Functional model of barrel mixer of bulk solids

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Abstract. The description of the researched barrel mixer with flat blades is carried out. Basing on experimental data, the authors have derived regression equations between barrel filling degree and drive power input and barrel capacity and angle of its setting, between coefficient of variation and mixing duration, between the share of the check component and barrel capacity and angle of its setting. An integrated functional model has been developed for the relationship between the main indicators of the mixer and the studied factors. Discrepancy between experimental data and calculated values of the functional model is about 15% of the calculated granularity of mixture. Inclination of the barrel at the angle of 15° to the horizontal is rational.

1. Introduction

For the preparation of mixtures [1] and composite materials [2] various mixers are widely used. Barrel mixers have a low energy intensity of mixture formation [3] compared with paddle vertical and horizontal [4, 5] mixers, vibration devices [1] and other designs. In this case, barrel mixers with different barrel lengths [5, 6] are used, both horizontal [5] and inclined [7] without and with blades [5,8,9], screws [7] and other elements [9]. To reduce the load and increase the reliability of the structure, the loading of the blades is studied [10]. And almost always the change in the quality of the mixture is studied [11, 12]. Authors, as a rule, describe the processes of specific proposed designs of mixers. At the same time a number of authors [8, 13] noted the perspectives of using multi-stage mixing that improves the quality of the mixture.

High-performance and automated mixers are not always effective for small volumes of products in the case of preparing feed mixtures with a small number of animals [14].

In free sale at a fairly low cost there is a wide variety of mobile barrel mixers with an inclined domeshaped barrel for the preparation of concrete mixtures and mortars. Changing the quality of building materials depending on the conditions of their preparation with such mixers is already known. For agricultural workers, such devices are required during construction and repair. However, in the winter, such faucets are idle. The question arose of the possibility of using such mixers for the preparation of animal feed mixtures.
Taking into account the diversity of feed mixtures in composition and properties, as well as the difference in their properties from building mixtures, the significant influence of structural, kinematic and technological parameters on the quality of the prepared mixture [14, 15], clarification of the influence of these parameters on the performance of the mixture being prepared for a given design of an already manufactured mixer is required. When establishing equations describing indicators of quality, productivity and energy intensity, it is possible to simulate the preparation of a mixture of various compositions [16]. There is no single complex mathematical model based on functions linking the quality indicators of the prepared mixture, energy consumption and productivity for the studied mixer design. Its presence will allow practitioners to determine the adjustment of operating parameters to the fraction of a smaller component of the mixture, and theoreticians - to verify the adequacy of theoretical provisions.

The aim of the research is to obtain a mathematical model of changing the values of the working process indicators of a barrel mixer with flat blades manufactured by the industry in the preparation of dry feed mixtures based on statistical experimental functions to find the required mixing time to a given mixture quality and the possibility of optimizing the working process for energy costs for a specific mixer performance, as well as checking the possibility of obtaining with this design of the mixer the proper quality of bulk mixtures for feeding animals.

2. Methods and materials
The research technique stipulates the statistical treatment of previously obtained experimental data. Basing on the revealed regression dependencies of operation behavior indexes, a functional model is developed that allows determining the calculated indexes of the mixture formation process for the set values of the process realization parameters. Using the calculated values of the indexes, conditions for searching rational or optimal parameters of the mixer fitting specific technological conditions of the barrel mixer application are created.

The mixer comprises a rotating operating reservoir – barrel 4, a drive 6 as a part of an electromotor and belt transmission with a gear rim outside the barrel, supports 2 and 9, hand wheel 5. The barrel comprises a cylinder with two truncated cones on end surfaces (figure 1). The upper cone has a vent for loading and unloading the material. The rotation axis of the barrel reservoir is at the angle of $\alpha$ to the horizontal. There are beaters inside the reservoir fixed on the walls.

![Figure 1. Batch barrel mixer: 1 – cross bar; 2 – support; 3 – gear rim; 4 – barrel; 5 – handwheel; 6 – power block; 7 – control unit; 8 – wheel; 9 – support.](image)

Having mounted the mixer’s barrel at a certain angle of the rotation axis inclination to the horizontal with the help of hand wheel 5, the mixture components are filled into the barrel. The components having
the least share in the mixture composition are filled after all the others. Having finished mixing, the hand wheel is turned and the prepared mixture is spilled out by gravity and centrifugal force.

During experimental research the masses of the loaded components were measured accurate to ±5 g, as well as power consumption with the measuring kit K505 (Tochelektropribor, Ukraine). While determining the mixture quality, 20 samples weighing 100±2 g were taken and coefficient of variation C_v of the check component content in the samples (mixture uneven) was determined.

The degree of filling of the mixer was determined by the ratio of the mass of material with a rotating inclined barrel to the mass of material with a fully filled vertical barrel. The measurements have been done three times. The arithmetic mean value was tabulated and then the data were statistically processed. Statistical processing of the results was carried out by the Statistica 5.5 Program via calculation, modeling and graphing using the mathematical package MathCAD 8.0.

During the research mixers with a volume of 0.063, 0.12, and 0.18 m^3 with a barrel rotation frequency of 26–29 min^1 were used. The density of the bulk mixture is 600 kg/m^3. The influence of the volume of the barrel, its angle of inclination (15–45°), the degree of filling of the barrel (taking into account the absence of material precipitation during operation), the fraction of the smaller component of the mixture (1–25%), and the duration of mixing (60–1200 s) were studied. Evaluation of the mixer was carried out according to a number of indicators: the mass of the prepared portion of the mixture, the degree of filling of the barrel, the change in the unevenness of the mixture, mixing performance, power consumption, unit energy consumption of the mixture formation. The type of functional empirical dependencies of the process indicators was chosen taking into account the preservation of generally accepted relationships between process indicators.

The mass of the prepared mixture (kg) is determined by the formula [16]:

\[ M = \rho \cdot V \cdot \varepsilon, \]  

where, \( \rho \) – packed density of mixture, kg/m^3; \( V \) – capacity of mixer’s barrel, m^3; \( \varepsilon \) – reservoir filling degree.

Specific expenditure of energy of mixture formation (J/kg) [16]:

\[ A_v = \frac{P \cdot T}{M}, \]  

where, \( P \) is the power consumption of the drive, W; \( T \) – duration of mixing, s.

Mixture formation efficiency (kg/s) was calculated as in [16]:

\[ Q_v = \frac{M}{T}. \]  

3. Experiment and calculations

The experimental results were approximated and the regression equations were obtained. While rotating the barrel set at the angle to the horizontal, mixture surpluses spill out. Filling degree \( \varepsilon \) (0.01%) of the mixer’s barrel with the minimal capacity reserve is described by the regression equation (figure 2):

\[ \varepsilon = \exp \left( -0.06482 \cdot \alpha^{-1.963} + 91.05 \cdot V^{0.32468} \right). \]  

where \( \alpha \) – angle of barrel’s rotation axis location to the horizontal, rad. Correlation coefficient of calculated and empirical values R=0.97539.

Consumed power (Wt) is described by the formula (figure 3):

\[ P = 0.054 \cdot M \cdot n \cdot \left( \sin \alpha - 0.42 \cdot \alpha \right) + 1994 \cdot V. \]  

Correlation coefficient of calculated and empirical values R=0.99973.

During a series of researching the mixture granularity, the authors have derived the formulae describing the influence of technological factors and the barrel’s capacity (figure 4), 0.01%:
\[ C_v = \exp\left(-0.7684 \cdot R^{0.105}\right), R = 0.93688; \]
\[ C_v = 0.01 \cdot \exp\left(3.97 - \frac{17.44}{\exp(3.4 \cdot D_0^{0.1188})}\right), R = 0.97677; \]
\[ C_v = 0.01 \cdot \exp\left(4.696 \cdot \alpha^{0.24} + 0.0283 \cdot P^{0.0764}\right), R = 0.99306. \]

**Figure 2.** Influence of barrel’s capacity \( V \) (m\(^3\)) and barrel’s inclination angle \( \alpha \) (rad.) on the degree of reservoir filling \( \varepsilon \) (0.01%).

**Figure 3.** Influence of barrel’s capacity \( V \) (m\(^3\)) and barrel’s inclination angle \( \alpha \) (rad.) on drive’s consumed power \( P \) (Wt).

Basing on these formulae and taking into account the function of the mixture’s quality change at diffusion [9], an aggregate model of the mixture uneven was derived (figure 5), 0.01%:

\[ C_v = \exp\left(-1.27 \cdot k' \cdot T\right), \]

where \( k' \) – empirical coefficient of mixing intensity:

\[ k' = k_T \cdot k_{DA} \cdot (0.998 \cdot k_a + 0.0283 \cdot k_T)^{-1}. \]

Here, empirical coefficients of mixing intensity taking into account: \( k_T \) – mixing duration (\( T \), s); \( k_{DA} \) – check component share (\( D_k \), %); \( k_a \) – angle of rotation axis’s inclination to the horizontal (\( \alpha \), rad.); \( k_T \) – capacity of mixer’s barrel (\( V \), m\(^3\)).

Basing on the formulae (4), the equations of the mentioned empirical coefficients of mixing intensity are derived (figure 6), 0.01%:

\[ k_{DA} = \left(1.172 - \frac{5.15}{\exp\left(\frac{3.4}{D_0^{0.1188}}\right)}\right)^{-1}; \]

\[ k_a = 1.38 \cdot \alpha^{0.24}, \]
\[ k_T = 0.605 \cdot T^{-0.805}, \]
\[ k_T = 3.19 \cdot P^{0.0764}. \]
Figure 4. Influence on mixture uneven $C_v$ (0.01%) of: (a) – mixing duration $T$ (s); (b) – check component share $D_k$ (%); (c) – barrel’s capacity $V$ (m$^3$) and barrel’s inclination angle $\alpha$ (rad.).

Figure 5. Influence on mixture uneven $C_v$ (0.01%) of mixing duration $T$ (s) and check component share $D_k$,% at the angle of barrel’s inclination $\alpha = 0.262$ rad. (15$^\circ$).
Figure 6. Influence on empirical coefficients of mixing intensity $C_\alpha$ (0.01%) of: (a) – mixing duration $T$, s; (b) – check component share $D_k$, %; (c) – barrel’s inclination angle $\alpha$, rad.; (d) – barrel’s capacity $V$, m$^3$.

Specific expenditure of energy of mixture formation (J/kg) is determined as (figure 7). Mixture formation efficiency (kg/s) is determined as (figure 8).

Figure 7. Influence on specific expenditure of energy of mixture formation (J/kg) of mixing duration $T$ (s) and barrel’s inclination angle $\alpha$ (deg.) at barrel’s capacity $V=0.18$ m$^3$.

The analysis of the obtained experimental data and the calculated values of the functional model has shown compatibility to a precision of about 15% of mixture uneven. Thus, due to randomness of the process of distributing the particles of a check component, e.g. when the mixture’s uneven is about 12%, there are fluctuations of values of mixing uneven on $12\pm2\%$ (figure 5).

Analyzing the obtained values and the character of the indexes’ change, one can notice that mixture’s quality in mixers with different capacities changes insignificantly. The best mixture’s quality is obtained when the barrel’s inclination is about $15^\circ$ (0.262 rad.). However, the degree of the reservoir’s filling
decreases sharply and amounts to 30–40%. The less the barrel’s capacity is, the more the filling degree is due to sidewalls’ influence. Mixing is absent in the lower part of the reservoir at the angle of more than 30°. The more the mixer’s capacity is, the more the mixture’s mass is and the more the consumed power and efficiency are. At first, the mixture’s quality improves intensively, and then (after 240 s) the intensity decreases significantly (figure 5, 6a). The check component share has major influence on the mixture’s quality. At the coefficient of variation $C_v=20\%$, mixing time of 70 s is needed for the share of the check component equal to 13% (240 s for 6%). For the mixture’s granularity (coefficient of variation $C_v=10\%$ according to production requirements) at the minimal share of the check component equal to 26%, mixing time equal to 660 s is needed. Thus, notwithstanding the low power inputs of barrel mixers, getting mixtures of high quality in them is problematic and requires high labor costs (mixing time of 14–35 kg depending on the barrel’s capacity is 11 min). Specific expenditure of energy is proportionate to mixing duration.

![Figure 8](image)

**Figure 8.** Influence on mixture formation efficiency $Q_c$ (kg/s) of mixing duration $T$ (s) and barrel’s inclination angle $\alpha$ (deg.) at barrel’s capacity: (a) $V=0.063$ m$^3$; (b) $V=0.180$ m$^3$.

**Conclusion**

The obtained functional model of the batch barrel mixer with flat blades adequately describes the mixer’s operation indexes. Discrepancy between experimental data and calculated values of the functional model is about 15% of the calculated uneven of the mixture.

Production of dry compound feed mixtures (with the density of 200-700 kg/m$^3$) on farms in the existing constructions of mixers is irrational due to the long duration of mixing to achieve the coefficient of variation $C_v=10\%$ according to the production norms. The existing construction of available mixers for the production of mixtures of high quality requires further upgrading: modernization of beaters inside the reservoir, which doesn’t significantly differ in the mixers under consideration at the angle of the barrel’s inclination equal to 15°.

The most effective way to improve the quality of the mixture is to set the 15 degree angle of the barrel from the horizontal plane. Obtaining dry feed mixtures (with a density of 200–700 kg / m$^3$) on farms in existing mixer designs is irrational, due to the high mixing time to achieve a coefficient of variation of 10% according to technological standards. Rational preparation of pre-mixes with a coefficient of variation of 20%. The existing design of commercially available mixers in the case of the preparation of high-quality mixtures requires further improvement. The direction of improvement is the modernization of intra-cavity blades with a tilt of the rotation axis of 15°.
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