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JUSTIFICATION OF THE CONSTRUCTIVE-TECHNOLOGICAL DESIGN OF THE FEED PELLETIZER

Increasing production and improving the quality of protein feeds, as one of the most important tasks in increasing the productivity of animals and poultry, can be achieved through the improvement of the meal processing technology, which is currently limited to grinding with subsequent incorporation into compound feeds. The advanced processing technology of meal developed at the Institute of Oil Crops, through the introduction of an additional mechanical fractionation operation of the ground meal into protein and husk fractions, allows for the extraction of more than 40 % of protein powder with a protein content of not less than 38 %. In addition to avoiding rapid oxidation, thanks to the granulation process, the storage volumes of pellets in warehouses will be reduced, and transportation costs will be minimized. Therefore, addressing the mechanization of meal processing through the improvement of technology and equipment for separating it into protein granules and husk fuel briquettes is quite relevant. The purpose – experimentally justify the constructive-technological parameters of the feed pelletizer. A screw installation design for manufacturing feed pellets from the protein fraction of oilseed meal has been developed as part of the technological line. The optimal design and technological parameters of the pellet manufacturing installation are a material feeding rate of q = 35.7 kg/h, a rotational speed of the working element of n = 50.5 rpm, and a moisture content of the protein fraction of W = 28.9%. In this case, the power of the installation is P = 973 W, and its productivity is Q = 48 kg/h.

Keywords: *feed, meal, preparation, processing, press, screw, forming nozzle, design, rotation frequency, experiment, pressing, pressure, compression, density, power, energy intensity, efficiency, regression equation.*

Introduction. Increasing production and improving the quality of protein feeds, as one of the most important tasks in increasing the productivity of animals and poultry, can be achieved through the improvement of the meal processing technology, which is currently limited to grinding with subsequent incorporation into compound feeds. The advanced processing technology of meal developed at the Institute of Oil Crops, through the introduction of an additional mechanical fractionation operation of the ground meal into protein and husk fractions, allows for the extraction of more than 40 % of protein powder with a protein content of not less than 38 % [1].

The husk fraction, which includes the main mass of fiber, is used for the production of fuel briquettes. The oil content in the protein powder of 8-12% promotes its rapid oxidation, leading to a decrease in the quality of the protein additive. To increase the oxidation process time, it is proposed to produce the protein fraction in the form of granules [2, 3].

In addition to avoiding rapid oxidation, thanks to the granulation process, the storage volumes of pellets in warehouses will be reduced, and transportation costs will be minimized. Therefore, addressing the mechanization of meal processing through the improvement of technology and equipment for separating it into protein granules and husk fuel briquettes is quite relevant.

Analysis of recent research and publications. Feed pellets are cylindrical-shaped compressed products made from agricultural raw materials and their processing by-products, waste from oil processing, and other productions. Abroad, feed pellets are widely used for feeding automated lines both for domestic and industrial-level animals due to their balanced composition, significant ecological component, and increased energy value [4].

Granulation is the process of transforming a powdery material into particles (granules) of a certain size – agglomeration with the formation of shape and surface [4].

Granulation allows improving the technological properties of granulated material: preventing its caking (agglomeration); increasing flowability, which is important for ensuring the possibility of using the material in small portions; facilitating loading, transportation, storage, etc. [5].

The main purposes of granulation are:

– improving material flowability;

– preventing segregation of mixtures of bulk materials;

– preventing the sticking of particles of different sizes and bulk densities.

The following types of granulation are distinguished [6]:

1) dry granulation – grinding to a certain size with or without prior compaction (briquetting);

2) wet granulation – carried out by pressing wet masses in a weighed layer followed by spray or contact drying;

3) structural granulation (granulation in a pseudo-fluidized layer).

Machines designed for granulation (pellet presses) work on the principle of extrusion: bulk feeds, feeds treated with steam, or mixed with water, molasses, when reaching the die, are extruded through its holes by pressing mechanisms. The length of the granule is formed by a cutting mechanism [7].

Granulated compound feeds usually have the form of small cylinders with a diameter of 2.4 to 20 mm, their length usually does not exceed 15-20 mm. The sizes of granules depend on their application. Small granules from 2.5-3 mm are mainly intended for poultry chicks (chickens, ducklings, etc.); granules of about 5 mm are used for adult poultry, fish; 8 mm - for weaned piglets; 10 mm - for adult pigs; 10-14 mm - for large cattle. During grain raw material granulation, vitamins and preventive preparations can be added to prevent various diseases and promote better growth of animals and poultry [8].

Matrix and screw pelletizers belong to forced material feeding systems and are machines of continuous action. Compared to presses of periodic action, the technological process of feed pressing takes place under constant loads and in more favorable conditions [9].

The main advantages of matrix and screw presses are the continuity of the process, absence of shock loads, and lower material consumption. The large number of pressing channels in the matrix ensures sufficient press throughput capacity. The disadvantages of presses are the energy intensity of the process, crushing of the compacted material, increased requirements for the pressed materials in terms of homogeneity of grinding and uniformity of moisture, complexity of matrix manufacturing, and high heating of both bearing and working units [10].

The specific energy consumption of matrix presses for feed granulation differs from the energy consumption of screw presses, which determines the high efficiency of their application [11].

The purpose and objectives of the research. Experimentally justify the constructive-technological parameters of the feed pelletizer.

***Presenting main material*.** Based on conducted patent-information research of modern technologies and analysis of the designs of pressing machine working elements, it has been established that the most acceptable design could be a screw assembly. Consequently, a structural scheme of a screw assembly for producing granules from the protein fraction of oilseed meal has been developed (Fig. 1).

The installation for granule production consists of a frame 1, an electric motor 2, pulleys 3, a bearing unit 4, a screw 5, a cylindrical casing 6, a loading hopper 7, five forming cams 8, a cylindrical die 9, and a knife 10.

The installation operates as follows: The entire assembly is mounted on the frame 1. The protein fraction from oilseed meal is uniformly fed into the loading hopper 7, from which it enters the screw 5. The screw 5, performing a rotational motion with the help of the electric motor 2, pulleys 3, and bearing unit 4, moves the protein fraction towards the forming cams 8. During this process, the protein fraction is compacted by reducing the height of the screw threads. Upon reaching the forming cam 8, which performs a rotational motion, the protein fraction is further compacted and extruded through the stationary cylindrical die 9. Then, the knife 10 cuts the compacted protein fraction, resulting in cylindrical granules.

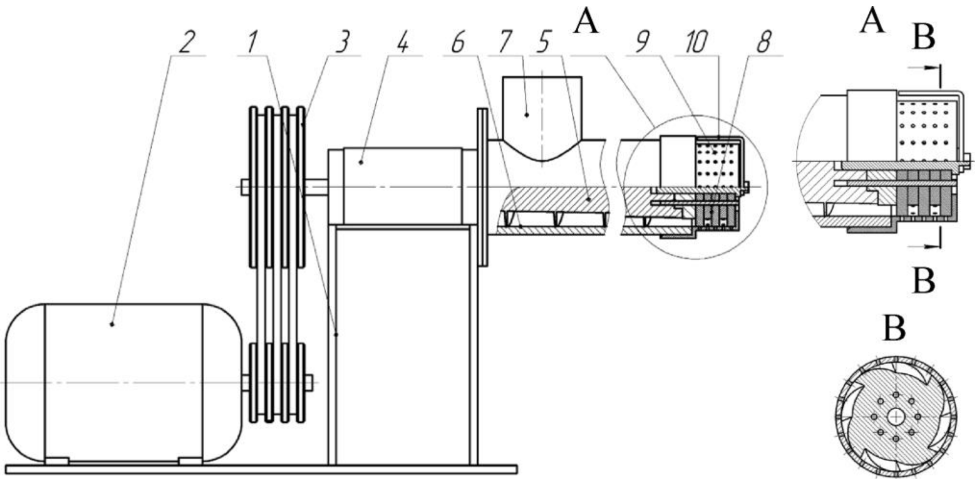
For the investigation of the technological process of pellet production from oilseed meal, a structural-technological scheme has been developed and an experimental setup (Fig. 2) has been created for its implementation.

The pelletizing setup allows for the installation of the necessary configuration of the forming cams 5. The setup includes a cylindrical die 6 with corresponding hole diameters of 3 mm.

The pelletizing setup is connected via the drive shaft 1 to a motor-reducer with a maximum power of 7.5 kW, which is connected to a Danfoss VLT Micro Drive frequency converter. Using the frequency converter, it is possible to change the drive shaft rotation frequency in the range of 0-100 rpm. The electrical schematic diagram illustrates the connection principle of the Danfoss VLT Micro Drive frequency converter to the motor-reducer electric motor.

The desired feed rate of the protein fraction into the loading hopper 4 is controlled by a regulating throttle. The feed rate of the protein fraction can be adjusted in the range of 0-80 kg/h.

Before commencing experimental studies, it is necessary to determine the conditions for conducting the research and prepare the protein fraction of oilseed crops (sunflower, mustard, rapeseed) with a mass of 10 kg for each experiment.



1 – frame; 2 – electric motor; 3 – pulleys; 4 – bearing unit; 5 – screw; 6 – cylindrical casing; 7 – loading hopper; 8 – forming cam; 9 – cylindrical die; 10 – knife

Fig. 1. Structural-technological scheme of the installation for granule production

general view; screw; forming cam; cylindrical die

Fig. 2. Experimental setup for pellet production (pelletizer)

As research criteria, productivity of the pellet creation process Q, pellet bulk density ρ, and power consumption of the electric motor P utilized in the process have been chosen.

The research factors include the drive shaft rotation frequency (30–90 rpm), the feed rate of the protein fraction (25–75 kg/h), and its moisture content (30–40%).

The studies are conducted according to a three-factor experiment plan (33), with the variation of factors utilizing a Box-Behnken experimental design matrix. The experiments are carried out in triplicate.

As research criteria, productivity of the pellet creation process Q, pellet bulk density ρ, and power consumption of the electric motor P utilized in the process have been chosen. Specific energy consumption E is selected as the optimization criterion for the research factors.

Research results. In accordance with the research results, a mathematical model of the influence of the investigated factors on the efficiency of the granule formation process from protein powder has been developed. The obtained mathematical model of the influence of the investigated factors on the bulk density of the granules had the form:

$$y_1 = 638,778 + 1,08333\,x_1 + 0,4444\,x_1^2 + \\ + 92,833\,x_2 + 1,16667\,x_1x_2 - 27,22\,x_2^2 + \\ +88,916\,x_3 - 2\,x_1x_3 + 2,16\,x_2x_3 - 21,72\,x_3^2. \quad (1)$$

For this equation, at a 95 % confidence level, the homogeneity of variances and the Cochran criterion values were determined: $G = 0.1674 < G_{0.05}(2,\ 15) = 0.3346$. The adequacy dispersion of the mathematical model $S^2 = 7.66$, the dispersion of experimental error $S_y^2 = 4.15$, the Fisher criterion value $F = 1.8469 < F_{0.05}(7,\ 30) = 2.33$; thus, the model is adequate at any confidence level.

Based on the calculated correlation coefficients and Student's criterion, significant coefficients at a confidence level greater than 95% are determined, resulting in the regression equation taking the form:

$$y_1 = 638,778 + 92,8333\,x_2 - 27,2222\,x_2^2 + \\ +88,9167\,x_3 ++ 2,16667\,x_2x_3 - 21,7222\,x_3^2 \quad (2)$$

In the decoded form, the model appears as:

$$\rho = -119,194 - 0,030246\,n^2 + 6,5074\,n + \\ + 0,007222\,W\,n + 21,8917\,W - 0,21722\,W^2 \quad (3)$$

Analyzing the equation (3), it can be stated that the bulk density of the granules is influenced only by the moisture content of the initial material and the rotational speed of the working element. Increasing these factors leads to an increase in the bulk density of the pellets. The optimal value for this equation is:

$$\rho\,(n = 90\text{ rpm},\ W = 40\ \%) = 775\ \text{kg/m}^3 \quad (4)$$

The obtained mathematical model of the influence of the investigated factors on the productivity of the production process of creating granules had the form:

$$y_2 = 57,8333 + 9,1375\,x_1 - 5,23333\,x_1^2 + \\ +4,475\,x_2 + 7,70833\,x_1x_2 - 9,525\,x_2^2 + \\ +15,71\,x_3 + 0,1167\,x_1x_3 - 0,125\,x_2x_3 - 9,833\,x_3^2. \quad (5)$$

For this equation, at a 95% confidence level, the homogeneity of variances and the Cochran criterion values were determined: $G = 0.1685 < G_{0.05}(2,\ 15) = 0.3346$. The adequacy dispersion of the mathematical model $S^2 = 0.872$, the dispersion of experimental error $S_y^2 = 0.91$, the Fisher criterion value $F = 0.9583 < F_{0.05}(7,\ 30) = 2.33$; thus, the model is adequate at any confidence level.

Based on the calculated correlation coefficients and Student's criterion, significant coefficients at a confidence level greater than 95% are determined, resulting in the regression equation taking the form:

$$y_2 = 57,8333 + 9,1375\,x_1 - 5,23333\,x_1^2 + \\ +4,475\,x_2 + 7,70833\,x_1x_2 - 9,525\,x_2^2 + \\ +15,7125\,x_3 - 9,83333\,x_3^2 \quad (6)$$

In the decoded form, the model appears as:

$$Q = -133,229 - 0,0105833\,n^2 + 0,9052\,n + \\ + 0,0102778\,q\,n + 0,586167\,q - 0,0083733\,q^2 + \\ + 7,47125\,W - 0,0983333\,W^2 \quad (7)$$

Analyzing the equation (7), it can be stated that all factors influence the productivity of the production process of creating granules. Increasing the moisture content of the initial material increases productivity, and when varying the values of the rotational speed of the working element and the feed rate of the initial material, a maximum is observed. The optimal value for this equation is:

$$Q\begin{pmatrix} q = 75\ \text{kg/h}, \\ n = 79,2\ \text{rpm}, \\ W = 37,9\ \% \end{pmatrix} = 71,91\ \text{kg/h}. \quad (8)$$

The obtained mathematical model of the influence of the investigated factors on the power consumption of the electric motor had the form:

$$y_3 = 1447,78 + 574,167\,x_1 + 143,61\,x_1^2 + \\ +1071,25\,x^2 + 482,5\,x_1x_2 + 1059,44\,x_2^2 + \\ +498,75\,x_3 - 9,166\,x_1x_3 - 6,66\,x_2x_3 + \\ +617,77\,x_3^{2.}. \quad (9)$$

For this equation, at a 95 % confidence level, the homogeneity of variances and the Cochran criterion values were determined: $G = 0.1447 < G_{0.05}(2,\ 15) = 0.3346$. The adequacy dispersion of the mathematical model $S^2 = 14572$, the dispersion of experimental error $S_y^2 = 16192$, the Fisher criterion value $F = 0.8999 < F_{0.05}(7,\ 30) = 2.33$; thus, the model is adequate at any confidence level.

Based on the calculated correlation coefficients and Student's criterion, significant coefficients at a confidence level greater than 95% are determined, resulting in the regression equation taking the form:

$$y_3 = 1447,78 + 574,167\,x_1 + 143,611\,x_1^2 + \\ + 1071,25\,x^2 ++ 482,5\,x_1x_2 + 1059,44\,x_2^2 + \\ +498,75\,x_3 + 617,778\,x_3^{2.}. \quad (10)$$

In the decoded form, the model appears as:

$$P = 8962,92 + 1,17716\,n^2 - 137,718\,n + \\ +0,643333\,q\,n - 38,6111\,q + 0,229778\,q^2 - \\ -320,792\,W + 6,17778\,W^2. \quad (11)$$

Analyzing the equation (11), it can be stated that all factors influence the power consumption of the electric motor. Increasing the moisture content of the initial material increases power consumption, and when varying the values of the rotational speed of the working element and the feed rate of the initial material, a minimum is observed. The optimal value for this equation is:

$$P\begin{pmatrix} q\ =\ 25\ kg/h, \\ n\ =\ 51{,}7\ rpm, \\ W\ =\ 25{,}9\ \% \end{pmatrix} = 834\ kW. \qquad (12)$$

The solution to the compromise problem was to minimize the power consumption of the electric motor with maximum granulator productivity. In this case, the bulk density of the obtained granules should not be less than 600 kg/m³:

$$\begin{cases} P(q,n,W) \to \min; \\ Q(q,n,W) \to \max; \\ \rho(q,n,W) > 600\,кг/м^3. \end{cases} \qquad (13)$$

By taking the power consumption to productivity ratio, the problem was transformed into the form:

$$\begin{cases} E(q,n,W) = \dfrac{P(q,n,W)}{Q(q,n,W)} \to \min; \\ \rho(q,n,W) > 600\,кг/м^3. \end{cases} \qquad (14)$$

Solving problem (14) using the Wolfram Cloud software package resulted in the optimal design and technological parameters of the granule production installation:

$$\begin{cases} E(q,n,W) = \dfrac{P(q,n,W)}{Q(q,n,W)} \to \min; \\ \rho(q,n,W) > 600\,кг/м^3. \end{cases} \qquad (15)$$

At these optimal values of design and technological parameters, the power consumption of the granule production installation's electric motor is 973 W, and its productivity is 48 kg/h.

Conclusions and prospects for further research. Based on the conducted patent and information research of modern technological lines for processing meal, a technology of comprehensive waste-free processing of meal from oilseed crops seeds has been developed, obtaining high-quality full-fledged protein additives in the form of pellets and solid biofuel.

A screw installation design for manufacturing feed pellets from the protein fraction of oilseed meal has been developed as part of the technological line. The optimal design and technological parameters of the pellet manufacturing installation are a material feeding rate of q = 35.7 kg/h, a rotational speed of the working element of n = 50.5 rpm, and a moisture content of the protein fraction of W = 28.9%. In this case, the power of the installation is P = 973 W, and its productivity is Q = 48 kg/h.

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ОБҐРУНТУВАННЯ КОНСТРУКТИВНО-ТЕХНОЛОГІЧНИХ ПАРАМЕТРІВ ФОРМУЮЧОЇ НАСАДКИ ГРАНУЛЯТОРА КОРМІВ

Збільшення виробництва та покращення якості білкових кормів, як одне з найважливіших завдань у підвищенні продуктивності тварин і птиці, може бути досягнуто завдяки удосконаленню технології переробки макухи олійних культур, яка наразі обмежується розмелюванням з наступним включенням до складних кормів. Сучасна технологія переробки макухи олійних культур, розроблена в Інституті олійних культур, за допомогою введення додаткової механічної фракціонування розмеленого борошна на білкові і оболонкові фракції, дозволяє видобути понад 40 % білкового порошку з вмістом білка не менше 38 %. Крім того, завдяки процесу грануляції уникнеться швидке окислення, що призведе до зменшення обсягів зберігання гранул у складах і мінімізації витрат на транспортування. Тому вирішення питання механізації переробки борошна шляхом удосконалення технології та обладнання для розділення його на білкові гранули та брикети з оболонки є досить актуальним.

Мета – експериментально обґрунтувати конструктивно-технологічні параметри гранулятора кормів. В рамках технологічної лінії розроблено конструкцію гвинтової установки для виробництва кормових гранул із білкової фракції насіннєвого борошна.

В результаті експериментальних досліджень оптимальні конструктивні та технологічні параметри установки для виробництва гранул, які включають швидкість подачі матеріалу q = 35,7 кг/год, обертову швидкість робочого елемента n = 50,5 об/хв та вологість білкової фракції W = 28,9%. У цьому випадку потужність установки становить P = 973 Вт, а її продуктивність – Q = 48 кг/год.

Ключові слова: *корми, шрот, приготування, переробка, прес, гвинт, формуюча насадка, конструкція, частота обертання, експеримент, пресування, тиск, стискання, щільність, потужність, енергоємність, ефективність, рівняння регресії.*

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