



## Justification of the Process of Extruding a Combustion, Improving the Design of the Extruder

<sup>1</sup>V. Kushnir, <sup>1</sup>N. Gavrilov, <sup>1</sup>S. Kim and <sup>2</sup>T. Shkotova

<sup>1</sup>Kostanay State University named after A. Baytursynov, Republic of Kazakhstan

<sup>2</sup>Saint Petersburg National Research University of Information Technologies, Mechanics and Optics, Russia

**Key words:** Extrusion technologies, extrusion process, extruder, screw surface, hydraulic shutter, processing of field crop waste, technical solution for improving the extruder design and increasing the extruder's productivity

### Corresponding Author:

V. Kushnir

Kostanay State University named after A. Baytursynov, Republic of Kazakhstan

Page No.: 1-8

Volume: 16, Issue 1, 2021

ISSN: 1815-932x

Research Journal of Applied Sciences

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**Abstract:** A theoretical calculation of the process of processing feed by creating a hydraulic shutter using the physical and mechanical properties of the material (the angle of pinching the material) is carried out. Theoretical problems of the fundamentals of material deformation are considered. A scheme is proposed for calculating the acting forces when creating a hydraulic shutter. In this case, the structural changes of the extruder screw are achieved by making the bevel angle of the screw extruder surface (View A). Theoretical analysis of the dependence of the torque on the viscosity of the feed, on the angle of the slope of the surface of the screw, analysis of the dependence of the power and capacity of the extruder on the speed of the screw and on the angle of the slope of the screw surface, on the viscosity of the feed.

## INTRODUCTION

Analytical dependencies for the performance of the extruder on its constructive-regime parameters during processing of feed are substantiated. In addition, the article provides a brief overview of the technological process of extrusion technology, its advantages and disadvantages. At the same time, the main shortcomings are identified-high energy intensity of the process, insufficient productivity, wear of the details of the working element and so on.

A number of technical solutions for the elimination of the listed deficiencies are described which was carried out by researchers at the Kostanay State University named after A. Baytursynov, the Republic of Kazakhstan. The proposed technical solutions are protected in the form of innovative patents and patents. Extruding feed (feed mix) is an energy-intensive process, so, reducing the energy consumption of the extruder, increasing its productivity is an urgent task. This can be achieved by improving the design and operating parameters of the extruder.

Extrusion makes it possible to create a homogeneous mass consisting of different feeds, changing their chemical composition, increasing digestibility, eliminating microbiological contamination.

Homogeneous food becomes in the zone of plastic deformations that is at the outlet from the channel of the spinneret. Here, from the property of relative homogeneity follows the hypothesis of constancy or continuity we can assume that the material fills the entire volume bounded by the surface of the body (the body of the extruder). The displacements, deformations and internal interactions of the points of the body are continuous functions of the coordinates, therefore, it is possible to use the apparatus of differential and integral calculus.

From the whole complex of complex interactions that determine the physical state of a solid body, this model distinguishes only the relationship between stresses, deformations, time and temperature. The movement of the material inside the extruder is based on the principle of drawing while the role of the physical and mechanical

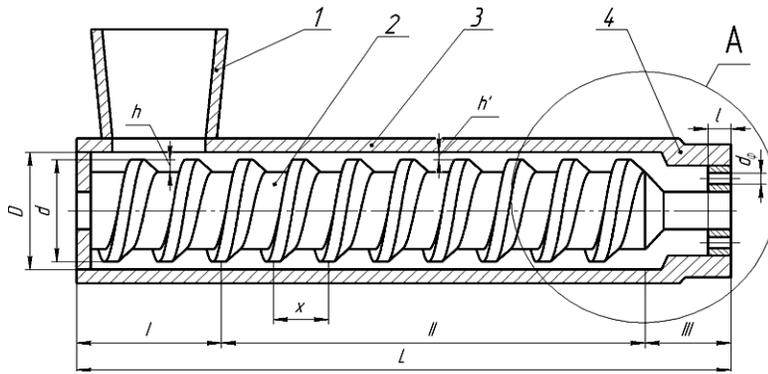


Fig. 1: Zones of material processing in the extruder 1-hopper hopper, 2-screw, 3-body, 4-spinner

properties of feed and metal is important. The process of compaction in an extruder can be divided into a zone of elastic (I), elasto-plastic (II) and plastic deformations (III), Fig. 1.

The theoretical basis of motion is the basic laws of mechanics of deformable media, the general equations of which are expressed by the three basic laws of nature: conservation of mass, momentum and energy. Research work processes single-screw extruders, according to researchers are associated with various factors that significantly affect these processes. They are: feed moisture, feed composition, temperature, pressure in the outlet (head)<sup>[1, 2]</sup>.

The flow of energy and material flow within the extruder during the processing of the feed occurs as a result of the application of the torque to the shaft of the screw. In the material, voltages are proportional to the area affected by the force F1 and its resultant forces Fi (Fig. 2). Of all the forces should be allocated forces F1, F2, F3, F5, increasing the voltage inside the feed and the forces F4, F6 reducing it.

The force F1 facilitates the movement of the feed along the axis of the screw of the extruder. The force F2 is the reaction of the wall of the spinnerets. The force F3 occurs in zone A in the manufacture of the bevel of the screw surface. The force F4 is the result of a feed leakage between the screw surface of the extruder screw and the body. The force F5 is the result of the action of the side surface of the screw. The force F6 provides the output of the material.

The material in the spinneret is a viscoplastic fluid that differs from the real liquid by the flow index (n). If the spinneret is represented as a nozzle, then it is possible to increase the discharge velocity (productivity) by 1.32 times with standing the ratio  $l/dp = 3 \dots 4$  where l, df is the length and diameter of the spinneret, m<sup>[2, 3]</sup>.

For a serial machine with a straight screw surface, the force F4 is maximum, i.e., the leakage of the feed can be reduced only by reducing the gap between the body and the end of the screw turn:

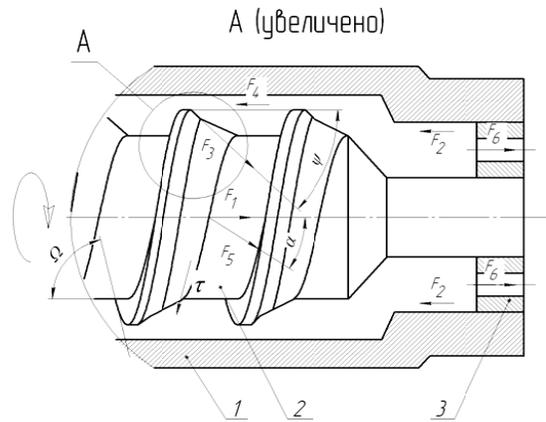


Fig. 2: Distribution of forces during machining in an extruder

$$F4 = F1 \cdot \sin \Omega; H \tag{1}$$

Then the equilibrium condition will have the form:

$$\Sigma Fi = 0; H \tag{2}$$

Or in a general way:

$$F1 = F2 + F5 - F4 - F6; H \tag{3}$$

One of the options for eliminating the leakage of food through the gap between the end of the screw turn and the body is the creation of a hydraulic seal using the physical and mechanical properties of the materials. The angle  $\Psi$  is greater than the angle of friction of the material of the feed about steel, this creates a condition for jamming the feed between the wall of the hull and the end of the auger turn that is the force F3 is created to ensure the elimination of feed leakage (Fig. 3, type B). This reduces the temperature of the hull, decreases the speed of movement of the feed relative to the hull, increases the share of useful work in the total energy balance<sup>[4, 5]</sup>.

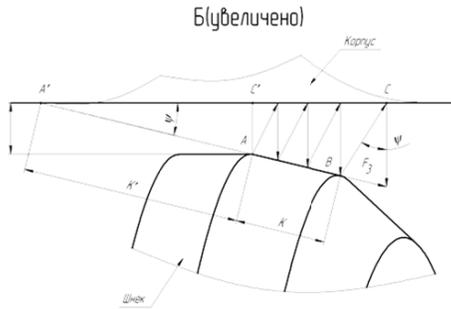


Fig. 3: Determination of the force (F3) to ensure the elimination of feed diversion

Figure 3 shows: L-gap between the screw auger and extruder body, m; K-thickness of screw auger, m; K'-continuation of the bevel of the helical surface to the extruder body, m; AB is the distance of the bevel of the helical surface, m. The condition of equilibrium of forces in this case will have the form:

$$F1 = F2 + F5 + F3 - F6; H \quad (4)$$

The strength of F1 is related to torque:

$$; H \quad (5)$$

Where:

M = The torque (N•m)

rsc = Average screw radius (m)

φ = The friction angle of the material (°)

The stress in the layer of the processed material can be expressed as:

$$\sigma = F / S; N / m^2 \quad (6)$$

Where:

F = The force (H)

S = The cross-sectional area (m<sup>2</sup>)

But since, the stresses arising in the layer of the material being processed depend on the parameters of the forces, they can be expressed as the sum of the stresses:

$$\sigma = \sigma_2 + \sigma_3 + \sigma_5 - \sigma_6; N/m^2 \quad (7)$$

$$N/m^2 \quad (8)$$

where, R the radius of the extruder body (m). L-Length of the working part of the extruder, m (Fig. 1):

$$\sigma_3 = \frac{F_1}{\pi \cdot d_{cp} (D - d)}; H/M^2 \quad (9)$$

Where:

D = The diameter of the extruder body (m)

d = He screw diameter of the extruder (m)

$$\sigma_6 = \frac{F_6}{S'} = \frac{F_6}{\pi \cdot d^2}; H/M_2 \quad (10)$$

$$\frac{\Phi}{4} \cdot 4$$

Where:

S = The area of the spinnerets (m<sup>2</sup>)

4 = Number of nozzle outlets

df = The diameter of the outlets

We determine the values of the forces F2, F5, F6:

$$F2 = F1 \cdot \cos \Omega; H \quad (11)$$

$$F5 = F1 \cdot \sin \Omega; H \quad (12)$$

$$F6 = F1 \cdot \sin \Omega; H \quad (13)$$

To calculate the values of the force F3, the value of the distance of the bevel of the helical surface (AB) was found (Fig. 3 type B):

$$AB = \frac{K}{\cos \psi}; m \quad (14)$$

Calculated the distances AC' and A'B:

$$AC' = \frac{M}{\cos \psi}; M \quad (15)$$

$$A'B = AB + AA'; M \quad (16)$$

где A'A = K', (рисунок 3)

where, A'A = K', (Fig. 3):

$$\text{Then}; m \quad (17)$$

Calculated the maximum and minimum values of the force F<sub>3</sub>:

$$F_{3MAX} = A'B \cdot \text{tg}^2 \psi = F_1 / \cos \psi; H \quad (18)$$

$$F_{3MIN} = AC' \cdot \text{tg} \psi; H \quad (19)$$

Then the stress values inside the feed σ<sub>3</sub> are:

$$\sigma_3 = \frac{F_{3MAX}}{S_{CK}}; H/M^2 \quad (20)$$

where, S<sub>CK</sub> is the area of the bevel of the screw surface, m<sup>2</sup> determine the area of the bevel:

$$S_{CK} = \pi(R_{max} + R_{min}) \cdot AB; M^2 \quad (21)$$

The area of the bevel along the entire length of the screw surface:

$$S_{CK} = \pi \cdot a \cdot (R_{MAX} + R_{MIN}) \cdot AB; M^2 \quad (22)$$

where is the number of turns. Substituted values of stresses in Eq. 20:

$$\sigma = \frac{F_2}{\pi \cdot R \cdot L} + \frac{F_3}{AB \cdot \pi \cdot a (R_{max} + R_{min})} + \frac{F_5}{\pi \cdot d_{cp} \cdot (D-d)} - \frac{F_6}{\pi \cdot d_{\phi}^2}; H/M^2 \quad (23)$$

got:

$$\sigma = \frac{F_1 \cdot \cos \Omega}{\pi \cdot R \cdot L} + \frac{F_1 \cdot \cos \Psi}{AB \cdot \pi \cdot a (R_{max} + R_{min})} + \frac{F_1 \cdot \sin \Omega}{\pi \cdot d_{cp} \cdot (D-d)} - \frac{F_1 \cdot \sin \Omega}{\pi \cdot d_{\phi}^2}; H/M^2 \quad (24)$$

After the corresponding transformations, we got:

$$\sigma = \frac{F_1}{\pi} \left( \frac{\cos \Omega}{R \cdot L} + \frac{1}{AB \cdot a \cdot (R_{max} + R_{min}) \cdot \cos \Psi} + \frac{\sin \Omega}{d_{cp} \cdot (D-d)} - \frac{\sin \Omega}{d_{\phi}^2} \right) = \frac{F_1}{\pi} \cdot T; H/M^2 \quad (25)$$

where, T is a quantity that depends on the design parameters of the extruder,  $1 \text{ m}^{-2}$  or:

$$\text{Or: } \sigma = \frac{M}{\pi \cdot r_{cp} \cdot \text{tg}(a + \varphi)} \cdot T; H/M^2 \quad (26)$$

From Eq. 26, the value of the torque (M) was expressed:

$$M = \frac{\sigma \cdot \pi \cdot r_{cp} \cdot \text{tg}(a + \varphi)}{T}; H \cdot M \quad (27)$$

For the viscous state of the material when processed in an extruder using the Ostwald-de Ville Eq. 28, the stress created in the material is expressed:

$$\tau = \mu' \cdot \gamma^n \quad (28)$$

Where:

- $\tau$  = The shear stress
- $\mu'$  = The material consistency coefficient
- $\gamma$  = Material shear rate
- n = The current index

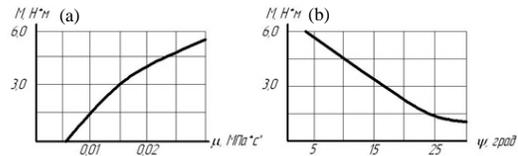


Fig. 4(a,b): The dependence of the twisting moment from the viscosity of the feed of the angular momentum from the angle of the slope of the surface of auger

Or:

$$\sigma = \frac{\mu \cdot \gamma^n}{f_{\text{сдвига}}}; H/M^2 \quad (29)$$

where, f shift = ftr at the maximum stress value. Then:

$$M = \frac{\mu \cdot \gamma^n \cdot r_{cp} \cdot \pi \cdot \text{tg}(\alpha + \varphi)}{T \cdot f_{\text{сд}}}; HM \quad (30)$$

The results of theoretical studies of the dependences of the torque are shown in Fig. 4a, b. Analysis of the dependencies shows that they have different character. With increasing values of the viscosity of the feed, the torque values increase and as the values of the angle of the bevel of the screw surface increase, the values of the torque decrease. The power used to process the feed is expressed by the formula:

$$N = M \cdot \omega; kW \quad (31)$$

where,  $\omega$  is the screw speed, rad/s. Based on the available power values expressed in terms of torque and rotation frequency, substituting them into Eq. 31, we obtained:

$$N = \frac{\mu \cdot \gamma^n \cdot r_{cp} \cdot \pi \cdot \text{tg}(\alpha + \varphi)}{T \cdot f_{\text{сд}}} \cdot \omega; kBT \quad (32)$$

According to theoretical studies, the power required to process the feed increases, depending on the rotational speed of the screw of the extruder. The productivity of the extruder for processing feed, taking into account the coefficient of slip was determined from Eq. 33:

$$Q = gk \cdot g_{max} \cdot \eta \cdot v_{02} \cdot h \cdot x \cdot i \quad (33)$$

The values of the dimensionless coefficient g k as a function of pressure gradients and viscosity anomalies are taken from 0-1, the coefficient g max is taken from 0.32-0.52 depending on the angle of rise of the helical line

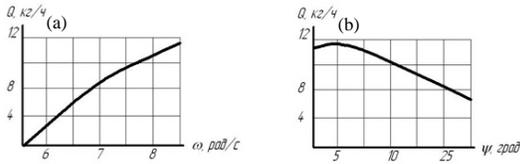


Fig. 5(a,b): Dependency performance from the frequency of performance from the anglerotation of auger screw

and viscosity anomalies<sup>[6, 7]</sup>. The coefficient of feed slippage ( $\eta$ ) during processing in the extruder depends on the coefficient of friction ( $f$  tp).

In theoretical calculations, the values of the coefficient of slip vary in the range from 0.1-1<sup>[6, 8]</sup>. The depth of the screw channel ( $h$ ), the screw pitch ( $x$ ), the number of screw runs ( $i$ ) are constant values depending on the extruder design. Taking into account the available values, the theoretical calculation of the productivity was carried out by changing the values of the peripheral speed of the extruder screw ( $V_0$ ).

Theoretical performance of the extruder in relation to the rotational speed, the angle of the bevel of the screw surface is shown in Fig. 5 a,b. Analysis of the dependence of productivity on the speed of the screw shows that productivity increases with increasing speed. Analyzing the obtained values of the dependence of productivity on the angle of the slope of the surface of the screw we can say that the maximum productivity of the extruder is reached in the investigated intervals at a slant angle of 5°.

The theoretical calculation of the extruder's performance as a function of the viscosity of the feed showed that the productivity increases in the intervals under study and has a maximum value with a feed viscosity of 0.02 MPa·cn. The values of the flow index ( $n$ ) in theoretical calculations are accepted to be 0.23<sup>[1, 9]</sup>. Waste from agricultural production, including grain waste, field crop waste has been and remains a valuable secondary raw material. One of the main directions of their use is the production of animal feed.

The search for new efficient ways of processing secondary raw materials, old stale food in nutritious animal feed is a very urgent problem. Modern economic conditions, toughening environmental legislation urgently require the introduction of low-waste and non-waste energy-saving technologies. The problem of bringing production to an “environmentally friendly” level is one of the most acute at the present time.

The need to develop environmentally sound technologies and equipment for waste neutralization and processing is becoming increasingly evident. The main principles in the field of waste management should be:

- Use of the latest scientific and technical achievements for the implementation of low-waste and non-waste technologies

- Complex processing of raw material resources in order to reduce the amount of waste

To obtain a high-quality feed product in which the biological value of the feedstock is kept to the maximum, it is necessary to minimize the time of heat treatment. It is desirable to use economical and environmentally friendly technologies. Extrusion technologies are the newest methods of processing biological waste that meet these requirements. Extrusion technologies have become a priority for the development of the food and feed industry in the most economically developed countries (USA, Japan, Western Europe)<sup>[10, 11]</sup>.

In the feed industry, extrusion is used for processing grain products of cereals and legumes. Because of the large content of starch, the digestibility of grain and its products by animals and poultry does not exceed 60%. It is especially bad for starch to be digested. Extrusion processing essentially modifies the grain. The main and most important changes occur in the “explosion”-a sharp drop in pressure and temperature when the product leaves the extruder: cell walls are broken, chemical bonds, the structure changes. High-molecular polysaccharide- starch, the main component of grain raw materials is converted into simple mono-saccharides and dextrans. The content of soluble substances is increased 5-8 times. At the same time, the nutritional value of the protein is maintained and harmful or harmful compounds such as protease inhibitors, trypsin are destroyed. As a result of rapid effervescence when water leaves the extruder which is present in the processed mass, the product becomes porous, increasing in volume<sup>[33]</sup>. Thus, it becomes more accessible to the action of digestive juices and enzymes, its digestibility and taste qualities are improved that is the forage increases value. The assimilability of grain forages increases to 90%<sup>[12]</sup>.

When processing in an extruder, the feed material has the following positive parameters, in comparison with traditional technologies (for example before crushing, pressing, pelletizing, etc.):

- Sterilized and disinfected (pathogenic microorganisms, fungi, mold completely destroyed)
- Increases in volume (due to rupture of molecular chains of starch and cell walls upon exiting the extruder)
- Homogenized (processes of grinding and mixing of raw materials in the barrel of the extruder continue, the product becomes completely homogeneous)
- Stabilized (neutralizing the action of enzymes such as lipase, inactivating harmful factors, toxins)
- Dehydrated (humidity is reduced by 50-70% of the original)

The process of extrusion processing which destroys the pathogenic microflora, allows obtaining high-quality

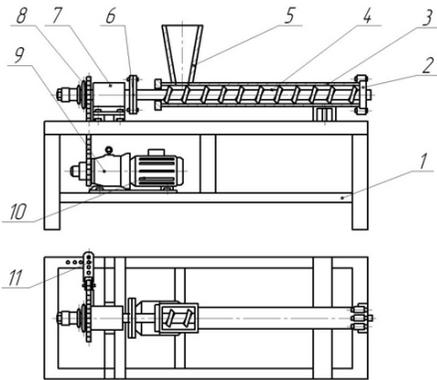


Fig. 6: Device for extruding coarse feeds 1-bed, 2-spinner, 3-body extruder, 4-screw, 5-loading chamber, 6-coupling, 7-intermediate, 8-drive, 9-reducer, 10-electric motor, 11-chain retainer

feed, even if the filler is represented by substandard grain products. The sterility of the feed is especially important when fattening young animals, since, up to 90% of the livestock is killed due to diseases of the gastrointestinal tract or infections introduced through the digestive system<sup>[12, 13]</sup>. The use of extrusion technology allows:

- To intensify the production process
- Reduce energy costs (except for electricity to ensure the technological process does not need other energy sources: gas, steam, hot water)
- To reduce labor costs
- Increase the degree of use of raw materials
- To improve the digestibility of products
- To reduce microbiological contamination of products
- Reduce environmental pollution (no emissions to the atmosphere, effluents and secondary waste)

But along with the above advantages of extrusion processing of waste and grain forage, there are some of its disadvantages:

- High energy intensity of the process
- Insufficient capacity of the extruder
- Increased wear of the parts of the working body
- Installation of additional devices for the removal of processed feed
- Restrictions when feeding animals, for example, cattle

In Kostanay State University named after Akhmet Baitursynov, the Republic of Kazakhstan, a group of researchers carried out a number of developments aimed at eliminating the aforementioned shortcomings of extrusion processing of grain materials and field crop wastes. The theoretical calculations described at the very beginning of the article are confirmed experimentally. The device for fodder extrusion is shown in Fig. 6.

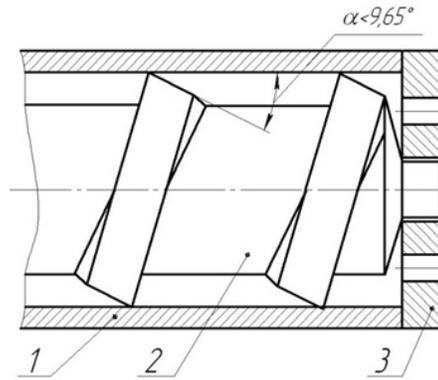


Fig. 7: Scheme of the extruder design 1-body extruder, 2-screw, 3-spinner

The formula of the invention lies in the fact that the edge of the screw adjoining the body is made at an angle ( $\alpha < 9.65$ , View A°) to the direction of feeding of coarse feed (Fig. 7). The created design provides a pinch angle of the material being processed, there by increasing the productivity of the extruder.

The device for treating coarse feed operates as follows. The material enters the feed chamber 5 is grasped by the screw 4 and under pressure which increases due to friction against the wall of the body 3 is forced through the die 2. In the process, the structure of the material breaks down, components with a high thickening capacity are created, microbiological contamination, pathogenic bacteria and fungi die or are suppressed to acceptable conditions

Based on the results of the studies, a preliminary patent of the Republic of Kazakhstan No. 15942 was received. The device for extruding coarse feeds and preliminary patent No. 18519. Extruder<sup>[9]</sup>.

The extruder for processing the feed mix is shown in Fig. 8. This device was developed on the basis of the research carried out, the preliminary patent of the Republic of Kazakhstan for No. 19144 was received. The extruder for processing the feed mix<sup>[14]</sup>, the innovation patent of the Republic of Kazakhstan for No. 26996. Extruder for processing the feed mix<sup>[15]</sup>, patent for the utility model of the Republic of Belarus for No. 8631. Extruder for processing of feed mixtures<sup>[14-16]</sup>.

The invention relates to devices for processing feeds and can be used in agriculture, in particular in animal husbandry, for the processing of feed mixtures. The technical solution is to increase the productivity, reduce the energy consumption of the extrusion process by improving the design of the extruder. This object is achieved by the fact that in a known apparatus including a charging chamber, a screw, a housing, a die; According

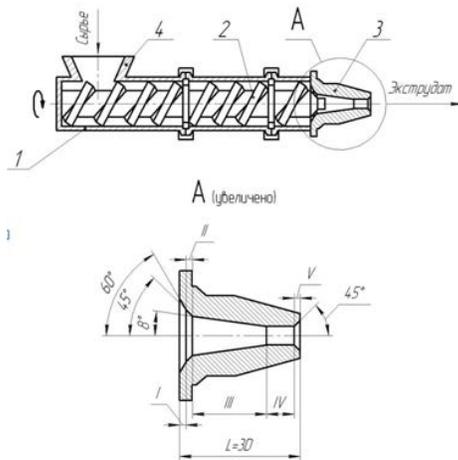


Fig. 8: Scheme of the extruder for processing the feed mix according to the innovative patent of the Republic of Kazakhstan No. 26996 1-body extruder, 2-screw, 3-die, 4-loading chamber

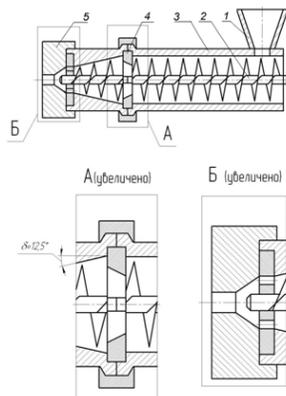


Fig. 9: Scheme of the extruder for processing mixed fodder under the innovative patent of the Republic of Kazakhstan No. 198961-charging chamber, 2-screw, 3-body extruder, 4-compression shutter, 5-spinner

to the proposed invention, the inner surface of the spinneret is designed in the form of stepped successive truncated cone-like surfaces which are formed at an angle of 600, 450, 8-120, respectively to the axis in the direction of the material being compressed with the outlet opening having an oblique angle of 450 (View B). The extruder for the processing of mixed fodders is shown in Fig. 9.

This device was developed on the basis of studies an innovative patent of the Republic of Kazakhstan for 1989. An extruder for the processing of mixed fodders<sup>[13]</sup>, innovation patent of the Republic of Kazakhstan No.

23311 Extruder for processing mixed fodders<sup>[13]</sup>, patent for the utility model of the Republic of Belarus for No. 8564. Extruder for processing mixed fodders<sup>[15]</sup>, conclusion on the grant of an innovative patent for invention No. 27484. Extruder for processing mixed fodder<sup>[14-17]</sup>.

The invention relates to devices for processing mixed fodders and can be used in agriculture, in particular in animal husbandry for processing mixed fodders. The object of the invention is to increase the productivity, reduce the energy consumption of the extrusion process by improving the extruder design.

To this end, in a known device including a charging chamber, screw, casing, compression seal, spinneret, according to the invention, the casing design in the die area (in the plasticizing zone of the material) is made at an angle ( $\delta$ -12.5°) to its longitudinal axis in the direction of the spinnerets (View A). In addition, the screw design in the plasticization zone is manufactured with an increasing number of turns and the sealing and plasticization zone is separated by a compression seal (Type B).

The device for extruding compound feeds consists of a loading chamber 1, a screw 2, a casing 3, a compression seal 4, a spinneret 5. The use of the putative extruder allows to reduce power consumption, increase productivity, this is confirmed experimentally.

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