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IDENTIFYING THE DESIGN AND TECHNICAL PARAMETERS OF A MIXING AND DOSING UNIT OF THE PROCESS OF PREPARATION OF COMPOUND FEEDS WITH DISPERSING FORCED MIXING

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The object of research in this study is a screw dispenser that dispenses dry, dispersed feed. The problem to be solved is this: when using dispensers of complex design, labor and material costs for their repair and maintenance increase, as well as the efficiency of their use decreases.

When using the proposed model of a device for preparing mixed feed with a scattering force, it is possible to determine the following rational design modes and kinematic parameters: rotation speed of the screw of the mixing section $\omega = 4...12\ s^{-1}$, number of blades 6...8, feed rate or component u = 0.005...0.045 m/s.

Using a model of a device for preparing feed for forced mixing using appropriate methods and measurements, the following rational constructive, modal and kinematic parameters were determined: rotation speed of the screw of the mixing section $\omega = 4–12\ s^{-1}$; number of blades 6...8 pcs.; feed rate or feed component v = 0.005...0.045 m/s.

With the specified values of parameters, heterogeneity or uniformity of the feed mixture, the total required power, respectively, was: $\delta = 7...11$; $\lambda = 93...89\%$; N = 3.5...4.94 kW. The design features of the metering mixer, the parameters of the constructive mode of operation and practical recommendations for use, justified as a result of the study, are of practical importance for feed mills.

The results and optimized values obtained during the dosing of feed material in the preparation of concentrated feed mixtures, in comparison with their continuous operation over time, are of theoretical importance for subject programs, scientific research and experimental design work on the preparation of feed mixtures

Keywords: design, screw-loop, dispersed feed, system, mixer dispenser, optimization, mixing

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1. Introduction

A progressive and promising direction for the development of animal husbandry is the dosing of concentrated and concentrated-mixed feeds, depending on the productivity of animals. It should also be borne in mind that the share of these feeds in the feed balance is increasing annually. The effectiveness of feeding with concentrated mixed feeds is explained by the presence of separate concentrated feed components and trace elements in them. In this regard, it should be noted that technical means must provide each animal individually or a group of animals with the necessary amount of feed, depending on the diet and productivity in accordance with zootechnical requirements. Currently, concentrated feed dispensers offered on the livestock equipment market do not meet the requirements of modern farms and complexes: they provide the animal with either significantly more or significantly less feed than required by the norm, which leads to justified costs [1].

The various additives that need to be diluted are usually very small, so it is necessary to choose a diluent with a particle size and density close to it. Suitable diluents or carriers include widely used feed ingredients such as soy flour, wheat flour, and low-fat rice bran. As a rule, materials with a small particle size, dust-free, and affinity for the active ingredients of additives are selected as diluents or carriers. If the diluent or carrier is selected correctly, the finished product does not need to be transported. If the active ingredient of the additive is not concentrated, there is no need to use a binder. If the premixed product needs to be transported over long distances, a lubricant should be used. The biggest disadvantage of using lubricants is that some of the active ingredients of the additives remain on the mixer blades and affect the cleaning process [2].

Feed dispensers used in feed mills and farms have a number of serious disadvantages. These include the complexity of the design, the presence of high metal consumption, the low quality of dosing and the high cost. When using dispensers with a complex design, labor and material costs for their repair and maintenance increase, and their efficiency decreases. In addition, the feed given to the animal is more than the norm and is not compensated for by the product received. This also leads to an irrational consumption of feed. To do this, it is necessary to investigate the effect on the feed preparation system, analyze the construction and processing of the result of the study, and determine the operating and design parameters of the feed preparation machine with forced-dispersing mixing [3]. From the above, it can be concluded that the development of a feed dispenser that ensures the effective use of concentrated and mixed feeds, promotes the normal development and productivity of dairy cows, a high level of mechanization and automation of the feeding process, as well as meets certain zootechnical and other requirements, is an urgent task and requires study based on the results of scientific research.

2. Literature review and state problem

Among the variety of mixing processes, low-volume rotary mixers and disk-operated dispersants are increasingly being used to intensify technological processes in industry. The design of the device allows efficient processing of homogeneous and heterogeneous mixtures. In this paper [4], the design of the small-volume mixer for receiving heterogeneous mixes is described. Constructive design of the device allows to carry out efficiently processing of homogeneous and heterogeneous mixtures. From the above, it can be concluded that the development of a feed dispenser that ensures the effective use of concentrated and compound feeds, promotes the normal development and productivity of dairy cows, and high mechanization and automation of the feeding process that meets specified zootechnical and other requirements, is an urgent problem and requires study based on the results of scientific research. This research work is aimed at developing a method for obtaining dry concentrated feeds, and no analysis of mixing and concentration of feeds is given.

In this paper [5], the author analyses most widespread is the preparation of loose feed mixtures. An analytical review of research works in the field of technology and technology for the preparation of complete feed mixes has shown the advantage of using periodic feed mixers. This is due to the fact that due to the circulation of feed components in the mixer, a high quality of the feed mixture is achieved. At the same time, the issue of research and selection of rational parameters of improved ideological options in the direction of saving energy costs remains relevant. Science and practice have proven that feeding animals with complete feed mixes can increase productivity. The most widespread is the preparation of loose feed mixtures. The authors of this study conducted research in the field of technology and devices for the preparation of complete feed mixtures. As in the previous work, the design of the mixers was not analyzed. At the same time, the issue of research and selection of rational parameters of improved ideological options in the direction of energy savings remains relevant.

In paper [6], the author the design parameters of a mixing system have a major impact on the quality of the final product. Therefore, identifying the optimum parameters of mixing systems is highly relevant to various industrial processes dealing with particulate flows. However, the studies on the influences of the mixer's design features are still insufficient. In this study, the Discrete Element Method (DEM) is used to examine the impact of paddle angle, width, and gap on the mixing performance of a twin paddle blender. The mixing performance and particle flow are assessed using the relative standard deviation (RSD) mixing index, velocity field, diffusivity coefficient, granular temperature, the force acting on particles, and the mixer's power consumption. The mixing performance is highest for a paddle angle of 0° at the cost of the highest forces acting on particles. The paddle width is indicated as a critical factor for achieving better mixing quality. In contrast, the powder mixing efficiency and the mixer's power consumption are not significantly affected by the paddle gap. The results regarding the power consumption denote that the mixer using the paddle angle of 60° has the minimum power consumption. Moreover, increasing the paddle width results in the enhancement of the mixer's power consumption. The authors of the study, like the previous study, were based on the development and manufacture of an industrial drying mixer for feed, but the authors did not specify the design and innovation of the dispenser, as well as the system and technology that is the basis of the process. In the paper [7], delves into the design and development of an intelligent mixer machine specifically for producing keropok lekor, a popular Southeast Asian wafer item. It begins by introducing the significance and market potential of kroepoek, high-lighting the need for improved quality and efficiency in its production. The design process is meticulously detailed, including the selection of materials, the use of Solid Works software for 3D modelling, and the evaluation of different design concepts. The chapter also addresses the economic aspects, such as break-even analysis and return on investment, ensuring the feasibility and profitability of the project. Additionally, it discusses potential improvements and recommendations for future enhancements, making it a valuable resource for professionals seeking to innovate in the food processing industry. This study focuses on the idea of mixing feeds using new technologies that have been generalized but not specified as mixing technology, as well as the design analysis of dispensers. In the paper [8], the author analyzed mechanical feed mixers are preferred for their higher efficiencies. A wide range of these feed mixers are available and used in the Ashanti and Brong Ahafo regions of Ghana due to a higher concentration of poultry farms in these regions. The performances of both local and foreign poultry feed mixers in the two regions were evaluated. This was carried out as a procedure to identify the types, measure machine parameters, operational parameters and feed characteristics relevant to the performance of poultry feed mixers. The authors researched the mixer design and determined the performance, which is necessary to identify the mixing quality. But the study does not analyze the feed, as well as the assessment and quality of the feed mixing. According author [9], in order to achieve high performance in animal husbandry, it is necessary to strengthen the technical equipment of production. This study analyses the general mechanized system of animal husbandry with modern resource-saving technologies and facilities, but unfortunately, the authors did not specifically address the equipment for the preparation of mixed feeds and the design of dispensers. In paper [10], the main focus of the paper farmers in remote areas of China who still rely on traditional methods to raise cattle and sheep, which results in low efficiency and high labor costs. Therefore, most ordinary farmers urgently need a miniature feed mixer to process crop by-products into feed that can be consumed by livestock. Although the micro mixer is small in size, due to the toughness and strength of the grass, it still has the same cutting force of the twisting arm and the kneading wire as the large feed mixer. Therefore, during the operation of the mixing operation, it will produce relatively large impact and vibration noise. In response to the above issues, this article uses the finite element method to model and analyze the vibration characteristics of the silo part of a small fully mixed feed mixer. It is found that the first two natural frequencies of the structure are exactly within its working frequency range, and resonance phenomena will inevitably occur. This will generate noise that causes harm to the human body and also damage the structure of the feed machine, affecting its normal operation and damaging working components, reduce the service life of the feed mixer. So, based on its first six modal shapes, the structure was optimized and improved, and finally a structure was designed that can effectively avoid the working frequency of a small fully mixed feed mixer. The analysis of the conducted research showed that the developed dispenser was in the form of a falling device, which was made in accordance with individual requirements, that is, the overall design was not developed. The article focused on the design parameters of the mixing system, which have a significant impact on the quality of the final product, but did not analyze the dispenser and the quality of the resulting feed. The papers [11, 12] provides information on the comparative technical characteristics of existing powerful feed aggregates that have found their application in everyday life. It is reported that these units can save feed grains used in farms by 15–20%, and reduce the cost of final products by using local feed resources by 30%. An analysis of the works devoted to feed dispensers revealed the following: when examining a screw-type dispenser with a diameter of 0.15 m, it was found that with increasing screw rotation speed (up to 100 min^{-1}), the dosing error decreases. After that, it increases proportionally. The researchers of this article do not recommend using a feed dispenser on farms due to its complex settings and low dosing accuracy. Examining vertical and horizontal screw dispensers and devices, I determined that with an increase in the angular velocity of the screw, its productivity increases proportionally, but the dosing error also increases. It is thanks to this feature of the mixer that they have more advantages. The author recommends reducing the design parameters and increasing the rotation speed, but as in previous studies, there is no analysis of the mixing quality and design differences. The analysis of the works [13–15] investigated drum feeders, as well as volumetric and weight belt feeders. He determined the technological and qualitative characteristics of these feeders depending on the angular velocity of rotation of the drum, its length, the number of blades, the moisture content of the material, its type and size. At the same time, he investigated energy performance in various performance modes. However, the author did not specify the dispenser design and the feed preparation technology system, and also investigated the design of one type of feed, focusing only on the formulation. In this study, the authors [16, 17] investigated sector dispensers. The authors of this study have put a lot of effort into improving the quality of the feed. However, their only goal was to determine the optimal rotation speed of the agitator screw. Although they did determine the optimal speed, they only tested the design on one type of feed and did not disclose the essence of their proposed design. The mass of the material is dispensed under the influence of inertial and gravitational forces. In this paper, the researcher analyses the technology of forced extraction, without fully specifying the mixing system, and the structural parameters of the technical means have not been analyzed [18].

As the above studies of feed dispensers have shown, it is advisable to conduct a study to improve the design of the dispenser, mainly the study of the physical-mechanical properties of dispersed materials, the mixing process of the dispersed components, as well as the design parameters of the dispersing feed dispenser of forced mixing.

3. The aim and objectives of the study

The aim of this study is to establish the design and technical parameters of a mixing and dosing unit to improve the accuracy of preparing the components of concentrated feed mixtures for cows.

To achieve the aim, the following objectives were set:

– to construct regression equations describing the effects of rational design, regime, and kinematic parameters;

– to determine the heterogeneity of the feed mixture, granulometric composition and energy consumption during dosing and mixing of feed components.

4. Materials and methods

The object of the study was a screw dispenser-mixer for feeding dry, dispersed feed in doses.

In general, the main function of the device for preparing a dispersed mixed feed mixture, based on the working hypothesis, is to ensure the dosage rates of the components and their uniform distribution in the final product. In this regard, a theoretical analysis of two processes (dosing and mixing) and, accordingly, two technical means (dispenser and mixer) is required [19]. Measurements related to the dosing process, as a rule, should be carried out in a short time. This is due to the instability of controlled indicators. These include indicators that characterize the environment and the materials being processed. These requirements can be implemented using the experiment planning method.

The assumptions made during the study are within the limits of 5%.

Considering that the conducted research has a significant share in the development of the industry, it should be noted that the aspects of dosing and mixing multicomponent dispersed feeds of the required quality still remain unexplored. In particular, the issues of uniform dosing and mixing of concentrated feeds and feed additives dispersed in multicomponent dosing and mixing devices combined into one design remain insufficiently studied. From this point of view, the rationale for the design of the mixer dispenser and its effective parameters, which make it possible to prepare concentrated compound feeds dispersed in a continuous stream with high uniformity, was born from the needs of modern enterprises producing livestock products.

The methodology is based on well-known laws of physics, theoretical mechanics and mathematical analysis. Scientific research and practice have proven that increasing the productivity of farm animals largely depends on the quality of the preparation of fortified animal feeds. The use of feed grains in the form of cereals is less efficient and economically unprofitable. A simple feed mixture made from several types of feed grains, balanced in composition, gives greater efficiency than cereals from only one type of grain. Balanced fortified feed is 25–30% more effective than conventional fortified feed (grain feed) in terms of basic nutrients, trace elements and vitamins. Feed grains (feed intended for feed) can be processed directly into their own compound feed on livestock farms. In this case, it becomes possible to reduce the cost of purchasing raw materials and transporting them, use feed grains and expensive protein and vitamin supplements more efficiently, and continuously provide nearby farms with fortified animal feeds. Numerous zootechnical studies have established that feeding farm animals, including cattle, should be carried out taking into account their body's needs for certain nutrients, trace elements and vitamins.

The methods are modelled by regression analysis, which is widely used in such studies. Thus, it can be noted that when using an automated quality control system in the processes of dosing and mixing feed preparation, it is sufficient to simultaneously connect the system to the system to determine the sensitivity function of the amplitude, phase, real and imaginary frequency characteristics. To determine the sensitivity of the time characteristic of the system, it is necessary to register sinusoidal oscillations and oscillator signals. The sinusoids obtained in the model device can be used as an example to determine the sensitivity function of the frequency response of a simplified system [20]. To compare the sensitivity of various dynamic characteristics of a feed preparation system, a dimensionless integral indicator is needed that takes into account the simultaneous influence of all observed parameters on the criterion functions. To do this, it is enough to use the sensitivity module. When conducting statistical processing, our goal was to group data, obtain sample characteristics, and find confidence intervals during the study. When processing statistical data, several key stages were performed: collection, data purification, classification of dosing machines, calculation of statistical indicators, and visualization, as shown in graphs 1–4, as well as analysis of the data carrying out statistical data processing, several key stages were carried out: collection, purification, classification of dosing machines, calculation of statistical indicators and visualization, which are indicated in graphs 1–4, as well as analysis of the data indicated in Tables 1–4. The method identifies patterns and used the Student's t-test to test hypotheses.

Given that the deviation of the component dose from the set value is undesirable and random, using the mathematical expectation as an optimization criterion is appropriate

$$\Phi_i\left(E_i\right)=M\int_{t_0}^{t_0+\tau_0}\left[\frac{\varepsilon_i\left(\tau\right)}{\varepsilon_i\left(t\right)}\right]\alpha\tau\rightarrow\min, \tag{1}$$

here ε – mistake; $\varepsilon_i\left(\tau\right)=Q_i\left(\tau\right)-Q_i'\left(\tau\right)$; $Q_i(\tau)$ and $Q_i'\left(\tau\right)-i$ – the actual and declared consumption of the component; M – the symbol indicating the mathematical expectation.

The generalized quality criterion can be calculated as a linear combination of criterion (1) functions for individual components

$$\Phi\left(E\right)=\sum\nolimits_{i=1}^{n}C_i\Phi_i\left(E_i\right)\rightarrow\min, \tag{2}$$

here c_i – weighting factors calculated based on the ratio of intake of dosed feed.

When describing the process of food preparation as a functional transformation of information, well-known mathematical expression methods can be used. One of the main dynamic characteristics of this process is the sensitivity of the generalized quality criterion (2) to changes in control systems. The sensitivity value allows to purposefully change the component parameters in the direction of ensuring the required quality. At such a rate that it becomes possible to change the optimization criterion, where the quality indicator of the feed mixture is one of the parameters that most strongly influence it. In connection with the management of feed preparation and its quality, sensitivity theory allows to change the quality indicator in any direction by changing the minimum number of parameters. In general, automation of the processes of preparing feed mixtures is expressed by ordinary linearized differential equations

$$f\left[Y_0^{(n)},Y_0^{(n-1)},.......Y_0,t,q_1.....q_m\right]=0. \tag{3}$$

If a parameter change is observed in the system over a period of time, then its behavior can be expressed by the following equation

$$f\left[Y^{(n)},Y^{(n-1)},.....,Y,t_1,q_1,....,q_m+\Delta q_m\right]=0. \tag{4}$$

The solution of equations (2) and (3) can be expressed in the form and period (where vectors in the space of the initial and variable systems). The three-factor dosing process of dispersed, protective and stimulating drugs can also be represented as a proportional system.

This reflects the dependence of the process characteristics on a number of parameters

$$Y=f\left(x_1,x_2,x_3,......,x_n\right), \tag{5}$$

where Y – there was an unevenness of dosing, expressed by the coefficient of variation; x_1 – area of the output window of the dozer; x_2 – amount of material in the bunker; x_3 – angular velocity of the coil.

To obtain optimal process conditions, it is necessary to determine the values of the system variables corresponding to the minimum of the function. Since the dosing process is complicated, let's use the following formula in the form of a second-degree polynomial

$$Y = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_1^2 + +b_5x_1x_2 + b_6x_1x_3 + b_7x_2^2 + b_8x_2x_3 + b_9x_3^2, \quad (6)$$

where b_0, b_1, ... b_9 – a regression coefficients are obtained by statistical processing of experimental results.

The essence of the methodology of the study is as follows: the dispenser is switched to a stable operating mode, after which a sample of dispersed material is taken every minute. Then the remaining parameters characterizing the working body are determined.

5. Results of the study of the effect of the system for the preparation of mixed and analysis of the operating and design parameters of the machine for the preparation of feed with dispersing forced mixing

5. 1. The constructing regression equations describing the effects of rational design, regime, and kinematic parameters

In general, the main function of the device for preparing a dispersed mixed feed mixture, based on the working hypothesis, is to ensure the dosage rates of the components and their uniform distribution in the final product. In this regard, a theoretical analysis of two processes (dosing and mixing) and, accordingly, two technical means (dispenser and mixer) is required. Measurements related to the dosing process usually need to be carried out in a short time. This is due to the instability of controlled indicators. These include indicators that characterize the environment and the materials being processed. These requirements can be implemented using the experiment planning method. The volume of a full-factor experiment is expressed by the well-known formula

$$n = r^k, \quad (7)$$

where n – number of trials in a full-factor dosing experiment; r and k – number of levels of factors and variables.

If $r \triangleright 2$ – so, then the volume of a full-factor experiment is quite large. The study of such processes by appropriate methods in some cases requires a lot of time and effort to conduct experiments, and the accuracy of experiments is often insufficient. Therefore, it is necessary to express technological processes in a strictly mathematical way. Knowledge of the basic patterns makes it possible to improve the design methodology and use the capabilities of computer systems. Complex processes are often represented approximately using mathematical models, the solution of which is not such a difficult task. One of these methods is the method of planning extreme experiments. This allows to determine the optimal dosing parameters using mathematical modelling and presentation of the results. In this case, the characteristics of the constituent elements of the studied object are expressed mathematically, taking into account the dominant factors. They differ very little from the corresponding indicators of the real system. Here, using the appropriate computer program, it is possible to check various options for parameters and operating modes.

A 2^k or 3^k type plan is usually used. The results of the study are approximated from the first or second level, and optimal values of variables are determined. The three-factor dosing process of dispersed, protective and stimulating drugs can also be represented as a proportional system. This reflects the dependence of the process characteristics on a number of (Y) parameters

$$Y = f(x_1, x_2, x_3, ..., x_n), \quad (8)$$

where Y – an uneven dosage, expressed as a coefficient of variation; x_1 – area of the output window of the dozer; x_2 – amount of material in the bunker; x_3 – angular velocity of the winding.

Based on mathematical modelling, a three-factor dosing process of materials dispersed on the basis of bran and a mineral-vitamin complex was studied. In accordance with the experimental plan, the number of repetitions of experiments was reduced to 3.6. The results were processed on a computer, regression coefficients and variables were determined, as well as those that correspond to the minimum of the function. Substituting the coefficients in formula (6), it is possible to obtain the formula for the dosing inequality in the hopper – screw section of the device:

– for bran

$$Y = 2.47 - 0.0224x_1 - 0.093x_2 + 0.066x_3 + +0.94x_1^2 - 0.0025x_1x_2 - 0.00038x_1x_3 + +0.00021x_2^2 - 0.00025x_2x_3 - 0.0068x_3^2; \quad (9)$$

– for the mineral and vitamin complex

$$Y = 1.25 - 5.48x_1 - 0.35x_2 - 0.96x_3 + +0.445x_1^2 - 0.0014x_1x_2 + 0.00027x_1x_3 - -0.00016x_2^2 + 0.00036x_2x_3 - 0.0055x_3^2. \quad (10)$$

During the analysis of the data obtained, the dependence of the dosage unevenness, that is, the coefficient of variation v (with a dosage uniformity of 100 – v%), on the pitch and speed of rotation of the screw winding was determined (Fig. 1).

As can be seen from Fig. 1, the unevenness of the dosage is 1%. The material varies along an equally evolving curve at different dosing heights. These curves tend to fix the rotation frequency of the screw, which is the working fluid of the dispenser, at values of 75–90 min^{-1}. The unevenness of the dosage was 32 cm for bran and 20 cm for the mineral and vitamin complex. Given that the minimum screw rotation speeds are in the very large ranges of 4.5–9.0%, if more precise ranges are required for special cases, the operating mode of the structural elements of the mineral-vitamin mixture will not change.

Fig. 2 shows that the unevenness of dosing at a large auger pitch is 7 cm, and the unevenness at a screw pitch is 3 cm (Fig. 3).

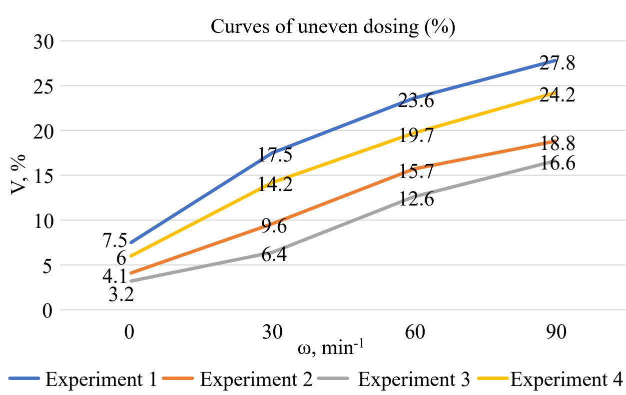

Fig. 1. Curves of uneven dosing (%) depending on the screw rotation speed: 1 – bran – spiral pitch 3 cm; the height of the material in the hopper: 1 – 8 cm; 2 – 14 cm; 3 – 20 cm; 4 – 32 cm

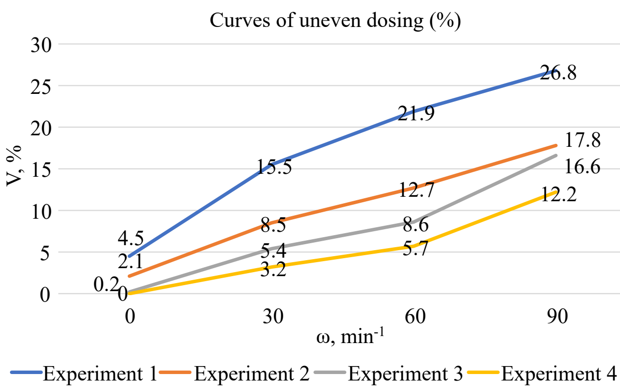

Fig. 2. Curves of uneven dosing (%) depending on the screw rotation speed: bran – spiral pitch 7 cm; the height of the material in the hopper: 1 – 8 cm; 2 – 14 cm; 3 – 20 cm; 4 – 32 cm

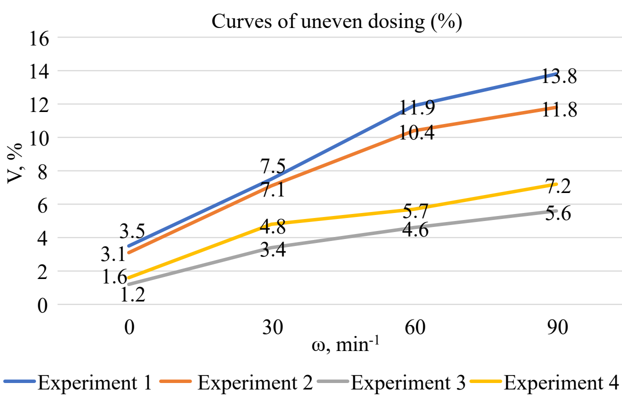

Fig. 3. Curves of uneven dosing (%) depending on the screw rotation speed: mineral and vitamin complex – spiral pitch 3 cm; the height of the material in the hopper: 1 – 8 cm; 2 – 14 cm; 3 – 20 cm; 4 – 32 cm

Fig. 4 shows that the results of this study are consistent with the results of the previous study. As a result, the errors are minimal, and the reliability of engineering calculations is ensured.

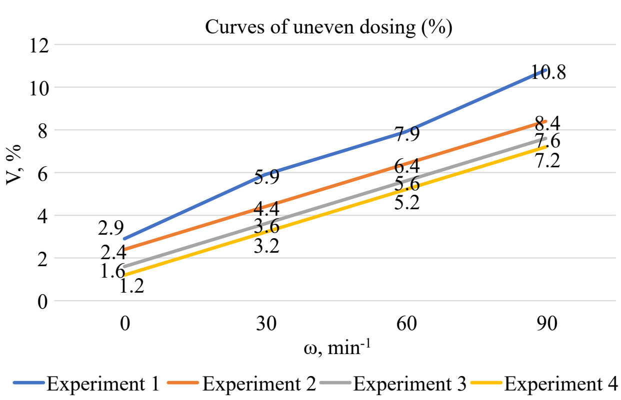

Fig. 4. Curves of uneven dosing (%) depending on the screw rotation speed: mineral and vitamin complex – spiral pitch 7 cm; the height of the material in the hopper: 1 – 8 cm; 2 – 14 cm; 3 – 20 cm; 4–32 cm

During the experiment, the variance was within acceptable values. This indicates the spread of experimental points according to the regression equation. As can be seen from the Fig. 2, as the screw speed (ω) increases (from 28 to 56 min^{-1}), the uneven dosage of bran increases from 1 to 10.5%, and the mineral and vitamin complex – from 1.2 to 15.8%. The maximum ν value is the same as the minimum amount of material in the hopper. This is due to the uneven filling of the loop space. Uniform filling is more stable in the range screw speed increases equal 24–34 min^{-1}, regardless of the amount of material in the hopper and the size of the outlet. At the same time, the maximum lateral slope does not exceed 8.5% (Fig. 3). At this level, the uniformity of dosing meets the standard requirements for dispersed materials. The factors affecting it during the dosing of dispersed materials may vary. Therefore, the study of ways to reduce the dosage error always remains relevant. A theoretical study of the factors ensuring the accuracy of dry-dispersed powdered mixtures in the chosen design is considered. The common parameters characterizing all dispensers, regardless of the dosing method and dispenser design, are mass consumption (load) and dosing accuracy (or error).

The load characterizes the dispenser in terms of quantity measurement and is determined taking into account geometric and kinematic parameters, which are not so difficult to determine when designing the dispenser. The dosing error characterizes the dispenser in terms of quantity and depends on a number of interrelated factors. They may also change during the dosing process.

One of the disadvantages of collecting bins used to distribute the components of mixed feed is the uneven flow of material from the hopper. This phenomenon is more common in cases where the humidity of the distributed material around the perimeter is unstable. The flow in some areas leads to the formation of stagnant zones in the hopper, as well as voids and lumps. In particular, when lumps are separated from the mass, the elements of uniformity of the flow of distributed material from the hopper are disrupted.

5. 2. The determination of the heterogeneity of the feed mixture, granulometric composition and energy consumption during dosing and mixing of feed components

Concentrated feeds are a complex homogeneous mixture of purified, ground to the required size of feed materials prepared according to scientifically proven recipes, and micro additives. Although they usually have dry, dispersible physical properties, they are not always stable, and when used as an object in any technical project, it becomes necessary to study their physical and mechanical properties. Depending on the purpose, primary mixed feeds are available in the form of complete feeds, combined concentrates and balancing additives (protein-vitamin, mineral additives, premixes).

Experiments show that the amount of filler in the total feed mixture plays an important role both in the preparation of highly enriched mixed feed or premix, as well as in the feed value and quality of the feed mixture. In this regard, experimental studies were continued to substantiate the individual modes and design parameters of both components of the dosing and mixing device (screw-liquid dosing device for dispersed feed and continuously operating sections with a blade for mixing dispersed feed components). The loading level of the device (Q, kg/min) was determined when the feed content in the screw-liquid dosing section was 20% and 30% (Table 1).

The recorded values correspond to the values of the coil pitch $\delta = 73$ mm (coil pitch) and the gap between the coil and the cover $b = 7.5$ mm. In this study, the load on the device was studied for coil pitch options 54, 73 and 91 mm at constant values of the coil diameter and the gap between the coil and the lid ($\delta = 73$ mm, $b = 7.5$ mm). The values obtained are shown in Table 2.

Table 1

The change in the load level of the device depends on the diameter of the spiral, which is the main working fluid of the metering device

No.	The percentage of filler in the composition, %	Load level, Q, kg/min		
		Step of the coil		
		50	70	90
1	20	1.8	6.4	11.0
2	30	1.8	4.2	5.0

Table 2

Coil pitch options with constant values of the coil diameter and the gap between the coil and the housing, the load on the device

No.	The percentage of filler in the composition, %	Load level, Q, kg/min		
		Step of the coil		
		51	73	91
1	20	4.0	6.4	7.2
2	30	2.4	2.5	2.75

From the values obtained (Tables 1, 2), it can be seen that with increasing diameter and pitch of the coil, the loading level of the device (in other words, the possibility of increasing device performance) increases. However, this increase was less with an increase in the proportion of filler in the composition. So, with a filler content of 20% in the mixture, the loading level increased from 4.0 to 7.2 kg/min with an increase in the pitch of the coil from 51 to 91 mm, and with a filler content of 30%, this increase increased from 2.4 to 2.75 kg/min. A similar phenomenon is observed with an increase in the diameter of the coil. Thus, with an increase in the diameter of the coil from 50 to 90 mm, the load of the device increased from 1.8% to 11.0 kg/min with a filler content of 20%, while with a filler content of 30%, the load increased only from 2.4 to 2.75 kg/min. This can be explained by the fact that the density of mineral additives is higher than the density of fillers (Fig. 4).

Subsequent studies investigated the effect of the pitch and diameter of the coil as a working medium on energy consumption. The obtained values are shown in Tables 3, 4. Also, the curves of change in the power consumption of the device and the coil metering area, depending on the coil pitch, are graphically shown in Fig. 5, 6.

When studying the influence of the coil diameter, its pitch ($\delta = 73$ mm) and the gap between the coil and the lid ($b = 7.5$ mm) remained constant.

Table 3

The power consumption of the device varies depending on the pitch of the coil

No.	The percentage of filler in the composition, %	Load level, Q, kg/min		
		Step of the coil		
		50	70	90
1	20	41.50	41.75	42.00
2	30	42.75	42.55	42.90

Table 4

The change in the power consumption of the metering device for corrugated cardboard (N_{doz}) depending on the pitch of the corrugated cardboard

No.	The percentage of filler in the composition, %	Load level, Q, kg/min		
		Step of the coil		
		51	73	91
1	20	42.00	42.50	42.90
2	30	42.10	42.54	43.10

Analysis of the results of experimental studies has shown that the heterogeneity of the feed mixture, the granulometric composition and energy consumption during dosing and mixing of feed components are determined by the initial physico-mechanical properties of the feed products and the design and modal parameters of the experimental device for preparing feed by forced mixing. Using a model of a device for preparing feed for forced mixing using appropriate methods and measurements, the following rational constructive, modal and kinematic parameters were determined: rotation speed of the screw of the mixing section $\omega = 4–12\ s^{-1}$; number of blades 6...8 pcs.; feed rate or feed component $v = 0.005...0.045$ m/s.

With the specified values of parameters, heterogeneity or uniformity of the feed mixture, the total required power, respectively, was: $\delta = 7...11$; $\lambda = 93...89\%$; $N = 3.5...4.94$ kW. A comparison of the results of experimental studies with the theoretical values in the main functional interaction for the proposed technical solution showed that they do not exceed the limit of 5–8%. Verification of the optimal parameters obtained in the proposed experimental samples confirmed their compliance with the criteria for optimizing zootechnical standards.

6. Discussion of the establishing the design and technical parameters of a mixing and dosing unit

The results of this study have shown that, unlike many authors who also study the dispenser, [16] focuses on emptying the metering elements or, as suggested in [17], reducing the design parameters of the screw and increasing the rotation speed. In this study, it was focused on processing the results of the study based on a working hypothesis. Regression coefficients and variables that correspond to the minimum of the function were determined. Substituting the coefficients into formula (6), in this study obtain a formula for the dosing inequality in the hopper-auger section of the bran device and for the mineral and vitamin complex. Based on calculations, graphs 1–4 curves of uneven dosing (%) were constructed depending on the speed of rotation of the auger as can be seen from Fig. 3, 4, as the screw rotation speed increases (from 28 to 56 min^{-1}), the unevenness of the bran dosage increases from 1 to 10.5%, and the mineral and vitamin complex – from 1.2 to 15.8%. The maximum value is the same as the minimum amount of material in the hopper. The results obtained during the study, evidence of a higher accuracy of feed material dosing in contrast research that mainly analyze a small-sized mixer for mixing feed and preparing feed, our research was based on the preparation of concentrated feed mixtures using a volumetric screw-spiral working fluid compared with a higher accuracy of feed material dosing in the preparation of concentrated feed mixtures using volumetric screw-spiral working fluid compared to its continuous operation.

Subsequent studies investigated the effect of the pitch and diameter of the coil as a working medium on energy consumption. The obtained values are shown in Tables 3, 4. Also, the curves of change in the power consumption of the device and the coil metering area, depending on the coil pitch, are graphically shown in Fig. 5, 6. They have theoretical significance for subject programs, research and development work on the preparation of concentrated feed mixtures. feed mixtures.

One of the disadvantages of collecting bins used to distribute the components of mixed feed is the uneven flow of material from the hopper. This phenomenon is more common in cases where the humidity of the distributed material around the perimeter is unstable. The flow in some areas leads to the formation of stagnant zones in the hopper, as well as voids and lumps. In particular, when lumps are separated from the mass, the elements of uniformity of the flow of distributed material from the hopper are disrupted.

The results and optimized values obtained during the dosing of feed material in the preparation of concentrated feed mixtures, in comparison with their continuous operation over time, are of theoretical importance for subject programs, scientific research and experimental design work on the preparation of feed mixtures. The design features of the mixer dispenser, the parameters of the constructive mode of operation and practical recommendations for use, justified as a result of the study, are of practical importance for enterprises engaged in the production of concentrated feed.

The limitation of this study is the use of bins for the distribution of feed components; it is the uneven flow of material from the hopper. This phenomenon is more common in cases where the humidity of the distributed material around the perimeter is unstable. The flow in some areas leads to the formation of stagnant zones in the hopper, as well as voids and lumps. In particular, when separating lumps from the mass, the elements of uniformity of the flow of distributed material from the hopper are violated.

The limitations of this study are mainly in the design. One of them is that the design does not guarantee complete mixing, which requires further improvements in both the workflow and technological aspects.

7. Conclusion

1. The optimization of the main parameters of modelling the preparation of dispersed feed by forced mixing based on the regression equation was carried out. Optimization was carried out in two variants for a filler (wheat bran) and a protein-vitamin-mineral complex for feed of forced mixing. In both variants, the minimum heterogeneity of the mixture was adopted as the optimization criterion (objective function). The area of the dispenser outlet window, the amount of material in the hoper, and the angular velocity of the auger were determined as input factors. The relative heterogeneity calculated by regression equation decreases to a certain level, and then slowly increases. Here, during the mixing time the absolute deviation is 0.4%. In fact, it takes only a few minutes to mix. This shows that the regression equation is suitable for the preparation of premixes or concentrated feed materials from selected dispersed materials. During the experiment, the variance was within acceptable values. This indicates the spread of experimental points according to the regression equation. As the screw speed (ω) increases (from 28 to 56 min^{-1}), the uneven dosage of bran increases from 1 to 10.5%, and the mineral and vitamin complex – from 1.2 to 15.8%. The maximum ν value is the same as the minimum amount of material in the hopper. This is due to the uneven filling of the loop space. Uniform filling is more stable in the range screw speed increases equal 24–34 min^{-1}, regardless of the amount of material in the hopper and the size of the outlet. At the same time, the maximum lateral slope does not exceed 8.5%.

2. Analysis of the results of experimental studies has shown that the heterogeneity of the feed mixture, the granulometric composition and energy consumption during dosing and mixing of feed components depend on the initial physico-mechanical properties of the feed products, as well as on the design and modal parameters of the experimental device for preparing feed by forced mixing. Using a model of a device for preparing feed by forced mixing with a dispersing force, the following rational constructive, modal and kinematic parameters were determined using appropriate methods and measurements: rotation speed of the screw of the mixing section $\omega = 4–12\ s^{-1}$; number of blades 6...8 pcs.; feed rate or feed component $u = 0.005...0.045$ m/s. With the specified values of parameters, heterogeneity or uniformity of the feed mixture, the total required power, respectively, was: $\delta = 7...11$; $\lambda = 93...89\%$; $N = 35...4.94$ kW. Verification of the optimal parameters obtained in the proposed experimental samples confirmed their compliance with the criteria for optimizing zootechnical standards.

Conflict of interest

The authors have no conflict of interest in relation to this study, whether financial, personal, authorship or otherwise, that could affect the study and its results presented in this paper.

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Data availability

Manuscript has no associated data.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

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Authors' contributions

Gabil Mammadov: Conceptualization; **Narmin Abdiyeva**: Conceptualization; **Rasim Saidov**: Formal Analysis; **Rovshan Hajiyev**: Formal Analysis; **Urfan Taghiyev**: Data Curation; **Gahira Allahverdiyeva**: Data Curation; **Natavan Imanova**: Resources; **Bahruz Aliyev**: Investigation; **Iskenderova**: Resources.

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