Regression Dependence of the Influence of the Installation Angles of Drum Mixer Blades on the Quality of Mixture

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Abstract. The aim of the research was to establish a regression model of the influence of the angles of installation of the wings of the L-shaped blades and to optimize their values. The methodology of the studies provided for the experimental determination of the coefficient of variation of the mixture with subsequent computer processing of the results, establishing the functional dependence of the quality of the mixture on the angles of the wings of the blades, finding the minimum values. The research technique implemented in this work allowed us to determine an adequate functional dependence of the quality of the mixture on the angles of installation of the wings of the blades. The optimum quality of the mixture of 20% for the share of the control component of 1% and the mixing time equal to 200 sec corresponded to the angles of the wings of the L-shaped blades: the lower part - 45 degrees and the upper part - 25 degrees between the direction of the wing of the blade and tangent to the circumference of the drum at the installation site of the wing of the blade (its closest point to the axis of attachment of the drum) in the range of angles was, respectively: 30-55 degrees and 0-45 degrees. Deviation of the indicated angles (except for increasing the installation angle of the lower wing of the blade) affects the quality of the mixture. In this direction, the stabilization of the coefficient of variation was observed.

1. Introduction

Modern livestock farming includes both enterprises with cyclical production and technologies close to industrial production, and small farms where traditional methods of raising animals are economically justified. At the same time, the costs of feed and their preparation for animals make up at least a third of the cost of production. This forces manufacturers to improve the quality of feed produced. Reducing the cost of feed is possible by feeding full-grain mixtures, rather than crushed grain. This requires the purchase of compound feeds or their independent production on the basis of purchased concentrates or additives, as well as local feed. But in any case, the purchase of a mixer is necessary. The volume of prepared mixtures does not allow to purchase mixers with a high cost.

For the preparation of animal feed, mixers of various designs and with different working bodies are used. Blade working bodies are widely used for mixing bulk materials. Their shaft can be both vertical [1, 2] and horizontal [3, 4]. The number of shafts can be different: one or several [2, 3].

The different profile of the blades and their location differently affect the occurrence of stresses in the material mass, contributing to the shear of the layers, and accordingly affect the energy consumption [2, 6]. The design features of the blades and the features of the movement of the working body also affect the quality of the prepared mixture [2, 7]. In some cases, to improve mixing, an eccentric...
arrangement of the working body [4], or vibration exposure [8] is used. However, despite a slight improvement in the quality of the mixture, a sharp decrease in energy consumption is not provided. Drum mixers have less energy consumption [9-11]. Their design is also constantly improving [12-14].

However, original design developments are expensive. Therefore, there are difficulties with their sale. The mobile drum concrete mixers available in retail chains are devoid of this drawback [13]. At the same time, refinement of the working bodies is required to improve the quality of the prepared feed mixture due to differences in the physicomechanical properties of building and feed materials [14, 15]. A fairly simple, but effective modernization of such drum mixers is to change the location of the blades.

The aim of the research was to establish a regression model of the influence of the angles of installation of the wings of the L-shaped blades and to optimize their values.

2 Methods and materials

The research methodology provided a regression analysis of the experimental studies of drum mixers in order to obtain a regression model of the quality of the mixture depending on the angle of attachment of the wings of the L-shaped blades and optimization of the angles of installation of the wings of the blades according to the quality of the mixture.

The angle of installation of the wing of the blade, farthest from the loading hole, relative to the tangent location of the wing of the blade is $\beta = B = 30, 42$ and 55 degrees. The angle of installation of the wing of the blade, closest to the loading hole, relative to the tangent location of the wing of the blade is $\alpha = A = 0, 22$ and 45 degrees.

The coefficient of variation of the particles of the control component in the filler was calculated using 20 samples. The density of the prepared mixture was 700 kg/m$^3$. The proportion of the control component was 1%. The mass of the prepared mixture was 50 kg with a density of 0.62 t/m$^3$. Using the results obtained, the Statistika program processed the data and the angles providing the optimal values for the quality of the mixture in the studied interval of the blade installation angles were found. A commercially available concrete mixer (Figure 1) with a drum volume of 0.26 m$^3$ and a rotational speed of 28 min$^{-1}$ was used as a basic mixer. Its typical blades were removed and six L-shaped blades (with different installation angles) with a height of 0.15m were installed.

![Figure 1. The studied drum mixer with the studied blades](image)
After loading the control component into the rotary drum of the mixer with the main components of the mixture and after mixing it at a given time, 60 samples were taken from the total volume of the mixture. Based on them, three values of the coefficient of variation were determined. Fluctuations in the coefficient of variation (unevenness) of the content of the control component in the same prepared mixture was 2-3%. Taking into account the unevenness of the mixture, an arithmetic average value was found to obtain the average value according to the results of mixing of 120 sec, 180 sec and 300 sec. The average mixing time was 200 sec. The calculated value of the arithmetic mean of the non-uniformity was used as the initial value for the regression analysis of the experimental results.

3. Experiment and calculations

A number of authors recommend using the exponential function of variation coefficient change when describing the quality of mixing materials, 0.01% [7]:

\[ v = e^{-kT} \]  

where \( k \) – experimental mixing intensity factor; \( T \) – the duration of mixing the components, sec.

The exponent \( w \) is presented as:

\[ w = -k \cdot T \]  

Using the obtained values of the arithmetic mean of the non-uniformity of the mixture (\( v, 0.01\% \)), we process them by logarithm with the base of the natural logarithm. The resulting values are summarized in a table and subjected to regression analysis.

As a result of processing the experimental data by the Statistika program, an expression that describes the interaction of the installation angles of the blades with the exponent \( w \) of the exponential expression of the quality of the mixture was obtained (Figures 2 and 3):

\[ w = -1.05438 + (247.3437 + 10.237 \cdot \alpha - 0.242 \cdot \alpha^2) \times \\
\times \left( -0.015 + 0.00014 \cdot \beta + 0.3172 / \beta \right). \]

The location of the residues not taken into account by the model of the exponent \( w \) (Figure 4) and the convergence of the calculated values of the exponent \( w \) with the experimental data (Figure 5), as well as the values of the statistical criteria \( F \)-test = 0.963263 and the Pearson correlation coefficient \( R = 0.985894 \) indicate the adequacy of the obtained regression models.

![Spatial graphical representation of the statistical model of the exponent w of the expression of the quality of the mixture from the angles of the wings of the blades: A - angle of the wing of the blade near the discharge hole, deg.; B - angle of the wing of the blade at the mounting of the drum to the drive shaft, deg.](image)
The experimental coefficient of mixing intensity from $f.2$ can be expressed as:

$$k = \frac{-w}{T'}$$

where $T'$ – the duration of mixing (in this case, averaged, 200 sec).

Then the experimental coefficient of mixing intensity is described by the expression:

$$k = -k_1 \cdot \{0.005272 - (247.3437 + 10.237 \cdot \alpha - 0.242 \cdot \alpha^2) \times (-0.015 + 0.0014 \cdot \beta + 0.3172/\beta)/200\}.$$
Figure 5. The convergence graph of the calculated values of the exponent $w$ with numbers according to the experimental data.

As a result of modeling these dependencies, the MathCAD program obtained graphs of the exponent $w$ of the expression (Figure 6), the experimental coefficient of mixing intensity $k$ (Figure 7), and the coefficient of variation $v$ (Figure 8). Digital calculated values for this model are presented in Figure 9.

Figure 6. Two-dimensional cross-section of the statistical model of the exponent $w$ of the expression of the quality of the mixture on the angles of the wings of the blades: A - the angle at the wing of the blade near the discharge hole, deg.; B - the angle at the wing of the blade at the mounting of the drum to the drive shaft, deg.
Figure 7. Two-dimensional cross section of a statistical model of an empirical indicator of the intensity of mixing of the working body (-k) for the expression of the quality of the mixture from the angles of the wings of the blades: A is - the angle at the wing of the blade near the discharge hole, deg.; B - the angle at the wing of the blade at the mounting of the drum to the drive shaft, deg.

Figure 8. Two-dimensional cross section of the statistical model of the coefficient of variation v (0.01%) of the angles of the wings of the blades: A - the angle at the wing of the blade near the discharge hole, deg.; B - the angle at the wing of the blade at the mounting of the drum to the drive shaft, deg.
Figure 9. Two-dimensional graphical representation of the statistical model of the coefficient of variation $v$ (0.01%) of the angles of the wings of the blades: A - the angle at the wing of the blade near the discharge opening, deg.; B - angle at the wing of the blade at the mounting of the drum to the drive shaft, deg.

Comparing the graphs of changes in the values of the exponents of the exponent $w$ of the non-uniformity function (Figure 6) and the coefficient of variation $v$ (Figure 8), we can see their good correspondence to each other. A certain difference in the change in the boundaries of the lines of equal output of the indicator of the intensity of mixing of the working body ($-k$) and the above indicators is due to the difference in the grid of numerical values of the indicators. The nature of the change in numerical values is preserved.

An analysis of the operation of a drum mixer should be carried out, given that during the rotation of the drum there should be the circulation of the material in the drum. There are two such circulations. One circulation is associated with the rotation of the drum when the material is mixed in a plane perpendicular to the axis of rotation of the drum. In this case, the content of the control component can vary significantly. The second circulation is associated with the movement of material along the axis of rotation. It allows to average the content of the control component between the cross sections of the drum, and in the presence of stagnant zones near the axis of the drum, to destroy them by virtue of the removal of part of the material from the surface layers. The correct combination of the proportions of these circulations accelerates the distribution of the control component throughout the volume of the mixture. In this case, the inclined location of the axis of rotation of the drum should be taken into account. The material tends to pour from the top of the drum (from the discharge hole) to the bottom (closer to the axis of attachment of the drum). In the absence of forced withdrawal of the material up the drum, the circulation gradually passes into the plane of rotation. The averaging of the material content over the sections is terminated. Due to this phenomenon, the installation of the blades should contribute to the longitudinal pushing of the material.

The magnitude of these angles of installation of the blades is measured from the tangent line to the attachment point (the nearest point to the axis of attachment of the drum) of a particular wing of the blade. The smaller the magnitude of the investigated angle, the greater pressure on the material can be created by the blade, but at a lower speed of movement. That is, it contributes to the movement of the material along the axis of rotation. When the value of the angle changes in the direction of its increase, reaching a value \([90^\circ - \alpha] \) or \([90^\circ - \beta] \) comparable with the internal angle of friction (collapse) there will be a sharp increase in the transition to rotational mixing. The objective of the research was to find the optimal angle of installation of the wings of the L-shaped blade for the material under study. It should be noted that the section of the drum near the discharge hole has not a cylindrical shape, but a
truncated cone one. Therefore, the wing of the blade for this section should be performed with a different angle \( \alpha \), but not \( \beta \) for the cylindrical section.

Taking into account this analysis, with an increase in the angle (see Figure 8) of the installation of the lower wing of the blade \( (\beta = 30^\circ \ldots 45^\circ) \), the circulation along the axis of rotation increases, which significantly improves the quality of the mixture, decreasing the coefficient of variation. For an angle of more than 45 degrees \( (\beta = 45^\circ \ldots 55^\circ) \), the increase in the longitudinal displacement decreases sharply (the quality of the mixture changes little). An analysis of the graph in Figure 8 and the numerical values of Figure 9 shows in the last section \( \{\beta = 45^\circ \ldots 55^\circ\}, \alpha = 25^\circ \) a slight deterioration in the mixing conditions. However, directly the results of measurements of the coefficient of variation of the mixture indicate precisely the stabilization of the process, and not the deterioration of the quality of the mixture.

A similar effect is observed on the conical section of the drum, where the angle of the longitudinal inclination of the walls is not 15 degrees, but exceeds 45 degrees. In this case, with an increase in the angle of installation of the wing of the blade \( \{\alpha = 0^\circ \ldots 25^\circ\}, \beta = 45^\circ \), the longitudinal displacement of the material toward the discharge hole is accelerated. As a result, the quality of the mixture improves. A further increase in the angle of installation of the blade impairs the pushing of the material upward, capturing it in a rotational motion. This degrades the quality of the mixture.

As a result, an optimum is formed, which corresponds to the angles of installation of the wings of the L-shaped blades. It corresponds to a combination of the angles of installation of the wings of the blade \(- \{\alpha = 25^\circ\}, \beta = 45^\circ\\).

4. Conclusion
The aim of the research was to increase the efficiency of the mobile drum mixer due to the intensification of the mixing cycle by improving its design by optimizing the installation angles of the wings of L-shaped blades. The methodology of the studies provided for the experimental determination of the coefficient of variation of the mixture with subsequent computer processing of the results, establishing the functional dependence of the quality of the mixture on the angles of installation of the wings of L-shaped blades and optimizing their values.

The research methodology implemented in this work allowed to determine an adequate functional dependence of the quality of the mixture on the angles of the wings of L-shaped blades. The optimum quality of the mixture of 20% for the share of the control component of 1% and the mixing time of 200 s corresponds to the angles of the wings of the L-shaped blades: the lower part - 45 degrees and the upper part - 25 degrees between the direction of the wing of the blade and tangent to the circumference of the drum at the place of installation of the wing of the blade (its closest point to the axis of attachment of the drum) in the range of angles, respectively: 30-55 degrees and 0-45 degrees. The deviation of the indicated angles (except for increasing the installation angle of the lower wing of the blade) affects the quality of the mixture. In the given direction, the stabilization of the coefficient of variation is observed.

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