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Research on the effectiveness of means for intensifying oil compression in twin-screw extrusion presses

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Abstract. The relevance of the study is due to the problem that is characteristic of various types of screw press structures, which leave up to 16% of the oil in the cake when pressing sunflower oil. In this regard, the purpose of this study is to find rational methods to improve the design of twin-screw extrusion presses to increase the oil yield. The leading methods for solving this problem are empirical research methods that allow comprehensively considering the stages of improving the geometric configuration of the screw shaft based on observation and finding a rational solution to the problem by measuring and experimenting. The paper analyses the features of technical means for grinding oil-containing raw materials in presses and extrusion presses, justifies the need to develop new grinding working bodies. The need to supplement the existing ideas about the interaction of special grinding working bodies with transport and compressive

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screw nozzles and the development of grinding units for twin-screw extrusion presses produced in Ukraine are clarified. Experimental studies were conducted with the developed design of new working bodies – cylindrical-conical nozzles. They create an intermediate compression of oil-containing raw materials, aimed at intensifying grinding with simultaneous mixing of the processed oil-containing material. A triple repetition of the increase in the degree of compression was obtained when installing three pairs of cylindrical-conical nozzles along the length of the screw shaft. Their use allowed for intensifying the degree of pressure increase and the additional oil yield of up to 3.1%. With each processed ton of seeds, due to the increase in the amount of pressed oil, the profit of enterprises that will improve twin-screw extrusion presses with these working bodies will also increase accordingly.

Keywords: oil production, oil press, geometric parameters, cylindrical cone nozzles, oil yield

Introduction

Most vegetable oil in the food industry is produced in large industrial plants using solvent extraction, and screw presses are mainly used for pre-pressing seeds with a high oil content (Famurewa *et al.*, 2021). In modern economic conditions, the chosen technology for processing raw materials and the selection of necessary equipment, especially screw presses, is of great importance in the production of oil. In agricultural enterprises specialising in oil production, a mechanical method of squeezing oil in screw presses or extrusion presses is used.

Pressing oil-containing raw materials or pressing oil is the main technological operation in the production of oil, which determines the efficiency of the entire enterprise (Mushtruk *et al.*, 2020). In most cases, the oil is pressed from a mass (pulp) previously prepared from oilseeds. However, when using simplified technological schemes, it is possible to squeeze oil directly from purified oil-containing seeds. The main technological schemes (Alonge & Jackson, 2019) and various types of modern single-screw press designs (Indartono *et al.*, 2019; Fakayode & Ajav, 2019; Pedretti *et al.*, 2019), single-screw and twin-screw extrusion presses (Romero-Guzmán *et al.*, 2020; Evon *et al.*, 2021), which are used in agricultural processing plants and oil pressing enterprises, are described and widely investigated in the processing of various oilseeds. The development of screw presses and extrusion presses in various fields of technology is associated with using continuous production methods and the ability to convert extrusion presses to meet any industry requirements (Choton *et al.*, 2020). Screw presses for oil pressing have a simple design, are easy to maintain, do not require highly qualified technicians to operate, are adapted to different types of oil, can be quickly installed on small farms, and the by-product (cake) can be used as animal feed (Amiolemhen & Eseigbe, 2019).

Most often, the actual task in the design of oil presses is to create universal machines for squeezing oil from almost all types of oil-containing crops (with an oil content of at least 20-15%) (Mushtruk *et al.*, 2020; Lara-Ojeda *et al.*, 2021). The re-equipment of the press by replacing individual parts (screw nozzles, seer slats, yield nozzles in the press matrix, etc.) and setting specific technological parameters of the working process for this raw material is provided to reconfigure the work of the press from one raw material to another. In this regard, there are many different proposals

for combining preparatory operations (grinding, water-heat treatment) in one machine – a screw press. These proposals are partially implemented in the form of serial press units, twin-screw extrusion presses, or more often, in the form of described inventions to patents. In addition to design proposals, various types of optimisation methods used for various processes, including modelling and software used in optimisation processes for oil extraction from plant materials, are considered (Bup & Foncha, 2020).

In oil production, screw presses are constantly being improved to increase oil yield, reduce energy consumption during the pressing process, improve the quality of the pressed oil, etc. (Alonge & Jackson, 2019; Chowdhury & Mahmud, 2020). One of the main areas of development of modern presses for pressing oil is the intensification of their technological process by simultaneous action of various physical-mechanical factors on oil-containing raw materials. The design of twin-screw extrusion presses involves combining several processes in one machine: grinding, heating, and compressing oil-containing raw materials with their separation into oil and cake. The type of working elements of the pressing path of the extrusion presses and their design parameters have a substantial impact on these processes. Considering a substantial number of screw and extrusion presses designs (Badmus *et al.*, 2019; Romero-Guzmán *et al.*, 2020; Famurewa *et al.*, 2021), the current expansion of their functionality and, the development of designs of working bodies of these presses for low-production enterprises are becoming relevant.

The purpose of the study is to determine the trend in the development of designs of working bodies of screw presses due to the analysis of modern studies. The main task of the paper was to offer new development with improving the quality characteristics of the twin-screw extrusion presses.

Literature Review

Many studies by foreign researchers are aimed at understanding the mechanism of interaction of the state of preparation of oil-containing raw materials with the design and technological parameters of screw presses. Their work is being conducted to develop effective press designs to increase oil yield. Numerous attempts have been made to improve the efficiency of oil extraction by pressing. In

general, three areas of work were investigated: optimisation of the operating parameters of the oil pressing process; improvement of the geometric configuration of the screw path of the press; preliminary preparation of seeds for pressing. However, many of these studies are the result of criteria based on the experience and intuition of press manufacturers and operators, rather than a thorough theoretical analysis of the physical principles involved in the oil extraction process. Although screw presses have been used for decades in the oil extraction industry, there are no satisfactory mathematical models to describe the pressing process, especially in the case of solid and liquid phase separation processes.

The operating conditions of the screw press also have a substantial impact on the efficiency of oil pressing. These conditions are considered in the papers (Indartono *et al.*, 2019; Bogaert *et al.*, 2020; Eseoha & Akubuo, 2021): seed properties, temperature, seed feed rate, screw rotation speed, and screw profile, which can determine the degree of filling of the screw shaft, pressure increase and friction. Thus, the effect of pressure on pressing efficiency can be investigated by applying different seed moisture content and operating modes (conditions) during the oil pressing process with a screw press, and different screw configurations. For all the seed moisture values tested, the oil pressed at a pressing temperature of 60 and 75°C was greater than the amount of oil at 45°C, and the oil yield improved with increasing pressing temperature. Similar conclusions that oil pressure is affected by an increase in temperature are confirmed experimentally in the study (Karaj & Muller, 2021) when using various design parameters of a screw press.

The study by Indartono *et al.* (2019) covered the effect of seed moisture content, pressing temperature, and seed feed rate on oil yield and quality. An innovative single-screw press with various screw shafts was developed to determine the optimal performance of squeezing oil from *Calophyllum* seeds. It was confirmed that with a low moisture content (less than 5%) in oil-containing raw materials, the pressure in the screw press can increase due to increased seed hardness. It is known that the higher the pressure in the screw press, the larger the volume of oil pressed. It was identified that humidity of less than 5.5% does not improve oil yield.

Seed moisture is a parameter that can be measured and changed as needed. An important factor in optimising the process of pressing oilseeds is to determine the most effective humidity indicator, at which the oil yield is the highest (Antoniassi *et al.*, 2022). Based on the research of many scientific papers, the study (Bălțatu *et al.*, 2022) concluded that there is an optimal humidity level for each type of oilseed.

The pressing time of oil-containing raw materials in a screw press in operation (Bogaert *et al.*, 2020) is defined as a key parameter for intensifying oil compression. In the paper, two sets of working bodies were investigated (while the screw nozzles had different profiles of turns, had breaks, or were placed so as to create a reverse flow). The first set, consisting of the original Reinartz AP08 screw model

(recommended by the manufacturer), had a constant diameter and reverse trajectories of the compression screw nozzles. The second set, Olexa arrangement, had an increased diameter of compressive screw nozzles and a larger number of compression valves to break the flow of oil-containing raw materials in front of each compressive nozzle. This geometry ensured the alternation of high-pressure (compression) and low-pressure (relaxation-mixing) sections. Oil was pressed exclusively in the compression sections. Intensive mixing of the oil-containing material was detected in the low-pressure sections. In some designs of industrial screw presses, a special ring is added to the set of working bodies of the screw shaft, which is called a ripper. It slows down the flow of raw materials through it and increases intermediate shear forces in the area in front of it. This ripper is recommended for additional grinding of seeds with a high fibre content, such as flax seeds. If this is not done, the seeds stick together to form layers that make it difficult to extract oil.

The design of a twin-screw extrusion press equipped with set screw nozzles, some of which are wound in the opposite area, was proposed to obtain more intensive mechanical processing of seeds. This configuration leads to a longer time of raw materials in their zone and a high shear pressure in the upper engagement of the coils (Vasilachi & Biriş, 2019). The consistent placement of different screw nozzle combinations results in more efficient material compression, dynamic dynamic plug creation, and good oil compression, which is caused by an effective pressure increase. Due to the selection of replaceable elements of screw nozzles, it is possible to provide the necessary geometry of the working channel, and therefore the corresponding shear stresses in different sections along the length of the twin-screw extrusion press, which makes it more versatile.

The advantage of the modular design of a twin-screw extrusion press is described in the paper (Evon *et al.*, 2021). It confirms the effective ability to configure the screw using a variety of elements that have different profiles of screw turns, and the ability to swap different working sections in the extrusion presses. The correct choice of screw configuration is an important point to maximise the quality of extruded products.

In the study (Lyng *et al.*, 2022), experiments were conducted to examine the effect of a combination of different working bodies on the extrusion process and on the quality characteristics of the product. Various screw configurations were investigated. For example, configuration A consisted of one reverse element section, one mixing section, and five transport sections. Screw configuration B consisted of two reverse element sections and four transport sections, while screw configuration C consisted of three reverse element sections and three transport sections. All three screw configurations had one mixing section. The ability to combine both the working elements of the screw shaft and individual sections is a great advantage of the design of extrusion presses over conventional presses.

There are many different proposals for improving the design of oil-pressing screw presses in the scientific

literature (Olaoye *et al.*, 2020; Sheikh & Zakiuddin, 2019; Hudzenko *et al.*, 2020). Conventionally, they can be divided into two directions: creating a screw press for squeezing oil from a specific crop (Ogunlade & Aremu, 2020; Alabi *et al.*, 2022), or a universal screw press that combines not only pressing operations, but also the presence of auxiliary chambers (grinding, water-heat treatment (Fakayode & Ajav, 2019; Didur *et al.*, 2019), or even a complete set of individual new working bodies, leading to an increase in oil yield and press productivity and a simultaneous reduction in production areas due to a reduction in auxiliary equipment. For example, the paper (Evon *et al.*, 2021) describes a developed universal twin-screw extrusion presses to provide efficient thermo-mechanical-chemical pretreatment of lignocellulose biomass before using it as a source of mechanical hardening in fully bio-fibre boards. Various lignocellulose byproducts of crop production have already been successfully pretreated using this process, such as grain straw (especially rice), coriander straw, flax straw pods, and the bark of amaranth and sunflower stalks (Evon *et al.*, 2021). Its mixing ability and the ability to add various components at the end of the screw profile are also advantages of this extrusion press. Such a combined process

in one pass of the extrusion press reduces production time and costs and can lead to a reduction in enterprise size since all operations are performed in one step. Such a one-step extrusion operation can be a source of valuable intensification of the industrial process.

From the analysis of various scientific papers, it was identified that the implementation of additional intermediate compression of oil raw materials in the press path attracts great attention from engineers. Among many patented ideas, there are often structurally complex ones to create, which substantially increase the complexity of manufacturing, maintaining the structure, and, accordingly, the final cost of the product.

Materials and Methods

Experimental studies were conducted based on the training, research, and production laboratory on the vegetable oil production line (VOPL) and at the enterprise of PE "Plasma" from 2011 to 2019. The pressing equipment of this line consisted of serial twin-screw extrusion presses of the EK 75/1200 brand produced by NPP "Extruder" and a final pressing machine. The main technical characteristics of the EK-75/1200 serial press extrusion press are shown in Table 1.

Table 1. Technical characteristics of the EK75/1200 press extrusion press

Parameter	Value
Productivity (for whole sunflower seeds), kg/h	150-175
Installed capacity, kW	18.3
Power consumption, kW	up to 16
Electric motor power, kW	7.5
Power of electric heaters, kW	up to 12
Heating temperature of cases (depending on raw materials), °C	up to 150
Shaft speed, rpm	30-60

Source: EK 75/1200 extrusion presses operation data sheet

One of the three twin-screw extrusion presses was improved to examine the intensification of oil pressing in screw presses. In production conditions, experimental studies were conducted, which consisted of two stages. The

first stage was conducted with the design of the pressing path of the manufacturer and the second – with a new design of the pressing path and sets of working bodies, which included developed cylindrical-conical nozzles (Fig. 1).

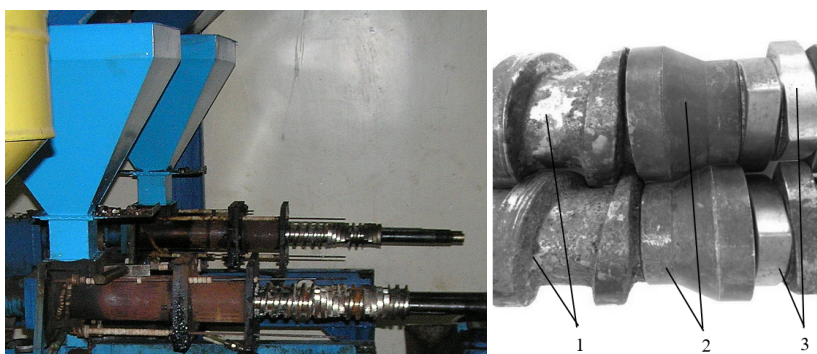


Figure 1. Fragments of working bodies of a twin-screw extrusion presses: a) – the experimental extrusion presses during the replacement of working bodies, b) – a fragment of working bodies, which included the developed cylindrical-cone nozzles: 1 – screw nozzles; 2 – cylindrical-cone nozzles; 3 – triangular cam nozzles

The design-technological parameters of the experimental extrusion press, the geometric parameters of the screw shaft, both factory and developed new nozzles, their ratio, composition, and characteristics of measuring devices are described in the papers (Hudzenko *et al.*, 2020; Gudzenko *et al.*, 2021).

The shaft speed was measured using a UNI-T UT-372 digital tachometer. The drive and the case heating system were controlled from the control panel, which is made as a separate unit. The control panel scheme is implemented based on the Microchip 16f874 microcontroller, with LCD display indicators that present the values of set and controlled parameters. During the experiment, the temperature values in two heating zones, the current consumed by the electric motor, and the voltage of each of the three supply phases were recorded. Temperature measurement in two heating zones of the extrusion presses case was performed with thermocouples with Philips KTY-81 elements.

A batch of whole sunflower seeds with a humidity of 7.4% was selected as the investigated raw material, which was determined by the Farmcomp WILE-55 moisture meter. Before pressing, the seeds were cleaned on an air-sieve separator. The choice of devices and measuring equipment was conducted on the condition that they provide measurement accuracy regulated by standard methods described more thoroughly in the paper (Hudzenko *et al.*, 2020). The methods of mathematical planning and those developed in the course of previous studies (Mushtuk *et al.*, 2020; Gudzenko *et al.*, 2021) were used, and a second-order central compositional plan was chosen as the basis to implement the experiment. Processing of data obtained during the experiment and their graphic design was conducted using Microsoft Office Excel 2016, Compass-3D v18.1 computer software.

A control batch of seeds in the general flow was processed in VOPL to determine the oil yield, considering the production conditions of operation. During the experiment, seeds entered the extrusion presses by gravity through a hopper. In order not to violate the technological conditions of oil compression and approximate the experiment to production conditions, the flow of seed mass into the extrusion press hopper was not interrupted, and all measurements were made when the extrusion presses reached steady-state operation. All readings from the control panel, temperature sensors, and oil yield measurement were performed in a control unit of time of 10 minutes. During this time, the oil and cake coming out of the extrusion press were collected in special containers, which were then weighed with Domotec Plus DT52 electronic scales. Thus, the oil yield was calculated based on equation (1):

$$Y_o = \frac{w_o}{w_c} \times 100 \quad (1)$$

where Y_o – oil yield, %; w_c – cake weight, kg; w_o – oil weight, kg;

All control measurements in this study were repeated three times, and the data obtained were presented on average.

Results and Discussion

From the conducted literature and patent search for means for intensifying oil pressing, the task of improving the twin-screw extrusion presses was conducted by introducing new working bodies that create intermediate support for oil-containing raw materials along the length of the press path and intensifying crushing with simultaneous mixing of the processed material.

The physical essence of the improvement made for the EK-75/1200 twin-screw extrusion press is confirmed and partially described when optimising the geometry of the screw shaft of the single-screw press reflected in the study (Carré, 2022). Namely, it indicates the generally accepted statements that high pressure is needed for maximum oil production. Thus, it is necessary to create a situation where the oil-containing raw material resists the traction of the screw turns, sufficient to create this pressure, without moving to a situation where the screw shaft can no longer overcome this resistance force, jamming the shafts. From the standpoint of screw shaft geometry, it is necessary to consider the importance of the phenomena of backflow and sliding of oil-containing raw materials, which reduce the performance of presses when the counteraction power exceeds the push power. Therefore, these phenomena have a limiting effect on pressure. In addition, increasing the time during which the material is compressed leads to additional heating, which should also be considered.

Special attention should be paid to the plasticity of oil-containing raw materials. It depends on parameters such as the water and oil content of the raw materials before pressing and their temperature and grinding condition. Plasticity, in turn, is explained as the compressibility of oil-containing raw materials, its ability to resist pushing through the turns of screws and, consequently, create pressure or move or flow backwards depending on the geometry of the screw and pressing cage. In order not to change the design of the extrusion presses within the working length of the screw shaft, which is 997 mm, when introducing into its composition the developed working bodies, the length of which is 45 mm, it is proposed to make changes to the set of working bodies of the screw shaft in several variants: reduce the length of the first pair of screw nozzles; apply a reduced number of triangular cam nozzles in groups with cylindrical-conical nozzles; by removing or reducing the length of intermediate rings.

An important point of intensification of oil displacement by new working bodies is the interaction of the working surfaces of a pair of cylindrical-conical nozzles 1 and 2 (Fig. 2). On the shafts 3, 13, screw nozzles 4, 5, 6, 7, cylindrical-conical nozzles 1, 2, groups of triangular cam nozzles 8, 9 are mounted through a keyway connection (not shown in the figure). Screw nozzles 4, 6 and 5, 7 are made with the same outer D_1 (75 mm) and inner d_1 (55 mm) diameters and differ only in the length of the nozzle, the pitch of the screw crest and its thickness, the values of which are given in Table 2.

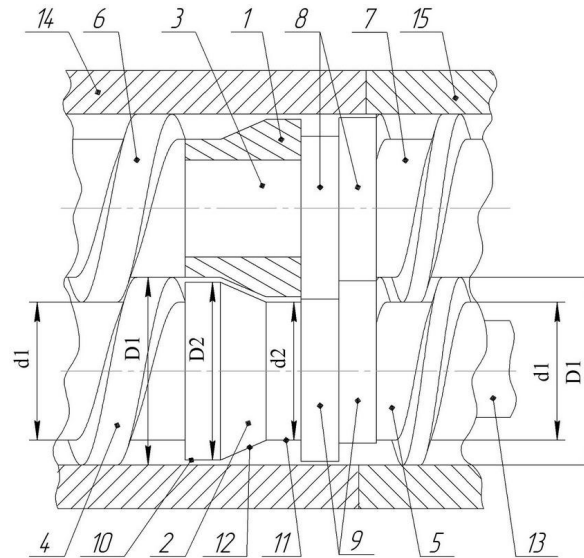


Figure 2. Layout of cylindrical-cone nozzles on the shafts of a twin-screw extrusion press.

Note: 1, 2 – cylindrical-cone nozzles, 3, 13 – shafts, 4, 5, 6, 7 – screw nozzles, 8, 9 – triangular cam nozzles, 10, 11 – cylindrical surfaces of the cylindrical-cone nozzle, 12 – cone surface of the cylindrical-cone nozzle, 14 – section with impermeable walls, 15 – pressing cage section with permeable walls for oil drainage, d1, D1 – inner and outer diameter of the screw nozzles, d2, D2 – inner and outer diameter of the cylindrical cone nozzle

Table 2. Geometric characteristics of screw nozzles (SN) according to scheme No.53

	SN1	SN2	SN3	SN4	SN5	SN6	SN7	SN8	SN9
Nozzle length, mm	144	88	96	96	96	48	48	48	48
Screw crest pitch (turn), mm	48	44	37	37	32	24	24	16	12
Screw crest thickness, mm	5	6	7	7	9.9	7.3	7.3	4.7	3.5

Cylindrical-cone nozzle 1 has a simple structure and is made in the form of a rotation part, which has two cylindrical floors on the outside 10, 11 of larger diameter D2 and smaller diameter d2 and truncated cone surface 12 between them. Cylindrical-conical nozzles are installed on parallel shafts 3, 13 in front of a group of triangular cam nozzles to create an intermediate compression zone for raw materials. Therewith, it is necessary to observe the condition that the cylindrical-conical nozzle 2 is directed to the screw nozzle 4 with the side with a larger diameter D2, and the second cylindrical-cone nozzle 1 is directed to the screw nozzle 6 with the side with a smaller diameter d2. It is recommended to produce the diameter D2 of cylindrical-conical nozzles within the limits given in the ratio (2):

$$D2 = (0.924 \div 0.987) \times D1 \quad (2)$$

where D1 is the outer diameter of the screw nozzles 4, 5 accordingly;

Reducing diameter D2 of a larger cylindrical surface 10 of the cylindrical-cone nozzle 2 in relation to the outer

diameter D1 of the screw nozzles, even by a few millimetres, ensures the penetration of oil-containing raw materials through the formed gaps with simultaneous compression in the area of action of the cylindrical-conical nozzle 1, and in the area of operation of the cylindrical-conical nozzle 2 a light flow of oil-containing raw materials is formed in the opposite area, which contributes to the renewal of oil-containing layers. Therewith, the live cross-section in the described nozzle area is sufficient to prevent the jamming of the shafts. The value of the diameter d2 of cylindrical-conical nozzles is assumed to be equal to the value of the internal diameter d1 of screw nozzles. As for the group of cam nozzles that are placed behind cylindrical-conical nozzles, their number in each group can consist of at least two or three triangular cam nozzles and an angular displacement of each subsequent one by at least 15°.

The process of intensifying oil compression in the area of action of cylindrical-conical nozzles is conducted as follows. With screw nozzles, oil-containing raw materials (sunflower seeds) are forcibly moved along the shaft to the area of operation of a pair of cylindrical-conical nozzles.

Some of the raw materials find resistance in the wall of the cylindrical-conical nozzle 2 with a diameter of D_2 , partially squeezed into the space between the outer cylindrical surface 10 and the inner surface of the section with impermeable walls 14. In this space, the oil-containing material undergoes intense compression. Most of the oil-containing material that met resistance in nozzle 2 under the pressure of a new portion of raw materials from the screw nozzles moves to the area of the cylindrical-conical nozzle 1 of the cylindrical body with a smaller diameter d_2 , which contains more free space in cross-section than a cylindrical body with a larger diameter D_2 . In the action of the zone of these cylindrical surfaces, there is a destruction of the stable flow of raw materials created by screw nozzles. In the contact area of cone surfaces 12 of both cylindrical-cone nozzles 1 and 2, the combined flow of oil-containing material is substantially compacted from the side of nozzle 1 and to a greater extent changes the trajectory of raw materials towards nozzle 2, although, in the area of cone surfaces, the live cross-section remains constant. In the next contact zone of the body, the part of the cylindrical surface of the larger diameter of the cylindrical-conical nozzle 1 with the inner surface of the section with impermeable walls, oil-containing raw materials are re-compacted. In the adjacent contact zone of the body of the part of the cylindrical surface of the smaller diameter of the cylindrical-conical nozzle 2, where the live cross-section of the free volume of the part is larger, the next change in the flow layers occurs while simultaneously delayering it. Moving to the zone of two groups of triangular cam nozzles 8 and 9, there is a sharp drop in internal pressure in the oil-containing raw materials, which contributes to loosening with the simultaneous process of crushing and grinding the seed petals compressed in the previous zone of cylindrical-cone nozzles, and therefore renewing the surfaces of oil-containing capillaries. Raw materials are intensively deformed, as a result of which oil flows out not only from the surface but also

from the internal capillaries of those particles that have been deformed. In the inter-turn space of pairs of subsequent screw nozzles towards the movement of the oil-containing mass 5 and 7, which have an even smaller free volume than the previous screw nozzles, raw materials are compacted while oil is squeezed out through special holes in the pressing cage section 15. Thus, the described interaction of the working surfaces of a pair of cylindrical-cone nozzles together with screw and triangular nozzles provides intermediate support for oil-containing raw materials and the intensification of destruction with simultaneous mixing. And the final support for oil-containing raw materials is created by cone nozzles located on the shafts after the last pair of screw nozzles in the matrix zone.

The main technological and design parameters that affect the efficient operation of the extrusion presses are: the heating temperature of the working area, the speed of rotation of the shafts, the gap in the matrix. Step-by-step studies were conducted at different values with the factory and a new set of working bodies of the pressing path, which included the developed cylindrical-conical nozzles. The results of the first stage of research are presented in the paper (Gudzenko *et al.*, 2021). The initial variable parameters were made the heating temperature of the buildings to obtain a more reliable assessment of the results. Regarding the size of the gap in the matrix (5.0 mm) and the speed of rotation of the shafts (56 rpm), they were left with the values obtained in previous studies. All other technological modes and conditions remained unchanged for the same batch of seeds.

First of all, the difference in geometric parameters and the nature of changes in the free volume along the length of the working path of the press for set No.1 (Fig. 3), which are recommended by the manufacturer and the updated set of working bodies No.2 (Fig. 4), which includes cylindrical-cone nozzles in each conjugate pair of nozzles will be analysed (“SN” – screw nozzles; “CN” – triangular cam nozzles; “CCN” – cylindrical-cone nozzles).

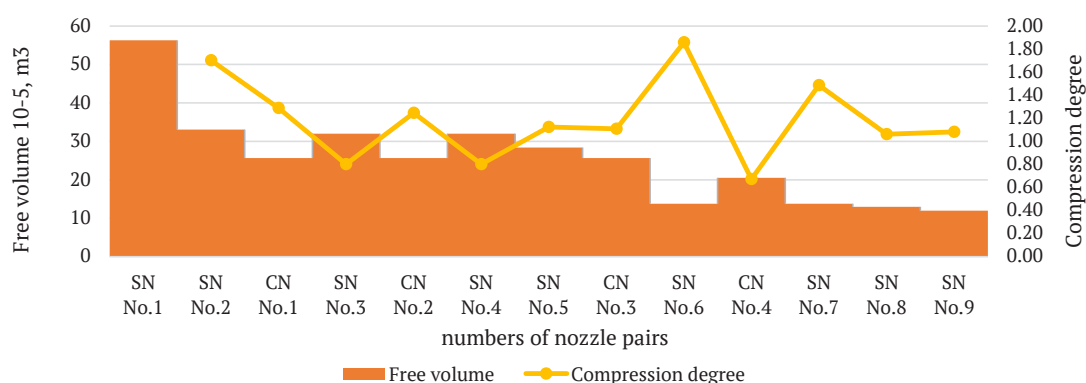


Figure 3. Change in the free volume of working bodies and the degree of compression of raw materials along the pressing path of the screw shaft (set No. 1 of working bodies for sunflower seeds with screw and cam nozzles)

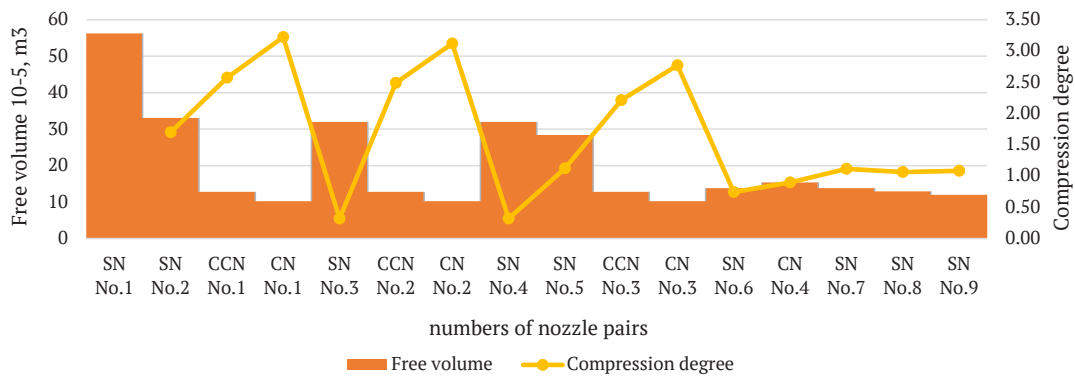


Figure 4. Change in the free volume of working bodies and the degree of compression of raw materials along the pressing path of the screw shaft (set No. 2 of working bodies for sunflower seeds with screw, cam, and cylindrical-cone nozzles)

When comparing charts (Fig. 3 and 4) it is noticeable that when using cylindrical-cone nozzles between screw and cam nozzles on shafts, the value of the compression ratio increases with the increase in the zone of grinding nozzles, and decreases in the screw nozzle following the movement of raw materials. When installing three pairs of cylindrical-conical nozzles along the length of the shaft, a triple repetition of a more rapid increase in the degree of compression is obtained. This ensures intermediate compaction of oil-containing raw materials and intensification

of destruction with simultaneous mixing of the processed material.

Based on the obtained experimental results, and after performing their computer processing, graphical dependences of oil yield depending on the set of working bodies (Fig. 5) at variable heating temperatures of enclosures are created. When comparing the obtained oil yield values, the effectiveness of using the developed cylindrical-cone nozzles is evident. Ultimately, with set No. 2, the yield of sunflower oil at different heating temperatures had an increase of up to 3%.

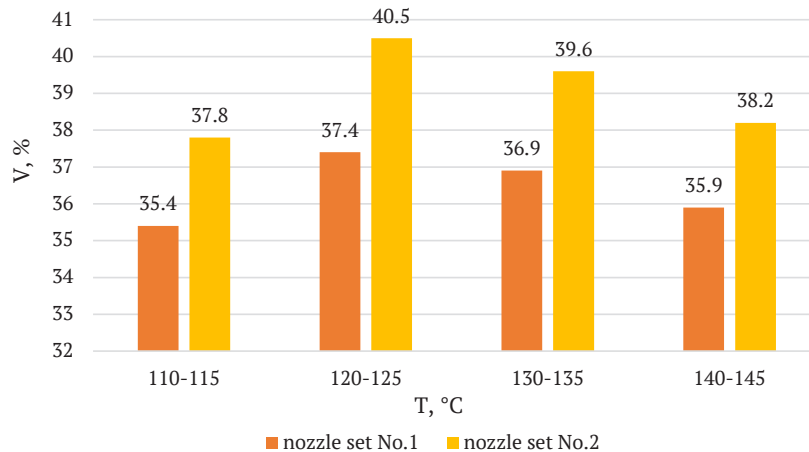


Figure 5. Dependence of the sunflower oil yield on the set of installed nozzles in the extrusion presses pressing path at different heating temperatures of the cases.

Note: 1 – with nozzles from manufacturer, 2 – with cylindrical-cone nozzles

As noted in the previous paper, (Gudzenko *et al.*, 2021) studies conducted with different sets of working bodies, and accordingly with changed geometric parameters of the extrusion presses path, confirmed their effect on the oil yield. With the same operating modes and technological adjustments of the extrusion presses, the presence of additional intermediate compression of raw materials by cylindrical-cone nozzles affects the throughput, namely the productivity of the extrusion presses. However, such changes in the press

path caused an increase in pressure at their limits, followed by a decrease in it in the groups of cam nozzles, which was accompanied by a slightly higher load on the engine. From the studies of the first stage of experiments with set No. 1, it is known that with an increase in the throughput from the increased gap in the matrix and with an increase in the speed of the screw shafts, the oil yield decreases.

In the research on single-screw presses (Indartono *et al.*, 2019) it is noted that the improvement in oil yield

was due to a forced increase in the degree of filling inside the screw press, which increased the pressure to 1400-1500 kgf*cm⁻² inside the screw press. In addition, this was due to the longer residence time of the material inside the screw press, so the pressing time was increased. However, if the seed feed rate is too high, it will block the filtration module of the pressing cage chamber and matrix with solid particles, which will lead to clogging of the oil outlet holes of the screw press. However, this disadvantage of single-screw presses was eliminated when using twin-screw extrusion presses with shafts that rotate in the same area and engage with each other. This ensures the forced movement of oil-containing raw materials along the press path to the cake outlet. Feeding the cavity between the turns of the twin-screw extrusion presses EK-75/1200 in the loading neck, when the extrusion presses enter a steady-state mode of operation, is provided by gravity seed flow from the hopper, without forced feeding seeds into it. There is a forced feeding device for feeding seeds to the working chamber. In the design of twin-screw extrusion presses that have been investigated in the paper (Dufaure *et al.*, 1999). For its use, the regulatory limits are specified. When the input seed flow rate was too low, the free volume of the working bodies was not fully filled, a dynamic plug could not form around the return screw, and therefore the pressure exerted on the raw material was insufficient to remove the oil through the filter module (pressing cage chamber), the raw material (crushed seeds) was simply transported to the yield of the extrusion presses matrix. If the input seed flow rate was too high, the working chamber of the extrusion press was clogged and its raw material contents were pushed back through the feed device on the first module. An increase in the maximum threshold value of the input seed flow rate could be obtained by increasing the speed of rotation of the screws, but this affected the reduced oil yield since the oil-containing raw materials were forced out of the extrusion presses faster. Notably, the speed of rotation of the shafts under study in operation (Dufaure *et al.*, 1999) of the BC21 twin-screw extrusion presses was 125-200 rpm, and the seed feed rate was in the range of 5-20 kg*h. Overall, the authors argue that the efficiency of pressing in the twin-screw extrusion presses was achieved by selecting the optimal configuration of the screw shaft profiles, controlling the internal parameters of the oil pressing operation (seed inlet flow rate, screw shaft rotation speed, pressing temperature) and controlling the external parameters (seed humidity). The paper notes that increasing the length of the reverse screw and reducing its pitch helped to seal the dynamic plug and increase the back pressure effect under the filtration module, which also led to a higher oil yield. It is also indicated that a twin-screw extrusion press can be used with greater efficiency than a single-screw press.

Since the screw press is a closed system, for a deeper understanding of the processes that occur in its working chamber, namely, the study of the flow areas of oil-containing raw materials from the influence of the configuration

of the screw shaft geometry in operation (Azizi *et al.*, 2015) it is proposed to apply simulation modelling of hydrodynamic flows of raw materials before implementing scientific findings in metal. The authors claim that computational hydrodynamics allows for a deeper analysis of aspects of flow dynamics due to local effects of the geometry of working bodies, modelling will provide information about the mixing behaviour of an inhomogeneous mixture of palm fruits and the degree of its compaction due to the applied hydraulic force. A successful simulation model is one of the available process tools that can replace expensive manufacturing and test runs of equipment to predict the performance of a screw press unit without compromising valuable metalworking resources, working time, and finances. However, the paper itself lacks detailed information about how this software papers in action. Only described are the expectations from its implementation that computational hydrodynamics will provide a solution to the problems associated with the operation of the screw press for palm oil, which will ultimately improve the speed of oil extraction. But the idea itself can be borrowed for implementation in future research

The results of investigating the dependence of oil yield at different heating temperatures of housings obtained in Figure 5 are confirmed by the trend of the obtained results of oil pressing research in other papers of researchers. For example, in operation (Fakayode & Ajav, 2019), when using a single-screw press with a roaster for squeezing moringa fruit oil, at a temperature of 80°C and a heating time of 30 minutes of raw materials in the roaster and an applied pressure of 20 MPa, it leads to an increase in oil yield – 81.66%. However, at higher temperatures and heating times, the oil yield decreased. This is due to the fact that at higher temperatures, protein coagulation and reduced viscosity occur faster, which leads to an increase in yield in a short period of time; while an increase in the heating duration at higher temperatures caused a substantial loss of moisture, which led to the solidification of the raw material, which, as a result, leads to a decrease in the efficiency of oil extrusion. Softening of tissues weakens the cellular structure, which makes it very susceptible to destruction under the influence of pressure. The interaction of temperature and pressure at higher levels tends to become counteracting, as increasing the temperature reduces the viscosity of the oil, thereby increasing its fluidity through the compressed medium, while increasing the pressure makes the oil harder, which limits the flow of oil. These results are similar to those of other researchers cited in the paper, who observed a similar trend when extracting *Jatropha* kernels, peanuts, and walnuts.

Considering new factors affecting the energy consumption and productivity of the extrusion presses, it was concluded that additional experiments should be conducted with changes in the size of the outlet hole in the matrix with different numbers of cylindrical-conical nozzles on the shaft. And given the change in electricity and oil tariffs, it is necessary to further investigate the rationality of the cost of increasing the oil yield at different energy

costs. Thus, in modern realities, these statements are the actual subject of subsequent research on the improvement of twin-screw extrusion presses.

Conclusions

Based on the analysis and systematisation of oil extrusion processes, principles of operation and designs of Ukrainian and foreign machines and assessment of their interaction with oil-containing raw materials, this study obtained new scientific results that expand the understanding of the patterns of grinding processes in different functional areas of twin-screw extrusion presses. Experimental studies have confirmed that the oil yield depends on the degree of compression, which is due to the geometric parameters of the screw shaft. The general nature of the change in free volume in the zones of conjugated cylindrical-cone nozzles leads to a more rapid increase in the degree of compression, but sufficient so that raw materials do not clog in their flow section. Experimentally confirmed the theoretical statement that the step-by-step intermediate compaction of oil-containing raw materials in the interface zone of cylindrical-cone nozzles and screw nozzles in front of them with simultaneous destruction and mixing of the upper and lower layers of the processed material relative to the inner shaft in the interaction zone of the surfaces of

cylindrical-cone nozzles and subsequent pressure relief in the zone of triangular cam nozzles destroys the layer gaps of encapsulated oil and leads to its more efficient extrusion from the extrusion presses. Comparing the obtained values of sunflower oil yield on a standard set of working bodies of the manufacturer (set No. 1) with an improved set of working bodies with cylindrical-cone nozzles in their composition (set No. 2), the effectiveness of set No. 2 was recorded. Namely, their use gave an increase in oil yield from 2.3% to 3.1% in all four cases with a change in the heating temperature of the cases. The practical importance of this study is relevant for owners of oil production enterprises that are equipped with twin-screw extrusion presses. After retrofitting the screw shafts of the extrusion presses with cylindrical-cone nozzles, up to 3% of the oil can be obtained additionally. When converted to the production capacity of the enterprise in hundreds of tonnes, the increase in profit due to additional litres of oil yield is evident. Based on the results of this study, the prospects for further research are outlined. They consist in clarifying the rational geometric parameters of the developed cylindrical-cone nozzles, from the standpoint of energy efficiency. That is, they should be considered in conjunction with other design parameters of the extrusion presses, which will reduce energy costs for the oil extrusion process.

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Дослідження ефективності засобів для інтенсифікації відтискання олії в двогвинтових прес-екструдерах

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Анотація. Актуальність дослідження зумовлена проблемою, яка характерна для різних видів конструкцій шнекових пресів, які при відтисканні соняшникової олії залишають в макусі до 16 % олії. У зв'язку з цим дане дослідження спрямоване на знаходження раціональних методів по вдосконаленню конструкції двогвинтових прес-екструдерів з метою збільшення виходу олії. Провідними методами для вирішення цієї проблеми є емпіричні методи дослідження, що дозволяють на основі спостереження комплексно розглянути етапи удосконалення геометричної конфігурації шнекового валу та шляхом вимірювань і експерименту знайти раціональний варіант розв'язку поставленої задачі. В роботі проаналізовано особливості технічних засобів для подрібнення олієвмісної сировини в пресах та екструдерах, обґрунтовано необхідність розроблення нових подрібнювальних робочих органів. З'ясовано необхідність доповнення існуючих уявлень про взаємодію спеціальних подрібнювальних робочих органів з транспортувальними і стискаючими гвинтовими насадками та розроблення подрібнювальних вузлів для двогвинтових прес-екструдерів вироблених в Україні. Проведено експериментальні дослідження з розробленою конструкцією нових робочих органів – циліндрично-конусних насадок. Вони створюють проміжне стискання олієвмісної сировини, спрямоване на інтенсифікацію подрібнення з одночасним перемішуванням перероблюваного олієвмісного матеріалу. Отримано потрібне повторення збільшення ступеню стискання при встановленні трьох пар циліндрично-конусних насадок по довжині шнекового валу. Їх застосування дозволило інтенсифікувати ступінь наростання тиску і збільшити вихід олії до 3,1 %. З кожної переробленої тони насіння, за рахунок збільшення кількості відтиснутої олії, відповідно, зростає і прибуток підприємств, які вдосконалять двогвинтові екструдери цими робочими органами

Ключові слова: виробництво олії, олієвіджимний прес, геометричні параметри, циліндрично-конусні насадки, вихід олії