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Methodological Aspects of Theoretical Determination of the Kmz-2 Extruder Performance

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***Abstract:** The purpose of the research is reducing the energy consumption of the KMZ-2 extruder, which will improve its performance. The research tasks are to achieve the purpose: to consider the sunflower seeds compression in the working chamber of the KMZ-2 extruder to obtain sunflower cake; to consider the material that exits through the matrix dies; to consider the movement of the pressed material in the matrix die of the KMZ-2 extruder. On the basis of the conducted research the following conclusions were made: stabilization of the extrusion pressure of the processed material to produce a sunflower cake at the end of the process leads to its friction force reduction on the KMZ-2 extruder auger shaft; the outcoming expression on the theoretical research results allows to change the KMZ-2 extruder capacity when processing the material and with increasing the extrusion speed its performance increases accordingly.*

***Keywords:** extruder productivity, sunflower seeds, fragments of calathidiums and stems, sunflower cake, winding pitch, energy consumption.*

I. INTRODUCTION

The animal husbandry intensification is inextricably linked with the feed production increasing, their range expanding and quality improvement. The effectiveness of feed increases with increasing its nutrients content for animals [1]. Without a high-quality feed, it is impossible to achieve the efficiency of livestock production [9]. The feed quality, the degree of its balance and digestibility affect the animals productivity, which is the main component of a sufficient quantity to provide the country's population with quality animal products. At the same time, the quality, balance and homogeneity of feed must be ensured by modern technology and production organization, which is why the extrusion technologies for processing raw materials of a vegetable origin arouse much interest [2,4]. Progressive technological processes in the feed industry are the extrusion of compound feeds and their components, which ensures high feed safety and increased productivity of animals [7,8]. Our own early theoretical studies of the KMZ-2 extruder conducted, have shown that the increasing of a sunflower cake density is proportional to the decrease of its auger winding pitch, and in turn, the density depends on its physical-mechanical properties [10].

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The purpose of the research is reducing the energy consumption of the KMZ-2 extruder, which will improve its performance.

Research tasks:

1. Consider the compression of sunflower seeds in the working chamber of the KMZ-2 extruder to produce sunflower cake.
2. Consider the movement of the pressed material in the matrix die of the KMZ-2 extruder.

II. RESEARCH MATERIALS

The instability of physical-mechanical properties of a feed mix coming to the extrusion, causes pressure fluctuations inside the extruder, which leads to instability of the process, and as a result, obtaining a product of a non-uniform composition and properties [2,3,11]. The analysis of works dedicated to the extrusion of various materials [12-16], shows that rational parameters of extruders are justified by many scientists on the basis of theoretical studies pertaining the processed raw materials movement under the action of their working bodies. From an engineering point of view, such studies must take into account not only the mechanical impact of the extruder auger on the material, but also changes in its physical state associated with its heating [6].
However, the conducted theoretical studies on the preparation of various feeds in extruders have shown their unacceptability for obtaining sunflower cake due to its physical-mechanical properties in comparison with other feeds. Advantages of extruders over other technical tools are the ease of use, absence of inertial forces and, related to this, reduction of metal consumption, absence of idling, a wide range of changes in the physical-mechanical properties of processed materials and the degree of impact on them. Their main drawback is their high energy intensity, and it is an important economic problem to reduce it [5].

III. RESULTS AND DISCUSSION

Consider the compression of sunflower seeds in the working chamber of the KMZ-2 extruder to produce sunflower cake.
We assume that the material after compression has the shape of a cylinder (figure 1).

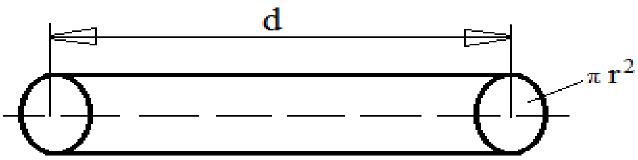

Figure 1 – Finished material after extrusion

The pressure exerted on the processed material is uniform and constant over its entire area.

Then the work of the pressure forces will be:

$$A = F \cdot d, \quad (1)$$

where F – the force of the auger pressure on the processed material, H;

d – the length of the finished material (the sunflower cake after its compression in the chamber), mm;

or

$$A = P \cdot \pi r^2 \cdot d, \quad (2)$$

where P – the pressure created by the auger on the processed material, H;

r – radius of the finished material (the sunflower cake), mm.

The work of the friction forces of the finished material on the surface of the extruder auger will be:

$$A = -F_{fr} \cdot d. \quad (3)$$

The friction force is determined by the expression:

$$F_{fr} = P \cdot 2\pi r \cdot d. \quad (4)$$

Substitute the expression (4) in the expression (3) and get an expression for determining the work of the friction forces:

$$A_{fr} = -P \cdot 2\pi r \cdot d^2. \quad (5)$$

The work required to the output of sunflower cake from the matrix die of the extruder will be:

$$A_{ex} = A + A_{fr}. \quad (6)$$

Then:

$$A_{ex} = P \cdot \pi r d(r - 2d). \quad (7)$$

That is, the pressure obtained at the exit of the finished material (the sunflower cake) from the matrix die increases with increasing the length (d) of the material.

Determine the concentration of holes in the matrix die before and after changes of the extruder auger shaft using the expression:

$$n_0 = \frac{N_0}{S_0}, \quad (8)$$

where n_0 – the concentration of holes in the serial auger matrix die;

N_0 – the number of holes;

S_0 – the die area of the matrix, m^2.

The die area of the matrix is determined by the expression:

$$S_0 = \pi(R^2 - r^2). \quad (9)$$

Substitute the expression (9) in the expression (8) and get

$$n_0 = \frac{N_0}{\pi(R^2 - r^2)}, \quad (10)$$

where r – the radius of the extruder auger shaft, mm.

We assume that the concentration of holes in the matrix die of the serial (figure 1) and modified auger shaft is the same, and then:

$$n_1 = n_0, \quad (11)$$

$$n_1 = \frac{N_1}{S_1}, \quad (12)$$

$$n_1 = \frac{N_1}{\pi(R^2 - R_{rs}^2)}, \quad (13)$$

where R, R_{rs} – the start and the end radiuses of the auger shaft after its changes, respectively, mm;

N_1 – the number of holes in the matrix die in a modified shaft.

Equate the expressions (10) and (13) and then get

$$\frac{N_0}{S_0} = \frac{N_1}{S_1},$$

$$\frac{N_0}{\pi(R^2 - r^2)} = \frac{N_1}{\pi(R^2 - R_{rs}^2)},$$

where

$$N_1 = N_0 \frac{(R^2 - R_{rs}^2)}{(R^2 - r^2)}. \quad (14)$$

The analysis of the expression (14) shows that the rational number of holes must be multiple of 2 or even of (2, 4, 6...).

Determine the pressure on the processed material during its extrusion (figure 2) using the formula:

$$P_x = P_{rs} + kx. \quad (15)$$

where P_x – the pressure acting along the «OX» axis on the material to be processed, MPa;

P_{rs} – the pressure created at the end of the extradition process by the shaft, MPa;

k – the coefficient of proportionality; x – the coordinate of the point on the material.

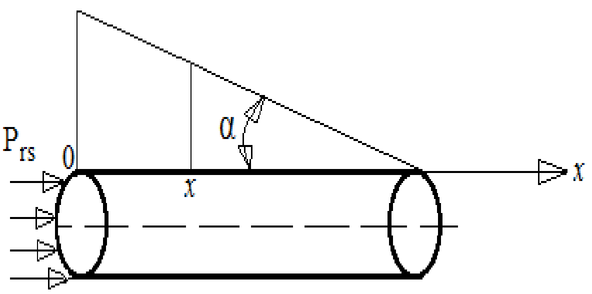

Figure 2 – Determination of the pressure P_x on the processed material

The value of the proportionality coefficient k is determined as

$$k = tg\alpha, \quad (16)$$

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$$k = -\frac{P_{rs}}{d}. \quad (17)$$

Then, substitute the expression (17) in the expression (15) and find the (created) pressure acting along the «OX» axis by the formula:

$$P_x = P_{rs} - \frac{P_{rs}}{d} x.$$

(18)

Determination of the friction force of sunflower cake through the matrix die auger in the serial KMZ-2 extruder.

Consider the material that exits through the matrix die (figure 3).

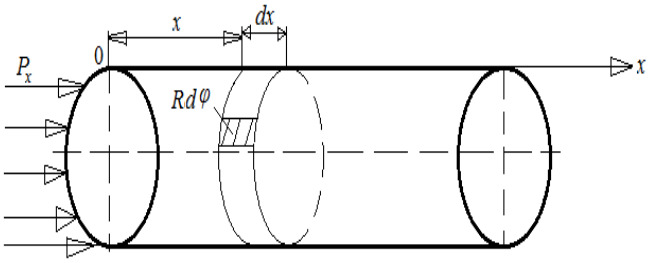

Figure 3 – The material that exits through the matrix die of the extruder

During the movement of sunflower cake through the matrix die, the pressure P_x and the reaction force N_x act both. Select a small area on the material with a thickness of «dx».

The path traversed by the material through the matrix die will be:

$$dS = R \cdot d\varphi \cdot dx.$$

(19)

The reaction force N_x will be:

$$dN_x = P_x \cdot dS.$$

(20)

The friction force F_f will be:

$$dF_f = f \cdot dN_x.$$

(21)

Substitute the expression (19), (20) in the expression (21) and get:

$$dF_f = f \cdot P_x \cdot R \cdot d\varphi \cdot dx.$$

(22)

The total friction force over the entire surface of the material will be:

$$F_f = \int\int_{S_s} dF_f,$$

(23)

$$F_f = fR\int_0^{2\pi} d\varphi \cdot \int_0^d P_x \cdot dx.$$

(24)

In the expression (24) substitute the expression (22) and get:

$$F_f = 2\pi \cdot f \cdot R \cdot P_{rs} \cdot d.$$

(25)

The analysis of the expression (25) shows that the friction force of the material against the matrix die depends on the pressure created at the end of the shaft.

Consider the movement of the pressed material in the matrix die of the KMZ-2 extruder (figure 4).

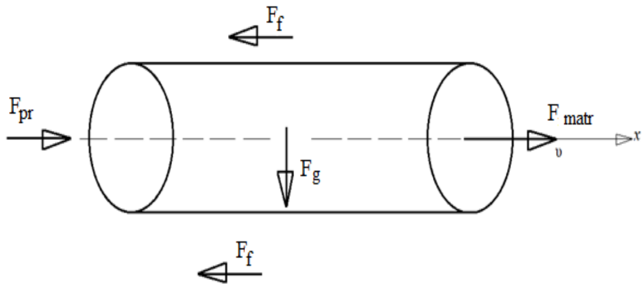

Figure 4 – The forces acting on a sunflower cake the matrix die of the extruder

According to Newton's 2nd law

$$m\bar{a} = \sum \bar{F}, \quad (26)$$

where m – the mass of the pressed material, kg;

$\bar{a}$ – the acceleration gained by the pressed material during its passage, m/s^2.

The following forces act on the material that is in the matrix die:

F_{pr} – the ressure force in the compression chamber, N;

F_{matr} – the pressure force acting on the material when it exits the matrix die, N;

F_f – the friction force distributed over the entire side surface of the material, N;

F_g – the gravity of the pressed material, N.

In the «X» axis projection, the equation (29) takes the following form:

$$ma_x = (P_{pr} - P_{matr}) \cdot \frac{\pi r^2}{4} - F_f.$$

(27)

The condition for the uniform output of the finished material from the matrix die is:

$$\vartheta = const \Rightarrow a_x = 0$$

This means that the equation (27) will be:

$$(P_{pr} - P_{matr}) \cdot \frac{\pi r^2}{4} - F_f = 0.$$

(28)

At different outlet velocities from the matrix die of the extruder, the equation (28) will have the following form:

with υ_1:

$$(P_{pr1} - P_{matr}) \cdot \frac{\pi r^2}{4} - F_{f1} = 0,$$

(29)

with υ_2:

$$(P_{pr2} - P_{matr}) \cdot \frac{\pi r^2}{4} - F_{f2} = 0.$$

(30)

It is obvious that the condition

$$\vartheta_2 > \vartheta_1, \quad (31)$$

to provide it, it is necessary that

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$$P_{pr2} > P_{pr1}. \quad (32)$$

The consequence of the condition (32) will be obvious that:

$$F_{f2} > F_{f1}. \quad (33)$$

The performance of the extruder is determined by a known expression:

$$Q = \frac{m}{t}, \quad (34)$$

where m – the mass of the pressed material that enters the extruder, kg;
t – the time of extrusion of the processed material (30…60s), s.

The speed of movement of sunflower cake in the matrix die of the extruder is determined by the expression:

$$\vartheta = \frac{N_1 \cdot d}{t}. \quad (35)$$

From the expression (35) we find the time of extrusion of the processed material:

$$t = \frac{N_1 \cdot d}{\vartheta}. \quad (36)$$

After substituting the expression (36) in the expression (34), we get the performance of the extruder:

$$Q = \frac{m \cdot \vartheta}{N_1 \cdot d}.$$

(37)

Thus, the productivity of the KMZ-2 extruder is proportional to the velocity (ϑ) of extrusion of the processed material.

IV. CONCLUSION

The conducted theoretical studies allow us to draw the following conclusions:

1. Stabilization of the extrusion pressure of the processed material (fragments of calathidiums and stems, sunflower seeds) with the production of sunflower cake at the end of the process leads to a decrease of its friction force on the auger shaft of the KMZ-2 extruder.
2. The resulting expression (37) allows to change the performance of the KMZ-2 extruder when processing material, as well as increasing the extrusion velocity rating leads to an increase of its performance.

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