Improving the working process of a modernized transportable drum mixer

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Abstract. The aim of the research was to increase the efficiency of the modernized (by replacing the blades) transportable drum mixer by intensifying the mixing stroke by improving its design and optimizing the mixing time of the components. The research methodology provided for a regression analysis of experimental results to establish the function of the influence of the mixing duration on the coefficient of variation. The best quality of the mixture is observed in the mixing time interval of 60-300 sec, with an optimum of about 120-140 sec. The average value of the coefficient of variation in this case corresponded to 10.9%. Due to the inconsistency of the results of a one-stage mixing with technological requirements for the quality of the mixture, the function for a two-stage mixing is justified. The optimum ratio of the pre-mix filler to the control component is about 4. The mixing time of the second mixing stage should correspond to 180 seconds. Moreover, the unevenness of the mixture (10%) meets the technological requirements. Compared to the typical design of the mixer used, a 7% improvement in the quality of the mixture is observed.

1. Introduction

By the volume of production, enterprises can be large, medium and small. As a rule, for large and medium-sized enterprises there is economic feasibility of using specialized stationary equipment that carries out the required technological processes. For small enterprises such equipment may not pay off economically due to the high price of the purchased equipment. Equipment with low productivity is cheaper, but this increases the duration of the work. Accordingly, owners of small enterprises should in such cases increase the cost of wages or spend their time excessively on other types of work. The solution to this problem is the use of mobile [1] devices mounted on mobile trailers or having the ability to easily move between several serviced objects in the back of a vehicle [2]. At the same time, in terms of internal design the technological device itself should be optimized as much as possible in terms of the speed of technological processes.

An example of such a device is a mixer for the preparation of animal feed on farm conditions with a small number of livestock based on purchased feed additives (with a full range of required substances), as well as on own cheap feed grain. If there are several similar small farms in one settlement, it is possible to optimize the costs of mixing through a mobile mixer. The cost of the mixer will be decomposed into serviced farms, i.e. reduced.
An analysis of the mixers used showed their wide constructive diversity. Mixers that use a fixed container have high polarity and a wide variety of designs [3,4]. Such mixers work either cyclically (by unloading portions of the finished mixture) or continuously (the prepared mixture constantly comes out with stable performance). The second mixers work as part of an aggregate having dispensers according to the number of metered (measured) components of the mixture [5]. The difficulty lies in fine-tuning the dispensers to the composition according to the proportion of the components of the mixture. Batch mixers are easier to operate. Only scales are needed to weigh the components one by one when they are loaded into the mixer.

To optimize the work process, both theoretical [6], numerical [7,8], and experimental studies [9] are carried out. Theoretical studies allow to identify the nature of the influence of a factor. However, in fact, the process is simplified using some assumptions. Numerical modeling allows to take into account the more complex effects of factors. However, they require preliminary adjustment to the nature of the process or its rating. Without it, it is possible to get a false result [10,11]. Therefore, experimental studies are a criterion of truth. However, due to the inevitability of errors in measurements and the inconsistency of the values of the process indicators, the experiment requires statistical analysis during dispersion or regression processing of the result [6, 9].

The main area of mixer research is focused on increasing the intensity [7, 8, 10] of mixture formation (improving the quality of the mixture while reducing the processing time) and reducing energy consumption [12, 13] by optimizing the design and kinematic parameters of devices and processes [14-16].

Smaller energy expenditures before stabilization of the kinetics of mixture formation are observed for mixers with a rotating tank [16, 17]. These include drum mixers. They are widely used for the preparation of building mixes [2, 18]. For the preparation of feed mixtures, mixer designs available on the market require modernization and testing for applicability to comply with technological requirements for the quality of the mixture [2, 18, 19]. It is important to obtain the characteristics of the modernized mixer by the quality of the mixture from the processing time [20].

The aim of the research was to increase the efficiency of the mobile drum mixer, which was modernized by replacing the blades, by intensifying the mixing cycle by improving its design and optimizing the mixing time of the components.

2. Methods and Materials

The research methodology provided for a regression analysis of the experimental studies of the drum mixer (Figure 1) to establish the effect on the quality of the mixture (coefficient of variation) of the mixing duration the components of the mixture. Due to the inconsistency of the results of a single-stage mixing with the technological requirements of the quality of the mixture, the dependence of the influence of time and the composition of the preliminary mixture for a two-stage mixing was further substantiated.

A modernized drum mixer with a capacity of 260 liters, rotating at an angular speed of 2.9 rad/sec was studied. Inside it there are six L-shaped blades with wing angles of 45 and 25 degrees relative to the tangents at the points of attachment of the wings of the blades.

The coefficient of variation (as an indicator of the quality of the mixture) of the controlled component in the mixture was calculated from 20 samples. The density of the mixture is 650 kg/m³. Computer programs MathCAD and Statistika conducted statistical processing of the results and performed their graphical analysis.
3. Experiment and calculations
The mixing quality of bulk materials is well described by the exponential function, 0.01% [13, 20]:

\[ v = e^{-k\cdot T} \]  

(1)

where \( k \) – the coefficient of mixing intensity determined experimentally for each working body; \( T \) – the duration of mixing the material of the mixture, sec.

The exponential dependence exponent is denoted by:

\[ -k \cdot T = w \]  

(2)

Using the average experimental values of the coefficient of variation (\( v, 0.01\% \)), we take their logarithm with the base of the natural logarithm. The obtained values are subjected to regression analysis. As a result of processing the numbers with the Statistika program, an expression that describes the change in the quality of the mixture is obtained (Figure 2):

\[ w = -2.14 - 0.00004 \cdot T + 10^8 \cdot T^{-4.856} - 9.417/T. \]  

(3)

The numerical values of F-test = 0.948698 (slightly do not reach the desired 0.95) and of the correlation coefficient R = 0.97199 for the exponent \( w \) for expressing the quality of the mixture, as well as F-test = 0.954884 and R = 0.97493 for the quality of the mixture itself indicate satisfactory adequacy of the obtained statistical mix quality models. However, an analysis of the residues not taken into account by the model (Figure 3) shows the presence of an unaccounted factor (points are located not randomly, but along a certain curve). An analysis of the correspondence between the calculated and experimental values of the variation coefficients (Figure 4) shows the mismatch of the trends in the mixture quality over the interval from 300 to 1200 sec. Therefore, an alternative dependence is determined.

A significant improvement in the quality of the mixture within the interval from 60 to 300 seconds is also seen (Figures 4, 5). A similar behavior of the change in the quality of the mixture in batch mixers was also observed by other researchers [21].
Figure 2. The graph of the statistical model of the exponent \( w \) of the expression of the dependence of the quality of the mixture on the mixing time \( T \) (sec) and experimental average values.

To build an alternative model, we used the existing hyperbolic tendency to change the quality of the mixture (exponent \( - w_0 \)) at the ends and middle of the studied time interval (Figure 6) and its subsequent correction (exponent \( - w_1 \)) with a functional factor (Figure 7). For this, the exponent was written as a function: \( w = w_0 \cdot w_1 \). Given the nature of the change in the difference between the calculated values according to the simplified hyperbolic model and the average values of the experimental data (functionally close to the Rayleigh rating), a fourth-order dependence was used.

Figure 3. The graph of unaccounted residues of the statistical model of the exponent \( w \) for the expression of the quality of the mixture.
Figure 4. The graph of the correspondence of the values of the statistical model of the quality of the mixture ($v_c$, %) to the experimental average values ($v_a$, %) of the mixing time $T$ (sec).

As a result of processing the numbers by the Statistika program, a refined expression that describes the change in the value of the exponent of the mixture quality function $v_3$ is obtained (Figure 8):

$$w = w_0 \cdot w_1 = \left(2.425 + 0.0000172 \cdot T + \frac{6.9}{T}\right) \times \left(1 + \frac{1.147525}{T} - \frac{1271.29}{T^2} + \frac{72117.7}{T^3} + \frac{18966.6}{T^4}\right).$$

The values of F-test = 0.994188 and the correlation coefficient R = 0.999318 for the mixture quality function indicate the adequacy of the identified model.

Based on the experimental values of the coefficients of variation by repetition, a 95% confidence interval for changing the quality of the mixture was determined for specific values of the mixing time (Figure 5).

Figure 5. The graph of the mixture quality change $v$ (%) depending on the mixing time $T$ (sec): 1 $v_c$ (%) - a statistical model of the mixture quality; 2 ($v_a$) - average experimental values; 3 ($v_1$, $v_2$, $v_3$) - experimental values of the corresponding repetition; 4 ($v_t$) - a value of technological requirements; 5 ($I_b$, $I_m$) - boundaries of the 95% confidence interval according to the experimental values.
All values of the coefficients of variation are located inside it. The variability of these indicators does not exceed 11.5% of the value of the coefficient of variation. If the boundaries of the confidence interval in the first half of the time interval (600 sec inclusive) have a significant spread (up to 34% or 25%), then subsequently it decreases to 14-19%.

Since in a one-stage mixing it was not possible to achieve compliance with the quality of the mixture by the modernized mixer, it was necessary to conduct studies to justify a two-stage mixing. The process is implemented as follows. First, a portion of the filler mixture is loaded (in proportion with a coefficient N to a portion of the entire controlled component) together with the controlled component. Mixing lasts 120 seconds, as was justified earlier. After that, the remaining filler is loaded. After the mixing time, the mixture is unloaded and its quality is determined. The duration of the second stage mixing was 120 and 180 seconds. The data processing results are shown in Figures 9 and 10.

The duration of mixing the second stage of 120 seconds did not provide the required quality of the mixture at any ratio of the components. Moreover, an increase in the proportion of the filler in the first mixing stage improves the quality of the mixture from 14.5% to 12% with a linear relationship.

With an increase in mixing time, an extremum of the mixture quality arises, corresponding to a filler share of about 4 parts relative to the control component. The coefficient of variation is less than 10%, i.e. technological requirements are being met. This is due to the fact that, at small proportions of the filler (from 1:1 /the control component : the filler/; to 1:4), the distribution of the control component in the preliminary mixture is impaired due to the disproportionate height of the blades to
the height of the volume of the preliminary mixture (too little material). With an increase in the proportion of filler, the height ratio is leveled and the quality improves to \( N = 4 \). Further, a decrease in the proportion of the control component relative to the mass of the primary mixture affects, and this increases the coefficient of variation.

The obtained statistical models for the time \( T \) (for both 120 sec and 180 sec) show the placement of experimental data in a 95% confidence interval (Figures 11, 12) relative to the obtained models. This indicates their adequacy and the validity of their use.

**Figure 8.** The graph of the mixture quality change \( \nu (%) \) depending on the mixing time \( T \) (sec): 1 \( \nu_c (%) \) - a statistical model of the mixture quality; 2 \( \nu_1 \) - average experimental values; 3 \( \nu_2 \) - a statistical refined model of the mixture quality; 4 \( \nu_3 \) - a value of technological requirements; 5 \( I_b, I_m \) and 6 \( I_b', I_m' \) - boundaries of the 95% confidence interval according to the experimental values, also their spline.

**Figure 9.** The graph of the change in the quality of the mixture \( \nu (%) \) depending on the value of the coefficient \( N \) (the ratio of the filler to the portion of the controlled component in the first mixing stage) with a duration of the second mixing stage of 120 sec.
Figure 10. The graph of the change in the quality of the mixture \( v \) (%) depending on the value of the coefficient \( N \) (the ratio of filler to portion of the controlled component in the first mixing stage) with a duration of the second mixing stage of 180 sec.

Figure 11. The graph of the probability of compliance with technological requirements \( (P_f) \) and non-compliance with them \( (P_v) \) for averaged indicators of the quality of the mixture depending on the mixing time \( T \) (sec).

Figure 12. The graph of the probability of compliance with technological requirements \( (P_f) \) and non-compliance with them \( (P_v) \) for averaged indicators of the quality of the mixture depending on the mixing time \( T \) (sec).
4. Conclusion
The best quality of the mixture is observed in the mixing time interval of 60-300 sec, with an optimum of about 120-140 sec. The average value of the coefficient of variation in this case corresponds to 10.9%. The variability of the mixture non-uniformity does not exceed 11.5% of the coefficient of variation. Due to the inconsistency of the results of one-stage mixing with technological requirements for the quality of the mixture, a function for describing a two-stage mixing is justified. The optimum ratio of the pre-mix filler to the entire control component is about 4. The mixing time of the second mixing stage should correspond to 180 seconds. Moreover, the unevenness of the mixture meets the technological requirements of 10%. Compared to the typical design of the mixer used, a 7% improvement in the quality of the mixture is observed.

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