Methods and results of research of the press extruder mixer-dosing unit

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Abstract. The article describes the design and technological scheme of the press-extruder mixer-dosing unit. The research of the dosing device for feeding the initial mixture into the press extruder is given. The results of the experiment were obtained as a result of realization of the experimental research plan. The equations of regression, which allow to determine the possibility of changing the amount of feed of the initial mixture into the press extruder and the power consumption depending on the design and regime parameters of the dozer, are given. Results of processing of models of power consumption and productivity depending on design and regime parameters are presented in the form of two-dimensional sections. Based on the results of the research and their analysis, the following methods of metering capacity adjustment and energy saving trends were determined.

1. Introduction

Various mixtures and composite materials are used in production processes (mechanical engineering, chemical, food industry, etc.) [1-5]. For the preparation of different types of mixtures, bladed [6, 7], drum [5], vibrating [8] and other types of mixers are used.

To increase the productivity of animals, one of the main tasks is the production of high-quality mixed fodder, for the preparation of which mixers of various designs are used, as well as press extruders. Extrusion preparation is a process that is constantly evolving, and is now considered an important process, both for animals and humans [9]. The issues of extrusion processing of various types of material are studied and presented in many scientific works [10-15].

However, many issues related to the technology of feed preparation by extrusion method are not sufficiently studied, in particular, the influence of design and regime parameters of the screw feeder on the uniformity of the loadability of the initial mixture into the extruder.

Uneven dosing of the initial mixture when it is fed into the extruder is a qualitative indicator of the work of the extruder’s dozer and characterizes the unevenness of the output material flow. The difference in the dispenser capacity leads to unstable operation of the extruder, therefore, it is necessary to identify the modes in which the dispensing irregularity is the smallest.

Samara SAU has developed a press-extruder mixer-dosing unit, on the basis of which regression equations of the proposed mixer-dosing unit performance have been established: dosing uniformity, productivity and specific energy consumption.
The purpose of this study is to obtain a functional model in the process of mixing and dosing mixer formation to determine the influence of the design and operating parameters of the screw dosing unit on the uniformity of the initial mixture loadability into the press extruder and specific energy consumption.

2. Methods of the research
Using the standard and developed research program, the process parameters of the developed mixer of the press extruder dosing unit were determined (Figure 1).

Components of the grain mixture are loaded into the mixing tank hopper 1. When the drive 2 is switched on, the blades 3 rotate, which ensures the mixing of the incoming components. Mixed mass, when the damper is opened, is fed through the unloading window 8 into the screw feeder 5, which loads the extruder with the finished mixture.

In the course of experimental researches the speed of the screw feeder changed (n =40, 80, 120 min⁻¹) with the help of frequency converter Altirar-71, for definition of influence of a pitch of a screw three kinds of screws with a pitch t=20, 30, 40 mm have been made, a degree of opening of an unloading window of the mixer was regulated within the limits of E=0,3; 0,5; 0,7. In each experiment we measured productivity (mass feed delivery), Q kg/h; power consumption N, kW and irregularity of dosing P, %.

3. Results of the research
Based on the results of the study, regression equations were obtained. The following equation was used to describe the dispensing irregularity:

\[ P = 48,7 - 0,238 \cdot n + 0,116 \cdot t - 91,5 \cdot E + 0,000691 \cdot n^2 + 72,64 \cdot E^2. \] (1)

The analysis of the numerical values indicates a better uniformity of dosing when the degree of opening of the damper grows. When the damper is opened, about 70% stabilization (small change of values) of uniformity is observed, regardless of the screw speed and pitch. The increase in the speed when the screw pitch decreases improves the uniformity of dosing (Figure 2).
Thus, a smaller dosing irregularity is ensured by opening the damper by 70%. Increasing the speed when the auger pitch is reduced improves dosing uniformity.

Figure 2. Two-dimensional cross-sections of P, % irregularity of dosing: (a)-depending on the frequency of rotation (n, min⁻¹) and the degree of opening of the damper (E, 0.01%) at t=40 mm; (b)-depending on the frequency of rotation (n, min⁻¹) and the pitch of the screw (t, mm) at E=0.7; (c)-depending on the pitch of the screw (t, mm) and the degree of opening of the damper (E, 0.01%) at n=120 min⁻¹.

Equation (2), kg/h is used to describe the capacity (mass flow) of the Q metering unit:

\[ Q = -302.6 + 5.915 \cdot n + 27.54 \cdot t + 84.09 \cdot E - 0.031 \cdot n \cdot n - \\
-0.7714 \cdot t \cdot t - 1303.5 \cdot E \cdot E + 49.776 \cdot t \cdot E. \]  

(2)

Figure 3. Two-dimensional cross-sections of the metering capacity Q (kg/h) in natural values of factors: (a)-depending on the rate of rotation (n, min⁻¹) and screw pitch (t, mm) at E=0.7; (b)-depending on screw pitch (t, mm) and flap opening degree (E, 0.01%) at n=120 min⁻¹; (c)-depending on flap opening frequency (n, min⁻¹) and flap opening degree (E, 0.01%) at t=40 mm.

Taking into account the main task of the dosing device - providing the mass supply of material in a given interval (400-600 kg/h - extruder capacity), according to Figure 3, a steady change in the dosing device capacity is possible. At the same time, it is impossible to adjust the output by changing the auger pitch, it is possible to use only the auger with the adopted pitch. It is possible to change the mass
feed of the material (capacity) by the position of the regulating flap or the speed of the screw, using a frequency converter.

Analysis of the above graphs shows the possibility of using the cheapest method - adjusting the performance of the damper with a characteristic close to linear, with a screw speed of about 120 min⁻¹ and a screw pitch of about 40 mm. Reduced screw pitch when adjusting the metering capacity by the flap impairs the linearity of the mass flow change, and does not provide the required performance interval.

To describe the power consumption of the drive (kW) of the metering unit, the equation is used taking into account the metering unit capacity (Figure 4):

\[
N = 0.213097 - 0.0005n - 0.00087t - 0.13524E + 0.000997Q. \quad (3)
\]

The analysis of the power change shows that the existing tendencies are still in place when the productivity changes. An increase in the factors under study (speed, screw pitch and opening of the damper) slightly reduces the proportionality between performance and power consumption. The power consumption of the metering unit varies from 0.45 to 0.7 kW depending on the material mass flow.

![Figure 4](image1)

**Figure 4.** Two-dimensional cross-sections of the metering drive power N (kW) in natural values of factors: (a)-depending on the rate of rotation (n, min⁻¹) and auger pitch (t, mm) at E=0.7; (b)-depending on auger pitch (t, mm) and degree of opening (E, 0.01%) at n=120 min⁻¹; (c)-depending on the rate of rotation (n, min⁻¹) and degree of opening (E, 0.01%) at t=40 mm.

Established statistical dependences - regression equations (2) and (3) allow to calculate specific energy consumption of dosing (Figure 5), J/kg:

\[
Y = \frac{1000 \cdot N}{Q}. \quad (4)
\]

![Figure 5](image2)

**Figure 5.** Two-dimensional sections of the specific energy consumption of the metering unit (J/kg) in natural values of factors: (a)-depending on the speed of rotation (n, min⁻¹) and auger pitch (t, mm) at E=0.7; (b)-depending on auger pitch (t, mm) and degree of opening (E, 0.01%) at n=120 min⁻¹; (c)-depending on the frequency of rotation (n, min⁻¹) and degree of opening (E, 0.01%) at t=40 mm.
Trend analysis shows a reduction in energy consumption with increasing speed, auger pitch and flap opening. Specific energy consumption varies from 1.0 to 1.2 J/kg when the mass flow (capacity) of the metering unit is controlled.

4. Conclusion

1. Taking into account the main task of the dosing device is to provide a mass supply of material in a given interval (400-600 kg/h - extruder capacity), it is required the possibility of stable change of the dosing device capacity. The offered dozer allows to apply the cheapest way - adjustment of productivity by a flap with the characteristic close to linear at speed of rotation of the screw about 120 min⁻¹ and step of the screw about 40 mm. Reduced auger pitch when adjusting the metering capacity by the flap impairs the linearity of the mass flow change, and does not provide the required performance interval.

2. A smaller dosing irregularity is ensured by opening the damper by 70%. Increasing the speed when the auger pitch is reduced slightly improves the uniformity of the dosing. The analysis of the power change shows that the existing tendencies are still in place when the productivity changes. An increase in the factors under study (speed, screw pitch and opening of the damper) slightly reduces the proportionality between performance and power consumption. The power consumption of the metering unit varies from 0.45 to 0.7 kW depending on the mass flow of the material. Trend analysis shows a reduction in energy consumption with increasing speed, auger pitch and flap opening. Specific energy consumption varies from 1.0 to 1.2 J/kg when the mass flow (capacity) of the metering unit is regulated.

References

[1] Zagorodnjuk L H, Lesovik V S and Volodchenko A A 2015 To the question of dry mortars components mixed in various mixing units Int. J. of Applied Engineering Research 10(24) 44844-44847 [in Russian] Retrieved from: https://elibrary.ru/item.asp?id=26291612

[2] Celik O and Bonten C 2019 A novel experimental setup for characterization of polymer blends in single-screw extruders AIP Conf. Proc. 2055 020008 Retrieved from: https://doi.org/10.1063/1.5084809

[3] Luo X, Li J, Yang W-L, Wu F-J and Ouyang J-Q 2015 Simulation analysis of mixing effect of straight double paddle for rare earth extraction Chinese Rare Earths 36(5) 146-150 Retrieved from: https://DOI:10.16533/J.CNKI.15-1099/TF.201505026

[4] Shenoy P, Vaiu M, Tammel K, Fitzpatrick J and Ahmé L 2015 Effect of powder densities, particle size and shape on mixture quality of binary food powder mixtures Powder Technology 272 165-172 Retrieved from: https://doi.org/10.1016/j.powtec.2014.11.023

[5] Zhumagalieva G, Pershin V, Tkachev A, Vorobiev A, Pasko A and Galunin E 2018 Using a rod drum mill for graphenemasterbatch production AIP Conf. Proc. 2041(13) 020010 Retrieved from: https://doi.org/10.1063/1.5079341

[6] Yaraghi A, Ebrahimi M, Ein-Mozaaffari F and Lohi A 2018 Mixing assessment of non-cohesive particles in a paddle mixer through experiments and discrete element method (DEM) Advanced Powder Technology 29(11) 2693-2706 Retrieved from: https://DOI:10.1016/j.apt.2018.07.019

[7] Ebrahimi M, Yaraghi A, Ein-Mozaaffari F and Lohi A 2018 The effect of impeller configurations on particle mixing in an agitated paddle mixer Powder Technology 332 158-170 Retrieved from: https://DOI:10.1016/j.powtec.2018.03.061

[8] Vandenberg A and Wille K 2018 Evaluation of resonance acoustic mixing technology using ultra high performance concrete Construction and Building Materials 164 716-730 Retrieved from: https://doi.org/10.1016/j.conbuildmat.2017.12.217

[9] Kearns J P 1998 Ingredient consideration, preparation of feeds, selection of extrusion equipment and automatic controls for extrusion of pet and aquatic feeds Int. Symp. on Animal and
Aquaculture Feedstuffs by Extrusion Technology/Int. Seminar on Advanced Extrusion Technology in Food Applications (Sao Paulo, Brazil)

[10] Yi H, Puri V M, Lanning C J and Dooley J H 2018 Computational modeling of the material equations of the continuum scale to improve the processing and transport systems of biomass feedstock 2018ASABE 2018 Annual Int. Meeting

[11] Henrist D, Lefebvre R A and Remon D P 1999 Bioavailability of hot-stage extrusion formulations Int. J. of Pharmacy 187(2) 185-191

[12] Bostijn N, Dhondt J, Ryckaert A, Vervaet C and de Beer T 2019 A multivariate approach to predict the volumetric and gravimetric feeding behavior of a low feed rate feeder based on raw material properties Int. J. of Pharmaceutics 557 342-353

[13] Shea Y, Zhang X, Xu Y and Lou S Influence of a single / twin screw feeder on the particle contact force The feeder is a single, two-headed spiral effect on the contact force of a particle group Jiangsu Daxue Xuebao (Ziran Kexue Ban)/J. of Jiangsu University (Science Edition) 40(1) 76-81

[14] Santos B, Carmo F, Schlindwein W, Westrup J and Pitt K 2018 Pharmaceutical excipients properties and screw feeder performance in continuous processing lines: a Quality by Design (QbD) approach Drug Development and Industrial Pharmacy 44(12) 2089-2097

[15] McLaughlin A M, Robertson J and Ni X-W 2018 On the use of a twin screw extruder for continuous solid feeding and dissolution for continuous flow processes Organic Process Research and Development 22(10) 1373-1382