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Study of structural and kinematic characteristics of an energy-efficient oil press

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Abstract. The technological process of vegetable oil production requires significant energy costs, while the introduction of new technologies requires investment, which is a challenge for small and medium-sized enterprises in the current environment. This makes it important to introduce energy-efficient equipment in the conditions of these enterprises, which does not require significant investments. The article was concerned with improving the technological process of pressing oilseeds by introducing an energy-efficient oil press into the technological process and studying its structural and kinematic characteristics. In the context of the study, the determination of the physical and mechanical properties of raw materials, methods of theoretical mechanics and solid mechanics, calculation of structural elements of technological equipment for processing oilseeds were used. The necessity and expediency of theoretical analysis and experimental research are substantiated. The main regularities of oil separation from the crushed mass are determined. The study of physical and mechanical characteristics, size and weight parameters of seeds and crushed mass allowed to substantiate the main kinematic and design parameters of the screw press. The principle of operation of an energy-efficient screw oil press is described. The design of the press is improved by a steam sprayer installed in the receiving hopper under the threaded rollers, which is equipped with a steam generator, which makes it possible to carry out moisture-thermal treatment with steam within one device. The proposed constructive solution includes: determination of the coefficient of friction of seeds on an inclined plane, study of the components of the crushed mass obtained with the help of an energy-efficient oil press, and theoretical aspects of oilseed pressing. A study of the design and operating parameters of the screw press has been carried out, namely: determination of the screw press productivity, use of an energy-efficient press for oil separation makes it possible to improve the quality of the technological process, determination of the press

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power consumption and its efficiency. It has been concluded that the improved design solution of the press meets the modern requirements for oil production machines. The use of the proposed constructive solution will reduce oil losses during pressing, which will significantly increase the efficiency of the process, reduce operating costs and promote the development of oil production in small and medium-sized oilseed enterprises

Keywords: screw shaft; crushed mass; density; pressure; technological process; productivity; oil yield

INTRODUCTION

The oil and fat industry is one of the leading sectors in the food industry. Its main products are vegetable oil (edible and technical), and additional products are proteins for food and feed. Vegetable edible oil is used both in its pure (unchanged) form and as a component of various products (margarine, cooking fat, mayonnaise, etc.). Technical oil is used to produce fatty acids and oxidised oil. In turn, fatty acids are used in the chemical industry to make soaps and detergents (household and industrial), while oxidised oil is used in the production of drying oils, varnishes and paints. Some types of vegetable oils are used as solvents for medicines and in the production of cosmetics. Oilcakes and meals, which are waste products from the processing of many oilseeds, are a valuable high-protein concentrated feed for farm animals. More than 50 sunflower species are cultivated in Ukraine, and when developing new varieties, the aim is to change the chemical composition of the seeds and reduce the content of the fruit coat (seed hulling). Sunflower occupies a predominant place among oilseeds in the Mykolaiv region, which led to the choice of the research area, which concerned the operation of press equipment for processing sunflower seeds and the possibility of using a certain design for processing other oilseeds.

The authors P. Rajkhowa & Z. Kubik (2021) studied the level and development of processing enterprises, in particular for the processing of vegetable raw materials. In their work, they concluded that increasing the level of mechanisation of the agro-industrial complex, in particular farms and small industrial enterprises, has a positive impact on the involvement of labour reserves in economic development. The article analyses the use of agricultural machinery, in particular, water-lifting equipment, tractors, agricultural machinery and equipment for processing crop production. It has been found that the impact of increasing the level of mechanisation of farms reduces the demand for hired labour and has a positive impact on the participation of women in agricultural labour, which is relevant in the context of constraints.

Researchers A.E. Obayelu & S.O. Ayanshina (2020) note that processing enterprises need an effective approach, in particular, compliance with the principles of food security and the transition to sustainable food systems. L. Lytovchenko (2022) notes that the use of waste-free production, namely the further processing of husks, the use of cake or meal for feed purposes, contributes to the development of sustainable production and helps enterprises to receive additional profit. A study conducted by M. Hamulczuk *et al*. (2021) shows that Ukraine is one of the world's leading countries in the production and export of sunflower oil. However, the key trend is towards integration into the European Union markets, which requires the development of various forms of enterprises and investments.

Researchers S. Balaji & S. Chandrasekar (2023) note that vegetable oil can be used as an alternative to mineral oil and used in a certain proportion with mineral oil for insulation and cooling medium in a transformer. In turn, P.A. Kandhan *et al*. (2023) note that the use of a mixture of saturated and unsaturated vegetable oil is a promising solution for the insulation of high-voltage liquid dielectrics. They studied such characteristics as viscosity, flash point, and pour point. Scientists I. Zakharov *et al*. (2019) presented the results of a study of the quality of sunflower seed processing using an improved line. The mechanical and technological parameters of the processed raw materials, in particular the concentration of oil in sunflower seeds, are presented. The team of authors P. Osadchuk *et al*. (2022) developed an experimental setup with an ultrasonic generator for the purification of sunflower oil under the action of an ultrasonic field, the paper presents the technological parameters of the process of sunflower oil purification by ultrasonic treatment.

V. Shevchuk & O. Sukach (2018) described in detail the study of the mechanical and technological properties of oilseeds, in particular for ellipsoidal seeds. The main attention was paid to rapeseed and the design of the oilseed huller. The authors developed technical solutions for oilseed processing and presented the design dependencies of the outlined structures, in particular, the interaction of the hulling rollers with the seeds and the dependence of their gap and diameter. The authors of S. Wang *et al*. (2022) developed a simulation modelling method for the comprehensive description and construction of a discrete element model for non-spherical particles for sunflower seeds using computer digital modelling technology. This study is relevant for identifying the sowing characteristics of sunflower seeds, but studies of the size and mass characteristics of seeds conducted using mathematical modelling can also optimise processing processes.

Many researchers pay attention to the quality characteristics of oil as a finished product, in particular, A. Sudhakar *et al*. (2023) provided a detailed report on chemical studies, chromatography, carried out in the field of assessing the falsification of edible oils, as well as methods for detecting and combating counterfeiting. Researchers Z. Ye & Y. Liu (2023) studied the fatty acid composition of rapeseed and the impact of the technological process of its processing on the properties of the oil. However, in the context of evaluating the finished product, it is important to assess the quality of the feedstock, identify the correlations between the physical and mechanical properties of the raw materials that are processed and the influence of the design and operating parameters of the equipment, which is the focus of this study.

The aim of the study was to intensify the pressing of sunflower seeds on a screw press and substantiate its design and kinematic parameters based on theoretical and experimental studies, technical and technological solutions that can significantly improve the efficiency of the process of separating oil from sunflower seeds. The analysis of literature sources on the state of vegetable oil production has identified the following tasks, the solution of which was necessary to achieve the research goal:

- describe the features of the proposed constructive solution of an energy-efficient oilseed press;
- to present the design and kinematic characteristics of an energy-efficient oil press;
- to conduct laboratory tests on the physical and mechanical characteristics of raw materials processed by the oil press.

MATERIALS AND METHODS

The study was carried out on the basis of the proposed design of an energy-efficient oil press, the peculiarity of which is that a steam generating device was introduced into the press design, which affects the intensification of the oil separation process and increases its yield and reduces the pressure on the material on the working bodies, which will extend their service life (Fig. 1).

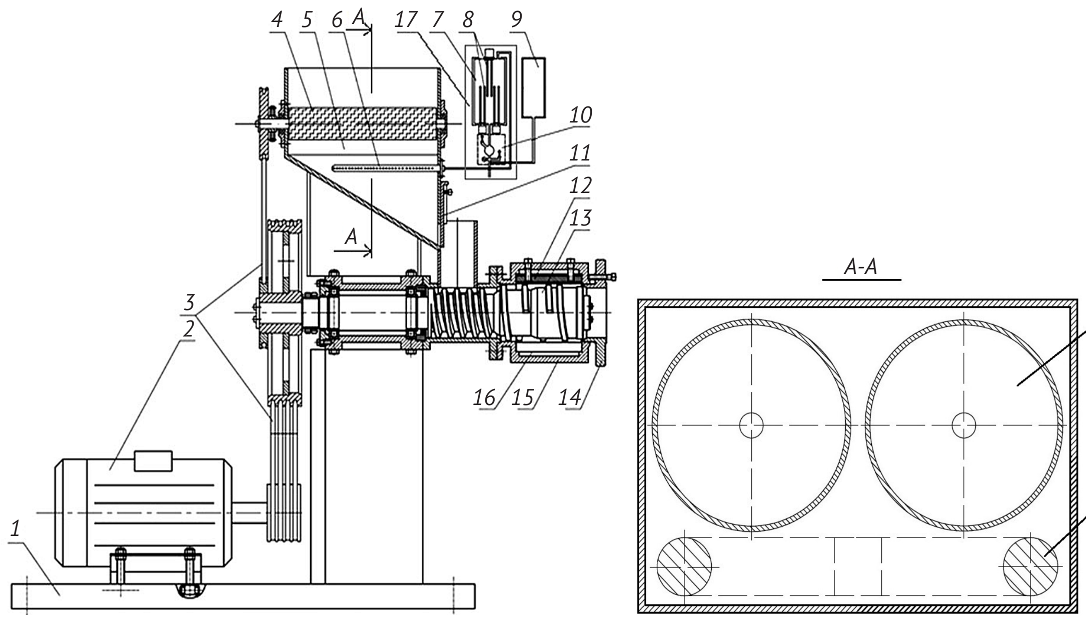

Figure 1. *Energy-efficient oilseed press with steam generator for moisture heat treatment*

Notes: *1 – frame; 2 – electric motor; 3 – V-belt transmission; 4 – threaded rollers; 5 – hopper; 6 – steam spray; 7 – heat exchanger; 8 – tubular electric heater; 9 – expansion tank; 10 – hydraulic groups; 11 – valve; 12 – tension wedge; 13 – auger; 14 – nut; 15 – perforated cylinder; 16 – perforated panels; 17 – steam generator*

Source: *N. Dotsenko et al. (2023)*

The most common varieties (hybrids) of sunflower seeds typical for cultivation in the Southern zone of Ukraine are: Alianze (RPG 406), Alamo (RT 933), Altsion, Arena, B-206, B-306, Visit, Hetman F1, Lan 26, Megasan (Makarchuk, 2022). The research was conducted on the seed varieties listed in Table 1.

Table 1. *Sunflower seed characteristics*

Variety	Dimensions, mm			Length to width ratio, L/a	Weight of 1,000 seeds, g	Fat content, %
	Length, L	Width, a	Thickness, b			
Alianze (RPG 406)	9.0	5.1	4.3	1.8	53	47.8
Arena	9.5	5.0	4.2	1.9	51	50.7
Visit	9.8	5.5	4.5	1.8	63.3	52.8
Hetman F1	10.0	5.4	4.4	1.9	55.5	49

Source: *developed by the authors*

In the course of studying the mechanical and technological properties of seeds, their frictional properties were also investigated. The friction angles of seeds on the following surfaces were determined: galvanised steel, white tin, sheet steel (rolled), and technical rubber. To confirm the theoretical assumption that pressure depends on material density, the setup shown in Figure 2 was used.

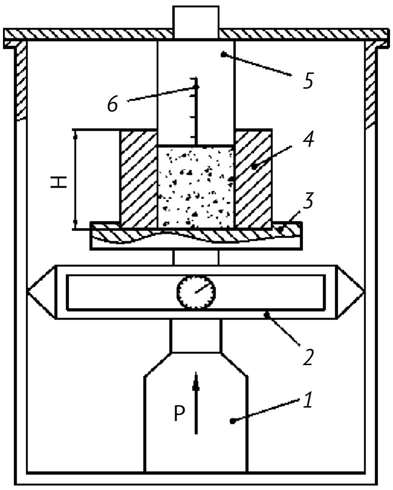

Figure 2. *Diagram of the device for determining the pressing pressure and pressing operation*

Notes: *1 – hydraulic jack; 2 – exemplary dynamometer; 3 – glass; 4 – matrix; 5 – punch; 6 – metric scale*

Source: *developed by the authors*

The main physical, mechanical and technological properties of sunflower seeds are shape, size, absolute and volumetric weight, density, and moisture content. The methodology is based on well-known guidelines and specific experimental conditions. Statistical methods of research and mathematical processing were used to separate natural changes from random indicators (Bortz, 2005).

To characterise the general population (all seeds under study) by discrete variation traits, sample statistical observation was applied on the basis of each value of trait X_i. The extreme values are denoted as X_{min} i X_{max}.

The total number of samples n for each of the traits was taken to be at least 50. In this case:

$$n = \sum_{i=1}^{n} l(i). \quad (1)$$

The statistical series of the feature X was divided into a number of classes N_k of $N_k = 10$, while $n \geqslant 50$. The class was calculated as:

$$t = \frac{X_{max} - X_{min}}{N_k}. \quad (2)$$

The boundaries for any k-th class were defined as:

- lower boundary: $X_{k-1} = X_{min} + t \cdot (k - 1)$;
- upper boundary: $X_k = X_{k-1} + t$.

Relative frequency of observations for any k-th class:

$$P_k = \frac{n_k}{n}, \quad (3)$$

where n_k – the number of options that fall into the k-th class.

The check was carried out according to the formula:

$$\sum_{k=1}^{N} P_k = 1. \quad (4)$$

The average arithmetic value of a feature across classes:

$$X_{k.avr} = \frac{(X_{k-1} + X_k)}{3}. \quad (5)$$

Formula for calculating the average value:

$$X_a = \sum_{k=1}^{N} X_{k.avr} \cdot P_k. \quad (6)$$

The estimate of the spread of the values of the random variable X around the average value of X_a was determined by the formula for the mean square of the deviation (variance) S:

$$S = \sum_{k=1}^{N} (X_{k.avr} - X_a) \cdot P_k. \quad (7)$$

To compare the spread of values near the centre of the distribution and a random variable, the standard deviation is determined σ:

$$\sigma = \sqrt{S}, \quad (8)$$

as well as the coefficient of variation or variability of the trait v:

$$v = \left(\frac{\sigma}{X_{avr}}\right) \cdot 100\%; \quad (9)$$

$$\rho = \pm\left(\frac{\sigma}{X_a \cdot \sqrt{n}}\right) \cdot 100\%. \quad (10)$$

The error rate (error) of the experiment, determined by formula (10), should not exceed 4.0%. The size and weight characteristics of seeds include: seed length *L*, mm; seed width *a*, mm; seed thickness *b*, mm; seed weight *m*, mm; absolute weight *M*, g; seed density ρ, kg/cm^3. Size and weight characteristics were determined by caliper SHC-1 (country of origin: Ukraine) with a scale division price of 0.05. The experiment was repeated 100 times. The absolute weight of seeds was determined by calculation:

$$m = \frac{M}{z}, \quad (11)$$

where *z* – the number of seeds in a random sample; *M* – the mass *z* of seeds.

For bulk materials, it is convenient to use the bulk density (kg/m^3), which depends on the actual density of the material particles and the voids between them:

$$\rho_H = (1 - \varepsilon) \cdot \rho_p, \quad (12)$$

where ε – the porosity; ρ_p – the density of the particle material, kg/m^3.

Porosity is defined as the ratio of the volume of pores V_p (m^3) in a loosely packed, uncompacted material to the volume of the entire loosely packed material *V* (m^3), i.e.:

$$\varepsilon = \frac{V_p}{V}. \quad (13)$$

RESULTS

Determination of the coefficient of friction of seeds on an inclined plane. One of the main physical and technological properties of seeds is their friction properties. The frictional properties of sunflower seeds are determined by the coefficients of external and internal friction, the indicator of which is the angle of natural slope. The calculation scheme of the device for determining the friction properties of seeds, and in particular for determining the static and dynamic friction coefficients, is shown in Figure 3. If a body is placed on an inclined plane, it will move downward under the action of its own weight $\vec{P} = m\vec{g}$ with constant acceleration $\vec{a}$, the normal reaction $\vec{N}$ of the inclined plane and the friction force F_{fr}, directed upward along the inclined plane, opposite to the body's motion. At $F_{fr} = f \cdot N$, where *f* – the friction coefficient. According to the basic law of dynamics:

$$m\vec{a} = \vec{P} + \vec{N} + \vec{F}_{fr}. \quad (14)$$

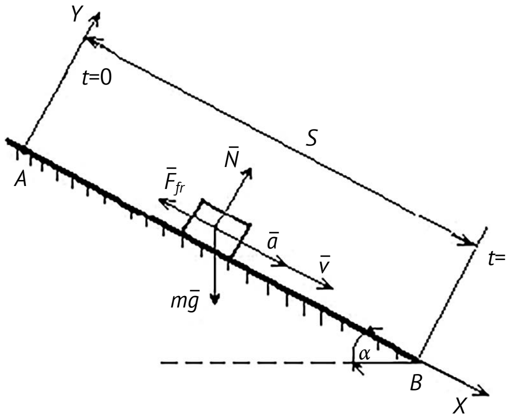

Figure 3. *Calculation scheme of the device for determining the dynamic coefficient of friction*
Source: *developed by the authors*

By projecting both parts of this vector equation onto the selected fixed coordinate axes, the differential equations of motion of a body on a rough inclined plane are obtained:

$$m\ddot{x} = mg \cdot sin\alpha - fN; \quad (15)$$

$$m\ddot{y} = -mg \cdot cos\alpha + N. \quad (16)$$

Since $y = 0$, then, accordingly, $\ddot{y} = 0$, and therefore from the differential equation (16) is determined:

$$N = mg \cdot cos\alpha. \quad (17)$$

Substituting this value of the normal response into equation (15) and reducing this equation by *m*, obtained:

$$a = \ddot{x} = g(sin\alpha - f \cdot cos\alpha) = const. \quad (18)$$

That is, the body is moving at an equally accelerated rate. Integrating this equation, obtained:

$$v = \dot{x} = g(sin\alpha - f \cdot cos\alpha)t + C_1. \quad (19)$$

Substituting the initial conditions into equation (18): $t = 0$, $v = v_0 = 0$, since the body motion is equally accelerated, $C_1 = 0$, and so on:

$$v = \dot{x} = g \cdot t \cdot (sin\alpha - f \cdot cos\alpha). \quad (20)$$

Integrating equation (20) and substituting the initial conditions into the resulting equation:

$$s = x = g \cdot t \cdot (sin\alpha - f \cdot cos\alpha) \cdot \frac{t^2}{2}. \quad (21)$$

Equation (16) is the law of motion of a body (material point) on a rough inclined surface. Solving equation (21) with respect to the friction coefficient *f*:

$$f = \frac{1}{cos\varepsilon}\left(sina - \frac{2s}{gt^2}\right) = tga - \frac{2s}{gt^2 \cdot cosa}. \quad (22)$$

Denoting the path travelled by the body in time $t = T$ from position A to position B by S, obtained the calculation form for determining the friction coefficient f:

$$f = tga - \frac{2S}{gT^2 \cdot cosa}. \quad (23)$$

The values of the friction coefficients cannot be determined by direct measurements, so the sliding angles were determined. The friction surfaces used were plates made of galvanised steel, white tin, rolled sheet steel and industrial rubber. When studying sliding friction, seeds were placed on an inclined plane of the device, with a sample of the material under study fixed on it. The inclined plane was raised to an angle φ, at which the seed began to move. The sliding friction coefficient f was determined by the formula:

$$f = tg(\varphi). \quad (24)$$

The angles and coefficients of seed sliding on the materials under study are presented in Table 2.

Table 2. *Sliding angles and friction coefficients of sunflower seeds*

Variety	Moisture content, %	Friction surfaces							
		Galvanised steel		White tin		Sheet steel (rolled)		Technical rubber	
		φ	f	φ	f	φ	f	φ	f
Alianze (RPG 406)	5	32.62	0.64	30.54	0.59	31.38	0.61	36.5	0.74
Arena	7	33.42	0.66	31.38	0.61	32.21	0.63	37.23	0.76
Visit	6	33.02	0.65	30.96	0.60	31.79	0.62	36.87	0.75
Hetman F1	8	33.82	0.67	31.8	0.62	32.62	0.64	37.6	0.77

Source: *developed by the authors*

Thus, the results of Table 2 show that the surface material has a negligible effect on the coefficient of friction of seed sliding. When sunflower seeds slide on a galvanised strip, the sliding friction coefficient ranges from 0.64 to 0.67; on a white tin strip – from 0.59 to 0.62; on a rolled strip – from 0.61 to 0.64; on a rubber strip – from 0.74 to 0.77.

Study of the components of the shredded mass. Theoretical studies have allowed to obtain calculations that reflect an idealised sunflower processing process, and therefore require experimental confirmation. Three areas of the pressing process have been experimentally identified: in the first area, the density of sunflower seeds increases within 500-600 kg/m^3; in the second area, the density increases from 500 to 650 kg/m^3 in proportion to the increase in pressure; in the third area, from 650 kg/m^3 with a rapid increase in pressure. The mathematical processing of the experimental results (Fig. 4) made it possible to determine the values of the coefficients (c) and (m), which characterise the effect of density, elasticity, size, and shape of seeds and allow theoretical calculation of the specific work by pressing. The probability of comparing the experimental and theoretical values of the specific work by pressing is within 5% (0.05).

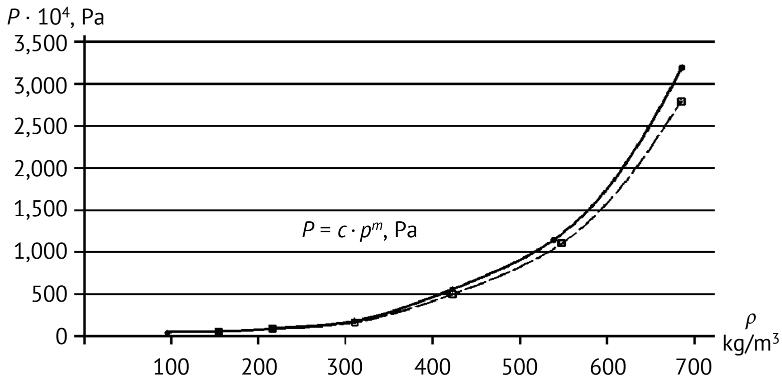

Figure 4. *Dependence of pressing pressure P on mint density*

Source: *developed by the authors*

Alignment of the experimental data with the theoretical curve allowed to establish that the relationship between the pressing pressure and the density of sunflower seeds is expressed by the following empirical relationship:

$$P = c \cdot p_m, \quad (25)$$

where P – the pressing pressure, Pa; ρ – the seed density, kg/m^3; c, m – coefficients.

The values of the coefficients (25) for sunflower are presented in Table 3.

Table 3. *Experimental values of the coefficients c and m*

Condition of sunflower seeds	c	m
Whole seeds	$1.76 \cdot 10^{-13}$	6.66
Crushed seeds (mint)	$3.3 \cdot 10^{-32}$	11.84

Source: *developed by the authors*

Determining the performance of a screw press. The working body of the screw is a screw that rotates in a fixed casing. In order to determine the design parameters of the working body, the movement of the material along the screw surface in the pressing zone is considered. Screw surfaces are formed as a trajectory from the movement of a straight line around and along a certain axis. The helical line described by any point of the line is called the directrix, or guide of the helical surface. The axial dimension that corresponds to the rise of the formed point in one revolution is the pitch of the helical line. A helical line is called regular if the forming point moves around and along a certain axis uniformly at a constant speed.

If a regular helical line corresponding to the outer cylinder with diameter D of the screw (Fig. 5) at a length of one step H onto a plane is turned, a right triangle ABC with a base equal to the length of the expanded circle of the cylinder πD and a height equal to the step of the helical line is fromed. This triangle is called a step triangle. The angle α made by the expanded helical line and the cylinder base is called the helical line rise angle. From the experience of many screw devices, it is known that material moves in a helical manner with variable speed in the axial and radial directions, depending on the distance of the material particles to the screw axis, the coefficient of friction and the pressure. The movement of the material along the screw surface of the screw can be conditionally represented as the movement of a number of unconnected individual particles with rather small gravitational forces. Under the assumption, each particle of material moves along its own helical line of the screw surface, the sweep of which is the hypotenuse of a step triangle.

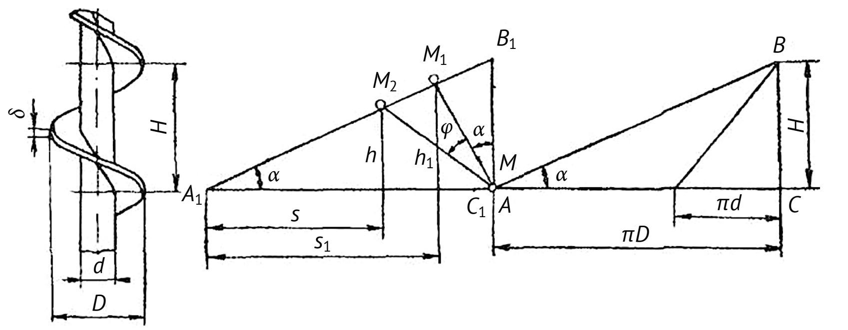

Figure 5. *Determining the screw parameters*

Source: *developed by the authors*

In the absence of friction between the screw surface (the expanded helical line AB) and a particle M of the transported material, the latter moves perpendicular to this surface, always in contact with it. With one rotation of the screw, the material particle in the axial direction passes the path h_1 and ends up at the point M_1.

$$h_1 = H \cdot cos^2\alpha. \quad (26)$$

In the presence of friction between the particle and the screw surface, the particle M will move at a friction angle φ to the normal C_1M_1 of the helical line and in one revolution of the screw will be at point M_2, having travelled in the axial direction the path:

$$h = H \cdot \frac{cos\alpha \cdot cos(\alpha+\varphi)}{cos\varphi} = H \cdot cos\alpha(cos\alpha - tg\varphi \cdot sin\alpha), \quad (27)$$

where H – the screw pitch of the screws; α – the angle of inclination of the screw lines; φ – the friction angle.

When the screw rotates, the material particles do not move in a straight line, but in helical lines – along and around the screw axis, which results in a decrease in their movement in the axial direction ($h < H$). This reduction can be accounted for by the coefficient K_o of lag or the coefficient k_b of rotation of the material particles, the analytical dependencies for which follow from the previously discussed scheme (Fig. 5).

Excluding friction forces:

$$k_0 = \frac{H-h_1}{H} = sin^2\alpha = \frac{\pi D - S_1}{\pi D} = k_b. \quad (28)$$

Taking into account friction forces:

$$k_0 = \frac{H-h}{H} = sin^2\alpha + 0.5 \cdot f \cdot sin2\alpha = \frac{\pi D - S}{\pi D} = k_b, \quad (29)$$

where $f = tg\varphi$ – the coefficient of friction of the material particles on the screw surface of the screw.

Since the pressed material is plastic-viscous and adhesive, the coefficient of friction is the coefficient of internal friction determined from the condition of particle bonding when the material layers are displaced. Thus, the movement of the product particles in the screw device can be accounted for by the displacement coefficient:

$$k = 1 - k_0 = cos^2\alpha - 0.5fsin2\alpha. \quad (30)$$

The axial displacement of the material particles ranges from h at the periphery to 0 at the point where the helical line angle is $\alpha_0 = (90° - \varphi)$. In the context of practical calculations, the average value is assumed:

$$\alpha_{aver} = 0.5(\alpha_D + \alpha_d), \quad (31)$$

where α_D – the angle of rise of the helical line on the periphery of the screw ($\alpha_D = arctg\frac{H}{\pi D}$); α_d – the angle of rise of the helical line on the screw shaft ($\alpha_d = arctg\frac{H}{\pi d}$).

The diameter d of the screw shaft must be greater than the maximum permissible diameter d_{np}, determined from the condition:

$$d_{np} = \frac{H}{\pi}tg\varphi. \quad (32)$$

Taking into account the above, the productivity (kg/h) will be:

$$Q = 600 \cdot V_j \cdot p_j \cdot \omega \cdot K_s \cdot K_V \cdot (1 - K_b) \cdot K_y \cdot K_p, \; j = 1, 2, ..., n, \quad (33)$$

where V_j – the theoretical volume of muscle per coil, m^3; ρ_j – the density of muscle per coil, kg/m^3 ($p_j = p_f \varepsilon_j$); $\rho_f = 450$ – the density of muscle in the feed zone, kg/m^3; ε_j – the degree of muscle compression on the coil ($\varepsilon_j = (1 + j)^{1.45}$); ω – the angular speed of the screw, rad/s ($\omega = \frac{\pi \cdot n}{30}$); n – the number of revolutions; $K_s = 2$ – the coefficient of muscle compaction; $K_V = 0.86$ – the coefficient of utilisation of the inter-twist volume; $K_b = 0.64$ – the coefficient for reverse movement; K_y – the coefficient of the oilseed (for sunflower $K_y = 1$, for flax $K_y = 0.5$); K_p – the coefficient that takes into account the mode of operation of the press (for single-stage pressing $K_p = 1$).

The design scheme of the screw press is shown in Figure 6. Before that, the theoretical volume of the pulp, m^3, is determined:

$$V_j = \frac{Q}{600 \cdot p_j . \omega \cdot K_S \cdot K_V \cdot (1-K_b) \cdot K_y \cdot K_p}. \quad (34)$$

On the other hand, the volume V_j is determined by the formula:

$$V_j = (\pi/4)(D_j^2 - d_j^2)[L_j - (ib_1 + b_2)/2cosa_j], \quad (35)$$

where D_j – the inner diameter of the sump cylinder at section j, m; d_j – the diameter of the hub of the j-th screw turn, m; L_j – the length of the j-th turn, m; b_1, b_2 – the thickness of the coil in normal section along the outer and inner diameters of the screw, respectively, m; $i = 1, 2$ – the number of screw turns; α_j – the angle of the screw line along the average diameter, degree ($a_j = arctg\frac{Dj-dj}{t_j}$); t_j – the coil pitch, m.

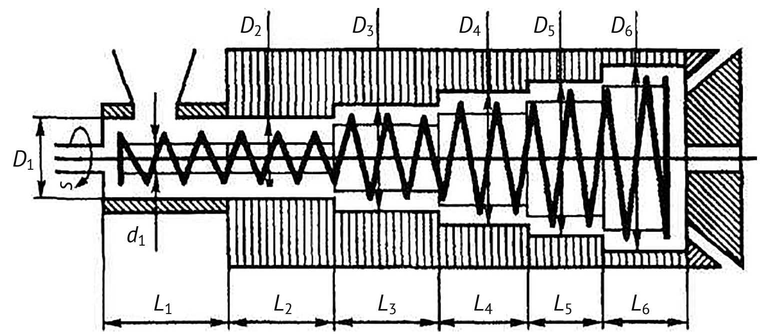

Figure 6. *Design diagram of a screw press*

Source: *developed by the authors*

By equating the right-hand sides of expressions (34) and (35), taking into account the above design relations, the equation is obtained from which the diameters D_j of the sections of the zeier cylinder are determined:

$$\frac{Q}{600 \cdot p_j \cdot \omega \cdot K_s \cdot K_V \cdot (1-K_b) \cdot K_y \cdot K_p} = (\pi/4) \cdot \left[D_j^2 - (D_j^2 - 0.025)\right] \cdot \left[1.08 D_j - (ib_1 + b_2)/\ 2cos\alpha_j\right]. \quad (36)$$

Muscle pressure in the inter-turn space of the *j*-th screw turn, Pa:

$$p_j = 2.52 a\varepsilon_j^{5.5} e^{0.022B}, \quad (37)$$

where $\alpha = 0.006$ – the empirical coefficient; $B = 4...5$ – the moisture content of the muscle, %.

With the calculated capacity, the screw parameters can be determined. The screw line pitch is equal to (0.7-0.8)*D*. At smaller values of the screw line pitch, the material may be torn off the inner surface of the device body due to the predominance of the screw surfaces of the screw above it, as a result of which the material will only rotate with the screw. Areas of the inner cylindrical surface of the housing:

$$F_H = \pi D \cdot (H - \delta); \quad (38)$$

$$F_W = \frac{1}{4\pi}(\pi DL - \pi dl + H^2 ln\frac{D+2L}{d+2l}), \quad (39)$$

where *l* and *L* – the scans of the helical lines corresponding to the shaft and screw diameters, m.

$$l = \sqrt{H^2 + (\pi d)^2}; \quad (40)$$

$$L = \sqrt{H^2 + (\pi D)^2}. \quad (41)$$

The axial force is calculated from the expression:

$$S = 0.392 n \cdot (D^2 - d^2) \cdot P_{max}, \quad (42)$$

where *n* – the number of screw strokes; P_{max} – the maximum pressure developed by the screw press.

Knowing the axial force, the stress on the shaft can be calculated:

$$\sigma_s = \frac{S}{F}, \quad (43)$$

where *F* – the cross-sectional area of the screw shaft.

The last turn of the screw must be designed for strength. The greatest bending moment in a steel screw turn will be on the inner contour of the plate and will be equal:

$$M_F = \frac{P_{max} \cdot D^2}{32} \cdot \frac{1.9 \cdot 0.7\alpha^{-4} - 1.2\alpha^{-2} - 5.2 ln\alpha}{1.3 \cdot 0.7\alpha^{-2}}. \quad (44)$$

Highest stress (equivalent):

$$\sigma = \pm\frac{6M_F}{\delta^2}, \quad (45)$$

where $a = D/d$ – the ratio of diameters.

Determining the power consumption of the press and its efficiency. The power (kW) required to drive the screw shaft of the press is determined by the formula:

$$N = N_0 \cdot Q, \quad (46)$$

where $N_0 = 0.045...0.055$ – the specific energy consumption for pressing oil in single-stage screw presses, kWh/kg.

The press efficiency is determined by the formula:

$$\eta = \frac{G + (M_C - \frac{M_C \cdot O}{100})}{G + O_P + (M_C - \frac{M_C \cdot O}{100})}, \quad 47)$$

where *G* – the amount of cake produced over a certain period of time (15-20 minutes), kg; M_C – the amount of crude unrefined oil produced over the same period of time as cake, kg; O_P – the amount of mill cake collected in the press collector over the same period of time, kg; *O* – the sediment in the oil supplied for refining, % by weight.

Practice shows that with proper preparation of the muscle for pressing and the screw presses in good working order, the efficiency is 0.94-0.96.

DISCUSSION

The technological process of oilseeds processing includes the following stages: preparation of raw materials (cleaning seeds from impurities, sorting, drying); extraction of mint – this operation is preceded by hulling (separation of husks), separation of the hull (separation of the “undershell”), crushing of the hulled kernel; oil extraction using one of the known methods. The resulting oil is subjected to preliminary purification, refining and sent for storage. The seed mass entering storage and processing is a heterogeneous mixture that includes both seeds and impurities that enter the mass during harvesting, temporary storage in the field and during transportation. The authors L.M. Alvarez-Gonzalez & I.J. Perea-Barrios (2023) point out that a large amount of impurities leads to moisture and seed deterioration, wear and tear of machine working parts, and a decrease in the subsequent oil quality.

The seed mass often contains metal impurities, primarily ferromagnetic ones (iron, steel, cast iron). Electromagnetic separators are used to remove them. The team of authors V. Shebanin *et al*. (2019) concluded that the efficiency of cleaning machines depends on the observance of a number of conditions during their operation. Seed flow into the machine should be uniform – underloading or overloading of the machine is unacceptable. If the machine is overloaded, the separation of impurities will be low, and if it is underloaded, seeds may get into impurities (in case of aerodynamic separation). The thickness of the seed layer on the machine sieve should not exceed 15 mm. The sieve installed in the machine must be selected according to the size of the most typical impurities and seeds. When the sieves are properly selected, the seeds should cover 2/3 of the total working length of the sieve. The angle of the sieve should ensure equal speeds of seed passing through the sieve and leaving the sieve. The sieve surface must be maintained in good technical condition (without dents, tears), systematically cleaned of debris using mechanical brushes or manually. The air flow rate must be adjusted so that no cleaned seeds come out with light debris and, at the same time, that heavy debris is also free of seeds. The processing should be done separately, as this will result in a higher yield of extra virgin oil.

The post-harvest stage involves bringing the seeds to moisture content standards (the exception is cottonseed, which sometimes has a moisture content 5…6% below the critical level when it arrives for processing and needs to be moistened before it can be processed). Prepared in accordance with the existing requirements, the raw material is sent for dehulling (separation of the hull from the kernel). In today's oilseed production facilities, dehulling is an important stage of the technological process. For this process, beater or centrifugal dehulling machines are usually used, with the former operating by breaking the hulls against the drum and drum beats, and the latter by hitting the drum beats once due to centrifugal forces. Technological standards allow the content of unshredded seeds to be up to 5%, and chaff – up to 3%. During the shucking process, the seeds are dehulled to form a hull, which includes the whole and crushed kernel, undershell and husk, and then threshed out on aspiration seeding machines. The hulled seeds are sent to the next technological operation – kernel grinding, which is aimed at obtaining an intermediate product called mint, which is obtained using rolling machines. The authors V. Shevchuk & O. Sukach (2018) note that rollers with grooves on the surface are used for primary and coarse grinding. The final grinding is carried out on rollers with smooth surfaces. The rotation speed of the rollers can be the same or different. The degree of grinding is regulated by changing the distance between the rollers. In terms of known methods, the mechanical method is one of the most common and most frequently used in oilseed processing plants. At the same time, the current study found that the process of compression of the pulp by pressing promotes oil separation and at the same time compacts the solid particles of the initial bulk material to form the cake. The process of compaction of the press material leads to the fact that the particles of the cake come closer together and the surface layers of oil are compressed. With a further increase in pressure on the material, the oil release virtually stops, despite the fact that some oil still remains in the middle of the material. The plastic properties of the pulp with high moisture content do not allow for the maximum pressure required for a given press design.

The authors of P.P. Ugarte-Espinoza *et al*. (2021) note that in the case of overdried pulp, the maximum possible pressure developed by the press is lower than that required for the appearance of the specified properties in the pulp. If the equipment is started up after a long shutdown, the cake should be fed into the press in a small amount until the press is fully heated and reaches thermal equilibrium with the cake and the heat losses of the press to the environment when the heated finished product (oil and cake) is removed from it. The main purpose of pressing the cake before extraction, or its full (final) pressing, is to obtain the maximum amount (80-90%) of pressing oil. The main working body of screw presses is the screw shaft. It consists of an axis, pressure coils and intermediate rings. All forging presses are equipped with stepped shafts. The screw shaft moves the material to be pressed with oil separation in the die cylinders. The mill cylinders consist of a set of mill plates. In the case of the pressing process, the following technological operations are carried out in the sequence shown below. The product obtained after rolling is fed into a fryer and then pressed using screw presses for complete oil separation, or so-called expeller presses. In the oilseed press industry, expellers are used for both single and complete oil separation in combination with fork presses. An expeller of the EP type is installed in a set with a three-chamber fryer. When the expeller is used in a double pressing scheme, the screw shaft has a rotation speed of 5-6 rpm. The capacity of the EP-type expeller with a double pressing scheme (FP-EP) for sunflower seeds is 20 tonnes per day, or 7-8 tonnes of oil cake with an oil content of 4-5%. The oil mills built in previous years, along with others, use the mechanical screw press MP-21, which can process 32 tonnes of sunflower seeds per day. This is a double-acting press, as it combines preliminary and final (complete) oil separation. The unit consists of a fryer, a vertical screw shaft that acts as a for-press, a horizontal screw shaft that acts as an expeller, a vibrating screen, a filter tank, pumps and an oil cooling system. The pulp prepared in the roaster is first fed for preliminary pressing into a vertical sieve drum with a vertical screw shaft installed in it. The design solution proposed in the results of this study allows combining hydrothermal treatment and pressing operations, which will reduce equipment costs, metal consumption and energy consumption, which is especially important in small industrial enterprises.

Based on the principle that the time spent by the muscle in each stage of the press tract is equal to the difference between the internal volume of the zener and the volume of the shaft (i.e., free space) divided by the volume of muscle passing through it per unit time. The authors of H. Jianjun *et al*. (2021) note that rheological dependencies indicate that one cannot be limited to only one of them to describe the behaviour of elastic-viscoplastic bodies, since the variety of structural and mechanical properties makes the deformation process quite complex. The proposed constructive solution of an energy-efficient screw press using a steam generator that treats raw materials with steam allows to significantly reduce the complexity of the deformation process, reducing the wear of the press working parts. The article by M. Mursalykova *et al*. (2023) is devoted to modelling the pressing process using an experimental screw press for the production of safflower oil in small processing enterprises. The problem of pressing the liquid phase from the dispersed material is described and solved. The proposed methodology for theoretical calculation of the pressing process allows determining the optimal parameters and pressing safflower oil. Taking into account the design solution of the oil press used for sunflower processing proposed in this paper, it should be noted that due to the fact that the oil moves through channels of variable cross-section and different shapes at a variable speed, the pressure on the liquid phase (hydrodynamic head) along the screw shaft also changes.

The authors of I.B. Muhammad *et al*. (2021) determine that the failure of a short drive shaft of a palm oil screw press is caused by fatigue crack formation, which was safe from stresses due to their concentration in its keyed areas. The plastic fracture observed on the surface of the shaft was found to be a result of the continuous rotational motion and the loading and unloading effect of the central drive system of the shaft. Therefore, the use of a steam generating device will reduce the stress on the screw and increase its service life. The authors Z. Barati *et al*. (2022) note that the total pressure and its radial and axial components are considered as the average values of the pressure on the oil and helium phases of the muscle. Practically, it is important to consider the change in total pressure and its components that occur along the screw shaft, since they affect the efficiency of oil pressing during pressing and the design of the presses themselves. The presented research on an energy-efficient oil press confirms the importance of an integrated approach to solving the issue of optimising the kinematic and structural parameters of screw presses for the oil industry. It is necessary to take into account the geometric parameters of the working chamber, the kinematic parameters of the equipment and the physical and mechanical properties of the seeds of the crop to be processed. Variations in the geometric characteristics of the working chamber or pressing elements of the equipment affect the ratio of pressure distribution and friction inside the chamber, and, consequently, the extraction efficiency and final oil yield. Thus, some physical and mechanical properties of oil-containing raw materials, in particular sunflower seeds, such as the coefficient of external friction, density, and pressure, are considered. Resistance to the movement of the material through the chamber is determined by the density of the pulp, the shape and distribution of the material is affected by lateral pressure and other factors. Kinematic parameters, such as the angular speed of the screw and linear speeds of movement, determine the material movement rate, which affects the time of contact between the raw material and the press working bodies and, accordingly, the quality and efficiency of oil extraction. To confirm the theoretical assumptions, experimental studies of the physical and mechanical characteristics of raw materials at all stages of the process are required. Such studies will help to correct the discrepancies between theory and practice and offer effective means of levelling them.

CONCLUSIONS

Oilseeds and their processed products, such as vegetable oil, cake, meal, and husk briquettes, are an important sector of the Ukrainian processing industry. To improve the efficiency of the technological process of oilseeds processing, the design and kinematic characteristics of an energy-efficient oil press were studied. A constructive solution of a screw press equipped with a steamer is presented, which allows to increase the oil yield due to the moisture-thermal treatment of mint, which is implemented in a single device. The physical and mechanical characteristics of sunflower seeds, which are typical for cultivation in the South of Ukraine, have been investigated. The coefficients of friction of sunflower seeds on an inclined plane, which affects the quality of their processing, were determined. Also, the components of the crushed mass were studied, on the basis of which the dependence of the pressing pressure on the density of the crush is presented. The calculation of the geometric parameters of the screw is presented. Based on these characteristics, the performance of the screw press, its capacity and efficiency were determined. Based on the data presented, it was concluded that the geometric parameters of the zeer chamber have the greatest impact on the pressing process. It is also necessary to take into account the physical and mechanical properties of the raw material entering the press. Kinematic parameters have a significant impact on the efficiency of an energy-efficient screw press. The presented theoretical dependencies can be used to calculate the technological process and select the most optimal parameters for its implementation. The theoretical analysis provides the initial data for understanding how the sunflower processing process proceeds. However, in order to optimise and implement this process in practice, it is necessary to conduct theoretical research, which can be attributed to the prospects for further research. This will allow to provide recommendations for improving the efficiency and cost-effectiveness of the oilseed processing process.

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CONFLICT OF INTEREST

None.

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Дослідження конструктивних і кінематичних характеристик енергоефективного олійного пресу

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Анотація. Технологічний процес виробництва рослинної олії потребує значних витрат на електроенергію, в той час як впровадження нових технологій потребує інвестицій, що в сучасних умовах є викликом для малих та середніх підприємств. Це спричиняє актуальність впровадження енергоефективного обладнання в умовах зазначених підприємств, що не потребує значних капіталовкладень. Стаття присвячена вдосконаленню технологічного процесу пресування олійної сировини шляхом впровадження в технологічний процес енергоефективного олійного пресу та дослідження його конструктивних та кінематичних характеристик. В контексті дослідження використовувалося визначення фізико-механічних властивостей сировини, методи теоретичної механіки та механіки твердого тіла, розрахунок конструктивних елементів технологічного обладнання для переробки олійної сировини. Обґрунтовано необхідність та доцільність проведення теоретичного аналізу та експериментальних досліджень. Визначено основні закономірності відокремлення олії з подрібненої маси. Дослідження фізико-механічних характеристик, розмірно-масових параметрів насіння і подрібненої маси дозволили обґрунтувати основні кінематичні і конструктивні параметри шнекового пресу. Викладено принцип роботи енергоефективного гвинтового олійного пресу. Конструкція пресу удосконалена паророзпилювачем, встановленим у приймальному бункері під нарізними валками, який комплектується парогенератором, що дає змогу здійснювати волого-термічну обробку парою в межах одного пристрою. Для запропонованого конструктивного рішення викладено: визначення коефіцієнту тертя насіння на похилій площині, здійснено дослідження компонентів подрібненої маси, отриманої за допомогою енергоефективного олійного пресу та представлено теоретичні аспекти пресування насіння олійних культур. Здійснено дослідження конструктивних і режимних параметрів шнекового пресу, а саме: визначення продуктивності шнекового пресу, використання енергоефективного пресу для відокремлення олії дає можливість поліпшити якість виконання технологічного процесу, визначення витрат потужності пресу та його коефіцієнт корисної дії. Підсумовано, що вдосконалене конструктивне рішення пресу відповідає сучасним вимогам, що ставляться до машин по виробництву олії. Використання запропонованого конструктивного рішення дозволить знизити втрати олії під час пресування, що значно підвищить ефективність процесу, дозволить знизити експлуатаційні витрати та сприятиме розвитку виробництва олії в умовах малих та середніх олійних підприємств

Ключові слова: шнековий вал; подрібнена маса; щільність; тиск; технологічний процес; продуктивність; вихід олії