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Influence of geometric parameters of screw nozzles of a twin screw extrusion press on the oil output

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Abstract. The relevance of the study is due to the search for rational geometric parameters of screw nozzles and the identification of the influence of the compression ratio of twin screw extrusion presses on the oil compression process. An important criterion in this paper is the indicator of the value of oil yield to obtain economic profit. From the analysis of optimisation methods in similar studies, the following variable geometric parameters of screw nozzles were selected for twin screw extruders: axial pitch, channel width between turns, rig width of the turn, and nozzle length. Two sets of experimental working bodies with modified geometric parameters were manufactured based on theoretical calculations and computer modelling to improve the working bodies of the EK 75/1200 twin screw extrusion press. Their theoretical compression ratio is determined, which is 5.50 and 4.33, respectively. It is also defined for the basic set of working bodies, which was recommended by the manufacturer, which was 4.69. It is established that the general nature of changes in the free volume along the length of the screw shaft is accompanied by an uneven decrease from 40 to 80% toward the press cake output. From the reviewed scientific literature, it was identified that the nature of changes in the free volume of turns along the length of the screw shaft characterises the correctness of its design. However, after analysing the results of the work performed, it was determined that the selection of rational geometric parameters of the working bodies should be considered in conjunction with other structural parameters, which will further intensify the oil compression process. It is experimentally confirmed that the oil yield

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depends on the degree of compression due to the geometric parameters of the screw nozzles. The oil yield increased by 0.9% when using a set of working bodies of set 1 when compared with the basic set of working bodies from the manufacturer's factory (set 2) in terms of volume of processed raw materials per unit will bring additional profit. It was determined that with the production volume of 50 tons of oil with an improved set of working bodies (set 1), the economic effect amounted to UAH 19,250

Keywords: oil production, double screw extrusion press, improvements, geometric parameters

Relevance

Over the past ten years, the area planted with oilseeds in Ukraine has grown substantially. From 1998 to 2020, sunflower production increased 6.7 times (from 2.26 to 15.254 million tons), while seed exports decreased by almost 17 times. The capacity for processing oilseeds increased 9.2 times (from 2.6 million tons to 24.0 million tons per year) and continues to grow as a result of the construction of new plants and the reconstruction and modernisation of existing ones. Sunflower oil production increased 16.3 times (from 432.8 thousand tons to more than 7.0 million tons). The fat-and-oil industry of Ukraine is export-oriented. The internal market consumes up to 10% of the total oil production in Ukraine [1]. The oilseed processing facilities created in Ukraine allow the processing of all grown crops (sunflower, soy, rapeseed). However, due to the constant increase in production capacity and mass export of soybean seeds, rapeseed, and partial export of sunflower seeds, processing enterprises are not fully loaded, which creates competition for raw materials in the internal market [2].

1,200 business entities are engaged in processing oilseeds in Ukraine. Therewith, the industry is characterised by a fairly high concentration of production: more than 90% of oil is produced by 51 specialised enterprises of large and medium capacity [3]. In small-capacity workshops, unrefined oil is usually produced by pressing. Basically, these workshops were created by agricultural enterprises to generate additional profit from processing their own agricultural products. Their products are focused mainly on the needs of the population of villages and district centres. Since the mid-90s of the 20th century, the range on the market among equipment for oil production has increased rapidly. Press equipment of low capacity (from 50 to 450 kg/h) was very diverse in the design of presses and the complexity of lines. However, most of them used unnecessarily energy-intensive, labour-intensive, and bulky complexes of machines and presses for oil production. Therefore, after a certain period of time, many manufacturers of unprofitable pressing equipment quit the market. Among the few manufacturers of equipment for oil production that remained in demand by processing enterprises, were manufacturers of twin screw extrusion presses. They occupied a certain niche among pressing equipment with a capacity of 150-500 kg/h. During the operation of twin screw extrusion presses, there is no need to use auxiliary equipment for preparing oilseeds: rudders, roller machines, roasters. This allowed substantially simplifying the technology of processing oilseeds by combining the operations of heat treatment, grinding, forming (granulating) the press cake, and pressing vegetable oil in one machine, which is certainly beneficial for raw material processing in small volumes. Notably, among other advantages of such extrusion presses is that they do not require complex installation and large rooms, can be serviced by unqualified workers, and within 2 hours they can be converted to other types of oilseeds. In addition, it is possible to press out the oil of unhulled sunflower seeds with twin screw extrusion presses [4].

Oil-pressing screw presses belong to the group of continuous machines, the main working body of which is a cylinder with one or more set screw shafts placed in it. Numerical values of the geometric parameters of the working path of the press substantially affect the characteristics of oil compression processes: productivity, oil yield, long-term operation, and power costs. Therefore, the study of geometric parameters of working bodies remains a very relevant issue for further substantiation of their rational values and determination of economic feasibility.

Analysis of Recent Studies and Papers

The main principle of operation of the screw press is to move oilseeds along the working chamber and compress it with a screw shaft. Compression of raw materials is conducted by reducing the free volume of the channels of the working area of the screw shaft, which is achieved by shifting the pitch, reducing the depth of the channel and the internal diameter of the seer cylinder. Therewith, there is a wide variety of specific combinations of these geometric parameters [4, 5, 6].

In the study [7], the influence of the design parameters of a screw shaft, the screw groove of which is made in the form of a curved triangle, on the energy indicators of a screw oil press is proved. These theoretical dependencies allow for calculating the total power consumption of an oil press.

Oil yield is one of the most important variables in the oil extraction process, so analysing this parameter is extremely important. Papers [8, 9, 10] are devoted to the modelling and optimisation of technological and design parameters for oil extraction. In the papers [11, 12], mathematical models have been developed that consider the parameters of controlling the pressing process with improved press characteristics. The optimal geometric parameters of the screw shaft design and optimal operating conditions for maximum oil yield were determined, and the influence of many parameters that affect the oil yield from the screw press was investigated.

The shortage of cost-effective oil press options is very noticeable in agricultural countries. Science-based advanced presses are the perfect solution to this particular problem. In the study [13], the design parameters of the screw press were improved. The screw length, pitch diameter, heating temperature, and rotation speed were determined to have a substantial impact on the oil yield efficiency.

The mechanical press method of oil extraction is the most common in the world. However, most screw presses used for this purpose leave about 8-14% of the oil in the press cake. A modified press was designed and developed based on the new principle of two-stage single-feed compression to improve the efficiency of oil extraction [14].

The paper [15], which contains an analysis of the use of twin screw extruders, deserves attention. It provides a comprehensive overview of the key parameters that affect the productivity of the oil pressing process. Therewith, considerable attention is paid to the development of innovative processes using twin screw extruders.

From the conducted literature research, it was determined that in the scientific literature more attention is paid to improving single screw oil presses than twin screw ones [4]. There are quite a lot of papers [16, 17, 18] in which the rheology of material behaviour in the geometric space of the channel is well described, formulas for calculating screw presses and extruders are given, and the effect of mixing and grinding working bodies of twin screw extruders related to the processing of rubber mixtures and plastics is described. From the standpoint of mathematical modelling, twin screw extruders are much more complex than single screw extruders, and therefore for a long time the choice of geometric parameters and processing modes was based on practical experience and experimental data, and, in addition, they had limited application due to a more complex design [4].

Little attention is paid to the problem of investigating the influence of geometric parameters of the oil pressing path and screw nozzles on the process of oil production in screw presses in the Ukrainian scientific literature. Insufficient coverage of issues related to the scientific justification of rational parameters and design of working bodies in twin screw extruders substantially hinders their technical development, leads to the appearance of imperfect equipment and unnecessary costs for its manufacture and operation. Therefore, there is a need to supplement the existing ideas about the interaction of special grinding working bodies with transporting and compressing screw nozzles and the development of grinding units for twin screw extrusion presses.

The purpose of the study is to determine the rational geometric parameters of screw shafts of twin screw extrusion presses through theoretical analysis and experimental studies. The main task of the study was to offer the best design and technological solutions, considering the characteristics of existing analogues of extrusion presses for oil pressing and rational geometric parameters of modern screw nozzles.

Materials and Methods

Experimental studies were conducted in production conditions on the extrusion press production facilities of SPE Extruder (Kharkiv) to determine the rational geometric parameters of the screw shafts of twin screw extrusion presses for the efficiency of the oil extrusion process. The research methodology included conducting preparatory works of the same type and experiments, namely – setting the maximum operating modes of the extruder for sunflower, rapeseed, and soybean seeds, determining the humidity of the selected batch of seeds for experiments. When performing experiments, generally accepted methods were used from literature sources and developed in the course of the study. The design-technological parameters of the extrusion press were controlled by various measuring devices. The choice of devices and measuring equipment was made on the condition that they provide the accuracy of measurements regulated by standardised methods. Processing of experimental data and graphic design of the work was conducted using computer software: Microsoft Office Excel.

Main Material Presentation

During the development and operation of screw presses of various designs, extensive experience has been accumulated. From the beginning of pressing, the seed passes from one physical state to another until the oil and press cake are released. The method of their separation (decomposition) and consideration in parts is used to examine these processes. Notably, such separation in most cases is purely conditional, since such parts are interconnected and have an impact on previous and subsequent processes. Therewith, each of the processes in a complex processing system can take place simultaneously (in parallel) or simultaneous-sequentially, which is implemented inside the pressing path of the extruder, where oilseeds, along with transportation, grinding, mixing, are subjected to heating and pressing.

Improving the quality of oil pressing in extrusion presses, in contrast to classic oil presses, is achieved by replacing traditional turns (screw nozzles) with two structural and technological zones (power, compression) with screw shafts with four main zones: power, compression, grinding and mixing, final pressing. As a result, twin screw extrusion presses are distinguished by longer screw shafts, which is associated with the introduction of special mixing and grinding elements into their design [20].

The working shaft of twin screw extruders is made as a set (Fig. 1) and consists directly of a shaft-rod *1*, on which screw nozzles are put on *3, 4, 6, 7*, triangular cam nozzles *5*, intermediate or mounting rings, if necessary, which are attached to the shaft by a spline or, preferably, keyway connection.

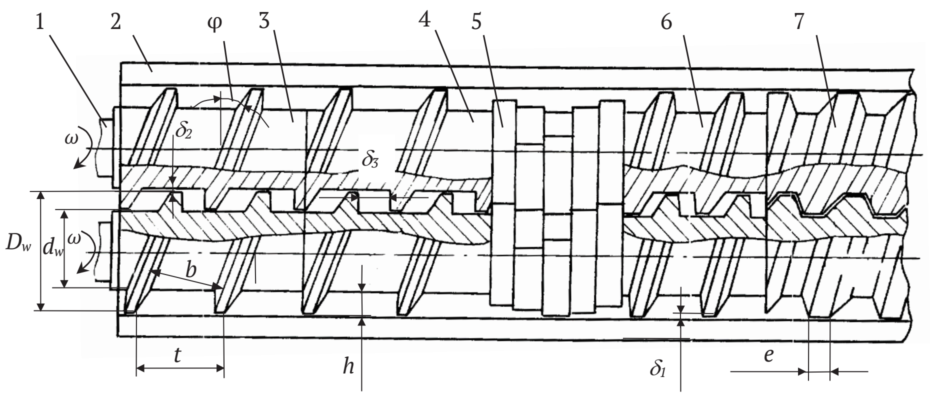

Figure 1. Geometry of the screw channel of a twin screw extrusion press: 1 – shaft; 2 – case; 3, 4, 6, 7 – screw nozzles; 5 – triangular cam nozzles

The outer surface of the screw nozzles and cams together with the inner surface of the housing form a screw channel. The screw nozzle (auger) and channel are characterised by external and internal diameters D_w and d_w, screw step t, channel height h, channel width b, rig width e, helical line lifting angle φ, the gap between the cylinder wall and the coil rigs δ_1, the gap between the rigs of one screw and the core of another δ_2, the gap between the side surfaces of the coil rigs δ_3, the length of the screw nozzles and the working area of the shaft, etc.

When describing a screw pressing mechanism, the principle of its division into sections is used. In general, a section is an elementary screw mechanism with conditionally constant parameters of the pressing process. The section can end with a matrix or compression gate – a section of the machine where the screw turn is interrupted and the flow section decreases [4].

In twin screw extrusion presses with hooked screws, the screw channels are divided by turns of conjugated screws into separate C-shaped volumes. Complete extrusion of C-shaped volumes due to the mutual hooking of the screw shafts ensures equal time of the material processing in the channels of the screw nozzles, and this is an important factor so that the oil-containing material does not overheat. However, the need to ensure geometric compatibility of the screws implies the presence of gaps δ_1, δ_2, which violate the isolation of C-shaped volumes and lead to material flow between them.

Compression of oil-containing material in the screw press during its movement through the working chamber is conducted due to a decrease in the free volume of channels in the working area of the screw shaft. The difference in the operating principles of twin screw and single screw extruders is due to different mechanisms for creating pressure in the processed material. In twin screw extruders, unlike single screw ones, there is a push-out effect of the turns of the conjugated shafts. If in a single screw extruder the ability to increase pressure is determined by the depth of the screw shaft, then in a twin screw extruder – by the geometric degree of closure of the screw channel (compression degree), which is determined from the Formula [4]:

$$k_{cc} = \frac{ie}{t-ie}, \qquad (1)$$

where e – width of the screw nozzle rig, t – screw pitch, and i – number of screw thread entries.

Value k_c shows which part of the channel cross-section overlaps, and characterises the compulsion to transport the processed material to the forming tool of the extruder and the ability of the augers to gain pressure.

In a screw press, the degree of compression of oil-containing material is the ratio of the free volume of the previous turn to the free volume of the next one.

$$k_{\text{ом}} = \frac{V_{\text{в}1}}{V_{\text{в}2}}, \qquad (2)$$

where $k_{ом}$– degree of compression of the oil-containing material; $V_{в1}$, $V_{в2}$– respectively, the free volume of the first (previous) turn and the next, m^3.

The seed mass, if it gets to the first transportation turn, has a large number of cavities between them, which should be eliminated as soon as possible. Therefore, the free volume of subsequent nozzles should be sharply reduced. At the end of the shaft, the free volume of the last nozzles should change less intensively, since the inner surface of the oil-containing material decreases due to compression of the capillaries of the gel part, the volume of which is relatively small. The nature of changes in the free volume of turns along the length of the screw shaft characterises the correctness of its design, and the degree of compression of the oil-containing material created by the screw characterises it from the quantitative side.

In a twin screw oil press with unidirectional shaft rotation, the diameter of the screw nozzles and the cylindrical surface of the case around them and the height of the turns of the screw nozzles are constant along the entire length of the working part of the screw shaft. Accordingly, the mass is compacted only by reducing the volume of the C-shaped section of the screw channels of each subsequent screw nozzle. This is done by stepwise reducing the pitch of the turns of the screw nozzles and changing the width of the rig of the turn. The width of the turn rig can vary from larger to smaller and vice versa, which means that there are a large number of options for changing configurations to find rational parameters. The pressure force generated by the screw nozzles depends on the screw thread pitch of the screw. Greater pressure forces can be created by reducing the pitch, but simultaneously reducing productivity.

The analysis of geometric parameters of three sets of working bodies of a twin screw extrusion press (set No. 2 – recommended by the manufacturer, sets No. 1 and No. 3 – experimental screw nozzles made based on the calculations of the study and partially by the manufacturer, respectively) is conducted. Calculations are made based on their geometric parameters for determining the free volume in each nozzle (screw nozzle "SN" and cam nozzle "CN") and the theoretical degree of compression in the working chamber. Usually, their number, type, and size differ depending on the oilseeds that are planned to be processed.

The results of determining the theoretical degree of compression of oil-containing material in the working chamber for three sets of working bodies (for sunflower seeds) of the EK 75/1200 extrusion press (SPE "Extruder", Kharkiv) by formula (2) are displayed in Table 1.

Table 1. *Degree of compression of sunflower seeds along the pressing path of the screw shaft of the working bodies*

Nozzle number													Total compression degree	
SN №1	SN №2	CN №1	SN №3	CN №2	SN №4	SN №5	CN №3	SN №6	CN №4	SN № 7	SN №8	SN № 9	SN №1/ SN № 9	Set
1	1.58	1.29	0.70	1.25	0.74	1.10	1.25	1.75	0.72	1.54	1.06	1.08	5.50	No. 1
1	1.70	1.29	0.80	1.25	0.80	1.12	1.11	1.86	0.67	1.49	1.06	1.08	4.69	No. 2
1	1.83	1.29	0.68	1.25	0.76	1.10	1.25	1.64	0.72	1.54	1.01	1.08	4.33	No. 3

The total degree of seed compression obtained by dividing the free volume in the zone of the first conjugate pair of screw nozzles by the free volume of the last pair of screw nozzles is only theoretical, which to a certain extent characterises the screw shaft. The nature of changes in the free volume and compression ratio of material along the length of the working path of the press in each conjugate pair of screw nozzles (SN), cam nozzles (CN) of the three analysed sets of working bodies is displayed in the diagram (Fig. 2) and chart (Fig. 3).

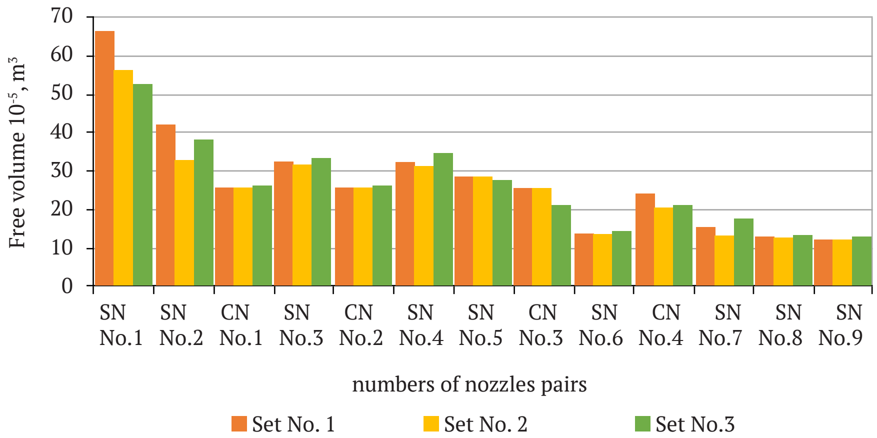

Figure 2. Change in the free volume within the conjugate pair of the screw (SN) and cam nozzles (CN) along the pressing path of the screw shaft

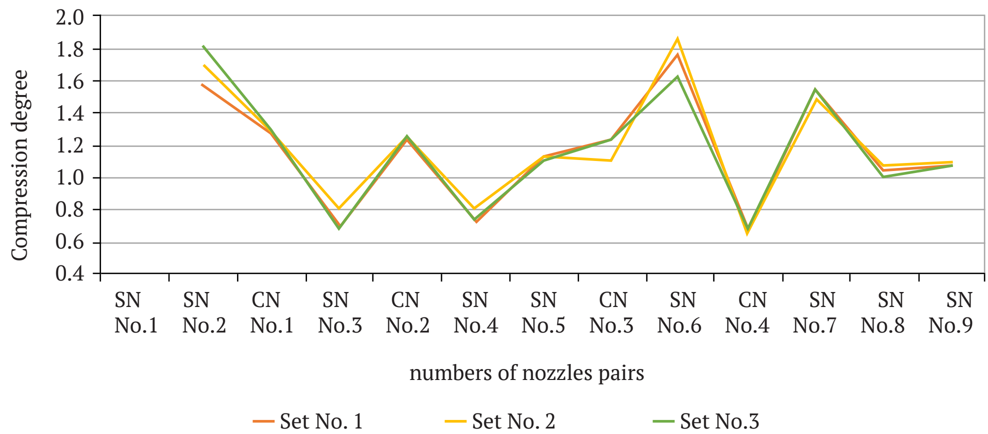

Figure 3. Change in the compression ratio of material within the conjugate pair of the screw (SN) and cam nozzles (CN) along the pressure path of the screw shaft

The difference in the position of the compression ratio curves of the material within the conjugated pairs of screw nozzles of sets of working bodies along the length of the pressing path of the screw shaft shows a smooth (smaller) or larger angle of the nature of changes in geometric parameters (screw pitch *t*, channel width *b*, rig width *e*) of the nozzles. The next step of the study was to identify the influence of the calculated geometric parameters of the analysed sets of working bodies of twin screw extrusion presses on the oil yield experimentally (Fig. 4).

Figure 4. General view of experimental extrusion presses EK 75/1200

Based on previous studies with modes and possible technological adjustments, rational design, and technological parameters of the upgraded extrusion press were established. The temperature of the first and second heating zones of the cases for sunflower seeds was 125-130°C. The size of the gap in the matrix for sunflower seeds was 5.0 mm. The angular velocity of the screw shaft is 6-7 rad/s, the time of technological influence on the oil-containing material in the press path is 60-75 s. Their use allowed for increasing the productivity of the machine and reducing energy costs for the oil pressing process.

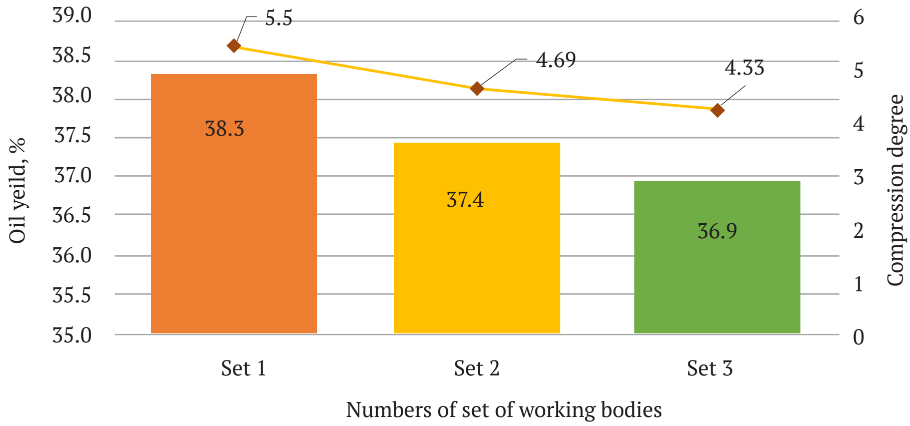

Figure 5. Dependence of sunflower oil yield and compression degree on the set of working bodies of installed nozzles

Studies conducted with sets of working bodies with different geometric parameters confirmed their effect on the oil yield. Even with the same operating modes and technological adjustments of the extrusion press, changing the geometric parameters of the first and second nozzles already affects the throughput of the number of seeds captured by the turns of the screw nozzles. However, further changes in the press path, namely a decrease in the free volume in the next screw nozzle, caused an increase in pressure at their edges, followed by a decrease in it in the cam nozzle groups. A rather rapid increase in pressure leads to a greater load on the engine. Notably, the change in the performance of the extrusion press also affected the oil yield. However, it should be considered in conjunction with the energy consumption of the machine. These statements may be the subject of further research on the improvement of twin screw extrusion presses.

Conclusions

The theoretical degree of compression determined for three sets of working bodies of a twin screw extrusion press for processing sunflower seeds according to calculations is 5.50, 4.69, and 3.33, respectively. It has been experimentally confirmed that the oil yield depends on the degree of compression due to the geometric parameters of the screw nozzles. The general nature of changes in the free volume in the zones of nozzle groups is accompanied by an uneven decrease of 40-80% toward the press cake output. The selection of rational geometric parameters of working bodies should be considered in conjunction with other structural parameters, which will allow intensifying the oil pressing process.

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Вплив геометричних параметрів гвинтових насадок двогвинтового пресекструдера на вихід олії

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Анотація. Актуальність дослідження зумовлена пошуком раціональних геометричних параметрів гвинтових насадок та виявлення впливу показника ступеню стискання двогвинтових пресекструдерів на процес відтискання олії. Значущим критерієм в даній роботі обрано показник величини виходу олії з метою отримання економічного прибутку. З проведеного аналізу методів оптимізації в аналогічних дослідженнях для двогвинтових екструдерів обрано наступні змінні геометричні параметри гвинтових насадок: крок черв›яка, ширина каналу між витками, ширину гребня витка та довжину насадки. На основі теоретичних розрахунків та комп'ютерного моделювання по вдосконаленню робочих органів двогвинтового пресекструдера ЕК 75/1200 виготовлено два комплекти експериментальних робочих органів зі зміненими геометричними параметрами. Визначено їх теоретичну ступінь стискання, яка становить, відповідно, 5,50 та 4,33. Також її визначено для базового набору робочих органів, який був рекомендований заводом виробником, яка склала 4,69. Встановлено, що загальний характер зміни вільного об'єму по довжині шнекового валу супроводжується нерівномірним зменшенням від 40 до 80% в сторону виходу макухи. З оглянутої наукової літератури стало відомо, що характер зміни вільного об›єму витків по довжині шнекового валу характеризує правильність його конструкції. Однак, проаналізувавши результати виконаної роботи, виявили, що підбір раціональних геометричних параметрів робочих органів слід розглядати в комплексі з іншими конструкційними параметрами, що дозволить додатково інтенсифікувати процес відтискання олії. Експериментально підтверджено, що вихід олії залежить від ступеня стискання, обумовленого геометричними параметрами гвинтових насадок. Збільшений вихід олії на 0,9 % при застосуванні комплекту робочих органів набору 1 при порівнянні з базовим набором робочих органів від заводу виробника (набір 2) у перерахунку на одиницю об'єму переробленої сировини принесе додатковий прибуток. Визначено, що при обсязі виробництва 50 т олії з вдосконаленим набором робочих органів (набір 1) економічний ефект склав 19250 грн

Ключові слова: виробництво олії, двогвинтовий пресекструдер, удосконалення, геометричні параметри