A model of the influence of the degree of filling of the drum mixer on the quality of the feed mixture

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Abstract. The aim of the research was to establish a functional dependence of the quality of the feed mixture on the degree of filling the volume of the modernized drum mixer and the proportion of the controlled component with the identification of the working area of the investigated working body. The methodology for studying the quality of the mixture of a drum mixer provided for the experimental establishment of the function of changing the coefficient of variation of the concentrated feed mixture with a three-level combination of the degree of filling of the tank and the proportion of the controlled component. The conducted studies based on the developed methodology allowed to identify an adequate functional dependence of the influence of the proportion of the controlled component and the degree of filling of the mixer drum. The results obtained indicate that an increase in the proportion of the controlled component improves the quality of the mixture with the nature of the hyperbolic dependence. Technological requirements for the quality of the mixture are observed when the proportion of the controlled component is at least 17%. This imposes a partial restriction on the use of the mixer for the preparation of dry concentrated mixtures based on protein-vitamin supplements and crushed feed grain. The effect of the degree of filling on the quality of the mixture is more complex and corresponds to a parabolic dependence. With the degree of filling 0.28-0.32 of the volume of the drum, the best indicators of the quality of the mixture are observed. The optimum mixing is observed with a batch mass of 45-51 kg at a density of 620 kg/m³.

1. Introduction

The economic feasibility of animal husbandry is determined by the amount of products produced from the used amount of feed and the funds spent on depreciation and operation of equipment and premises, wages. Current industry development trends are aimed at reducing the amount of feed per unit mass of products. This is ensured by the use of feed mixtures. The presence of the entire required amount of nutrients in the feed provided allows the animal to efficiently produce products. Therefore, it is important to use not just crushed grain (as a relatively cheap local feed), but use it as a component of compound feed fed to animals. This task is problematic for small livestock facilities, where due to lack of funding, the purchase of complete feed is complicated. The main source of nutrients for high-quality mixtures are premixes purchased from specialized enterprises (their share in the mixture is about 1-2%) or protein-vitamin supplements (their share in the mixture is about 10-20%). The remaining volume of the mixture is filled with crushed grain, which acts as a filler of the feed mixture.
Based on the ratio of additives and the finished mixture, a distribution of the proportion of additives (as a smaller, and accordingly controlled component in the mass of the mixture) is divided into two groups in the range of their ratios: 1:100 - 1:50, or 1:10 - 1:20. To reduce the energy consumption for the distribution of a small amount of additives in a large volume of the mixture and improve the quality of the finished mixture, stepwise mixing is used. For this, a preliminary mixture is prepared in a ratio of about 1 to 10 or less, and only then the specified preliminary mixture is mixed with the remaining mass of the filler. This is due to the fact that existing working bodies effectively mix components only in comparable proportions. The increase in differences in proportions sharply increases the required mixing time [1]. Therefore, as a rule, two mixing steps are used to prepare a mixture of feed premixes, and one step the protein-vitamin supplements.

Researchers are trying to increase the efficiency of mixing in different ways using various methods. Among them are: a displaced arrangement of the working body relative to the axis of rotation (or the planetary nature of its movement [2]), vibration [3], rotation of the planes relative to the direction of movement [4, 5], a complex profile of the working surface [5], selection of the kinematics of motion [2], different profile and volume of the working chamber [6, 7], the ratio of stationary and moving elements - the mixer moves [4, 8] or the tank moves [9, 10], changes to proportion of mixture components [11]. To improve the external quality indicators of the mixture, various control components are used [11]. To reduce the cost of manufacture, the design of the working elements is simplified [12-14]. The ways to reduce energy costs are looked for [2, 12, 15]. To speed up the construction, computer calculation is used, both analytical [12] and the finite element method [16, 17]. Due to the conditional reliability of such calculations, their experimental calibration is required [18]. As a result of such work, a new process of mixing the components and a specific design for its implementation is developed (or one of the previously existing options is modernized).

However, different working bodies have a different indicator of the intensity of mixing of the components, and accordingly there is a different zone of effective working capacity. Accordingly, any new working body (or already known, but in a new place of application) requires the establishment of its zone of applicability in accordance with technological requirements for the quality of the process.

It is proposed to expand the area of applicability of a relatively cheap, mobile, electrified drum concrete mixer widely used in retail chains for the preparation of animal feed in small-scale farming. Considering that due to the difference in physical and mechanical properties the indicated drum mixer does not provide the proper quality of the mixture [19], it was modernized: the blades inside the drum were replaced.

The aim of the study was to establish a functional dependence of the quality of the mixture of dry concentrated feeds on the degree of filling of the volume of the modernized drum mixer and the proportion of the controlled component with the identification of the working area of the investigated working body.

2 Methods and Materials

The experimental research methodology included the study of the quality of the mixture with a different proportion of the controlled component at different degrees of filling the tank. Instead of regular blades, 6 blades with different mounting angles (45 and 25 degrees from the tangent at the blades installation site) with a blade height of 0.15 m were installed inside the drum with a rotation axis angle of 15 degrees from the horizontal. The rotational speed of the modernized drum was preserved - 28 revolutions per a minute. The control component of a dry concentrated feed mixture (barley grain) was added in the proportion of 1:20; 1:10 or 1:6 relative to the weight of the mixture. Components weighing about 35; 50 or 65 kg with a bulk density of the mixture of 0.62 t/m³ were poured into the volume of the drum of 0.26 m³. After 120, 180 and 300 seconds 20 samples weighing 0.1 kg were taken. The coefficient of variation (unevenness) of the feed mixture was determined. Due to the randomness of events, after a triple repetition of the experiment, the average value of the mixture non-uniformity was found. The average mixing time was 200 sec.
3. Experiment and calculations

By analogy with diffusion in the work [2, 20], it is recommended to describe the quality of the mixture as a coefficient of variation in the content of the control component in the samples taken (v, %), and use the exponential dependence to describe the process:

\[ v = 100 \cdot \exp(-k \cdot T) \] (1)

The product in parentheses of the function \((-k \cdot T)\) is denoted by the exponent w:

\[ w = -k \cdot T \] (2)

where \(k\) is the intensity of the distribution of the controlled component by the working body; \(T\) is the duration of mixing the components. In our case, the average value.

In order to establish a functional dependence on the degree of filling (\(E, 0.01\%\)) of the mixer drum with the feed mixture material and the share of the controlled component (\(D_k, \%\)), we first recalculated the results of the experiment to determine the coefficient of variation of the mixture (\(v, 0.01\%\)) through the natural logarithm. We used logarithmic values to establish a functional relationship.

After the statistical processing of the recalculation results, an expression was obtained (Figures 2,3):

\[ w = 4.4492 - 26.16 \cdot E + 43.52 \cdot E^2 - 2.083 \cdot D_k^{0.107} + 0.023/D_k \] (3)

The numerical values of the Pearson correlation coefficient \(R = 0.938565\) and \(F_{test} = 0.931143\) indicate the adequacy of the obtained model of the index \(w\). The location of residues not taken into account by the model (Figure 4) and the results of the convergence of experimental data and calculated values (Figure 5) confirm the conclusion made.

Given that the indicator of the used function includes, inter alia, the mixing time, we can identify the dependence of the indicator of the intensity of mixing of the studied working body:

\[ k = \frac{w}{T} \] (4)
For the proposed blade working body of the drum mixer, the function of the empirical indicator of the intensity of mixing of the working body is:

\[
k = -0.005 \cdot k_1 \cdot \left( 4.4492 - 26.16 \cdot E + 43.52 \cdot E^2 - 2.083 \cdot D^{0.107} + 0.023/D_k \right),
\]

(5)

where \(k_1\) is an empirical coefficient of the effect of mixing time on the quality indicator of the feed mixture. For the studied variant, it is equal to: \(k_1 = 1\).

The results of a graphical analysis of the indicators \(w\) and \(k\) are shown in Figures 6 and 7.

After modeling the approximation results by the MathCAD program, two-dimensional sections of the lines of equal output of the obtained model of the mixture quality were obtained depending on the degree of filling of the mixer drum with the mixture material and the proportion of the controlled component in the mixture (Figure 8).

The value of the Pearson correlation coefficient \(R = 0.952165\) and \(F_{\text{test}} = 0.95466\) when checking the convergence of the experimental and calculated values of the coefficient of variation indicates the adequacy of the obtained model of mixture unevenness.

The obtained results indicate that an increase in the proportion of the controlled component improves the quality of the mixture with the nature of the hyperbolic dependence. Process requirements to the quality of the mixture are observed when the proportion of the controlled component is more than 17%.

This imposes a partial restriction on the use of the mixer for the preparation of animal feed based on protein-vitamin supplements and ground feed grain. However, due to the low power of the installed engines and the speed of mixing (at 120 seconds and 180 seconds of mixing, the quality of the mixture did not differ significantly), there is the possibility of stepwise mixing of the components. To do this, a mixture is prepared from comparable volumes of additives and the filler (crushed grain), and as the preliminary mixture is ready, the rest of the filler is added to it and the entire volume of the mixture is mixed.

The effect of the degree of filling on the quality of the feed mixture is more complex and corresponds to a parabolic dependence, due to the influence of the ratio of the volume of the mixture and the height of the blades. With the degree of filling of the corresponding proportion 0.28-0.32 of the volume of the drum, the best indicators of the quality of the mixture are observed. With a decrease in the volume of the mixture, the mixer blades capture all the material on the bottom of the drum, resulting in mixing of the components inside the cross section of the drum.

The circulation of the feed mixture along the drum decreases. This impairs mixing. With an increase in the volume of the mixture above the recommended values, the longitudinal movement of the material of the mixture in the drum is accelerated compared with transverse mixing. It also impairs mixing. Optimum mixing is observed with a batch weight of 45-51 kg at a density of 620 kg/m\(^3\).

**Figure 2.** A spatial graphical representation of the statistical model of the exponent \(w\) of the expression of the quality of the mixture depending on the degree of filling of the tank E (0.01%) and the proportion of the control component Dk (%).
Figure 3. A two-dimensional graphical representation of the statistical model of the exponent \( w \) of the expression of the quality of the mixture depending on the degree of filling of the tank \( E \) (0.01\%) and the proportion of the control component \( D_k \) (%).

Figure 4. A location chart of residues not considered by the model.

Figure 5. A convergence graph of the calculated values \( w \) with the experimental data.
Figure 6. A two-dimensional graphic representation of the statistical model of the exponent $w$ of the expression of the quality of the mixture depending on the degree of filling of the tank E (0.01%) and the proportion of the control component Dk (%).

Figure 7. A two-dimensional graphic representation of the statistical model of the exponent $-k$ of the expression of the quality of the mixture depending on the degree of filling of the tank E (0.01%) and the proportion of the control component Dk (%).

Figure 8. A two-dimensional graphic representation of the statistical model of the quality of the mixture depending on the degree of filling of the tank E (0.01%) and the proportion of the control component Dk (%).
Conclusion
The conducted studies based on the developed methodology allowed us to identify an adequate functional dependence linking the proportion of the controlled component of the feed mixture and the degree of the mixer drum filling. The obtained results indicate that an increase in the proportion of the controlled component improves the quality of the mixture with the nature of the hyperbolic dependence. Technological requirements for the quality of the feed mixture are observed when the proportion of the controlled component is at least 17%. This imposes a partial restriction on the use of the mixer for the preparation of animal feed based on protein-vitamin supplements and ground feed grain. The effect of the degree of filling on the quality of the mixture is more complex and corresponds to a parabolic dependence. With the degree of filling of the corresponding proportion 0.28-0.32 of the volume of the drum, the best indicators of the quality of the mixture are observed. Optimum mixing is observed with a batch mass of 45-51 kg at a density of 620 kg/m³.

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