Theoretical aspects of the working process of a press extruder with a variable step auger for preparation of concentrated feed

Vladimir Y Frolov, Elena A Kotelevskaya and Marina I Tumanova

Kuban State Agrarian University named after I.T. Trubilin, Faculty of Mechanization Krasnodar, st. Kalinina, 13

E-mail: tumanova-kgau@mail.ru

Abstract. The article discusses the labor-intensive process of extruding soybeans. The parameters of production lines, methods and technical means intended for the implementation of the processes of preparing concentrated feeds based on insoluble soybean residue are theoretically substantiated. The results of theoretical studies to determine the optimal structural and technological parameters of a press extruder are presented: productivity, energy consumption, angular velocity, radius of the screw.

1. Introduction

For growing animals [1] at all stages of their development, a huge role is played by feed mixtures designed for both certain types of animals and their age characteristics, these mixtures contain nutrients that stimulate the growth and protective properties of the animal’s body. In all feed mixtures [2], [3] should be predominantly freshly prepared, have a certain taste and not have sharp unpleasant odors. Soya is a key crop plant in the world in terms of ensuring a full-fledged diet for animal feeding. The process of pressing the hay-of straw materials are devoted to many researchers.

However, questions devoted to the pressing of concentrated feeds based on insoluble soya bean residue are not fully covered, since the designs of press-extruders made in the form of a body with a profiled inner surface containing mixing and barothermal processing zones were not considered.

2. Materials and methods

In the process of research, the technological scheme for preparing final feeds based on insoluble soybean residue (figure 1) was considered, it is more expedient to use the extrusion process, since it is possible to combine mixing and barothermic processing of the material [21, 22].
Analysis of the studies showed that the mixing and barothermal process using the extruder of the proposed design has not been studied, therefore, there is no data on choosing a rational scheme for its use in production conditions, as well as optimal parameters in the mixing mode and barothermic processing of the mixture of grain feed and insoluble soy residue.

The working body [4] of the proposed extruder with annular outlet is a screw with a variable pitch (figure 2).

For the parameter determining the position of point M, we can take the angle \( \varphi \), formed by the x axis and the projection OP of the segment OM. The coordinates x and y of point M will be the same as that of point P. As for the vertical displacement Z, it grows in proportion to the angle of rotation \( \varphi \), i.e.

\[
Z = C \cdot t. \tag{1}
\]
Figure 3. Screw surface selection.

The rotation surface for a helical surface is a drawing.

\[ X = \cos \varphi; \ Y = \sin \varphi; \ Z = \psi(u); \]

(2)

It is known from surface theory that helical surfaces are superimposed on their surface of revolution. The surface of rotation for the considered screw surfaces has the form

\[ X = \cos \varphi; \ Y = \sin \varphi; \ Z = d \]

\[ (R_2 \geq u \geq R_1) \]

(3)

Where, \( d = \frac{\delta}{2} \) for the upper surface \( P_1 \);
\( d = -\frac{\delta}{2} \) for the lower surface of \( P_2 \).

Figure 4. To the rationale for the selection of screw surfaces.

From equations (3) it follows that the surfaces of revolution is part of a circle located in the horizontal plane and bounded by circles of radius \( R_2 \) and \( R_1 \).

The rotation surface for \( L_1 \) is

\[ X_1 = \cos \varphi; \ Y_1 = \sin \varphi; \ Z_1 = (R_2 - u)\tan \alpha; \]

(4)
For L2

\[ X_2 = \cos \varphi; \quad Y_2 = \sin \varphi; \quad Z_2 = -(R_2 - u)\tan \alpha; \quad (5) \]

The helical surface P 1 is described by the equations

\[ X_1 = \cos \varphi; \quad Y_1 = \sin \varphi; \quad Z_1 = (R_2 - u)\tan \alpha + c(\varphi)\varphi; \quad (6) \]

The helical surface P 2 is described by the equations

\[ X_2 = \cos \varphi; \quad Y_2 = \sin \varphi; \quad Z_2 = -(R_2 - u)\tan \alpha + c(\varphi)\varphi; \quad (7) \]

Thus, screw surfaces (6) and (7) as conical surfaces have, as follows from (4) and (5), conical surfaces. Since the screw surfaces (6) and (7) are superimposed on (4) and (5), respectively, and they, in turn, are linear surfaces developing on a plane, the considered screw surfaces are technological from the point of view of manufacturing.

Productivity is the main indicator characterizing the operation of a screw press. It can be defined as the sum of the screw cavity volume along the length of the screw filled with material per unit time.

The final expressions of performance for a screw press with a variable pitch and shaft diameter can be written

\[ Q = 0.188 \cdot m \cdot \alpha \cdot \int_0^l (R_{2i}^2 - R_{1i}^2) \cdot (s - \frac{\Delta b}{\cos \alpha}) \cdot \gamma \cdot \frac{M_i}{s_i(z-1) + \sum_{i=1}^{n} \Delta b S_{i\text{non}}i} \cdot dt \cdot \beta \cdot k_n \quad (8) \]

where, \( m \) is the number of visits of the screw;
\( \omega \) - angular velocity of the screw, s-1;
\( R_{2i} \) and \( R_{1i} \) - outer and inner radius of the screw in the i section, m;
\( S_i \) is the screw pitch in the i section, m;
\( \Delta b \) - Width of the helical blade in the i section, m;
\( \alpha \) - angle of elevation of the helix of the blade along the average diameter of the screw, deg;
\( \gamma \) - pressing ratio, characterizing the ratio of the final and initial density of the OKM or the ratio of the initial volume to the final volume during the passage of OKM along the entire length of the pressing chamber;
\( M \) is the mass of the processed material, kg;
\( z \) is the number of turns of the screw;
\( S_{\text{non}i} \) is the OKM cross-sectional area in the i section, m²;
\( \beta \) - screw fill factor;
\( k_p \) - coefficient taking into account the degree of change in feed, depending on changes in pitch and internal diameter of the screw.

OKM pressing time can be determined

\[ t_{press} = \frac{L_{i\mu}}{2\pi(K_2 - K_1) \cdot \omega} \quad (9) \]

It was noted above that the auger should be with different reduction stages, since the CKM moves along it. This follows from the fact that as this movement moves, the CMM becomes denser and closer to the condition of close ability to take the necessary shape in accordance with the requirements of the process.
Let the OKM density at the time of loading be equal (established experimentally). We assume that in the auger, the OKM is a continuous continuous medium (figure 5). Therefore, the OKM of volume \( dv \) has mass

\[ dM = \rho dv, \]

where \( \rho \) is the OKM density.

By point \( A_1 \) we mean the point of intersection of the section \( Z \) with the surface \( P_1 \) at \( u = r = R \). From the third equation (6) it follows

\[ C(\varphi)\varphi = z - (R_2 - u)\tan \alpha. \]

The cross section of the OKM at different levels of \( Z \) differs only in the area of the curved triangle \( A_1B_1B_2A_2 \) enclosed in the circuit \( A_1B_1B_2A_2 \). We see that the area of the triangle increases with \( Z \). The cross sectional area of OKM changes very little with increasing \( Z \). About relations section for \( S_0 \) the \( S \) can be taken as a unit and then can be written as

\[ \rho = \rho_0 \frac{C(\varphi_0)}{C(\varphi) + \varphi C(\varphi)}. \]

When \( C(\varphi) = C e^{-b \varphi} \), expression (12) takes the form

\[ \rho = \frac{\rho_0}{e^{-b \varphi}(1-b \varphi)}. \]

We substitute the value \( b = bk \), into expression (13), we obtain the final formula for determining \( \rho \)

\[ \rho = \rho_0 \frac{1}{e^{-b_k \varphi}(1-b_k \varphi)}. \]

The required power on the motor shaft is determined by the formula:
\[ N = \frac{A \cdot \omega}{1000 \cdot 2 \cdot \pi \cdot \eta}; \]  \hspace{1cm} (15)

Where, \( A \) is the work spent on moving the material along the axis of the screw, Nm;
\( \omega \) - angular velocity of the screw, s\(^{-1}\);
\( \eta \) - efficiency transmission from the motor shaft to the screw drive shaft.

The work involved in moving the material is determined by the expression

\[ A = v \cdot dF_{mp}, \]  \hspace{1cm} (16)

Where, \( v \) - the speed of movement of the material, m / s ;
\( F_{mp} \) - friction force, H.

In expression (6) \[ F_{mp} = \rho \cdot S, \]  \hspace{1cm} (17)

where, \( \rho \) - density OKM, kg / m\(^3\) ;
\( S \) - the cross-sectional area of the material, m\(^2\).

Taking into account expressions (16) and (17), expression 2.65 takes the form

\[ N = \frac{v \cdot \rho \cdot S \cdot \omega}{1000 \cdot 2 \cdot \pi \cdot \eta}. \]  \hspace{1cm} (18)

Given the expression (14), the dependence (18) is written

\[ N = \frac{v \cdot \rho \cdot S \cdot \omega}{1000 \cdot 2 \cdot \pi \cdot \eta} \cdot \rho_0 \cdot \frac{1}{e^{\beta \cdot \varphi \cdot (1 - b \cdot \varphi))}}. \]  \hspace{1cm} (19)

**3. Results and discussion**

An analysis of the presented dependences (figure 6) shows that with an increase in the rotational speed of the screw \( n \) from 5 s\(^{-1}\) to 6 s\(^{-1}\), there is a continuous increase in productivity from 140 to 160 kg / h. The dependence built on the basis of theoretical research is in good agreement with the experimental one. The discrepancy between the results does not exceed 3.5 ... 6%.

![Figure 6](image-url) The influence of the angular speed of rotation of the screw \( \omega, \) s\(^{-1}\) on the productivity \( Q \) of the press extruder: 1 - theoretical; 2 - experimental.
4. Conclusion

Based on the studies performed, the scientific problem of improving technologies and technical means for preparing concentrated feeds based on insoluble soybean residue, which is of great economic importance, has been solved.

The analysis of research materials from foreign and domestic literary sources shows that the use of soy protein in animal feed diets is a promising direction. However, despite this, at present, the mechanization of the concentrated feed preparation process using soy protein has not been resolved. All this leads to a large expenditure of labor, energy, a decrease in the nutritional value of feed and, as a result, a decrease in the productivity of animals.

Theoretical studies of the technological process of the press-extruder for the preparation of final feeds using soy protein made it possible to substantiate the structurally-operational parameters: the energy consumption of the process is 0.048 ... 0.05 kW / kg, productivity 230 ... 250 kg / h, screw pitch 0.04 ... 0.045 m.

The implementation of the proposed technology, through a press extruder allows to obtain an annual economic impact of $ 50502 rubles at reduced costs, limit price amounted to 284,944 rubles, while reducing energy consumption by 1.6 times.

References

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