degree of 4 mm and a screw rotation speed of 60 rpm, resulting in the highest oil yield of 15.6 g/s. Additionally, the residual oil content of the seed cake decreased significantly as pressure increased during pressing, particularly with 4 mm grinding. Power consumption increased with higher screw rotation speeds and finer grinding degrees, indicating the influence of grinding components on energy demand. The cake density increased with higher screw rotation speeds and finer grinding degrees, highlighting the impact of grinding mechanisms on cake compactness. Moreover, the temperature of the cake rose with increased screw rotation speed and the presence of grinding sieves. These findings provide valuable insights into optimizing the sunflower oil pressing process, highlighting the importance of selecting appropriate grinding degrees and screw rotation speeds to maximize oil yield and pressing efficiency.

Keywords: screw press; sunflower seed; grinding; oil yield; rotation; seed cake

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1. Introduction

Vegetable oil processing belongs to the essential sectors of the food industry. Vegetable oil is used in the food industry, in food production, and as a raw material in the chemical and medical industries. Since 2011, the Republic of Kazakhstan has been steadily strengthening its position as a producer of oilseeds. The most popular type of vegetable oil in Kazakhstan is sunflower oil; it is consumed by almost 96% of Kazakh families [1]. Sunflower is a major agricultural oilseed crop. In order to ensure food security in the Republic of Kazakhstan, measures are being taken to increase the production of oilseeds. In Kazakhstan, the Northern, Eastern, and part of Western regions are the leaders in sunflower cultivation [2]. The sowing area for sunflower seeds increased from 960.5 thousand hectares in 2021 to 1 million hectares in 2022. There are more than 36 high-yielding varieties and hybrids of sunflower, which are characterized by high oil content (46–52%) and low huskiness (23–28%). Production of unrefined sunflower oil in the Republic of Kazakhstan at the end of 2022 increased twofold compared to 2021. At the end of 2021, Kazakhstan oil plants produced 183.6 thousand tonnes of unrefined sunflower oil. In 2022 (from January to November), the processing companies produced 337.6 thousand tonnes of these products [3,4].

Sunflower oil is a widely consumed and valuable vegetable oil known for its various culinary, industrial, and nutritional applications. Its extraction can be achieved through different methods, such as hard pressing, prepress solvent extraction, expeller pressing (also known as cold pressing), and aqueous extraction [5]. At present, the continuous method of pressing on screw presses is mainly used. It is effective not only because it provides for the mandatory inclusion of screw presses in continuous action lines, but also allows for the complete mechanization of production processes [6,7].

The screw press, operating within a cylindrical cage, exerts high pressure on the material, resulting in oil extraction. The process begins with feeding the processed sunflower seeds into the hopper of the screw press. Preheating the pressing cage raises the temperature before the actual pressing. As the screw rotates, it pushes the seeds forward against the pressing cage, creating pressure and friction that lead to oil extraction. The oil flows through the gaps in the pressing cage and is collected, while the remaining crushed seeds form the seed cake [8,9]. Using a screw press ensures a mechanical extraction method without additional chemicals, preserving the oil's quality and nutrient content. The efficiency of oil recovery from sunflower seeds through this method typically ranges from 86% to 92% [10,11]. During the pressing process, several physical changes occur in the sunflower seeds. The compression exerted on the seeds in the pressing chamber causes them to be crushed and flattened. Squeezing, induced by the pressure and friction from the rotating screw, separates the oil from the solid components of the seeds [12]. The applied pressure can also create cracks in the seeds, facilitating easier oil extraction. The resulting seed cake contains the solid material after oil extraction, rich in protein and dietary fiber, and suitable for use as animal feed [13,14].

Oilseed screw press manufacturers are mainly focused on the production of large-sized and high-capacity screw presses. For example, the screw presses of Goyum Company (Punjab, India) produce oil presses for high-capacity oil millers (up to 250 tons per day) [15]. Screw presses of MIKIM Machinery (Tianjin, China) are characterized by high capacity (up to 14 tons per day) and high oil yield [16]. In addition to large-sized and highly productive presses, more compact oil presses are produced, specially designed for mini-enterprises and farms. For example, Farmet Company (Česká Skalice, Czech Republic) is producing screw presses for pressing oilseeds without preliminary preparation of the processed raw material. The equipment has low requirements for installation space and a very simple setup. The presses are an ideal solution for small and medium-sized farms [17]. Jasko Company (Volgograd, Russia) produces small-sized cold presses with a capacity of up to 60 kg/h. The temperature of the oil at the outlet of the oil press does not exceed 60 °C, as a result of which its beneficial and therapeutic properties are preserved [18]. The Moldavian plant JSC "Alimentarmash" produces the press of the final pressing of oil of the M8-MShP brand with a capacity not less than 7 tons per day, and the residual oil content of the oil cake is not more than 12% [19]. Jain and Jain (2015) developed a design of continuous spiral screws for screw-press oil expellers. The oil flow rate for sunflower oilseeds was 0.003 kg/s at a screw speed of 48 rpm [20].

Known technical solutions for pressing oilseed raw materials have low efficiency, do not always provide high oil yield, and consume a lot of energy. Thus, an important task is to develop a small-sized, low-energy-consuming screw press used in the conditions of farms with small production volumes. The use of a combined press in production conditions will intensify the process of oil separation due to the preliminary crushing of the seed kernel to mint condition. Existing pressing equipment is mainly intended for large-capacity enterprises, is highly productive and energy-intensive, and is not entirely rational for equipping small and medium-sized enterprises. In addition, there are a number of disadvantages in the pressing process that have not yet been resolved. These include the high pressure required for pressing the product and the associated increased energy consumption, and an increase in the number of additional operations before and after pressing, in particular, for pre-grinding the raw material before pressing; loss of raw material during interoperation transportation; and an increase in labor costs.

In this regard, as one of the options for intensifying production processes, it is relevant to combine a number of processes in one unit of equipment. It should also be noted that when pressing the product, issues such as establishing and maintaining the duration of pressing, pressing pressure, and residual oil content of the cake are very important, and without taking these factors into account, it is impossible to come to the right engineering solutions [21–23]. Understanding the underlying physical changes during sunflower seed pressing is essential for optimizing the extraction process and achieving higher oil yields. Factors such as the seed moisture content, pressing temperature, and screw press design influence specific physical transformations. Further research and experimentation will provide valuable insights to enhance the efficiency and sustainability of sunflower seed oil extraction.

The scientific novelty of this work lies in the development of a press design that allows for combining the processes of grinding and pressing sunflower seeds to obtain high-quality sunflower oil. The aim of the work is to improve the pressing process on the basis of combined processes of grinding and pressing in one piece of equipment and to study the influence of the degree of grinding of sunflower seeds and the speed of rotation of the press screw on the oil pressing process.

2. Materials and Methods

2.1. Study Objects

The material for the study is sunflower seeds of the variety "Kazakhstan 1", which were subjected to peeling. The oil content of the seeds is 45–47%, and moisture 7–9%.

2.2. Determination of Residual Oil Content of Seed Cake

The essence of the method consists of the extraction of crude oil from the sample with diethyl or petroleum ether in a Soxhlet apparatus, removal of the solvent, and weighing of the defatted residue, according to the procedure described in GOST 13496.15-2016 [24].

The mass fraction of crude fat X_1, %, in the analyzed sample on the absolute dry matter is calculated by Formula (1):

$$X_1 = \frac{m_2 - m_3}{m_2 - m_1} \cdot 100, \tag{1}$$

where m_2—mass of the bucket with the bag and sample before defatting, g;
m_3—mass of the bucket with the bag and sample after defatting, g;
m_1—mass of the dried bucket with bag, g;
100—percentage conversion factor.

2.3. Determining the Power Required for Pressing

The measuring bench (Figure 1) consists of voltmeter 1, ammeter 2, and phase meter 3 (device for measuring "cosφ"). All devices are included in the electric circuit controlling the electric motors of the unit drive. To determine the power characteristics of the experimental unit, a methodology was developed, the essence of which is to find the power determined by the values of current, voltage, and cosφ, directly measured with these devices [25].

To measure the current, voltage, and cosφ, sunflower seeds were loaded into the hopper of a screw press. Then, the electric motor was switched on. The corresponding values of electrical quantities were recorded on the instruments using a WEB camera connected to a computer. After that, the results of measurements were processed on the computer.

Figure 1. Measuring stand for determining the energy characteristics of a screw press. 1—electricity meter; 2—switch; 3—ammeter; 4—voltmeter; 5—phase meter.

During pressing, the power N can be determined by Formula (2):

$$N = \sqrt{3} \cdot U \cdot I \cdot \cos\varphi \tag{2}$$

where U—voltage indicated by the voltmeter, V;
I—current intensity indicated by the ammeter, A;
$\cos\varphi$—power factor.

2.4. Determination of the Density of Oil Cake

Three batches of 5 g each of cake were introduced into a noncorrosive steel mesh basket with a thickness of 0.6 mm. Prior to conducting the experiment, the weight of the mesh basket with hangers was measured. Subsequently, the mesh basket was placed inside a measuring cup filled with ethyl ether, which was then placed in a thermostatic vessel with the water temperature maintained at 20 ± 0.5 °C. To eliminate any air bubbles from the mesh basket containing the cake, the ether in the beaker was stirred. The readings on the measuring instruments were adjusted using weights that were suspended on the beaker's arm [26].

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

$$V = \frac{m_{\text{г}} - m_{\text{п}}}{\rho_{\text{ж}}} \tag{3}$$

where $m_{\text{г}}$, $m_{\text{п}}$—mass, respectively, of the load and the sample, kg;
$\rho_{\text{ж}}$—density of ether at 20 °C, kg/m^3.

The density of seed cake in each sample ρ (kg/m^3) was calculated by Equation (4):

$$\rho = \frac{m}{V} \tag{4}$$

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

The density of dry seed cake ρ_c (kg/m^3) was determined by Equation (5):

$$\rho_c = \frac{\rho \cdot (100 - V)}{100 - W\rho} \quad (5)$$

where W—moisture content of safflower cake, %.

2.5. Statistics

The results of measurements were analyzed using Excel 2007 and Statistica 12 PL software (StatSoft, Inc., Tulsa, OK, USA). The differences between the samples were evaluated using a one-way ANOVA. A p-value < 0.05 was considered statistically significant.

3. Results and Discussion

3.1. Experimental Unit Design Characterization

According to Figure 2, the experimental press consists of the following main parts: a cylindrical body 1, a hopper 2, and a drain pan for collecting the liquid fraction 3. The cylindrical body 1 consists of grinding and pressing chambers. The grinding chamber is constructed of a conveying screw 4 and a grinding mechanism comprising a receiving plate 5 and a grinding plate 6, a knife 7, and a ring 8 mounted on the outside of the knife (Figures 3–5). Three holes are cut on the receiving plate 5, and the holes are made in the direction of the raw material flow.

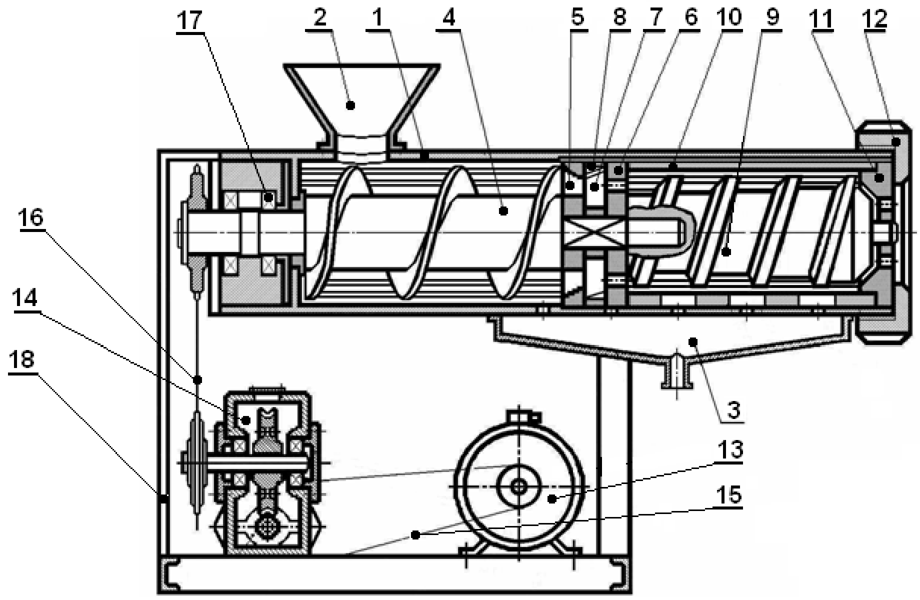


Figure 2. Schematic diagram of the oil screw press. 1—cylindrical frame; 2—hopper; 3—tray for collecting liquid fraction; 4—conveying screw; 5—receiving plate; 6—cutting plate; 7—knife; 8—ring; 9—pressing screw; 10—Zeer cylinder; 11—diaphragm cone grating; 12—clamping nut; 13—electric motor; 14—worm gearbox; 15—V-belt transmission; 16—chain transmission; 17—bearing support; 18—base.

Figure 3. Conveying screw.

Figure 4. Receiving plate.

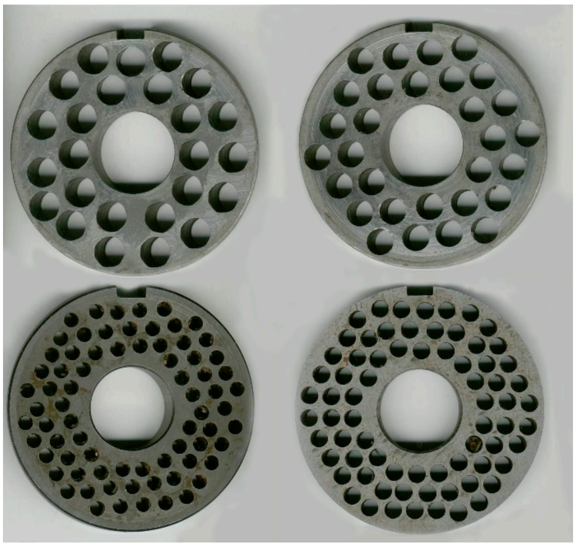


Figure 5. Grinding plate set.

The constructed grinding mechanism is a multi-pass screw-shaped knife, of which the angle of the screw lines elevation is in the range of 15 ÷ 45 degrees (Figure 6). Its design consists of two cutting edges 1, 2; front surface 3; and pressing and forcing surfaces. The length of the knife rotation axis is taken equal to one-third of the knife diameter and greater than the width of the outer ring.

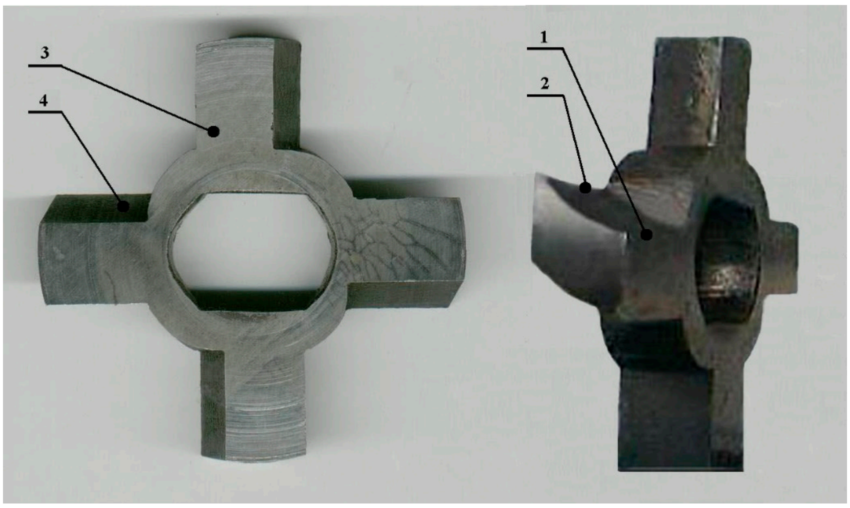


Figure 6. Helical knife. 1—cutting edge; 2—front surface; 3, 4—pressing and pressurizing surfaces.

The pressing chamber consists of a Zeer cylinder 10 and a pressing screw 9 installed therein (Figures 7 and 8). The press chamber is made collapsible for easy disassembly of the press due to the difficulty of sanitary treatment of the Zeer cylinder 10. The pressure on the oilseeds is produced under the influence of the sequential increase in the diameter of the shaft of the pressing screw 9 in the direction of seed movement. The pitch of turns of the pressing screw 9 is constant, and the thickness of the turns is uniformly and consistently increased in the direction of the product movement.

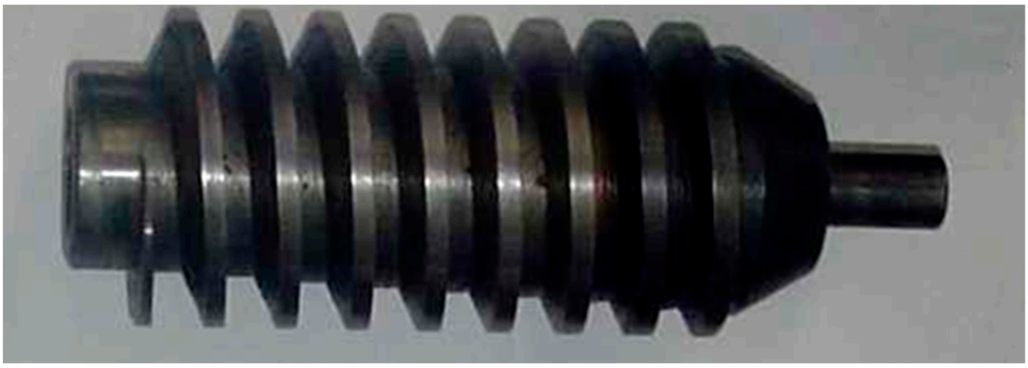


Figure 7. Pressing screw.

Figure 8. Zeer cylinder.

A uniform pitch of the screw guarantees constant equipment performance, and a uniform and sequential increase in the thickness of the screw in the direction of product movement increases the strength and reliability of the design. On the inner surface of the Zeer cylinder, grooves are cut for the flow of the liquid fraction through the holes, providing resistance to the rotation of the cake together with the screw and improving its transportation. At the end of the cylindrical body, a diaphragm cone and a tightening nut are installed (Figure 9). Holes are made in the diaphragm cone for thermoplastic molding (granulation) of the cake.

According to Figure 10, the press drive consists of an electric motor 13, a worm gearbox 14, and a V-belt transmission 15. The worm gearbox 14 is connected to the tail bearing support 17 via the chain transmission 16. The shafts of the press are connected to the tail bearing support, which is fixed to the welded frame 18. During the research, the speed of rotation of the shafts was changed by changing the pulleys of the V-belt transmission.

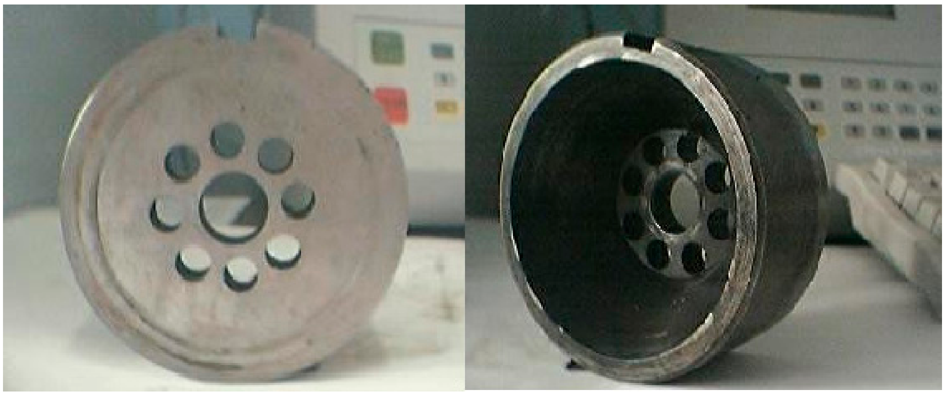


Figure 9. Diaphragm cone grid.

Figure 10. General view of the experimental press.

The press works as follows: sunflower seeds are loaded into hopper 2, from where they enter cylindrical body 1 with cut grooves, and are transported by screw 4 to the grinding mechanism, where they are ground. The ground meal passing through the pressing chamber is pressed by pressing screw 9. The oil separated from the cake, through the holes located in the grain cylinder 10 and cylindrical body 1, drains into a tray 3 for oil collection, installed in the lower part of the cylindrical body. The pressed cake in granulated form is removed through an adjustable conical grate (Figures 11 and 12).

The obtained sunflower oil by organoleptic and physicochemical indicators meets the requirements of normative documents for vegetable oils. Thus, by smell and taste, it is characterized as sunflower oil without extraneous odor, taste, and bitterness and meets the normative indicators. The acid number was 2.3 mg KOH/g, and the peroxide number was not more than 8 mmol/kg, which also does not exceed the normative indicators (4.0 mg KOH/g for acid number, 10 mmol/kg for peroxide number). In the obtained oil, the mass fraction of moisture and volatile substances is not more than 0.16%, and the mass fraction of non-fatty impurities is not more than 0.07%. According to food safety, no heavy metals, pesticides, and mycotoxins were detected in the oil (Supplementary File Table S1). Thus, the analyzed samples of sunflower oil showed full compliance with the requirements of normative and technical documentation on quality and safety indicators. This indicates the use of high-quality raw materials and the efficient process of pressing sunflower seeds on the designed press.

Figure 11. Pressed granulated seed cake.

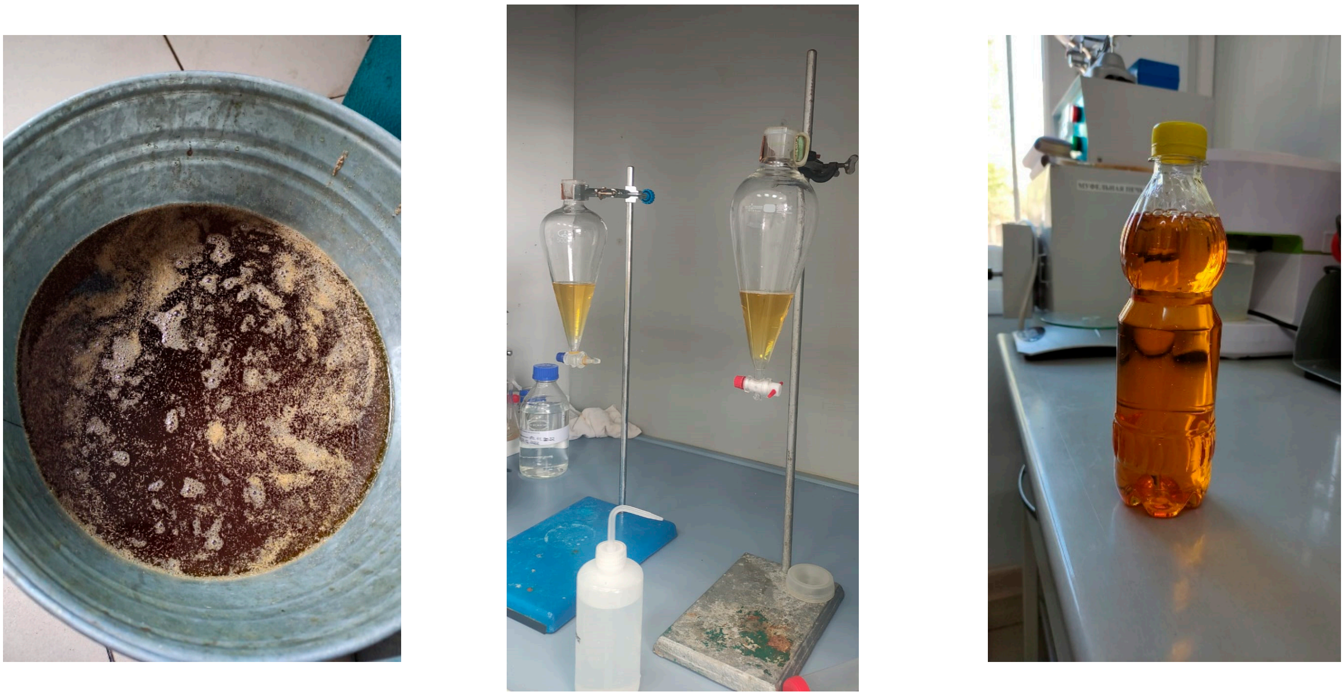


Figure 12. The oil separated from the cake.

3.2. Study of the Degree of Grinding and Screw Rotation Speed on the Oil Mass Flow Rate

The mass yield of oil was the primary outcome measure to assess the efficiency of the pressing machine under different conditions. At a screw rotation speed of 30 rpm, the results indicated that without pre-grinding, the oil output was 10.8 g/s. However, as the grinding degree increased, the oil yield also increased ($p < 0.05$), reaching 12.6 g/s when ground to 5 mm and 15.3 g/s when ground to 4 mm. Further reduction in grinding size to 3 mm resulted in a decreased oil output of 8.4 g/s, while grinding to 2 mm led to a further decrease to 6.9 g/s ($p < 0.05$). The same trends were observed when the screw rotation speed was increased to 60, 120, and 250 rpm (Figure 13).

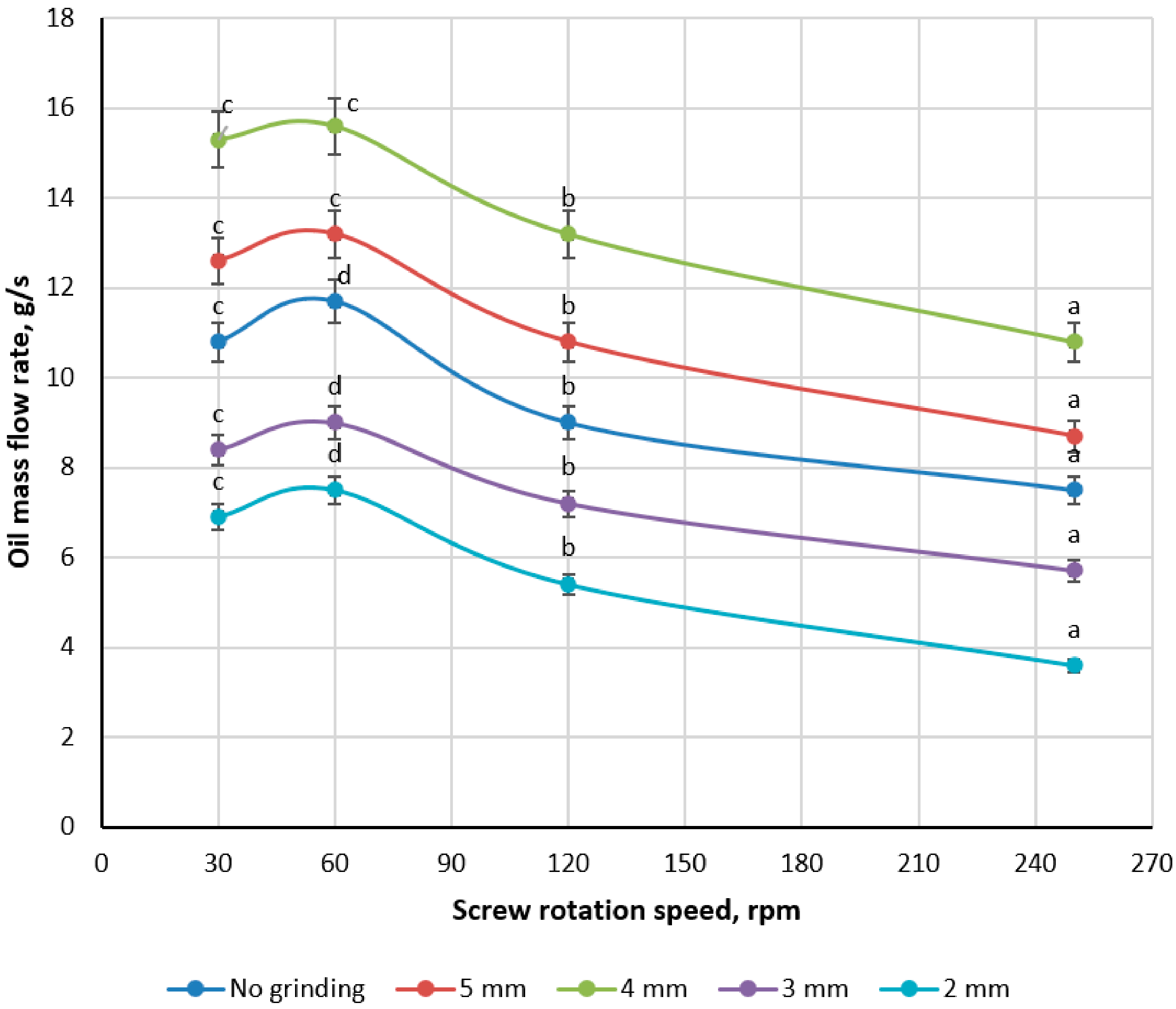


Figure 13. Dependence of oil mass flow rate on the degree of sunflower seed grinding and screw rotation speed (different letters above the lines indicate significant differences between samples, $p < 0.05$).

The findings from this study provide valuable insights into the optimal conditions for sunflower oil pressing. The results indicate that a grinding degree of 4 mm consistently yielded higher oil outputs across different screw rotation speeds. Additionally, a lower screw rotation speed of 60 rpm appeared to be optimal for achieving higher oil yields, as it consistently outperformed the higher speeds of 120 rpm and 250 rpm.

As can be seen from Figure 13, the most optimal degree of grinding is the use of the plate with a hole diameter of 4 mm and a screw rotation speed of 60 rpm. At these parameters, the highest oil yield (15.6 g/s) was registered. Increasing the rotational speed leads to an insufficient pressing duration, i.e., to incomplete oil extraction from sunflower seeds and to an increase in the power required for pressing.

Deli et al. (2011) investigated the pressing of black seeds using a KOMET Screw Oil Expeller with a shaft screw diameter of 11 mm and nozzle sizes of 6 and 10 mm. They achieved the highest oil yield of 65% under these specific conditions [27]. It is worth noting that their study involved a different seed type and equipment specifications compared to our research. Harmanto et al. (2009) studied Jatropha seeds pressing with a screw press and found that the highest oil yield was obtained at a rotational speed of 45 rpm and nozzle size of 6 mm [28]. Although they worked with a different seed type, rotational speed, and nozzle size, their findings align with our observations that adjusting operational parameters can influence the oil yield. Mursalykova et al. (2023) investigated the pressing of safflower seeds using a RAWMID Dream Modern oil press. They reported the highest oil yield at a diaphragm gap of $\delta = 0.1$ mm and a screw rotation speed of $\omega = 6.2$ rad/s (372 rpm) [29]. Their research, focusing on safflower seeds and a specific oil press model, reinforces the notion that optimizing operational parameters can enhance oil yield.

In line with Bogaert et al. (2018), our results also support the idea that increasing the rotation speed of the screw press can enhance its capacity and decrease the passage time [30]. However, it is important to note that higher rotation speeds may result in a reduced extraction yield and specific energy consumption, implying the need for a careful balance between efficiency and oil yield.

Overall, comparing our findings with other research results showcases the significance of adjusting pressing parameters to achieve optimal oil yield. The specific characteristics of the seeds, equipment, and experimental conditions in each study contribute to variations in the outcomes. Our research provides valuable insights into the pressing of sunflower seeds, demonstrating the influence of the grinding size and screw rotation speed on the oil yield. Future investigations exploring additional parameter combinations to optimize the oil extraction process for sunflower seeds can further build on these findings.

3.3. Study of the Degree of Grinding and Squeeze Pressure on the Residual Oil Content of Seed Cake

At the next stage of research, we determined the residual oil content, depending on the screw pressing pressure and the degree of sunflower seed grinding. Residual oil content is an important indicator of the efficiency of the pressing process and the quality of the obtained oil. If the initial oil content of seeds before pressing was 45%, then with the beginning of pressing and the gradual increase of pressure inside the pressing chamber, the cake oil content decreases significantly ($p < 0.05$). At that, the most significant reduction ($p < 0.05$) of seed cake oil content was recorded when seeds were ground with the use of a plate with a diameter of holes at 4 mm. It should be noted that grinding through 2 mm and 3 mm plates and further pressing does not lead to the desired oil yield (residual oil cake fat content is high) (Figure 14). It is known that a low residual oil content indicates high oil extraction efficiency and good quality of the oil product, as most of the oil has been removed from the raw material. On the contrary, a high residual oil content may indicate an inefficient pressing process or equipment problems [31,32].

In a screw press, the seeds are moved along a helical screw, and under the influence of the screw rotation, the pressure increases along the length of the press. This causes compression and crushing of the raw material, which results in the release of oil from the seed. The screw, as it rotates, grabs the sunflower seed coming from the feed hopper and pushes it forward, increasing the pressure in the raw material from the feed area to the matrix. The pressurized seeds are enclosed between the moving surfaces (base and side walls of the screw channel) and the stationary inner surface of the housing (cylinder) [33,34]. On the other hand, due to the increased pressure in the molding head (matrix), a counterflow (backflow) also occurs, which can be considered as a flow of material in the opposite direction from the molding head to the loading zone [35,36].

In typical oil extraction from oilseeds, the yield is limited by the fact that the applied mechanical pressure has two opposing effects: On the one hand, the pressure acts as a driving force for oil extraction. On the other hand, under the influence of pressure, the compaction of the oilseed material leads to a reduction in the oil flow and, thus, reduces the pressing capacity [37,38].

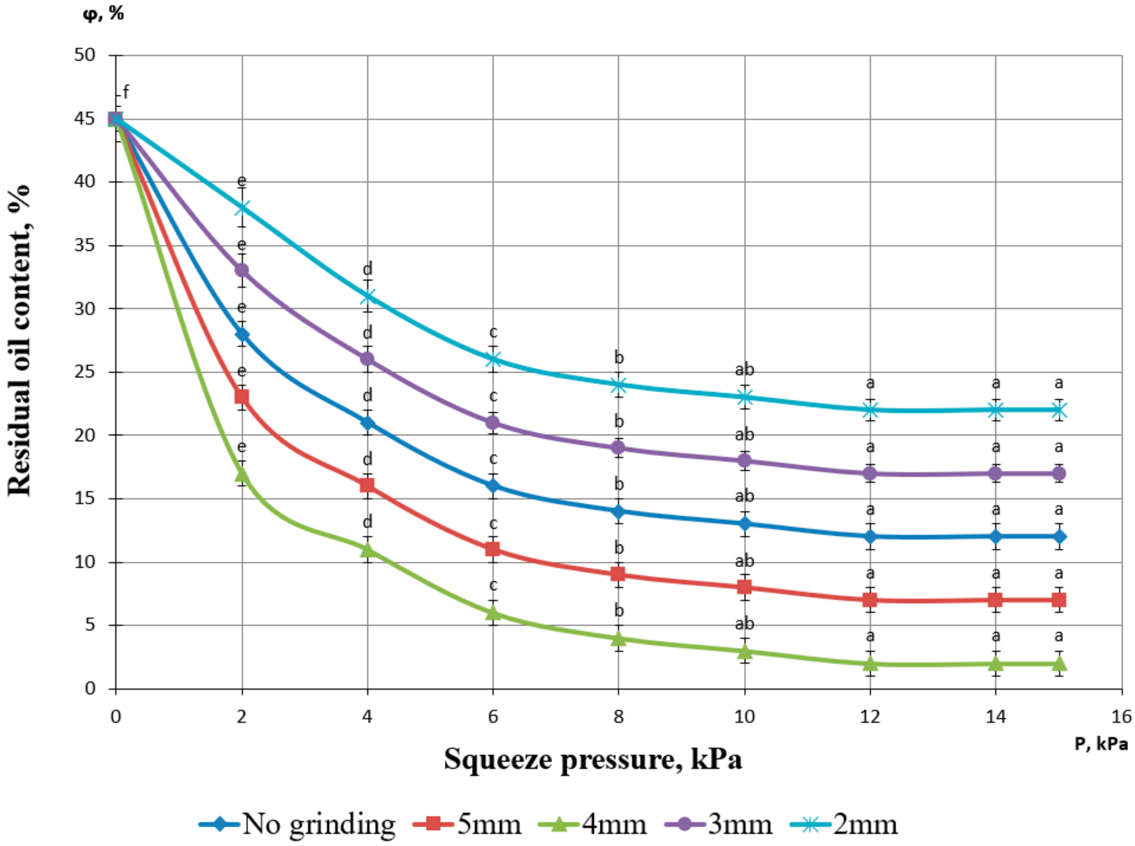


Figure 14. Dependence of residual oil content of cake on squeeze pressure and degree of grinding (different letters above the lines indicate significant differences between samples, $p < 0.05$).

3.4. Study of the Degree of Grinding and Screw Rotation Speed on the Power Consumption of Screw Press

The power consumption of the press was measured to evaluate the energy requirements for pressing the cake under different grinding degrees and screw rotation speeds. The obtained data provided insights into the optimal parameters for efficient oil pressing.

The results revealed that increasing the screw rotation speed during the pressing process led to a corresponding increase ($p < 0.05$) in power consumption. For instance, at a screw rotation speed of 30 rpm, the power consumption varied depending on the grinding degree, ranging from 0.48 kW without pre-grinding to 2.88 kW when the seeds were ground to 2 mm. Similarly, at higher screw rotation speeds of 60 rpm, 120 rpm, and 250 rpm, the power consumption increased consistently ($p < 0.05$) with finer grinding degrees (Figure 15).

Moreover, the installation of grinding sieves with smaller hole diameters resulted in higher power consumption compared to pressing without the use of grinding mechanisms. This indicates that the presence of grinding components in the oil pressing process imposes an additional energy demand.

As can be seen from Figure 15, the capacity of the oil press increases with increasing screw speed. This trend is due to the increase in the amount of seed mass that passes through the press in a certain period of time. This results in a heavier load on the screw and increases the power required to move it and press the seed. In addition, the pressure generated by the screw increases, resulting in an increase in the force that must be applied to compress the raw material and squeeze out the oil.

When grinding and pressing processes are combined, the power required to overcome the cutting and squeezing forces through the grids also increases. The smaller the diameter of the grinding plate, the more power is required for the operation.

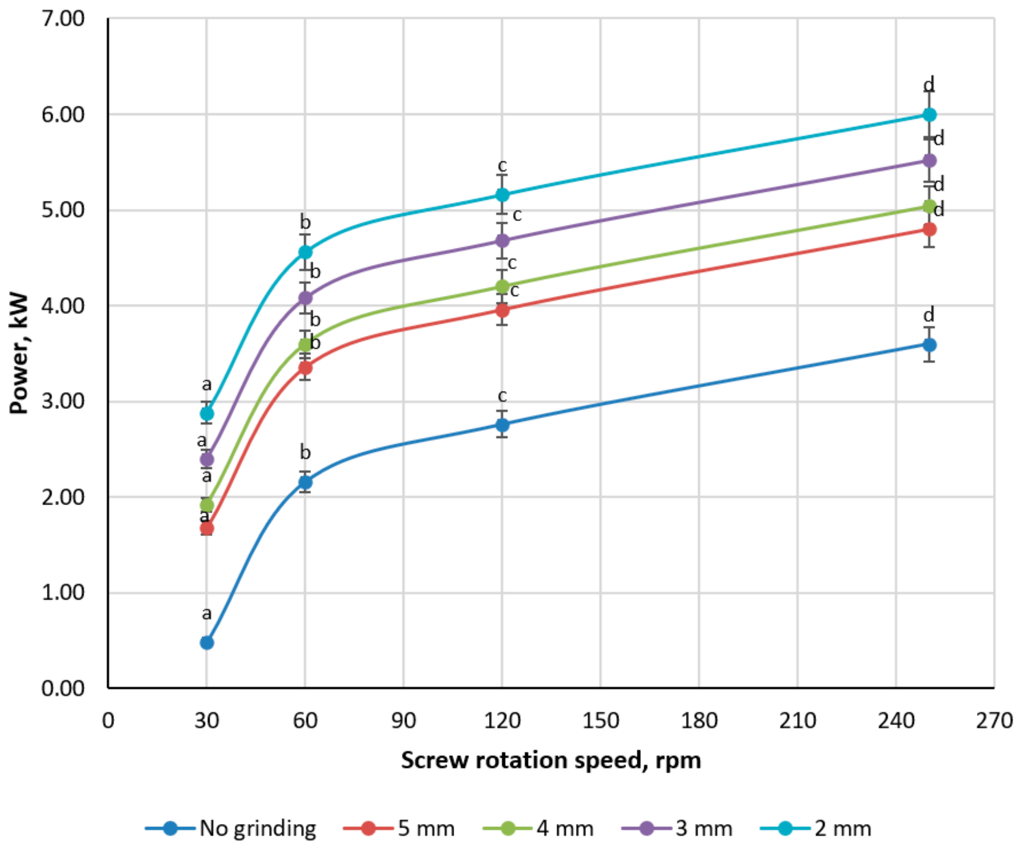


Figure 15. Dependence of power on the degree of sunflower seed grinding and screw rotation speed (different letters above the lines indicate significant differences between samples, $p < 0.05$).

3.5. Study of the Degree of Grinding and Screw Rotation Speed on the Cake Density of Seed Cake

In accordance with Figure 16, the change of cake density depending on the degree of grinding and screw rotation speed was investigated. The density of the cake obtained after pressing was measured as the primary outcome. The data obtained at different screw rotation speeds and grinding degrees were analyzed to identify the optimal parameters for the oil pressing process. The results indicated that increasing the screw rotation speed during the pressing of sunflower seeds led to an increase in the density of the cake ($p < 0.05$). For instance, at a screw rotation speed of 30 rpm, the density of the cake varied depending on the grinding degree. Without pre-grinding, the density was 367 kg/m^3, while grinding to 2 mm resulted in a density of 1467 kg/m^3. At higher screw rotation speeds, such as 60 rpm, 120 rpm, and 250 rpm, similar trends were observed, with denser cakes produced as the grinding degree decreased.

Additionally, the installation of grinding sieves with smaller hole diameters also contributed to an increase in cake density compared to using the oil press without grinding mechanisms. This suggests that the presence of grinding components enhances the compactness of the cake during the pressing process.

A significant increase in cake density is observed both when increasing the screw speed and when grinding the cake with different hole diameters. The increase in density is due to more intensive compression during grinding in the "knife-plate" system, and more intensive compression in the pressing chamber due to increased screw speed and pressure in the chamber, as well as greater squeezing of oil from the cake.

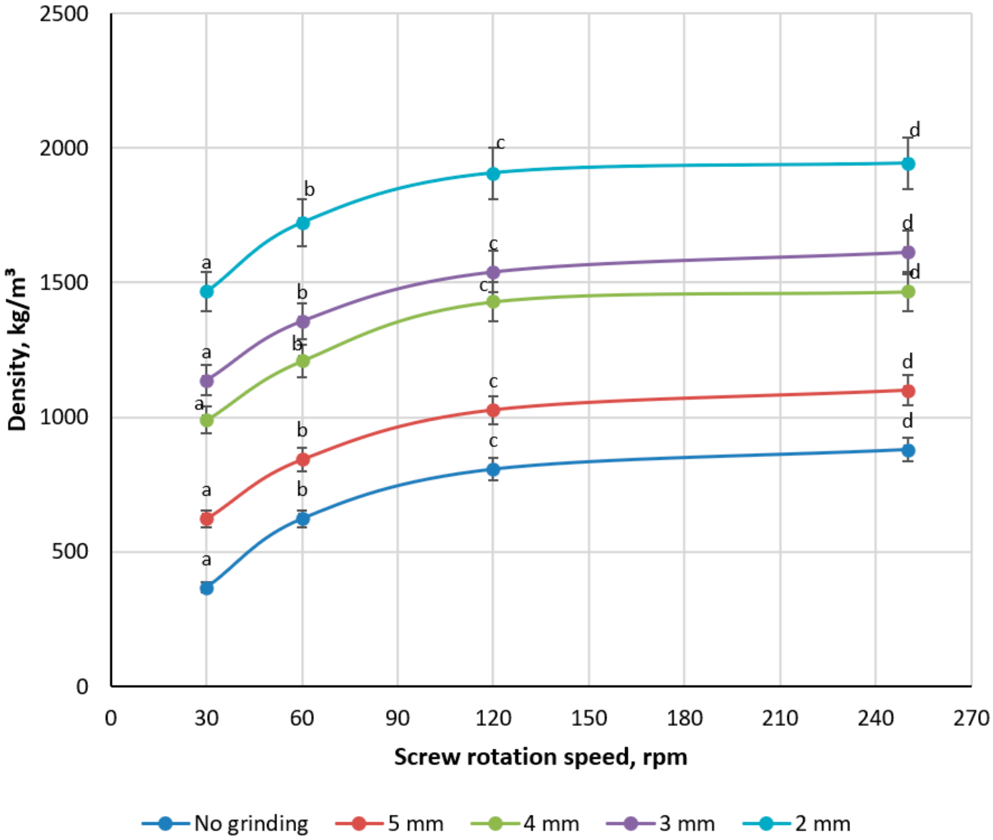


Figure 16. Dependence of cake density on the degree of sunflower seed grinding and screw rotation speed (different letters above the lines indicate significant differences between samples, $p < 0.05$).

3.6. Study of the Degree of Grinding and Screw Rotation Speed on the Temperature of Seed Cake

The obtained data revealed the temperature of the cake after pressing at different screw rotation speeds. At a screw rotation speed of 30 rpm, the cake temperature ranged from 92 °C to 105 °C, depending on the grinding degree. Increasing the screw rotation speed to 60 rpm led to slightly higher temperatures, ranging from 93 °C to 106 °C. Further increasing the speed to 120 rpm and 250 rpm resulted in temperatures ranging from 95 °C to 107 °C and 108 °C, respectively (Figure 17).

The findings indicate that increasing the screw rotation speed during the pressing process leads to an elevation in the temperature of the cake. Moreover, the installation of grinding sieves with smaller hole diameters also contributes to an increase in the cake temperature compared to the oil press without such grinding mechanisms.

These results offer valuable insights for optimizing oil pressing operations. It is important to consider the desired temperature range for the cake during the pressing process, as temperature can influence the quality and characteristics of the extracted oil. Depending on the specific requirements, operators can adjust the screw rotation speed and choose appropriate grinding sieves to achieve the desired temperature conditions for the cake.

The degree of grinding significantly affects the temperature of the cake after pressing. Thus, if the temperature of the cake after pressing without preliminary grinding was 92 °C, then grinding the cake through a 2 mm grating raises the temperature at the output to 105 °C. At the same time, the increase in the number of revolutions insignificantly affects the temperature of the cake after pressing.

The main factors of the cake temperature increase are mechanical friction due to the screw rotation speed, the work of grinding elements (knife and grid), intensive compression of the cake, and energy conversion into heat.

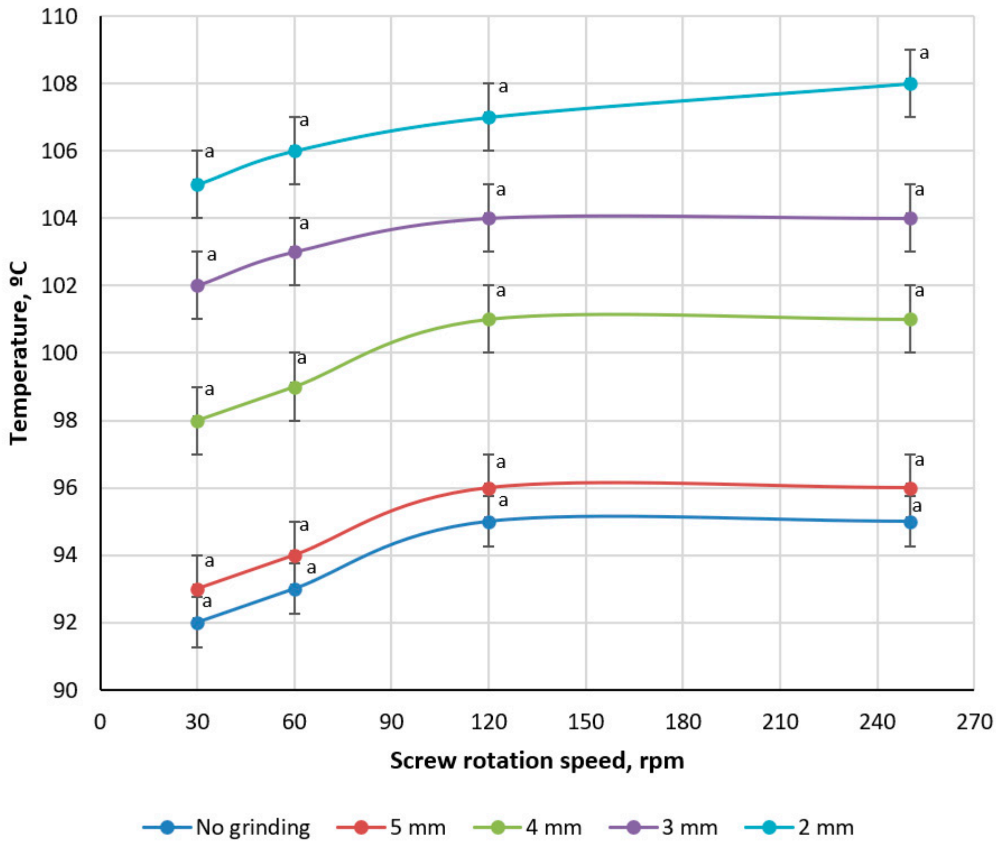


Figure 17. Dependence of temperature of seed cake on the degree of sunflower seed grinding and screw rotation speed (different letters above the lines indicate significant differences between samples, $p < 0.05$).

3.7. Theoretical Calculations of Product Movement in the Screw Press

The equations describing the movement of raw materials are compiled, and their solutions are proposed.

The continuity equation for the steady fluid motion $\frac{d\rho}{dt} = 0$ is as follows:

$div\vec{v} = 0$ or

$$\frac{\partial v_x}{\partial x} + \frac{\partial v_y}{\partial y} + \frac{\partial v_z}{\partial z} = 0, \tag{6}$$

For an incompressible fluid $div\vec{v} = 0$, the equations of the motion of a viscous fluid are described by the Navier–Stokes equation [39,40].

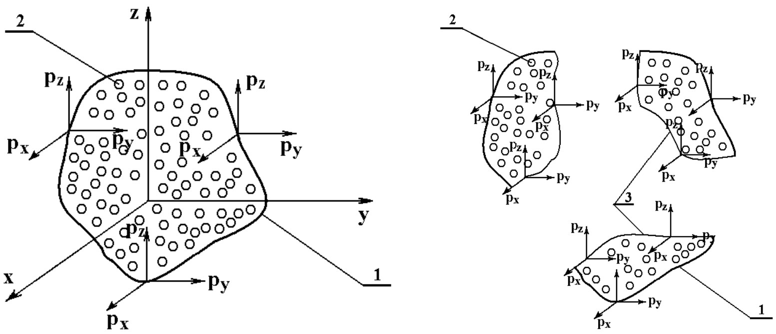
$$\frac{d\vec{v}}{dt} = F - \frac{1}{\rho}grad\vec{p} + \nu\Delta\vec{v}, \tag{7}$$

Accordingly, according to Figure 18a,b, we consider the acting pressure forces along the x, y, z axes before and after grinding.

Accordingly, since the surface of the uncrushed product is curvilinear (Figure 18a), during the pressing process, the forces form a system of non-parallel forces, and the force dF is divided into components [41]:

$$\left.\begin{array}{l} dF_x = p_x dS\cos\alpha \\ dF_y = p_y dS\cos\beta \\ dF_z = p_z dS\cos\gamma \end{array}\right\}, \tag{8}$$

where α, β, γ—angles of inclination of elementary forces to coordinate axes, which are different for different sites dS.



(**a**) product before grinding (**b**) product after grinding

Figure 18. Pressure forces acting before and after grinding. 1—outer surface of the sunflower seeds; 2—macro and micro capillaries consisting of the liquid phase; 3—new surfaces after the grinding process.

Accordingly, if we take into account all acting forces on the new surfaces of the product after grinding (Figure 18b) and determine the pressure on these surfaces, it is necessary to find the corresponding projections of the equal force:

$$\left.\begin{array}{l} f_x = \sum p_x dS \cos\alpha \\ f_y = \sum p_y dS \cos\beta \\ f_z = \sum p_z dS \cos\gamma \end{array}\right\}, \tag{9}$$

From here, $f = \sqrt{f_x^2 + f_y^2 + f_z^2}$, where $\cos\alpha = \frac{f_x}{f}$, $\cos\beta = \frac{f_y}{f}$, $\cos\gamma = \frac{f_z}{f}$.

If the pressure p along the length of the channel l and with a variable radius r_t is equal to the pressure change Δp, to solve the problem of the mechanics of the homogeneous medium on the basis of the first Equation (1) and taking into account the pressure forces $f_z = \Delta p \cdot \pi \cdot r_t{}^2$, and the force acting on the side surface is equal to $f_{mp} = \mu \frac{dv}{dz} \cdot 2\pi \cdot r_t \cdot l$, then the pressure drop can be written in the following form, kPa:

$$\Delta p = \frac{B}{\exp(\alpha, n)H} F\left(\frac{\mu v_z}{h}\right)^{1-n} l \cdot k_T ctg\alpha, \tag{10}$$

Here, it must be taken into account that the inclination angle $tg\alpha = \left(\frac{h}{W}\right)^{1-n}$ of the ground product depends on the pitch $W = S_t \cdot cos\alpha$.

For fluids that follow the power law [42,43], the velocity of the product in the channel (Figure 19) along the z-axis (m/s) will be expressed by the formula:

$$v_z = \frac{r_t n}{1+3n}\left[\frac{r_t}{2\mu}\left(\frac{dp}{dz}\right)\right]^{\frac{1}{n}}, \tag{11}$$

where r_t—internal radius of rotation of the screw channel, m.

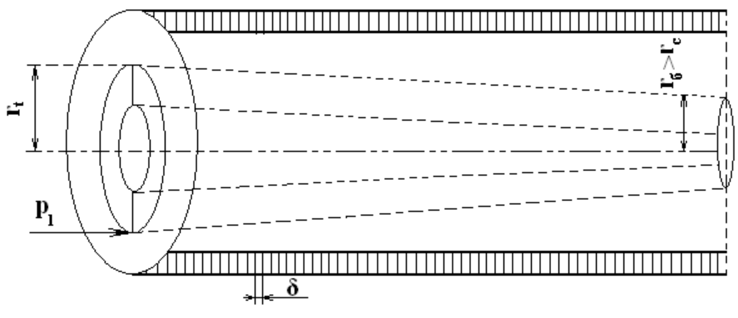


Figure 19. Geometrical scheme of a Zeer cylinder.

Taking into account the effect of pressing pressure on the formation of fat capillaries on the surface of the product during the pressing process, based on the theory of Buckingham [44,45], we determine the volume flow rate of separated oil by the following equation, m^3/s.

The output of the product in the screw channel can be written in the following form, m^3/s:

$$Q_0 = \frac{\pi d p H^4}{128 \mu W} f(i), \tag{12}$$

where $f(i) = \left[1 - \frac{4}{3} i + \frac{1}{3} i^4\right]$—grinding function;
i—grinding ratio;
H—height of the lifting of raw material by the screw, 10^{-3} m;
W—width of the screw channel, 10^{-3} m.

By dropping the pressing pressure due to the interaction of pressures during the separation of the liquid phase from the newly formed surfaces under the influence of grinding, we determine the required power for pressing.

During the grinding process and the separation of the liquid phase from the new surfaces by direct pressure contact, it is possible to reduce the pressure and power, kW:

$$N = \frac{\pi \cdot i \cdot \rho \cdot V \cdot v_z}{l^2 \cdot \omega^2 \cdot \eta} {r_t}^2 \cdot \eta_a, \tag{13}$$

where ρ—liquid density, kg/m^3; V—volume of extracted liquid, m^3; l—length of screw channel, m; η_a—power reserve factor; ω—rotation speed, rad/s; η—drive efficiency.

4. Conclusions

The current study aimed to evaluate the performance of a designed oil pressing machine for sunflower seeds. The novelty in this research is centered around the creation of a press design that effectively integrates the procedures of sunflower seed grinding and pressing, resulting in the production of sunflower oil. The machine incorporated two main processes: grinding the seeds and pressing the obtained cake to extract the oil. This was achieved using a two-screw system, where the first screw transported the seeds to the knife and plate with holes, and the second screw conducted the crushing and squeezing of the cake, allowing the oil to drain through a Zeer (drainage) cylinder while expelling the cake through an outlet grid. Overall, the findings suggest that the optimal parameters for oil pressing involve a balance between screw rotation speed, grinding degree, and power consumption. It is essential to consider both the oil yield and the energy efficiency of the pressing machine. The results imply that moderate screw rotation speeds of 60 rpm and grinding degrees of 4 mm may provide an optimal balance between oil extraction efficiency and power consumption. Based on these findings, it can be inferred that optimal oil pressing parameters involve a combination of lower screw rotation speeds and finer grinding degrees. Further investigations can focus on exploring additional parameters, such as temperature and moisture content, to enhance the overall efficiency and quality of oil extraction.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/app13179958/s1, Table S1: Physico-chemical parameters of sunflower oil obtained after pressing.

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References

1. Toishimanov, M.; Nurgaliyeva, M.; Serikbayeva, A.; Suleimenova, Z.; Myrzabek, K.; Shokan, A.; Myrzabayeva, N. Comparative Analysis and Determination of the Fatty Acid Composition of Kazakhstan's Commercial Vegetable Oils by GC-FID. *Appl. Sci.* **2023**, *13*, 7910. [CrossRef]
2. Available online: https://www.apk-inform.com/ru/news/1531489 (accessed on 24 July 2023).
3. Available online: https://www.kt.kz/rus/ekonomika/proizvodstvo_rastitelnogo_masla_rastet_v_kazahstane_1377948402.html (accessed on 20 August 2023).
4. Nasiyev, B.; Dukeyeva, A. Influence of Mineral Fertilizers and Methods of Basic Tillage on the Yield and Oil Content of Sunflower. *OnLine J. Biol. Sci.* **2023**, *23*, 296–306. [CrossRef]
5. Afzal, M.F.; Khalid, W.; Armghan Khalid, M.; Zubair, M.; Akram, S.; Kauser, S.; Noreen, S.; Jamal, A.; Kamran Khan, M.; Al-Farga, A. Recent industrials extraction of plants seeds oil used in the development of functional food products: A Review. *Int. J. Food Prop.* **2022**, *25*, 2530–2550. [CrossRef]
6. Savoire, R.; Lanoisellé, J.L.; Vorobiev, E. Mechanical continuous oil expression from oilseeds: A review. *Food Bioprocess Technol.* **2013**, *6*, 1–16. [CrossRef]
7. Jacobsen, L.A.; Backer, L.F. Recovery of sunflower oil with a small screw expeller. *Energy Agric.* **1986**, *5*, 199–209. [CrossRef]
8. Mridula, D.; Saha, D.; Gupta, R.K.; Bhadwal, S. Oil expelling of dehulled sunflower: Optimization of screw pressing parameters. *J. Food Process. Preserv.* **2019**, *43*, e13852. [CrossRef]
9. Amalia, K.I.; Pontalier, P.Y.; Rigal, L. Extraction of sunflower oil by twin screw extruder: Screw configuration and operating condition effects. *Bioresour. Technol.* **2006**, *97*, 2302–2310. [CrossRef]
10. Pawlicki, L.T.; Rostocki, A.J.; Tefelski, D.B.; Siegoczyński, R.M.; Ptasznik, S. Mechanical properties of sunflower oil under pressure. *Eur. Food Res. Technol.* **2022**, *248*, 283–287. [CrossRef]
11. Evon, P.; Vandenbossche, V.; Pontalier, P.Y.; Rigal, L. Aqueous extraction of residual oil from sunflower press cake using a twin-screw extruder: Feasibility study. *Ind. Crops Prod.* **2009**, *29*, 455–465. [CrossRef]
12. Kasenov, A.L.; Kakimov, M.M.; Orynbekov, D.R. Experimental study of intensification of the process of pressing. In *Materials of the International Scientific and Practical Conference "Food, Ecology and Quality"*; Kemerovo Technological Institute of Food Industry: Kemerovo, Russia, 2009; pp. 127–129.
13. Le Clef, E.; Kemper, T. Sunflower seed preparation and oil extraction. In *Sunflower*; AOCS Press: Urbana, IL, USA, 2015; pp. 187–226. [CrossRef]
14. Wang, S.; Wang, J.; Dong, G.; Chen, X.; Wang, S.; Feng, L.; Su, X.; Bai, Q. Effect of Different Extraction Methods on Quality Characteristics of Rapeseed and Flaxseed Oils. *J. Food Qual.* **2022**, *2022*, 8296212. [CrossRef]
15. Available online: https://www.oilexpeller.com/oil-expeller-presses/ (accessed on 23 August 2023).
16. Available online: https://mikimoilpress.com/screw-oil-press-machine/ (accessed on 23 August 2023).
17. Available online: https://www.farmet.cz/ru/complex-oilseed-processing (accessed on 23 August 2023).
18. Available online: https://jasko.ru/ (accessed on 23 August 2023).
19. Slyusarenko, V. Press for pressing oil from oilseeds. In *Horticultură, Viticultură şi Vinificaţie, Silvicultură şi Grădini Publice, Protecţia Plantelor*; Universitatea Agrară de Stat din Moldova: Chișinău, Moldova, 2010; Volume 24, pp. 183–188.
20. Jain, D.; Jain, S. Performance evaluation of screw-press oil expeller using a continuous spiral and decreasing length of pitch of screw. *AgricEngInt CIGR J.* **2015**, *17*, 213–222.
21. Gukasyan, A.V.; Borodyansky, V.P.; Smychagin, E.O. Development of a twin-screw press for obtaining oil from sunflower seeds by cold pressing. *Izv. Vuzov Food Technol.* **2020**, *5–6*, 82–84. [CrossRef]
22. Kakimov, M.M.; Kasenov, A.L.; Parimbekov, Z.A.; Orynbekov, D.R.; Kuandykova, A.A. Theoretical study of some characteristics of the pressing process. In *Materials of the International Scientific and Practical Forum "Innovations in Agro-Industrial Complex"*; Novosibirsk State Agrarian University: Novosibirsk, Russia, 2009; pp. 176–178.
23. Brătfălean, D.; Cristea, V.M.; Agachi, P.Ş.; Irimie, D.F. Improvement of sunflower oil extraction by modelling and simulation. *Rev. Roum. Chim.* **2008**, *53*, 881–888.
24. *GOST 13496.15-2016*; Feeds, Mixed Fodder, Mixed Fodder Raw Materials. Methods for determining the Content of Crude Oil. Standardinform: Moscow, Russia, 2016.
25. Bekeshova, G.; Ibragimov, N.; Kakimov, A.; Suychinov, A.; Yessimbekov, Z.; Kabdylzhar, B.; Tokhtarov, Z.; Zhumadilova, G.; Abdilova, G. Effect of Rotational Speed and Gap between Rotating Knives of the Grinder on the Yield Stress and Water-Binding Capacity of Fine Ground Chicken Bone. *Appl. Sci.* **2022**, *12*, 3533. [CrossRef]

26. Sobolev, S.N. Development of a Method for Obtaining Amaranth oil by Pressing on a Single-Screw Press. Ph.D. Thesis, Voronezh State University of Engineering Technology, Voronezh, Russia, 2007.
27. Deli, S.; Masturah, F.M.; Aris, T.Y.; Nadiah, W.W. The Effects of physical parameters of the screw press oil expeller on oil yield from Nigella sativa L seeds. *Int. Food Res. J.* **2011**, *18*, 1367–1373.
28. Harmanto, A.; Hendriadi, E.; Rahmarestia, M.; Wiyono, J. Performance test of a screw-press machine for extracting Jatropha curcas seed into crude oil as an alternative energy source. *Indones. J. Agric.* **2009**, *2*, 35–40.
29. 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. [CrossRef]
30. Bogaert, L.; Mathieu, H.; Mhemdi, H.; Vorobiev, E. Characterization of oilseeds mechanical expression in an instrumented pilot screw press. *Ind. Crops Prod.* **2018**, *121*, 106–113. [CrossRef]
31. Chapuis, A.; Blin, J.; Carré, P.; Lecomte, D. Separation efficiency and energy consumption of oil expression using a screw-press: The case of *Jatropha curcas* L. seeds. *Ind. Crops Prod.* **2014**, *52*, 752–761. [CrossRef]
32. Mašán, V.; Vaštík, L.; Burg, P.; Sotolář, R.; Macák, M. The evaluation of extraction of some nut oils using screw pressing. *Slovak J. Food Sci.* **2020**, *14*, 847–853. [CrossRef]
33. Mikalauskas, I.R.; Preys, V.V. Parametric design of a screw press for pressing juice from grape pulp. *Izv. Tula State Univ. Tech. Sci.* **2021**, *5*, 3–8.
34. Singh, J.; Bargale, P.C. Development of a small capacity double stage compression screw press for oil expression. *J. Food Eng.* **2000**, *43*, 75–82. [CrossRef]
35. Herak, D.; Kabutey, A.; Divisova, M.; Simanjuntak, S. Mathematical model of mechanical behaviour of *Jatropha curcas* L. seeds under compression loading. *Biosyst. Eng.* **2013**, *114*, 279–288. [CrossRef]
36. Savoire, R. Screw pressing applications to oilseeds. *Ref. Modul. Food Sci.* **2017**. [CrossRef]
37. Kabutey, A.; Herák, D.; Mizera, Č. Determination of Maximum Oil Yield, Quality Indicators and Absorbance Spectra of Hulled Sunflower Seeds Oil Extraction under Axial Loading. *Foods* **2022**, *11*, 2866. [CrossRef] [PubMed]
38. Tataryants, M.S.; Zavinsky, S.I.; Troshin, A.G. Development of a methodology for calculation of screw loads and energy consumption of screw presses. *Sci. Rise* **2015**, *6*, 80–84.
39. Shah, R.K.; London, A.L. (Eds.) Chapter IV—General Methods for Solutions. In *Laminar Flow Forced Convection in Ducts*; Academic Press: Cambridge, MA, USA, 1978; pp. 61–77. [CrossRef]
40. Wang, Z.; Qi, X.; Zhuang, Y.; Wang, Q.; Sun, X. Effect of flow field and electric field coupling on oil–water emulsion separation. *Desalination Water Treat.* **2023**, *283*, 79–96.
41. Kakimov, M.M.; Kasenov, A.L.; Parimbekov, Z.A.; Abdilova, G.B.; Orynbekov, D.R. Mathematical modeling of the process of separation of the liquid fraction from the solid phase during pressing. In *Collection of Articles of the III International Scientific-Practical Conference "Agrarian Science to Agriculture"*; Altai State Agrarian University: Barnaul, Russia, 2008; pp. 179–181.
42. Afenchenko, D.S.; Sokolov, A.S. Investigation of particle mass transfer of liquid and viscoplastic products processed by high pressure. In *Food Technologies: Research, Innovation, Marketing, Proceedings of the I International Scientific and Practical Conference Dedicated to the Year of Science and Technology, Kerch, Greek, 23–25 September 2021*; Kerch State Marine Technological University: Kerch, Russia, 2021; pp. 21–31.
43. Li, Y.; Hsieh, F. Modeling of flow in a single screw extruder. *J. Food Eng.* **1996**, *27*, 353–375. [CrossRef]
44. Rendón-Castrillón, L.; Ramírez-Carmona, M.; Ocampo-López, C.; Gómez-Arroyave, L. Mathematical Model for Scaling up Bioprocesses Using Experiment Design Combined with Buckingham Pi Theorem. *Appl. Sci.* **2021**, *11*, 11338. [CrossRef]
45. Bako, T.; Enyi, O.S.; Imolemhe, U.V. Mathematical modeling of mechanical horizontal screw oil extractor. *Agric. Eng. Int. CIGR J.* **2020**, *22*, 244–254.